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

ENGLISH RIVER FIRST NATION, SASKATCHEWAN

APM-REP-06144-0043

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

English River First Nation, Saskatchewan

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Executive Summary

In January 2012, the English River First Nation (ERFN), Saskatchewan, expressed interest in continuing to learn more about the Nuclear Waste Management Organization's (NWMO) nine-step site selection process, and requested that a preliminary assessment be conducted to assess potential suitability of the ERFN area for safely hosting a deep geological repository (Step 3). This request followed a successful completion of an initial screening conducted during Step 2 of the site selection process (Golder, 2011). 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 report (NWMO, 2013).

This report presents the results of a desktop geoscientific preliminary assessment of potential suitability to determine whether the ERFN 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 ERFN reserves (and their periphery) that are situated on the Canadian Shield, which is referred to as the "ERFN 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 and radiometric);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on the characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification 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 ERFN area contains at least three general areas that have the potential to satisfy NWMO's site evaluation factors.

The bedrock (felsic gneiss) in the three identified potentially suitable areas appears to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. It has a sufficient depth and extends over a large area at surface. It also appears to be potentially lithologically homogeneous, with low

potential for natural resources and limited surface constraints. One of the three identified areas has poor access compared to the two others.

While the ERFN area appears 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 for the ERFN area include the low resolution of available geophysical data over most of the potentially suitable areas, the lithological homogeneity of the felsic gneiss, the complexity of structures (as shown by complex lineament orientations) and the potential influence of the Needle Falls shear zone.

Should the community of ERFN be selected by the NWMO to advance to Phase 2 of the 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 ERFN 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, field geological mapping and the drilling of deep boreholes.

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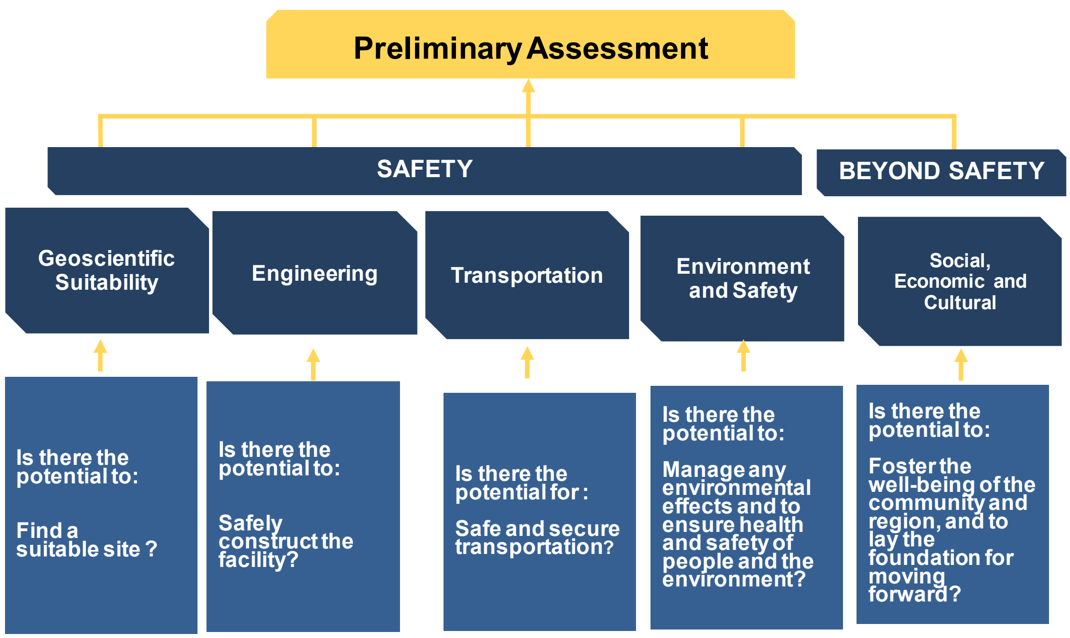
1.0 INTRODUCTION

1.1 Background

In January 2012, the English River First Nation (ERFN), Saskatchewan, expressed interest in continuing to learn more about the Nuclear Waste Management Organization's (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the ERFN area, Saskatchewan for safely hosting a deep geological repository (Step 3). This request followed the successful completion of an initial screening conducted during Step 2 of the site selection process (Golder, 2011).

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



The objective of the geoscientific preliminary assessment is to assess whether the ERFN area contains general areas that have the potential to meet MWMO'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 the geoscientific preliminary assessment of potential suitability (Phase 1) conducted by Golder Associates Ltd.

1.2 Desktop Geoscientific Preliminary Assessment Approach

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

For the purpose of the initial screening (Golder 2011), the thirteen ERFN reserves included in the study were grouped into three distinct geological regions: the Athabasca Basin (Region 1), the Canadian Shield (Region 2) and the Western Canada Sedimentary Basin (Region 3). The initial screening indicated that only the ERFN reserve areas located on the Canadian Shield (Region 2) were potentially suitable for hosting a deep geological repository. The other reserve areas located within Region 1 and Region 3 did not meet all of the initial screening criteria.

The desktop geoscientific preliminary assessment focussed on the reserve areas within Region 2, which is referred to as the “ERFN area”. For the purpose of the assessment, Region 2 was further divided into three sub-regions (2.1, 2.2 and 2.3) as shown on Figure 1.1. The boundaries of the three sub-regions were defined to encompass the main geological features within the ERFN reserves and their surroundings.

The desktop preliminary assessment built on the work previously conducted for the initial screening (Golder, 2011) and included the following 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 and radiometric);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on the characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification and evaluation of potentially suitable siting areas based 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, 2013a); geophysical interpretation (PGW, 2013); and lineament interpretation (JDMA, 2013b). 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 ERFN 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 ERFN area was obtained from several data sources, including maps, reports, databases and technical papers. The review of existing information identified that there was sufficient geoscientific information available to conduct the Phase 1 preliminary geoscientific assessment and to identify potentially suitable general siting areas in the ERFN area. Key geoscientific information sources are summarized in this section, with a complete listing provided in Appendix B.

1.4.1 Satellite Imagery and Airborne Geophysics

Low- to moderate resolution geophysical data, particularly the magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC) covers the entire ERFN area (Figure 1.2 and Table 1.1) (GSC, 2012). The magnetic data consists of four surveys (Saskatchewan #5, #8, #9, and #10) flown at terrain clearances of 305 m, with a variability of flight line spacing of 402 m, 805 m, and 1609 m, providing these surveys with a relatively low spatial resolution. Data from these surveys were recorded on analog charts, with navigation and flight paths determined mainly based on analysis of photomosaics. The quality of the data is mainly a function of the flight line spacing, the sensor height and equipment sensitivity (Table 1.1). Two additional magnetic/radiometric surveys obtained from the GSC provide higher resolution coverage in the ERFN area located in the northwest and northeast corners. These surveys were flown at lower terrain clearance of 127 m and 147 m, and slightly tighter line spacing of 400 m. Data from these two surveys comprise the southern portion of the GSC Athabasca Basin Compilation of airborne geophysical surveys flown between 2004 and 2009. . Gravity data for the ERFN area consists of an irregular distribution of 107 station measurements, comprising roughly a station every 10 to 15 km. Additionally, deep seismic surveys have been conducted (50 to 100 km) to the south of the ERFN area as part of the Lithoprobe initiative (Lucas et al., 1993; Lewry et al., 1994; White et al., 2005).

The digital elevation model data for the ERFN area is the Canadian Digital Elevation Data (CDED). The CDED is a 1:50,000 scale, 20 m resolution elevation model constructed by the Mapping Information Branch of Natural Resources Canada (NRCan). It was constructed using 1:50,000 scale source data from the National Topographic Data Base (NTDB) which was created from black and white aerial photographs (1:60,000 and 1:70,000 scale) acquired in the late 1960s and 1980s (Table 1.1; GeoBase, 2011a).

SPOT multispectral (20 m resolution) and panchromatic (10 m resolution) orthoimagery were available for the ERFN area (Table 1.1; GeoBase, 2011b). Nine SPOT images (scenes) provided complete coverage for the ERFN area (Table 1.1). The scenes are from the SPOT 4 and 5 satellites with image acquired between May 2006 and September 2009.

Table 1.1: Summary of Satellite and Geophysical Source Data Information for the ERFN Area

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	20 m	Entire ERFN area	1978 - 1995	Hill shaded and slope rasters used for mapping
Satellite Imagery	Spot 4/5; Orthoimage, multispectral/ panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire ERFN area	2006 - 2009	Panchromatic mosaic used for mapping
Geophysics	Saskatchewan #5	Geological Survey of Canada	805 m line spacing, sensor height 305 m	North-central part of ERFN area	1964	Magnetic data. Recorded on analog charts, Low resolution
	Saskatchewan #8	Geological Survey of Canada	1609 m line spacing, sensor height 305 m	SW part of ERFN area	1952	Magnetic data. Recorded on analog charts, Low resolution

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
Geophysics (Cont)	Saskatchewan #9	Geological Survey of Canada	805 m line spacing, sensor height 305 m	SE part of ERFN area	1969	Magnetic data. Recorded on analog charts, Low resolution
	Saskatchewan #10	Geological Survey of Canada	402 m line spacing, sensor height 305 m	Near SE corner of ERFN area	1958	Magnetic data. Recorded on analog charts
	Cree Lake South	Geological Survey of Canada	400 m line spacing, sensor height 127 m	877.6 km^2 of NW corner of ERFN area	2007	Magnetic and Radiometric data. Mudjatik domain
	Upper Foster Lake	Geological Survey of Canada	400 m line spacing, sensor height 147 m	1,074.5 km^2 of NE corner of ERFN area	2005	Magnetic and Radiometric data. Mudjatik-Wollaston contact
	GSC National Gravity Compilation	Geological Survey of Canada	10-15 km	Entire area	1960-1967	Bouguer gravity field, first vertical derivative, horizontal gradient and the isostatic residual gravity field
	GSC National Radiometric Compilation	Geological Survey of Canada	5000 m line spacing, sensor height 120 m	Entire area	1975-1976	Grids of potassium, equivalent uranium, equivalent thorium, natural air absorbed dose rate, and ratios of eU/K, eTh/K and eU/eTh

1.4.2 Geology

The bedrock geology of the ERFN area was mapped in the 1970s and 1980s at a scale of 1:63,360 to 1:250,000 in order to assess mineral potential (Munday, 1972; Pearson, 1972; Munday, 1977b,c; Pearson, 1977b; Scott, 1977b; Munday, 1978b; Thomas and Slimmon, 1985). Some 1:20,000 scale maps are also available for small portions of the ERFN area (Card and McEwan, 2008; Card et al., 2008a, b; Harper, 1988a; Thomas, 1978; Tran, 1999a, b, c; Tran and Yeo, 1999). Figure 1.2 shows the coverage of these maps within the ERFN area. The maps include all of the detailed areas (described in Section 2.1) that are situated on the Canadian Shield within the ERFN area and greatly enhance the regional information available through Saskatchewan Geological Survey (SGS) mapping (Saskatchewan Industry and Resources, 2010) (e.g., 1:1,000,000 scale regional bedrock geology map). These maps and their associated reports provide information on geologic history, structural geology and lithology. Research on the major structural boundary (Needle Falls shear zone) adjacent to the ERFN area has provided further insight to the geological history of the area and large scale structure (Gilboy, 1985; Thomas and Slimmon, 1985; Delaney, 1993; Card and Bosman, 2007; Yeo and Delaney, 2007). A number of peer-reviewed articles have also addressed the possible origin of brittle deformation features in the area (Byers, 1962; Elliot, 1996; Davies, 1998).

Regional mapping of the surficial geology is available through the SGS Atlas of Saskatchewan (Saskatchewan Industry and Resources, 2010). Additionally, the surficial geology of the ERFN area has been mapped at a scale of 1:250,000 (Schreiner, 1984b, c, d).

The seismic record in Canada was reviewed to provide an indication of seismic stability in the area (Gendzwill and Unrau, 1996; NRCan, 2012).

1.4.3 Hydrogeology and Hydrogeochemistry

Limited site-specific information exists on shallow hydrogeological conditions in the ERFN area. Hydrogeological information was obtained from the Saskatchewan Watershed Authority (SWA) Water Well Record (WWR) database (SWA, 2009), as well as geological (SGS), and hydrological maps (NRCan) of the ERFN area. Combined with regional surface water drainage patterns and surficial geology maps, this information assists with the preliminary characterization of shallow groundwater.

No information is available regarding deep hydrogeochemistry within the ERFN area, so inferences have been made based on studies at similar sites elsewhere in the Canadian Shield. These studies have shown that the hydrogeochemical conditions at repository depth are similar across the Canadian Shield (Frape et al., 1984). Specific reports and studies include: Frape et al. (1984); Frape and Fritz (1987); Gascoyne et al. (1987); Farvolden et al. (1988); Gascoyne (1994, 2000 and 2004); Everitt et al. (1996); and Rivard et al. (2009).

1.4.4 Natural Resources – Economic Geology

The primary source of information on past and present mining activities is the Saskatchewan Energy and Resources (2012) Mineral Deposit Index. Active exploration and mining dispositions in the ERFN area, as well as the known mineral occurrences, were extracted from this source of information. A search of the Mineral Deposit Index also provided associated geological reports and borehole logs available for the area. Information on mineral potential and past exploration is reported by Munday (1977a), Pearson (1977a), Scott (1977a), Gilboy (1985), and Harper (1988b).

1.4.5 Geomechanical Properties

Rock geomechanical properties have been inferred from information obtained at sites with similar rock types elsewhere in the Canadian Shield. Much of this information is a result of the work done by AECL in the 1980s and 1990s as part of the Canadian Nuclear Fuel Waste Management Program.

Information on the geomechanical properties of granitic rocks with conditions ranging from intact rock to highly fractured fault zones is available from AECL's Underground Research Laboratory (URL) near Pinawa, Manitoba, and the Atikokan research area in Ontario (Brown and Rey, 1989; Brown et al., 1989; Stone et al., 1989). Gneissic rocks and migmatites were characterized at AECL's Chalk River Laboratories property, initially to develop characterization techniques and more recently from the standpoint of low level waste management (Davison et al., 1995).

2.0 PHYSICAL GEOGRAPHY

2.1 Location

The thirteen reserves of the ERFN were grouped in the initial screening into three distinct geological regions: the Athabasca Basin (Region 1 of the initial screening), the Canadian Shield (Region 2 of the initial screening), and the Western Canada Sedimentary Basin (Region 3 of the initial screening). Based on the initial screening of the ERFN area (Golder, 2011), the areas located in the Athabasca Basin and Western Canada Sedimentary Basin (Regions 1 and 3) have been excluded from further consideration as potentially suitable for hosting a deep geological repository. Only the Canadian Shield region (Region 2) is considered in this report. To maintain continuity with the initial screening report for the ERFN area (Golder, 2011) and thus avoid confusion during cross-reference, the regional boundary for this preliminary geoscientific assessment is also referred to as Region 2. Satellite imagery for the ERFN area (SPOT panchromatic, taken from 2006 to 2009) is presented on Figure 2.1.

The ERFN area (Region 2) considered in this desktop study is a rectangular area measuring 119 by 126 km, and covering an area of about 15,000 km^2. The approximate western, northern, eastern and southern limits of the ERFN area are defined by UTM (Zone 13, NAD83) coordinates: 321700, 6308800, 439900 and 6182300 m, respectively. For Phase 1 of the preliminary assessment, Region 2 was further subdivided to encompass the reserves and to understand the local geoscientific characteristics. The sub-regions are illustrated on Figure 1.1 and are as follows:

Sub-Region 2.1 is located in the northeast corner of the ERFN area, covering an area of about 1,550 km^2. This sub-region includes the following reserve (IR) area:

- Haultain Lake IR: This reserve area covers 2 km^2 and is located on the east shore of Haultain Lake, approximately 9 km west of Highway 914.

Satellite imagery of Sub-Region 2.1 (SPOT panchromatic) is presented on Figure 2.2.

Sub-Region 2.2 is located in the west-central area of the ERFN area, covering an area of about 2,324 km^2. This sub-region includes the following reserve areas:

- Flatstone Lake IR: This reserve area covers 2.3 km^2 and is a remote site located 37 km north of the community of Patuanak.
- Porter Lake Island IR: This reserve area covers 0.425 km^2 and is another remote site located north of the Churchill River, near the winter road route leading to Cree Lake.

Satellite imagery of Sub-Region 2.2 (SPOT panchromatic) is presented on Figure 2.3.

Sub-Region 2.3 is located at the south end of the ERFN area, covering an area of about 2,892 km^2. This sub-region includes the following reserve areas:

- Dipper Rapids IR: This reserve area covers 8.4 km^2 and is located 22 km east of Patuanak along the Churchill River system.
- Primeau Lake IR: This reserve area covers 17 km^2 and is located 29 km east of Patuanak along the Churchill River system.

- Knee Lake IR: This reserve area covers 5 km^2 and is located 40 km east of Patuanak along the Churchill River system.
- Elak Dase IR: This reserve area covers 14 km^2 and is located 51 km east of Patuanak along the Churchill River system.

Satellite imagery of Sub-Region 2.3 (SPOT panchromatic) is presented on Figure 2.4.

2.2 Topography and Landforms

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

The ERFN area is located in the Kazan upland physiographic region of the western Precambrian Shield (Bostock, 1970). The Kazan upland topography is typical of the Canadian Shield, with large areas of exposed bedrock that form broad, smooth uplands and lowlands. First-order relief is smooth and gently rolling, while second-order relief is more complex. Second-order relief consists of ridges and valleys that are controlled by bedrock conditions. Much of this relief is the result of bedrock structure, and some is the result of differential erosion of different rock types by glacial ice. Ice movement smoothed and polished resistant bedrock hills and scoured out low-lying areas. Valleys and depressions between bedrock ridges and knolls are typically filled with lakes and bogs. Lakes and ridges in the Canadian Shield region are often aligned in a northeast-southwest direction, reflecting the direction of glacial ice advance (Schreiner, 1984a).

The topography of the ERFN area is presented on Figure 2.5. Ground surface elevation ranges from about 631 metres above sea level (masl) near Norbert Lake to 385 masl on the Churchill River in the southeast near Sandfly Lake. Two primary topographic highs are evident, informally known as the Haultain and Norbert highs (JDMA, 2013a). The Haultain high extends southwest from Haultain Lake, which is situated in the northeast corner of the ERFN area. The Norbert high is located in the east-central portion of the area and also extends to the southwest. The two high areas are separated by a low area through which the Haultain River flows. The tops of these bedrock-controlled uplands are greater than 600 m in elevation, with the surrounding lowlands being about 150 to 175 m lower.

The most prominent topographic lows in the ERFN area are informally referred to as the Heddery and Churchill lows (Figure 2.5) (JDMA, 2013a). The Heddery low is located in the northwest corner of the regional ERFN area (immediately north of Sub-Region 2.2) and consists of an outwash plain that developed as glacial melt water flowed through the Cree Lake Moraine. Schreiner (1984b) indicated that large outwash fans or aprons composed of stratified sands occur south of the Cree Lake Moraine and suggested that the thickness of most outwash deposits in northern Saskatchewan is between 5 and 10 m. Together, this outwash plain and the Cree Lake Moraine comprise the most prominent Quaternary landforms in the regional ERFN area.

The Mudjatik River is a remnant of the outwash feature that drains water from the Heddery low into the Churchill low. The Churchill low is the area of lowest elevation within the regional ERFN area. It is oriented in an east-southeast direction at the southwest corner of the ERFN area (across the southern half of Sub-Region 2.3). In the region, the Churchill River generally follows the boundary between the Canadian Shield (Region 2) and the Western Canada Sedimentary Basin (Region 3). Both the Haultain and Mudjatik Rivers drain into the Churchill River.

The margins of many of the rugged landforms such as ridges and knobs in the high relief areas can often be associated with bedrock topography, with some notable exceptions (e.g., end moraines, kames, drumlins, melt water channels); it is assumed that the presence of steep slopes in this landscape is often indicative of bedrock exposure.

Figure 2.6 and its inset map show areas with exposed bedrock within the ERFN area. Additionally, bedrock topography appears to be only minimally covered in areas characterized by morainal veneer in the ERFN area (Figure 2.6). Due to the general lack of high relief surficial deposits in the region, the majority of knobs and ridges with 20 to 30 m (up to 150 m) of relief appear to reflect the underlying bedrock topography and structure. As such, the areas with the thinnest overburden are likely correlated to the areas with highest relief. This suggests that extensions of the Haultain and Norbert highlands situated south of the Cree Lake Moraine are the main areas with thin overburden. Based on relief, areas with good bedrock exposure or only a thin veneer of glacial deposits are expected to the south and southeast of Haultain Lake, in the area surrounding Porter Lake extending to the east, and to the northeast of the Churchill River. Conversely, thicker deposits are expected in the Heddery low, along the Haultain and Mudjatik River channels, and in the Churchill low. Relatively thicker overburden in the west and extreme south end of the ERFN area largely hides the underlying bedrock relief. Many of the broad, flat plains in the ERFN area are locations where organic landforms such as muskegs, fens and peat bogs are situated over relatively thick overburden deposits.

2.3 Watersheds and Surface Water Features

As part of the terrain study, JDMA (2013a) carried out a drainage basin analysis in order to confirm and, where possible, partition the most detailed available mapping of watersheds by the Agriculture and Agri-Food Canada (AAFC) (formerly known as the Prairie Farm Rehabilitation Administration (PFRA)). The resulting mapping is shown on Figure 2.7 and was used to infer regional and local surface water and shallow groundwater flow directions.

The majority of the ERFN area is within the Churchill River basin, which drains to Hudson Bay. The exception is a small area at the northwest corner of the ERFN area around Black Birch Lake, which drains via the Athabasca River to the Arctic Ocean. The Churchill River begins at the outlet of Churchill Lake near the community of Buffalo Narrows and flows from west to east through Saskatchewan and Manitoba.

Four of the seven reserves in the ERFN area are located on the shores of lakes that form part of the Churchill River. These include (from west to east) Dipper Lake, Primeau Lake and Knee Lake. The Churchill River flows from west to east through these lakes. The Dipper Rapids IR is located adjacent to White Inlet on the west shores of Dipper Lake. The Primeau Lake IR is on the south shores of Primeau Lake. The Knee Lake IR is on the north shore of Knee Lake, and the Elak Dase IR is on the north shore of the Churchill River at the east end of Knee Lake.

The tributaries entering the Churchill River from the north flow through exposed Canadian Shield terrain. The current drainage pattern is controlled by bedrock topography with long, narrow lakes connected by fast-flowing rivers. Since the lakes are oriented parallel to the bedrock structure, a trellis-like drainage pattern has developed. Many of its tributaries entering the Churchill River from the south flow through poorly drained boreal plain (generally associated with the Western Canada Sedimentary Basin, which is not being considered in this assessment).

The northern portion of the ERFN area is drained by the Haultain and Mudjatik rivers (Figure 2.5), both of which flow south into the Churchill River. These rivers acted as main melt water channels as glacial ice retreated (Schreiner, 1984b). A northeast trending drainage divide separates these two rivers in this northern area, with the Haultain River located in the east and the Mudjatik River located in the west.

Haultain Lake drains into the Haultain River, which flows south and joins the Churchill River downstream of Knee Lake immediately south of Elak Dase. Most of the flow draining into the Haultain River is divided into two watersheds by a linear complex of bedrock knobs extending to the south from Haultain Lake. The wetlands in this area are primarily confined to narrow troughs between bedrock knobs.

The Mudjatik River flows between the Flatstone Lake IR and the Porter Lake Island IR and flows into the Churchill River to the east (upstream) of Dipper Lake. The upland areas surrounding Porter Lake, including Porter Lake itself, drain north along Porter Creek which enters the south flowing Mudjatik River. The Flatstone Lake IR is on the shores of Flatstone Lake, which drains into the Mudjatik River just before it enters the Churchill River. Excluding the uplands surrounding Porter Lake, the Mudjatik River is associated with some of the most extensive wetlands in the ERFN area. This is especially the case toward the south, adjacent to Flatstone Lake. The average monthly flow along the Mudjatik River is approximately 25 m^3/s (for the period of 1971 to 1995).

The ERFN area contains a large number of lakes of various sizes, sixteen of which are larger than 10 km^2 and six of which are larger than 20 km^2, with about 13% (1,907 km^2) of the area occupied by water bodies. The larger lakes are sufficiently large to conceal geological structures up to about 10 km in length, and clusters of small lakes have additional potential to conceal structures, especially when the lakes are located in areas where geological structures are already largely concealed by overburden. In general, the interconnected lakes that are a part of the Churchill River in the south tend to be larger (>20 km^2) than those located further to the north. These larger lakes include Lac Île-à-La-Crosse, Shagwenaw Lake, Dipper Lake, Primeau Lake and Knee Lake (Figure 2.7). Nearly all of the surface flow within the ERFN area drains through these lakes on the Churchill River into Hudson Bay. Table 2.1 summarizes the size of the larger lakes in the ERFN area. In the ERFN area, bathymetric data exist only for Shagwenaw Lake on the Churchill River and record a maximum water depth of 16.5 m.

Table 2.1: Dimensional Characteristics of Selected Lakes in the ERFN area.

Lake	Area (km^2)	Maximum Recorded Depth (m)
Churchill River [a]	338.4	16.5
Black Birch Lake	66.6	N/A
Porter Lake	53.8	N/A
Keller Lake	28.5	N/A
Gordon Lake	28.3	N/A
Haultain Lake	22.4	N/A
Ithingo Lake	18.3	N/A
Flatstone Lake	18.3	N/A
Unnamed Lake	17.2	N/A
Little Flatstone Lake	17.1	N/A
Heddery Lake	15.8	N/A
Soaring Lake	13.2	N/A
George Lake	12.6	N/A

Lake	Area (km^2)	Maximum Recorded Depth (m)
Forcier Lake	11.4	N/A
Holt Lake	11.1	N/A
Blackstone Lake	10.4	N/A

N/A = Information not available

(a) Includes Lac Île-à-La-Crosse, Shagwenaw Lake, Dipper Lake, Primeau Lake and Knee Lake

Wetlands cover an additional 13% of the ERFN area (1,962 km^2). The most extensive wetlands in the ERFN area are located in topographic lows, particularly along the Mudjatik and Haultain Rivers and in the Heddery low. Wetlands appear elongated and oriented on the glacial cover over the Phanerozoic rocks in the southwest corner of the area. In addition to these extensive wetlands, lower concentrations of small and discontinuous wetlands are dispersed throughout the ERFN area, particularly in areas of relatively high relief such as the Haultain and Norbert topographic highs, where wetlands occupy the lows between bedrock knobs and ridges. The wetlands in each of these areas can be expected to be associated with relatively thick, poorly drained overburden deposits.

2.4 Land Use and Protected Areas

Figure 2.8 shows a summary of land disposition and ownership within the ERFN area including known protected areas. The following summarizes the status of current land use and protected areas within the ERFN area.

2.4.1 Land Use

The ERFN area being considered in this assessment is located in a remote portion of northern Saskatchewan that is almost completely undeveloped. Four of the ERFN reserves are located on the shores of the Churchill River including Dipper Rapids IR, Primeau Lake IR, Knee Lake IR and Elak Dase IR. The Churchill River represents a major traditional transportation corridor through the Provinces of Alberta, Saskatchewan and Manitoba. It was used extensively during the fur trade by the Hudson's Bay Company in the early 1800s.

Recreational lodges are located at Complex Lake and Holt Lake, both of which are located in the center of the ERFN area, but outside of all of the local sub-regions. Several outfitters are located at George Lake, Cup Lake and along the Churchill River (Figure 2.8).

Forestry is generally not an active industry in the area, and there is no evidence of logging roads or clearcuts in the satellite imagery of the area (Figures 2.1 through 2.4). The ERFN area is situated in an Observation Zone designated by the Saskatchewan Wildfire Management Plan. This Observation Zone extends north from the Churchill River to the northern Provincial boundary. In such areas, wildfires are observed but generally not suppressed unless the cost of suppression is less than the value of the potential losses.

2.4.2 Parks and Reserves

The ERFN area was screened for national, provincial and municipal parks, conservation areas, nature reserves and national wildlife areas. There are no parks, wildlife areas, or conservation reserves within or adjacent to the ERFN area. However, the Gordon Lake Recreation Site is located approximately 10 km southeast of the Elak Dase IR at the southern boundary of the ERFN area, along Highway 914 (Figure 2.8). Less than 1.5 km^2 lies within Sub-Region 2.3 of the ERFN area

2.4.3 Heritage Sites

Heritage resources include all of Saskatchewan's Historic and Precontact archaeological sites, architecturally significant structures, and paleontological resources. Heritage resources are property of the Provincial Crown, and as such, are protected under *The Heritage Property Act* (Government of Saskatchewan, 1980). The database for previously recorded heritage resources maintained by the Saskatchewan Ministry of Tourism, Parks, Culture and Sport (TPCS, 2012) was consulted to identify recorded heritage resources found within the ERFN area.

The results of the heritage resources database search indicate that 19 archaeological sites have been recorded on the same NTS map sheets as the ERFN area. The majority, 15 of the sites, are pre-contact artifact find and scatter sites; of the remainder, one is a pre-contact artifact/feature combination site, and one is historic recurrent feature site. Two heritage resources have insufficient information to be given a site type designation.

The Churchill River was a significant waterway during both precontact and historic times. Archaeological evidence indicates that people were occupying the Churchill River area as early as 10,000 years ago (Meyer, 1995). During the early fur trade period, explorers and traders began travelling the Churchill River in the 1770s. This was soon followed by the establishment of fur trade posts by both the English and French beginning in 1775 and continuing through to the 1930s (Russell and Meyer, 1999). At least two other fur trade posts have been documented in the area. This includes the Hudson's Bay Company Dipper and Elbow (Knee) Lake Posts established in 1905 and 1921, respectively. The presence of heritage sites in the area would need to be further discussed with the community and Aboriginal people in the area.

3.0 GEOLOGY

This section provides a description of the geology and seismicity of the ERFN area located within the Canadian Shield, based on a review of available geoscientific information. As stated above in Section 2.1, based on the initial screening of the ERFN area (Golder, 2011), the land located on the Athabasca Basin (Region 1 in the initial screening) and Western Canada Sedimentary Basin (Region 3 in the initial screening) has been excluded from further consideration as potentially suitable to host a deep geological repository. As such, only Region 2 (Canadian Shield) from the initial screening is considered in this report. Region 2 has been further divided into sub-regions including Sub-Region 2.1 (Haultain Lake IR), Sub-Region 2.2 (Porter Lake IR and Flatstone Lake IR), and Sub-Region 2.3 (Dipper Rapids IR, Primeau Lake IR, Knee Lake IR, and Elak Dase IR). The discussion of regional geology will provide a general overview of the Canadian Shield region being considered, while the local geology discussion will focus on geological conditions within each sub-region.

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The ERFN area is situated on the Canadian Shield. The Canadian Shield is a collage of ancient (Archean) cratons, accreted juvenile arc terranes, and sedimentary basins that were progressively amalgamated over a period of more than 2 billion years during the Proterozoic Eon (see Figures 3.1 and 3.2, and further discussed in Section 3.1.2 below). Among the major orogenies that contributed to the assembly of the Canadian Shield is the Trans-Hudson Orogen, which resulted from the closure of the Manikewan ocean and terminal collision of the Rae-Hearne, Superior and Sask cratons during the approximate period 1.9 to 1.8 Ga (Ansdell, 2005; Corrigan et al., 2005; Hajnal et al., 2005; Corrigan et al., 2007; Whitmeyer and Karlstrom, 2007; Corrigan et al., 2009). The Canadian Shield now forms the stable core of North America, and was the first part of the continent to be permanently elevated above sea level.

Regional geophysical surveys have been used to assist in mapping geologic structures within the Precambrian provinces and zones of northern Saskatchewan (Hajnal et al., 2005; White et al., 2005). Figure 3.2 shows a cross section through the Trans-Hudson Orogen in the ERFN area that was constructed by White et al. (2005) based on geophysical surveys conducted as part of the Lithoprobe project (a multi-year continent-scale geophysical subsurface mapping initiative). Geophysical surveys conducted as part of this initiative include airborne magnetic, gravity, airborne radiometric, audio magnetotelluric and deep seismic surveys (Lucas et al., 1993; Lewry et al., 1994; Hajnal et al., 2005; White et al., 2005). The geophysical trends of the major Precambrian structures within the regional area (i.e., Mudjatik and Wollaston domains) can be traced to the south beneath the Western Canada Sedimentary Basin (White et al., 2005), particularly the magnetic high of the Wollaston domain, which is one of the most prominent magnetic features in the Canadian Shield. These geophysical trends are traceable to some degree to the north, beneath the Athabasca basin. These trends reflect the fact that the rocks of the regional area are the oldest, forming the stable continental craton beneath the entire area, which were then overlain by the younger rocks adjacent to the regional area (Whitmeyer and Karlstrom, 2007; Corrigan et al., 2009). The aeromagnetic response decreases into the Mudjatik domain.

The ERFN area is located within the Hearne craton that comprises the eastern portion of the Western Churchill Province of the Canadian Shield. The Hearne craton (south of the Athabasca basin) is generally composed of high-grade metamorphic Archean to Paleoproterozoic rocks older than 1.8 Ga, such as gneissic granitoid rocks, metasedimentary rocks and granitic rocks (Orrell et al., 1999). The Hearne craton (historically called Cree Lake zone) is further divided into several lithostructural domains (Figure 3.1) (Lewry and Sibbald, 1980), with most of the ERFN area being primarily located within the Mudjatik domain and only a small portion of it in the Wollaston domain in the southeast corner near Knee Lake and the northeast corner east of Haultain Lake (Figure 3.3). The western boundary of the Mudjatik domain, to the west of the ERFN area, has been historically marked by the Cable Bay shear zone. This structural feature divides the Mudjatik domain from the Virgin River domain further to the west. However, a new domainal reclassification has been proposed where these two domains are to be merged and renamed as the Mudjatik domain (Card, 2012). For the purpose of simplicity, the old domainal classification has been retained in this report, given that it is used by all referenced sources and does not impact the objectives of this assessment.

To the east, the Mudjatik domain is generally thought to pass transitionally into the Wollaston domain (e.g., Munday, 1977a, 1978a; Lewry and Sibbald, 1980; Tran, 2001) where a marked change in structural style from arcuate to linear, and a less apparent change in lithology in some areas has been observed (Lewry and Sibbald, 1980). Annesley and Madore (1989, 1991, 1994) and more recently Annesley et al. (2005), however, have argued that the boundary between both domains corresponds to a major crustal transcurrent fault-shear zone or thermotectonic discontinuity, at least in the northern segment of the domain boundary nearby the Athabasca basin where they have found evidence of mylonitization and abundant kinematic indicators along the boundary zone. To the south, no evidence of major structural features have been reported in the literature. Furthermore, Tran et al. (1999) did not find evidence of this structural feature in the McKenzie Falls area, Tran and Smith (1999) pointed out that such a structural feature was not existent in the area of the Cup-Keller-Schmitz Lakes and that if a domain boundary existed then it must have existed in pre-Hudsonian Orogeny time.

The eastern portion of the ERFN area, which falls in the Wollaston domain, is bounded to the east by the Needle Falls shear zone, adjacent to the Wathaman batholith of the Reindeer zone (Delaney, 1993; Yeo and Delaney, 2007). The Needle Falls shear zone is a prominent topographic feature (Figure 2.5). The contact with the Needle Falls shear zone is sharp and distinct (Munday, 1978a). The Reindeer zone consists, from west to east, of the Wathaman batholith, and the Rottenstone, La Ronge, Kisseynew, Glennie and Flin Flon domains (Ansdell, 2005), where the Wathaman batholith stitches the Archean Hearne Province to the domains of the Reindeer zone.

The rocks of the Mudjatik and Wollaston domains are bounded to the south and overlain by Phanerozoic rocks of the Western Canada sedimentary basin, in the southwest corner of the ERFN area, whereas to the north rocks of the Hearne Province are overlain by sedimentary rocks of the Athabasca Group, within the Athabasca basin (Figure 3.3).

The Mudjatik domain consists of extensive Archean felsic gneisses with interspersed mafic gneisses (Annesley et al., 2005). Metamorphic grade in this area is between upper amphibolite to granulite metamorphic facies (Tran, 2001). Felsic gneisses predominate among any other type of rock found in the Mudjatik domain. These gneisses are also found in the literature as *granitic* gneisses and occasionally as *eastern* gneisses. The origin of the mafic gneisses is uncertain, but is generally interpreted as metamorphosed gabbroic and dioritic sills or dykes (Annesley et al., 2005).

The Archean felsic gneiss rocks are thought to have served as a basement for the deposition of the metasedimentary rocks, which are dominated by psammopelitic to pelitic rocks and amphibolite (Card and Bosman, 2007). The metasedimentary rocks occur in narrow, arc-shaped bands throughout the Archean felsic gneiss, defining a dome-and-basin pattern that distinguishes the Mudjatik domain from the Virgin River domain to the west and the Wollaston domain to the east (Card et al., 2008c).

The Wollaston domain is characterized as a north-northeast-trending, tightly folded belt of Archean felsic orthogneissic rocks and Archean to Paleoproterozoic metasedimentary rocks with minor metavolcanic rocks (Delaney, 1993). Generally, the felsic gneisses of the Wollaston domain range in composition from syenogranite to granodiorite (Annesley et al., 2005). The metasedimentary rocks and subordinated metavolcanic rocks of the Wollaston domain form the Wollaston Supergroup (as defined by Yeo and Delaney, 2007), which was deposited along the eastern edge of the Hearne craton first in a rift/passive margin setting marking the opening of the Manikewan ocean, and later in a foreland basin setting, due to the closure of the Manikewan ocean between the Hearne and Superior cratons. These rocks are mapped as narrow bands of psammitic to pelitic gneisses, defining the north-northeast-trending linear grain in the Wollaston domain. The predominance of metasedimentary gneisses of the Wollaston Supergroup in the north and central parts of the Wollaston domain declines to the south, where they become discontinuous in bands intercalated with Archean felsic (ortho) gneiss and younger granitoid rocks.

3.1.2 Geological History

Direct information on the geological and structural history of the ERFN area is limited. The geological and structural history summarized below integrates the results from studies undertaken elsewhere throughout and proximal to the area shown on Figure 3.3. It is understood that there are potential problems in applying a regional D_x numbering system into a local geological history (Section 3.1.3 below). The summary below represents an initial preliminary interpretation for the ERFN area, which would need to be reviewed through detailed site-specific field studies.

The chronology of tectonic events that occurred during the Trans-Hudson Orogeny provides a framework for the understanding of the structural conditions of the region and in particular for the ERFN area. The important phases of the Trans-Hudson Orogeny that influenced the present structural conditions observed in the rocks of the region are summarized in Table 3.1, based on several past geological investigations in the region (e.g., Cumming and Scott, 1976; Lewry and Sibbald, 1980; Stauffer and Lewry, 1993; Ansdell, 2005, Ansdell et al., 2005; Corrigan et al., 2005; Hajnal et al., 2005; Card and Bosman, 2007; Corrigan et al., 2007; Card et al., 2008a, b; Whitmeyer and Karlstrom, 2007; Corrigan et al., 2009).

Table 3.1: Summary of the Geological and Structural History of the English River First Nation Area

Time Period (Ga)	Geological Event
2.7	Approximate crystallization age of the felsic gneiss in the region that comprises the Hearne craton.
2.1 to 1.92	Initiation of rifting on the eastern margin of the Hearne craton and opening of the Manikewan ocean. Passive margin in the eastern margin of Hearne craton during rifting, with sedimentation of the Wollaston Supergroup.
1.92 to 1.88	Initiation of subduction underneath the eastern margin of Hearne craton leading to the beginning of both closure of the Manikewan Ocean and creation of the Rottenstone magmatic arc. Continued deposition of Wollaston Supergroup in a back-arc basin. This was followed by collisional compression of the rocks of the Wollaston Supergroup, Rottenstone and La Ronge domains. Collision resulted in D_1 ductile deformation that produced isoclinal folds and imparted the S_1 foliation to felsic gneiss.
1.88 to 1.865	Ongoing subduction resulted in the accretion of juvenile island arc terranes (La Ronge-Lynn Lake) to the southeastern margin of the expanded Rae-Hearne craton resulting in the

Time Period (Ga)	Geological Event
	formation of the Rottenstone accretionary complex, while the Wollaston back-arc basin shifted to a foreland basin.
1.865 to 1.83	Closure of Wollaston basin at approximately 1.86 Ga with concomitant emplacement of Wathaman batholith between ca. 1.865-1.855 Ga along eastern margin of Rae-Hearne craton. Regional D_2 ductile deformation produced upright folds that overprinted the S_1 foliation. Ongoing subduction resulted in the accretion of the Glennie-Flin Flon complex to the Rae-Hearne craton. Collision of the Sask craton with the Rae-Hearne craton, which thrusted the accreted juvenile terranes over the Sask craton.
1.83 to 1.80	Terminal collision of Superior craton with the Rae-Hearne craton leading to final closure of the Manikewan ocean. Crustal shortening that occurred during this period resulted in movement along the Needle Falls shear zone. D_3 ductile deformation creates NNE-striking upright folds dominant in the Wollaston domain. Activation (reactivation?) of the Needle Falls and Virgin River shear zones at ca. 1.83 Ga. Development of thick-skin imbrication in Mudjatik domain and thin-skin imbrication in Wollaston domain. D_4 ductile deformation creates NW-striking upright folds orthogonal to F_3 after movement on the Virgin River and Cable Bay shear zones.
1.80 to 1.72	Activation of the Tabbernor fault zone (1.8 Ga) and the D_5 steep-brittle faults observed within the Wollaston domain, extending into the Mudjatik domain.
1.72 to 1.5	Development of successor basins across parts of the Hearne craton, including formation of Athabasca basin.
< ca. 0.5	Deposition of Deadwood Formation in Phanerozoic Williston basin. Progressive infilling of Phanerozoic Western Canadian Sedimentary Basin in southern Saskatchewan and other regional areas.

Around 2.075 Ga, initial deposition of the Wollaston Supergroup took place in a passive to incipient rift setting on the eastern side of the Hearne craton. Between 1.92 and 1.88 Ga, deposition continued on the Hearne craton. To the east of the Hearne craton a series of tectonic assemblages, including the La Ronge-Lynn Lake arc and a series of arc oceanic assemblages coexisted in the Manikewan ocean. Late during this interval, the Manikewan ocean began closing, due to a subsequent reversal in the subduction polarity, bringing together various arc assemblages against each other and against the Hearne craton, resulting in the formation of the Wollaston domain in a back-arc basin setting and the Rottenstone magmatic arc. The collision and associated regional D_1 deformation overprint imparted an early (S_1) foliation within the felsic gneisses.

Ongoing subduction between ca. 1.88 and 1.865 Ga resulted in the accretion of juvenile island arc terranes (La Ronge-Lynn Lake) to the southeastern margin of the expanded Rae-Hearne craton forming the Rottenstone accretionary complex. During the same period of time, the Wollaston back-arc basin shifted to a foreland basin.

Final accretion of the La Ronge Arc along eastern margin of Rae-Hearne craton brought closure of the Wollaston basin (approx. 1.86 Ga) and emplacement of the Wathaman batholith sometime between ca. 1.865-1.855 Ga. Ongoing subduction between ca. 1.845 and 1.83 Ga was associated with the accretion of the Glennie-Flin Flon domain to the Hearne craton and the northward migration of the Sask craton micro-continent. The deformation involved underthrusting beneath the Rae-Hearne craton along the Pelican thrust, Duck Lake shear zone, Granville Lake structural zone, and Nistowiak thrust. A contemporaneous, ca. 1.865 to 1.83 Ga, D_2 ductile deformation event produced upright folds that overprinted the S_1 foliation.

Terminal collision with the Superior craton and final closure of the Manikewan ocean occurred between ca. 1.83 and 1.8 Ga. The collision produced the thick-skinned imbrication evident in Mudjatik domain and the thin-skinned imbrication evident in Wollaston domain. Deformation features that formed during this event of crustal shortening are assigned to the D_3 ductile deformation episode. D_3 created north-northeast-striking upright folds, dominant in the Wollaston domain, and resulted in D_3 activation (reactivation?) of the Needle Falls and Virgin River shear zones at ca. 1.83 Ga. Subsequently, D_4 ductile deformation created northwest-striking upright folds orthogonal to F_3. D_4 is poorly constrained in absolute timing but is interpreted to have post-dated the formation of the Virgin River and Cable Bay shear zones (e.g., Card et al., 2008c).

Later deformation involved the development of regional-scale brittle structure, including the Tabbernor fault zone (ca. 1.80 Ga, see Figure 3.1) and the steeply-dipping brittle faults observed within the Wollaston domain (see Figures 3.2 and 3.3). These brittle structures are assigned to the D_5 deformation phase. An additional brittle deformation event, D_6, may also be included in the deformation history. Although poorly constrained, the D_6 event is interpreted to encompass all post-1.695 Ga old brittle deformation events that overprinted the entire region. The dominant feature associated with D_6 is the large-scale Tabbernor fault system that has a long history of reactivation that may have continued until the Mesozoic Era (e.g., Byers, 1962; Elliott, 1996).

Mesoproterozoic rocks (i.e., approximately 1.6 Ga) of the Athabasca Basin nonconformably overlie Precambrian basement rocks approximately 40 km to the north of the ERFN area. The Athabasca Basin has an elliptical shape in map view, extending over 400 km in the east-west direction and over 200 km in the north-south direction. The basin consists primarily of fluvial sandstones derived from the Hudsonian mountains that were deposited in a shallow basin. The maximum thickness of the basin is about 1.5 km in the center of the basin (Card et al., 2010). The unconformity between the flat-lying and weakly deformed Athabasca Group and the highly strained underlying Archean basement rocks is where the uranium deposits of northern Saskatchewan are typically found (Jefferson et al., 2007).

Phanerozoic rocks (i.e., rocks younger than 541 million years old) of the Western Canada Sedimentary Basin nonconformably overlie Precambrian basement rocks over the entire southern half of Saskatchewan (Figures 3.1 and 3.3). The present day zero thickness erosional edge of the basin trends northwesterly across the province and the southwest corner of the ERFN area. Regional Phanerozoic depocentres of the Hudson Bay and the Western Canada Sedimentary basins, preserved to the northeast and south of the exposed Precambrian basement rocks in northern Saskatchewan, respectively, suggest that the sedimentary 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).

Paleozoic sedimentary rocks of Ordovician age (approximately 485 to 443 million years old) nonconformably overlie the Precambrian basement approximately 200 km southeast of the ERFN area. These rocks represent a remnant of the Cambrian to Devonian sedimentary succession that was deposited while much of the Churchill Province was inundated by shallow seas during the Paleozoic Era. Given the close proximity of the Western Canada Sedimentary Basin to the south and the apparent continuation of the sequence in the Hudson Bay area of Manitoba to the northeast suggests that the ERFN area was also previously covered by an undetermined amount of Paleozoic strata.

A long period of uplift, exposure and erosion separated the Paleozoic strata from the overlying Mesozoic strata (i.e., 252 to 66 million years old). The erosional edge of the Mesozoic succession cuts across the southwest corner of the ERFN area and is characterized by sedimentary rocks of Cretaceous age (i.e., 145 to 66 million years old). The Cretaceous strata were deposited during a series of regressions and transgressions of the Cretaceous sea over the western interior of North America (Mossop and Shetsen, 1994). The prior extent of Mesozoic cover in the ERFN area is uncertain. However, given the proximity of the erosional edge of these rocks, it is likely that coverage was extensive in the ERFN area.

3.1.3 Regional Structural History

The tectonic and structural history of the Hearne craton, as described above, includes several regionally distinguishable deformation episodes inferred to also have overprinted the bedrock geological units of the ERFN area (Byers, 1962; Munday, 1977a; Munday, 1978a; Tran and Smith, 1999; Card and Bosman, 2007; Yeo and Delaney, 2007; Card et al., 2008). Although the age of these deformations is difficult to determine precisely, within the Mudjatik and Wollaston domains, five phases of deformation (referred to as D_1 to D_5 below, with corresponding fold sets indicated by F_n, and foliation indicated by S_n) can be identified (Yeo and Delaney, 2007; Card et al., 2008), and are consistent with the geological history described in Section 3.1.2 above. The numbering system established by Card et al. (2008) is adopted here and in the following discussion.

There is some disagreement between different authors regarding the sequence of deformation events in this part of northern Saskatchewan. For example, a discrepancy in the application of the D_x terminology to distinct folding events whereby Annesley et al. (2005) do not appear to recognize the same number of folding events as were recognized by Card and Bosman (2007) and Card et al. (2008). The Annesley et al. (2005) study was undertaken in the area to the east of the Athabasca Basin, quite a distance further away from the ERFN area than the work undertaken by Card and Bosman (2007) and Card et al. (2008). For the discussion below, the primary sources for the interpretation was the report by Card and Bosman (2007) and Card et al. (2008). It is understood that this is only a preliminary interpretation for the ERFN area which may be altered during subsequent stages of the site evaluation process.

The earliest recognizable deformation event (D_1) resulted in supracrustal and felsic rocks being isoclinally folded. A prominent mineral foliation imparted by this phase, S_1, is a composite fabric defined by the compositional layering and alignment of metamorphic minerals. It also included rootless isoclinal hinges and rare boudins and intrafolial folds.

A second deformation (D_2) identified by Card et al. (2008) is marked by rare intrafolial folds with hinges defined by the S_1 foliation. Card and Bosman (2007) indicate D_2 involved the development of upright, northwest-trending F_2 folds that re-oriented the S_1 fabric in an area to the north of the ERFN area. Little information is available regarding this event, and it was not reported in earlier studies (e.g., Munday, 1978a).

The third deformation event, D_3, was characterized by the development of upright, north-northeast-trending folds that also reoriented the S_1 foliation. The north-northeast-trending F_3 fold limbs generally tighten towards the Virgin River and Cable Bay shear zones to the northwest of the ERFN area and towards the Needle Falls shear zone near the southeast corner of the ERFN area. The folds are more open within most of the Mudjatik domain away from the zones of higher strain.

The Virgin River, Cable Bay and Needle Falls shear zones developed late during or after the D_3 event, as evidenced by the shear displacement along F_3 fold limbs, but prior to the development of a second (weak) phase of northwest-trending folds (F_4), during a localized D_4 event in the westernmost part of the Mudjatik-Virgin River domains. The shear zone deformation is therefore ascribed to a D_3 event. Card et al. (2008) noteed that the F_4 folds are orthogonal to the north-northeast-trending F_3 fold axial planes. The result of these two orthogonal-folding events was the development of a local dome-and-basin pattern outlined by the re-oriented S_1 fabric in the westernmost part of the Mudjatik domain. Card and Bosman (2007) and Card et al. (2008) suggested that these F_4 folds postdate the Virgin River and Cable Bay shear zones and are likely of Trans-Hudson age.

Brittle D_5, deformation resulted in a late series of dominantly north- to north-northwest-trending faults that bisect the ERFN area, and cross-cut the structures associated with the D_1 to D_4 events (Figure 3.3). These features have likely had a long history of reactivation consistent with the interpretation that they are related to the Tabbernor fault system located about 150 km to the east of the ERFN area (Figure 3.1). The orientations of D_5-related lineaments are dominantly north-northwest and minor east-northeast sets (Figure 3.3), possibly associated with movement along the north-south-striking Tabbernor fault. The Tabbernor fault initially formed during the Trans-Hudson Orogeny approximately 1.83 Ga, but has likely had more recent periods of reactivation, as features in overlying sedimentary rocks and apatite fission tracking indicate reactivation of the fault in the late Devonian and early Cretaceous Periods (Elliot, 1996; Davies, 1998; Hajnal et al., 2005).

3.1.4 Mapped Regional Structure

The most prominent structural features in the ERFN area are the domain-bounding shear zones and brittle faults that overprint these shear zones (Figure 3.3).

The Hearne craton is bounded to the west by the Rae craton along the Snowbird tectonic zone, and is bounded to the east by the Reindeer zone along the Needle Falls and Parker Lake shear zones. These shear zones are oriented in a north-northeast to northeast direction, which is the predominant alignment of major structural features and lithologies within the Precambrian in Northern Saskatchewan.

The Cable Bay shear zone is a crustal scale feature that designates the boundary of the Mudjatik domain with the Virgin River domain to the west. It has a width of 200 to 300 m (Gilboy, 1985), and a length of more than 200 km, extending from just north of the Western Canada Sedimentary Basin to the middle of the eastern portion of the Athabasca Basin (Card and Bosman, 2007), and exhibits a significant aeromagnetic anomaly. The Cable Bay shear zone does not occur within the English River First Nation reserve area being considered in this assessment, but it is interpreted to continue under the Athabasca Basin in the Cree Lake area. The Cable Bay shear zone does not appear to be a major lithologic boundary (Card and Bosman, 2007). Based on geophysical evidence, it is sub-vertical with a steep dip to the northwest (Card, 2012b).

The Needle Falls shear zone is a crustal scale feature that extends for over 400 km separating the Hearne craton to the west and the Wathaman batholith to the east (Figures 3.1 and 3.2) (Stauffer and Lewry, 1993). The mylonites associated with this zone were derived from the adjacent Wathaman batholith (Stauffer and Lewry, 1993). Seismic imaging and mapping by Coombe (1994) suggests this feature dips steeply to the west (Lewry et al., 1994). Field evidence suggests that the shear zone developed late, during the main phase of the Trans-Hudson Orogeny, between approximately 1.83 and 1.80 Ga, with a (most recent) dextral movement of 40 to 60 km (Stauffer and Lewry, 1993; Orrell et al., 1999; Hajnal et al., 2005). This most recent movement is bracketed by the emplacement of the Wathaman batholith at approximately 1.865 Ga and post-orogenic uplift and cooling which was likely complete by 1.79 Ga for the Trans-Hudson Orogeny (Stauffer and Lewry, 1993).

The results of geophysical surveys conducted as part of the Lithoprobe Trans-Hudson Orogen transect (White et al., 2005) suggest the presence of two sub-horizontal to low-dipping (to the east) faults at depths of about 5 km and 13 km beneath the Mudjatik domain (Figure 3.2). The mapped contact between the Archean basement rocks and the metasedimentary rocks of the Wollaston domain may also be associated with some faulting. It should be noted that the above faults were identified for a transect located 50 to 100 km south of the ERFN area and should therefore be only considered an indicator of possible conditions within the ERFN area.

A series of steeply dipping faults that cross cut a series of sub-horizontal faults are noted at the east end of the Wollaston domain, close to the (subvertical) Needle Falls shear zone (White et al., 2005). These steep faults were interpreted by Hajnal et al. (2005) to be the north-northwest-trending faults discussed below (i.e., part of the Tabbernor fault system). Hajnal et al. (2005) further noted numerous east-dipping fracture zones within the upper portions of the Wollaston domain. These features were also noted along the east side of the Mudjatik domain, but are much less abundant to absent in the central to western portions of the Mudjatik.

A series of steeply dipping and north-northwest-trending brittle faults that cross-cut a series of sub-horizontal faults are noted at the east end of the Wollaston domain, close to the Needle Falls shear zone (Figures 3.2 and 3.3) (White et al., 2005). The longest of these brittle structures are over 120 km in length and appear as prominent topographical lineaments. They have been associated with brecciation, shearing, mylonitization and hydrothermal alteration (Byers, 1962). Sinistral horizontal displacement of up to 800 m is observed along the faults, and geophysical interpretations suggest near vertical dips for the fault planes. Some evidence suggests that reactivation and displacement has occurred along these faults as recent as the Cretaceous period (Byers, 1962). These steep faults were interpreted by Hajnal et al. (2005) to be the north-northwest-trending faults discussed above (i.e., part of the Tabbernor fault system (discussed below)). Another prominent trend of relatively long mapped (D_5) faults is east-northeast to east-southeast (Figure 3.3). These faults are much less pervasive and relatively sparsely populated throughout the area compared to the more prominent north-northwest-trending faults discussed above.

The Tabbernor fault zone is a north-south trending topographical, geophysical and geological lineament (Figure 3.1) that extends a lateral distance greater than 1,500 km from the Northwest Territories to the states of North and South Dakota (Giroux, 1995). Based on geophysical evidence, the fault zone extends to a depth of approximately 30 km (White et al., 2005). In Saskatchewan, the fault has a north-south strike and displays sinistral movement. Several researchers have discussed evidence that the Tabbernor fault zone was active as recently as the Phanerozoic Era (Davies, 1998; Elliot, 1996; Kreis et al., 2004). This is suggested by an outlier of Ordovician dolomite positioned 150 m below the projected base of the unconformity. Parallel glacial striae indicate that the more recent deformation occurred before the last glaciation (Elliot, 1996). In addition, features in overlying sedimentary rocks and apatite fission track analyses indicate reactivation of the fault in the late Devonian and early Cretaceous periods (e.g., Byers, 1962).

3.1.5 Metamorphism

The Mudjatik and Wollaston domains belong to the Western Churchill Province (Corrigan et al., 2009). As such, all Archean and Paleoproterozoic rocks of the Mudjatik and Wollaston domains record part of the regional metamorphism to which the Churchill structural province was subjected to. The metamorphic overprint of the Trans-Hudson Orogeny on the Superior Province was primarily focused within a restricted zone along the western border of this craton. Conversely, the metamorphic effects of the Trans-Hudson Orogeny on the western Churchill Province were substantially more profound (Corrigan et al., 2009) and involved substantial reworking of the internal portions of the orogen (e.g., Reindeer zone) and the hinterland (Hearne craton). For example, in the exposed area of the Reindeer zone near the Saskatchewan-Manitoba border, high-temperature metamorphism, widespread anatexis and migmatization (e.g., Ansdell et al., 1995; Lucas et al., 1996; Gale et al., 1999; Machado et al., 1999) attest to the occurrence of a pervasive regional-scale metamorphic overprint.

Rocks of the Hearne craton (Mudjatik domain and Wollaston domain) were exposed to high-grade metamorphism, reaching upper amphibolite to granulite facies (e.g., Pearson, 1977a; Tran, 2001). Orrell et al. (1999) proposed that all metamorphic fabrics observed in the Hearne craton were the result of a single thermotectonic cycle caused by the Trans-Hudson Orogeny. This view has been disputed by other authors (e.g., Bickford et al., 1994; Tran, 2001) who have interpreted the high-grade metamorphism undergone by the rocks of the Hearne craton as having occurred during two distinct periods of high temperature, low pressure metamorphism. It is quite possible though that M_2 may have occurred as a continuum of substages rather than occurring as a single event; for example, Annesley et al. (2005) reported three metamorphic events associated to the peak of the Trans-Hudson Orogeny.

The timing of the first metamorphic event has remained poorly constrained, mostly due to lack of evidence by almost complete overprinting of M_1 by M_2. For example, Tran (2001) proposed underplating of the Hearne craton associated to the beginning of rifting in its eastern margin as a source for M_1, which would place a minimum age of approximately 2.075 Ga for M_1 (Ansdell et al., 2000). Bickford et al. (1994) in turn suggested that thermotectonic reworking could have occurred as early as approximately 2.3 Ga, possibly associated to the Thelon Orogeny, whereas Annesley et al. (2005) suggested two granulite-facies metamorphic events around 2.689 Ga and 2.566 Ga, respectively. Although the timing may remain elusive, M_1 seems to have begun before peak D_1 conditions and to have outlasted them (e.g., Tran, 2001; Card et al., 2006; Card and Bosman, 2007).

The second metamorphic period occurred concomitantly with the peak of the Trans-Hudson Orogeny, during the approximate period 1.84 to 1.80 Ga, and later outlasted it (Tran, 2001). This interval overlaps the D_2 to D_4 deformation interval described in Sections 3.1.2 and 3.1.3 above. Orrell et al. (1999) calculated peak metamorphic conditions at 750 ±50°C and about 5.5 kbar. These values agree very well with those estimated by Tran (2001), 725°C and a maximum pressure of 5 kbar followed by decompression to >600°C and >3.4 kbar, and those estimates of Annesley et al. (2005) for three stages comprising initial pressure conditions of >4 to 5 kbar, increased to 6 to 9 kbar at >775°C and later followed by decompression at 3 kbar and increased temperatures of 750 to 825°C.

3.1.6 Erosion

There is no site-specific information on erosion rates for the ERFN area. Past studies reported by Hallet (2011) and McMurry et al. (2003) 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 about 2 metres per 100,000 years (Merrett and Gillespie, 1983). Higher erosion rates are associated with glaciation. The depth of glacial erosion depends on several regionally specific factors, such as the ice geometry, topography, and local geological conditions, such as overburden thickness, rock type and pre-existing weathering.

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

3.2 Local Bedrock and Quaternary Geology

Information on local geology for the ERFN 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 preliminary assessment (PGW, 2013). Findings from the geophysical, lineament and terrain analysis studies carried out as part of the preliminary assessment of the ERFN area (JDMA, 2013a; JDMA, 2013b; and PGW, 2013) are integrated in this assessment to provide insight on the lithological variability, structures and extent of the overburden cover for areas considered in the ERFN area.

3.2.1 Bedrock Geology

The initial screening study (Golder, 2011) identified the felsic gneiss of the Mudjatik and Wollaston domains as geological environments that could contain potentially suitable areas to host a deep geological repository site. A brief description of the felsic gneiss and other predominant lithologies in the Hearne craton are included below. Local bedrock geology of the ERFN area is shown on Figure 3.4.

3.2.1.1 Felsic Gneiss

Felsic gneiss is the predominant rock type found in the Mudjatik domain and covers a substantial portion of the Wollaston domain. The term *felsic gneiss* was first used by Sibbald (1973) to describe a complex group of rocks of broadly granitic composition (noting that it was before appearance of Streckeisen (1976) terminology), in which the minerals quartz, plagioclase and K-feldspar range between 10% to 40% with minor components of biotite, hornblende, hypersthene, garnet, cordierite, and magnetite, and which fabric covers a broad range between well-developed layering, including *lit par lit*, to massive unfoliated domains. Harper (1988a, b) later refined this term by classifying the felsic granitoid gneisses in central and northwestern Mudjatik domain in three different units: tonalitic orthogneiss, generally-layered felsic gneiss of probable supracrustal origin, and granite and granite pegmatite; whereas Card et al. (2008) considered them all to be orthogneisses. While the first two lithologies are thought to underlie the supracrustal rocks, mainly metasedimentary gneissic rocks, the latter intrude them all. Although the exact thickness of the felsic gneiss in the ERFN area is unknown, regional geophysical studies (Hajnal et al., 2005; White et al., 2005) have interpreted its thickness to be in the range of 5 to 10 km in the Mudjatik domain. The Archean felsic gneiss has an approximate crystallization age of approximately 2.7 Ga (Orrell et al., 1999).

Tonalitic gneiss is the predominant lithology in the felsic gneiss. According to Harper (1988a, b), the tonalitic gneiss is grey, coarse-grained, and has well developed swirly foliation. Presence of hypersthene indicates that the tonalitic gneisses were subjected to granulite-facies metamorphism. In some areas, the tonalitic gneisses may be accompanied by scattered rafts evidencing high-grade migmatization. The tonalitic gneiss is thought to be of igneous origin (orthogneiss), with a crystallization age dated at approximately 2.7 Ga (Orrell et al., 1999).

The layered felsic gneiss is largely migmatitic in nature (Harper, 1988b; Orrell et al., 1999). According to Harper (1988b), the paleosome is colour-banded and layered, fine-grained, granoblastic equigranular, predominantly biotitic and quartzofeldspathic, of probable psammitic to psammopelitic origin; although, Card et al. (2008) considered it to be of dominantly tonalitic composition. The neosome resulting from extensive anatexis of the paleosome is a coarser-grained, equigranular, massive to weakly foliated leucogranite, occurring either in fine-banded parallel veins or in irregular masses.

The youngest components of the felsic gneiss are leucogranites and granite pegmatites. Harper (1988b) described the granites as pink to red, varying from fine to coarse to porphyiritic in texture, while typically being massive to weakly foliated. He suggested their emplacement as sheet-like bodies into migmatite nappe lobes before the occurrence of dome-and-basin folding. Contact with the other two types of rock is generally gradational, and the transition from the layered gneiss is characterized by progressive increase in neosome and exclusion of supracrustal relics. Finally, pink granite pegmatite intrudes all other gneissic rocks and occurrs as irregular veins in the granites.

Very similar lithologies to the three ones above described by Harper (1988 a, b) have been reported by Orrell et al. (1999) and Card et al. (2008) for northwestern Mudjatik domain, and partly by Card and Bosman (2007) close to the southern border of the Athabasca basin. Variation to granodiorite from the dominant tonalitic lithology has been reported by Tran (2001) in the eastern Mudjatik domain-western Wollaston domain and by Card and Bosman (2007) and Card et al. (2008) in the northwest of the domain, and Card and Bosman (2007) to the north.

3.2.1.2 Metasedimentary and Metavolcanic Rocks

Mafic gneiss is the second most common rock type in the Mudjatik domain. These rocks occur in folded arc-shaped bands, narrow septa and pods within the felsic gneiss. Due to the extensive reworking to which they have been subjected, their origin and age is unknown. For example, Card and Bosman (2007) found differences not only between rocks at Cree Lake and other parts of Mudjatik domain, but also they found no similarity between rocks of the Mudjatik domain and those of the Wollaston Supergroup. Card et al. (2008), however, interpreted them as parts of the same depositional system of the basal Wollaston Supergroup (i.e., the Courtney Lake Group).

Mafic gneiss is found mainly as psammitic to pelitic gneiss, less amphibolite, and subordinate iron formation; hypersthene-bearing mafic granulite (metavolcanics); subordinate quartzite and calc-silicate, possibly associated stratigraphically (Lewry and Sibbald, 1980; Harper, 1988 a, b; Card et al., 2008). Ultramafic intrusions are more common toward the central portion of the Mudjatik (Harper, 1988a, b).

The Wollaston Supergroup consists of a sequence of four unconformity-bounded Paleoproterozoic siliciclastic metasedimentary groups that include minor carbonate and metavolcanic rocks (Yeo and Delaney, 2007). The rocks display generally gneissic fabrics. Gneissic rocks including quartz monzocharnockite, a monzonite-granite-granodiorite suite, a granodiorite-tonalite suite, amphibolite and a heterogeneous assemblage of intrusive and metasedimentary rocks serve as basement to the Wollaston Supergroup (Tran et al., 1999; Yeo and Delaney, 2007).

The Daly Lake and Geikie River Groups make up most of the Wollaston Supergroup. The former group comprises a succession of gneiss, pelite and psammopelite, arkose and quartzite. The latter group comprises a finer grain upward succession of conglomerate, arkose, calc-silicate-bearing arkose, calc-silicate rock and marble (Yeo and Delaney, 2007).

3.2.1.3 Distribution of Rock Types within Sub-Regions

The English River First Nation reserves and their proximate surroundings have been grouped into the Sub-Regions defined in Section 2.1, as shown on Figure 1.1. Region 2.1 includes the Haultain Lake IR area, Region 2.2 includes the Flatstone IR and Porter Lake IR areas, and Region 2.3 includes the Dipper Rapids IR, Primeau Lake IR, Knee Lake IR and the Elak Dase IR areas. The local bedrock geology of these sub-regions is shown on Figures 3.5, 3.6 and 3.7, respectively.

The ERFN area occurs primarily within the Mudjatik domain, comprising the Haultain Lake IR, Porter Lake IR, Flatstone Lake IR, Dipper Rapids IR, Primeau Lake IR and Knee Lake IR in this geological zone. The exception is the Elak Dase IR, which is situated within the Wollaston domain (Figure 3.4). Table 3.2 provides a summary of the primary rock types found in each sub-region. The following sections present the local bedrock geology present in each of the three sub-regions. Where more than one reserve area exists, the sub-region is further divided for the purposes of addressing each in detail. The local bedrock geology of Sub-Regions 2.1, 2.2 and 2.3 is shown on Figures 3.5, 3.6 and 3.7, respectively.

Analysis and description of the different rock types in the potentially suitable areas was aided by a geophysical study carried out in 2012 (PGW, 2013). Geophysical data used is of regional quality throughout most of the ERFN area (PGW, 2013). Two higher resolution magnetic (and radiometric) surveys provide improved coverage at the northwest and northeast corners of the ERFN area. In these areas, airborne geophysical data is available on 400 m line spacings, and covers the eastern third of Sub-Region 2.1. For the balance of the ERFN area, the geophysical data is regional, on 805 m or 1609 m line spacings. The total magnetic field and the first vertical derivative of the residual magnetic field over the ERFN area are shown on Figures 3.8 and 3.9, respectively. The regional Bouguer gravity data is shown on Figure 3.10.

Table 3.2: Summary of Rock Types within the English River First Nation Reserve Areas Located on the Canadian Shield

Sub-Region	English River First Nation Reserve Area	Rock Types Present
Sub-Region 2.1 (Figure 3.5)	Haultain Lake IR	Felsic gneiss
Sub-Region 2.2 (Figure 3.6)	Flatstone Lake IR	Felsic gneiss
	Porter Lake Island IR	Felsic gneiss, minor metasedimentary gneissic rocks (pelitic/psammopelitic gneiss) and amphibolite
Sub-Region 2.3 (Figure 3.7)	Dipper Rapids IR	Felsic gneiss
	Primeau Lake IR	Alaskite (alkali feldspar granite), minor felsic gneiss and metasedimentary gneissic rocks (pelitic/psammopelitic gneiss)
	Knee Lake IR	Felsic gneiss and metasedimentary gneissic rocks (pelitic/psammopelitic gneiss)
	Elak Dase IR	Felsic gneiss and metasedimentary gneissic rocks (pelitic/psammopelitic gneiss)

Sub-Region 2.1

Haultain Lake IR Area

Sub-Region 2.1 is located in the northeast corner of the ERFN area and straddles the boundary between the Mudjatik and Wollaston domains. With reference to Figure 3.5, the main rock type found within the Haultain Lake area is the Archean felsic gneiss unit, interspersed in some places with arc-shaped bands of metasedimentary gneissic rock, which increases in frequency towards the west of Haultain Lake (Munday, 1977a, b, c). Psammitic metasedimentary rocks of the Wollaston domain are located approximately 5 km to the east of Haultain Lake.

The bedrock surrounding the Haultain Lake area was mapped at a scale of 1:100,000 by Munday (1977a,b,c), while Tran et al. (1999) mapped the McKenzie Falls area, some 40 km south of the Haultain Lake IR. To the south of Haultain Lake, there is a 500 km^2 area of interest, composed of relatively homogenous bedrock. Munday (1977a) described the rock within this area as felsic gneiss with a granitic to granodioritic composition, pink to grey, containing two types of feldspar minerals, while mafic minerals dominantly biotite and hornblende possibly constituting up to 20% of the rock volume, but mostly up to 10% of it. Predominant supracrustal rocks are psammitic metasedimentary rocks and biotitic pelitic gneisses with accessory metamorphic minerals.

The complexity in lithology across the area tends to be variably reflected in the aeromagnetic data (Figures 3.8 and 3.9). The magnetic response is predominantly coincident with the mapped distribution of felsic gneiss of the Mudjatik domain in the western two thirds of the sub-region, which shows a relatively weak magnetic signal with subtle variability of the magnetic field intensity. Although minor amounts of pelitic, psammitic and psammopelitic gneiss are mapped locally, they do not tend to dominate or influence the magnitude and variability of the magnetic data. Much of this area is characterized by a magnetic low located to the south and southwest of the Haultain Lake IR. Although this response is consistent with the felsic gneiss mapped in the area, it does not appear to be consistent with the magnetic response shown by the felsic gneiss mapped in other regions of the ERFN area. The lower magnetic response in this area may reflect source rocks with lower magnetite content, or which have undergone secondary alteration along the boundary of the Wollaston domain. The division between the high resolution aeromagnetic data to the east and the low resolution data to the west runs through the center of this magnetic low, and the response appears consistent on either side of the division. Towards the northwest, the aeromagnetic response is moderately noisy, showing some domal structures in the Mudjatik domain (PGW, 2013). The aeromagnetic response increases and becomes noisy further east into the Wollaston domain, showing a more linear, north-northeast-trending fabric. The Bouguer gravity field is relatively high in Sub-Region 2.1; this could be a reflection of higher density rocks of the Wollaston domain along the eastern side of the sub-region, an increase in thickness, or possibly an underlying source at depth (Figure 3.10).

The nearest boreholes to the area are located approximately 15 km south of Haultain Lake, adjacent to the Key Lake Road. Two exploration drilling investigations were conducted in this area by Forum Uranium Corporation as part of the Key Lake Road Project between 2006 and 2008 (Tan, 2007; Tan and Wheatley, 2007; Tan and Wheatley, 2008).

Archean rocks encountered in the Key Lake area during these investigations are described as foliated, pink granite gneiss with 30 to 50% quartz, 20 to 50% feldspar, and up to 10% biotite and hornblende in composition. Layers of gabbro/amphibolite occur within the gneiss, ranging from a few metres to several tens of metres in thickness. These layers are composed of 30 to 50% amphiboles and hornblende, 30 to 50% plagioclase, and up to 5% each quartz, biotite and pyroxene. The metasedimentary rocks of the Wollaston Supergroup were described primarily as pelitic gneiss and overlying arkosic metasedimentary units.

The first drilling investigation targeted an area that spans the Mudjatik domain and the Wollaston domain. A shear zone (identified as the Key Lake Road shear zone by Annesley and Madore (1989)) is located at the transitional boundary between the Mudjatik and Wollaston domains, and extends to the north and south of the property. Fourteen boreholes advanced as part of this investigation found uranium mineralization was intersected within hematitic breccias, pegmatite and graphitic pelitic gneiss in the hanging wall of what was referred to as the C1 conductor. Borehole lengths of this investigation ranged from 102 m to 203 m, all drilled at a dip of 53°. The pelitic gneiss was found to be strongly sheared, fault-gouged and with presence of massive graphite. Strong clay alteration was also observed. An intense hydrothermal alteration zone was consistently identified at the contact between metasedimentary rocks and Archean granite. A strong fault zone was intersected in one area, with hydrothermally altered hematitic and kaolinitic clay infill material encountered in the same borehole. Based on the geological conditions above and considering that it constitutes a major alteration corridor, it was concluded that the C1 conductor was similar to the other uranium deposits in the Athabasca Basin and may have potential for an economical uranium deposit.

A subsequent 28 borehole drilling investigation conducted in 2007 and 2008 intersected spotty, low grade uranium mineralization hosted by fractures and breccias within graphitic pelitic gneiss. Borehole lengths of this investigation ranged from 71 m to 317 m, with dips ranging from 50° to 65°. Anomalous radioactivity was noted in a strongly chloritized pelitic gneiss with uranium mineralization. An area with several pegmatite uranium occurrences and a notable thrust fault was also found. The uranium mineralized area is centred on what appears to be a dominant (D_3) synform. The synform is large, with a distance of about 8 km to the peak of the adjacent antiform to the southeast. There is a significant margin on either side of the area of interest before relatively complex geology is encountered. Approximately 5 km to the west of this mineralized area, the dome-and-basin structure becomes apparent and is associated with interspersed arcs of mafic gneiss. Similar conditions are encountered to the south of the mineralized area. Felsic gneiss remains the predominant rock type in this eastern area, with an increasing occurrence of pelitic metasedimentary rocks as the contact with the Wollaston domain is approached (Figure 3.5).

Evidence of brittle deformation is displayed by an offsetting fault through a basin defined by bands of mafic gneiss and psammitic metasedimentary rocks. This feature is observed at Basin Lake, located approximately 40 km southwest of Haultain Lake. The fault has an azimuth of 335º, which is similar to the inferred regional pattern of faults (Figure 3.3). As described earlier, these north-northwest-striking lineaments are interpreted to correspond to D_5 brittle structures.

Sub-Region 2.2

Porter Lake Island IR Area

Porter Lake is located in the south-central area of the Mudjatik domain (Figures 3.4 and 3.6). Pearson (1977a, b) mapped the area surrounding Porter Lake at a scale of 1:100,000. This included a 55 km (in the north-south direction) by 30 km (in the east-west direction) area on the east side of the Mudjatik River with exposed bedrock. Bedrock exposure on the west side of the Mudjatik River is sporadic, with the area being mostly covered by drift (Pearson, 1977b). Further mapping of Harper (1988b) concentrated in the upper right quadrant of Pearson's (1977b) mapped area.

Felsic orthogneisses in this area are fine to medium grained, light coloured and granoblastic. Predominant supracrustal rocks are mafic gneisses and pelitic gneisses. The general occurrence of foliation in the felsic gneiss of the Porter Lake area is generally consistent with aeromagnetic data for the sub-region which shows a large area to the west of Porter Lake that is characterized by a quiescent response consistent with the mapped felsic gneiss (Figures 3.8 and 3.9). Mafic gneiss in the Porter Lake area consists mainly of hypersthene-bearing granulites (Harper, 1988b). Hypersthene-bearing mafic granulites, considered by Harper (1988a) as amphibolite in this area due to the high content of hornblende, are grey to black, medium- to coarse-grained, granular, foliated to massive, and of volcanic origin (Harper, 1988a,b).

Aeromagnetic data in the Porter Lake area suggest that the bedrock geology may exhibit more lithological heterogeneity, reflected in the abundance of curvilinear ductile structures that are not present on the bedrock geology map (Figures 3.8 and 3.9). Few of these ductile structures tend to correlate with mapped psammitic and pelitic gneiss units, and some correlate well with amphibolite gneiss. The remaining curvilinear structures do not reflect changes in lithology as shown on the bedrock geology map. Although mapping by Harper (1988b) implies the bedrock is dominated by felsic gneiss, the aeromagnetic data for the sub-region may provide some evidence of more widespread inclusion of these supracrustal rocks, perhaps at depth, through the Porter Lake area (PGW, 2013). However, these curvilinear features may simply reflect alternating magnetite content within ductile deformed features within similar lithological unit.

The eastern half of the area mapped by Pearson (1977a, b) displays a history of ductile deformation. The dome-and-basin structure that is characteristic of the Mudjatik domain is well defined in the Porter Lake area. These ductile structures are defined by foliation in the felsic gneiss and accentuated by bands of the amphibolite and mafic gneiss rocks. They are also evident in the aeromagnetic data shown on Figures 3.8 and 3.9. One of the clearest examples of these structures is the Porter Lake dome which surrounds the eastern portion of the lake. The Porter Lake dome is relatively symmetrical and characterized by gently dipping walls with rock foliation that follows the contours of the dome (Shklanka, 1957; Pearson, 1977b). Further west and south, the intensity of folding appears to decrease with the domes becoming broad and gentle.

The foliation visible in aerial photographs and noted on the available bedrock geology maps define the-dome-and-basin structure in the area corresponding to D_3 and D_4 deformational events. Relatively less apparent deformation and mafic occurrences are noted to the west and south of Porter Lake. This includes an area between Porter Lake and the Mudjatik River. Only one north-northwest-striking fault was noted by Pearson (1977b) in this area. The felsic gneiss appears to be less intensely folded in this area of interest, and with the exception of one band of mafic rock at the south end of Porter Lake, may be relatively homogeneous. For example, a 7 km by 20 km block of rock is located immediately west of Porter Lake (at Kirby Lake). Additionally, an 8 km (in the east-west direction) by 20 km (in the north-south direction) block of relatively homogeneous rock is located immediately south of Porter Lake. Foliation in this block of rock suggests that this area may consist of a large, elongated basin structure. Pearson and Lewry (1974) interpreted a north-northeast-trending synformal axis running through the center of this area.

Brittle deformation in the area is characterized by a series of long, well-spaced faults trending north-northwest. A (20+ km long) fault skirts the east side of the Porter Lake dome with a strike of 155º. Two more sub-parallel faults are noted by Pearson (1977b), spaced approximately 12 km further to the northeast. One of these faults extends approximately 20 km through Holt Lake and Fault Lake, also with a strike of about 155º.

Flatstone Lake IR Area

Flatstone Lake is located about 20 km southwest of Porter Lake (Figure 3.6). It is situated on the west side of the Mudjatik River in an area characterized by relatively extensive drift cover. Bedrock exposure around the lake is sporadic.

Based on the available outcrop in the area, the bedrock in the immediate area surrounding Flatstone Lake consists of felsic gneiss similar to that described above for the Porter Lake area. A band of mafic gneiss and metasedimentary rocks is located to the northwest of the lake, indicating that the underlying structure is likely of similar complexity to that in the area east of Porter Lake (Pearson, 1977b).

The nearest bodies of rock that may be of interest to this assessment are located on the east side of the Mudjatik River and correspond to the same bodies of rock described above for Porter Lake.

Sub-Region 2.3

Dipper Rapids IR Area

The Dipper Rapids area is located along a chain of lakes comprising the Churchill River near the south end of the ERFN area. The Dipper Rapids area consists of lowlands, through which the Churchill River flows, and are infilled with bogs and glaciofluvial materials deposited in the Quaternary Period (discussed further in Section 3.3). Throughout this southern portion of the ERFN area, much of the bedrock is obscured by overburden cover. Bedrock mapping at a scale of 1:63,360 undertaken by Scott (1977a, b) in the Dipper Lake area indicates relatively limited (approximately 10%) bedrock exposure with some sporadic outcrops at the south end of the lake. Greater bedrock exposure associated with higher elevations is located to the north of the chain of lakes (i.e., towards Porter Lake). The northernmost extent of Palaeozoic sedimentary rocks mark the southern boundary of the area being considered, about 7 km southwest of Dipper Lake.

Being within the Mudjatik domain, the Dipper Rapids area lies on abundant exposed Archean felsic gneiss (Figure 3.7). The oldest rocks in the area, which are known as the Dipper Lake Complex, consist of pink, fine-grained, feldspar-rich, felsic gneiss, including charnockite and amphibolites similar to those described for the Porter Lake area above. These rocks have been partially retro-metamorphosed from granulite to amphibolite facies (Scott, 1977a). The felsic gneiss displays weak compositional banding with its gneissosity defined by the preferred orientation of biotite. Additionally, the felsic gneiss is commonly intruded by (alaskite) granite, and has been mapped as migmatite where the rock contains 25% to 50% granite. The intruding granite is distinguished by its dark quartz and massive appearance (Scott, 1977a).

Felsic gneiss, charnockite, migmatite and alaskite granite form north-northeast-trending bands within the Dipper Lake complex, at the south end of Dipper Lake (Figure 3.7). Based on Rb/Sr dating, the charnockitic gneiss rock within the Dipper Lake Complex is 2.670 Ga and the intruding alaskite granite is approximately 1.826 Ga (Cumming and Scott, 1976).

Elongated folds in the area trend primarily in a north-northeast direction. These folds range from open to isoclinal and correspond to the third phase of folding in the area (Pearson and Lewry, 1974; Scott, 1977a). Scott (1977a) suggested that the bands of rock observed at the south end of Dipper Lake comprise the west limb of an anticline with its core centered through Primeau Lake and extending to Knee Lake. With the exception of mild, local cataclasis on the east side of Dipper Lake, no evidence of faulting has been observed in the area (Scott, 1977a). This is likely due to the limited bedrock exposure in the area, especially in the south.

Primeau Lake IR Area

Primeau Lake is the next community on the Churchill River downstream of Dipper Rapids (Figure 3.7). Similar to the above, this lowland area is occupied by bogs and glaciofluvial materials deposited in the Quaternary Period (Section 3.3), which conceals much of the bedrock. Bedrock mapping at a scale of 1:63,360 undertaken by Scott (1977a,b) in the Primeau Lake area indicates relatively limited (i.e., 10%) bedrock exposure with some sporadic outcrops at the south end of the lake near Faibish Bay. Larger areas of outcrop are located to the north of the lake. The northernmost extent of Palaeozoic sedimentary rocks marks the southern boundary of the ERFN area and is located about 8 km southwest of Primeau Lake.

The dominant rock type in the Primeau Lake area is alaskite granite, which occupies the core of the north-northeast-trending anticline that spans the Dipper Lake to Knee Lake areas (Figure 3.7). This rock is exposed in a 3 km wide area north of Primeau Lake, extending approximately 12 km toward the northeast. Smaller (~1 km^2) outcrops are located to the south of Primeau Lake on the east shore of Faibish Bay. According to Scott (1977a), this rock is fine to medium grained, pink in colour and massive to foliated in texture. It contains clear dark quartz grains and less than 5% mafic minerals. The quartz grains are strained sufficiently to display a planar fabric that can include biotite, hornblende and garnet (Scott, 1977a; Thomas and Slimmon, 1985). It can also have inclusions of felsic gneiss, pelitic gneiss and amphibolite (Thomas and Slimmon, 1985), and the contact of the alaskite with the surrounding felsic gneiss is generally sharp (Scott, 1977a). This unit has been dated at approximately 1.826 Ga (Cumming and Scott, 1976), intruding the older rocks of the Dipper Lake Complex. In contrast, the felsic gneiss comprising the fold limbs on either side of the core of alaskite granite has more mafic minerals with better defined compositional banding, and the quartz crystals have a cloudy appearance. Elongated pods of migmatite, consisting of 25% to 50% alaskite granite, have been mapped within the core of the north-northeast-trending anticline.

No evidence of faulting has been observed in the immediate surroundings of Primeau Lake (Scott, 1977a). This is likely due to the limited bedrock exposure in the area, especially to the south of the Churchill River. The nearest mapped fault is located approximately 5 km east of the northernmost point of mapped alaskite granite and is oriented generally east.

Knee Lake IR Area

Knee Lake is the last lake along the Churchill River before it flows out of the ERFN area. Bedrock mapping at a scale of 1:63,360 undertaken by Scott (1977a,b) and Munday (1978b) in the Knee Lake area indicates better bedrock exposure compared to the other communities upstream along the Churchill River, especially to the north of the lake. Extensive overburden cover extends to the south and southwest of the lake. The northernmost extent of Palaeozoic sedimentary rocks that marks the southern boundary of the ERFN area are located about 10 km southwest of Knee Lake.

The eastern limb of the anticline that is observed in the Dipper Rapids and Primeau Lake areas is located along the west side of Knee Lake (Figure 3.7). These rocks consist of felsic gneiss containing pods and bands of alaskite granite, charnockitic rock and migmatite (Scott, 1977a,b; Munday, 1978b) as described earlier. This area corresponds to the most magnetically quiescent portion of Sub-Region 2.3 (Figure 3.8).

To the northeast of Knee Lake, the dome-and-basin structure becomes again apparent (Munday, 1978b). These structures are associated with bands of amphibolite (as in the Porter Lake area), calc-silicates and psammitic rocks. The calc-silicates are medium-grained and consist of a wide range of felsic and mafic minerals, commonly containing equal parts of diopside and feldspar, with lesser amounts of hornblende, actinolite, biotite, quartz scapolite and calcite. The psammitic rocks consist of fine- to medium-grained meta-arkose and quartzite (Munday, 1978b).

Elak Dase IR Area

The Elak Dase area is also located at the eastern end of Knee Lake (Bentley Bay), on the Wollaston domain side of the boundary zone between the Mudjatik and Wollaston domains (Figure 3.7). The transition from the Mudjatik domain to the Wollaston domain has been historically marked by the beginning of the north-northeast-trending linear banding of metasedimentary rocks that span the ERFN area. This mapped boundary passes through the eastern branch of Knee Lake (Bentley Bay) and extends to the northern end of the ERFN area, approximately 6 km east of Haultain Lake.

Felsic gneiss within the Wollaston domain can be described as fine- to coarse-grained, equigranular, massive to well foliated, and mostly granitic to granodioritic in composition (Thomas and Slimmon, 1985), making it similar in composition to the lithologies found in Mudjatik domain. Mineral associations include biotite, hornblende, hypersthene, diopside, garnet and magnetite. Mafic mineral content is typically on the order of 10%, rarely exceeding 20% (Munday, 1978a). In the area surrounding the eastern portion of Knee Lake, the metasedimentary rocks are interspersed with migmatites and felsic gneiss of similar description to those mapped in the Mudjatik domain. The metasedimentary rocks consist primarily of psammitic and pelitic metasedimentary rocks occurring in sparse pods less than 1 km^2 to the north and south of Elak Dase (Figure 3.7). They are fine- to medium-grained, massive to foliated rocks, which can be locally colour-banded. This unit can include interbanded calc-silicates and pelitic gneiss with quartz, feldspar, biotite, muscovite, sillimanite, cordierite, garnet, diopside, epidote and andalusite (Thomas and Slimmon, 1985). The boundary between the Mudjatik and Wollaston domains is a complexly deformed and highly metamorphosed area (Munday, 1978a).

Further east of the boundary between the Mudjatik and Wollaston domains, there is a large and relatively homogenous area consisting of felsic gneiss (Munday, 1978b). This body of rock extends approximately 75 km to the north-northeast (toward the Haultain Lake area) and is approximately 15 km wide. Bedrock exposure throughout this area is good, with little overburden coverage. Highway 914, running from Pinehouse past Haultain Lake, cuts over the south end of this area of potential interest, and then parallels the body of rock, following the boundary between the Mudjatik and Wollaston domains.

In 1970, Denison Mines Limited, as part of their Pinehouse Project, drilled a borehole 125.88 m deep at a dip of 45º into the rocks of the Wollaston domain rocks approximately 25 km northeast of Elak Dase near Zaharik Lake. The generalized lithology encountered within this borehole consisted of overburden to approximately 27.7 m along the length of the borehole, followed by quartzose-calcareous biotite gneiss to 53.6 m, calc-silicate pegmatite to 58.2 m, and varied biotite gneiss to the termination of the borehole. The biotite gneiss was subdivided into calcareous biotite gneiss between 58.2 and 78.9 m, biotite gneiss to 109.1 m, and garnetiferous biotite gneiss to the termination of the borehole. The shallow quartzose calcareous biotite gneiss is described as medium grey and fine-grained with a gneissosity at 45° to the core axis. The biotite content is estimated at 20%, with 5 to 10% pyrite and pyrrhotite. Buff pegmatite and weakly radioactive quartzose chloritic bands were noted. The calc-silicate pegmatite is described as coarse grained, white- to pink-coloured feldspar and quartz. The composition is visually assessed as 15 to 20% greenish calc-silicate minerals, with minor pyrrhotite and pyrite. The calcareous biotite gneiss is described as very fine-grained, medium grey with a gneissosity at 45° to the core axis. Visual assessments indicate 20 to 30% of each biotite and graphite, and less than 5% combined pyrite and pyrrhotite. The biotite gneiss is described as very fine-grained, medium grey, with a porphroblastic texture with white feldspar porphroblasts and gneissosity ranging from 45° to 60° to the core axis. Visual assessments identified 10 to 15% each pyrrhotite and graphite, with minor pyrite. The garnetiferous biotite gneiss was described as fine even-grained, medium grey, with gneissosity at 70 to 80% to the core axis. The garnet composition is estimated at 15 to 20%, with 15 to 20% white pegmatite veining.

A series of long, but well-spaced, north-northwest-trending faults cut through the area (Figure 3.7). The closest mapped fault to Elak Dase is located approximately 6 km northeast of Bentley Bay. These faults traverse the

ERFN area, extending for lengths of over 100 km. Spacing between these long faults is on the order of 2 to 8 km

Although not within the ERFN area, it is worth mentioning the presence of the Needle Falls shear zone, which skirts the southeast corner of the area. This feature represents a major structural boundary and may influence shallow and deep hydrogeological flow systems in the area. The Needle Falls shear zone has a steep dip and trends with an azimuth of 20º, approximately parallel to the interpreted boundary of the Mudjatik and Wollaston domains (Munday, 1978a). It is marked by long linear features (for example Burrell Lake) and coincident bands of mylonite.

3.2.2 Quaternary Geology

Overburden deposits within the ERFN area were mapped as part of a regional surficial mapping program covering the Precambrian Shield of Saskatchewan and undertaken between 1974 and 1984 by the Saskatchewan Research Council under contract to the Saskatchewan Geological Survey (Schreiner, 1984a). Field investigations were preceded by interpretation of aerial photographs at a scale of about 1:60,000 and photo-mosaics at a scale of about 1:50,000. Much of the field campaign consisted of shoreline mapping around lakes sufficiently large to accommodate float-equipped aircraft, with additional field investigations conducted along roads where exposures and borrow pits provided valuable sections. Schreiner et al. (1976) summarized the field investigations forming the basis of the 1:250,000 scale surficial geology map sheet covering the ERFN area (Schreiner, 1984b).

During the Quaternary Period, several advances and retreats of continental glaciers occurred in the ERFN area. These glaciation periods eroded the bedrock and typically any surficial deposits associated with previous glacial events. The present conditions are a result of the latest Wisconsinan glaciation, during which the Laurentide Ice Sheet covered the entire ERFN area (Schreiner, 1984a).

The Laurentide ice sheet scoured and transported sediments beneath (subglacial), within (englacial) and on (superglacial) the glacier. End moraines were formed at the glacial limits, the most notable of which was the Cree Lake Moraine. The Cree Lake Moraine bisects the ERFN area, trending in a northwest-southeast direction (Figures 2.5 and 2.6). Its location represents the frontal ice position approximately 10,000 years before present (B.P.) (Prest, 1970). Ablation tills and ground moraines were subsequently deposited as the glacier retreated. Melt water that was impounded against the retreating glacier drained south through the Mudjatik and Haultain River channels and into the Churchill River system. These channels were the most prominent in the ERFN area and directed a significant amount of flow between approximately 10,000 years B.P. and 9,000 years B.P. As such, relatively coarse-grained glaciofluvial deposits of sand and gravel can be seen associated with these channels. Finer grained sediments were transported further and deposited in deltas as these rivers flowed into the Churchill River. The Churchill River's southward drainage of melt water flowed into Glacial Lake Agassiz, before switching north to Lake Athabasca as the ice receded sufficiently north of the ERFN area. It is estimated that Glacial Lake Agassiz drained from the area between 9,000 and 8,500 years B.P. (Schreiner, 1984a).

Figure 2.6 shows the terrain features and Quaternary geology of the English River First Nation area. Regionally, the main Quaternary deposits include morainal plains, and glaciofluvial plains, with sparse occurrences of glaciolacustrine plains. Ground moraines are the dominant glacial landform in northern Saskatchewan and vary from flat to hummocky (Schreiner, 1984a). Glaciofluvial plains mainly consist of outwash plains that were incised through the morainal deposits as the glacier receded and melt waters drained. The primary examples of these features in the ERFN area include the Heddery low and Sylvester plain (Figure 2.5). The expected thickness of the associated outwash deposits is in the order of 5 to 10 m. Both types of glacial deposits are primarily sandy, with varying amounts of silt and clay fractions (Schreiner, 1984a).

The descriptions of the Quaternary deposits are based on surface mapping, and little to no information is available on the variation of the deposit types and compositions at depth. Thickness of the Quaternary strata over the Canadian Shield is variable and is generally thicker down ice (southwest) of the Athabasca Basin.

Most of the hard rock of the Canadian Shield was resistant to glacial erosion. Where bedrock is exposed, glacial features including scouring, roche moutonnées, drumlinoids, northwest-trending wind flutings and striae are evident (Schreiner, 1984a; Gilboy, 1985). Rugged local relief was enhanced as glaciers eroded low lying areas and polished resistant bedrock knobs. These features indicate that the ice flow direction was generally from northeast to southwest over the ERFN area. The direction of ice movement was almost parallel to the structural trend of the bedrock, thus enhancing the erosion of less resistant rock (Schreiner, 1984a).

The following sections provide further details regarding the Quaternary geology of the areas being considered in this assessment.

3.2.2.1 Sub-Region 2.1

Haultain Lake IR Area

Haultain Lake is surrounded by a lobe of glaciofluvial sediments that were deposited in an outwash plain (Figure 2.6) (Schreiner, 1984a, b; JDMA, 2013a). The outwash plain extends to the northeast and joins a similar outwash plain that follows the Haultain River located to the east. These sandy outwash sediments become hummocky to the north of the Haultain Lake area. Several eskers are associated with this hummocky terrain, and are located to the north, northeast and east of Haultain Lake (Munday, 1977a; Saskatchewan Industry and Resources, 2010). All of the eskers display a northeast to southwest trend, reflecting the local bedrock control on the direction of ice movement. The glaciofluvial sediments exist in a thin band along the west and south shores of Haultain Lake, which are contained by bedrock ridges that define the outwash plain. The overburden material associated with these deposits primarily consists of sandy till. The glaciofluvial channel currently occupied by the Haultain River served as a major melt water channel. The wide sand and gravel plains bordering the river indicate a high rate of discharge, which flowed south into the Churchill River system (Schreiner, 1984c).

The bedrock to the west and south of Haultain Lake are generally covered by a thin veneer of morainal sediments, such that the fabric of the bedrock is evident (Schreiner, 1984a). Munday (1977b) was able to map a large area of bedrock exposure to the west and south of the lake. Areas of exposed bedrock extend 10 km to the west, and over 30 km to the south of Haultain Lake. Outcrops tend to be more scattered toward the north where there is increased morainal coverage.

3.2.2.2 Sub-Region 2.2

Porter Lake Island IR Area

The surficial geology of the Porter Lake area is characterized by bedrock outcrop, beneath a veneer of morainal deposits (Figure 2.6) (Schreiner, 1984a, b). Pearson (1977b) mapped bedrock exposures within at least a 5 km radius around the lake (and extending further east and south), indicating that the veneer of morainal sediments is quite thin in the area. Thicker deposits of Quaternary sediments that obscured bedrock mapping efforts are noted to the west of the Mudjatik River. The boundary of covered bedrock generally parallels the Mudjatik River located approximately 7 km to the west of Porter Lake. The sediments that surround the Mudjatik River were deposited in a glaciofluvial outwash plain and consist primarily of sand. The glaciofluvial channel currently occupied by the Mudjatik River served as a major melt water channel, draining glacial melt water south into the Churchill River system. The Mudjatik River has since eroded meandering paths into the older outwash sediments (Schreiner, 1984a, b, c). Bog plains flank the river at several locations to the west of Porter Lake. A lobe of glaciofluvial outwash deposits extends northeast, from the north end of Porter Lake, following a stream that drains the lake. Similar to the Haultain Lake area, the overburden in the area consists primarily of sandy till, with sand and gravel located along the Mudjatik River (Schreiner, 1984c).

Flatstone Lake IR Area

Flatstone Lake is located to the west of the Mudjatik River, approximately 20 km southwest of Porter Lake. The surficial geology of the area is characterized by a veneer of morainal and glaciofluvial deposits (Figure 2.6). Glaciofluvial outwash deposits and a bog plain become dominant closer to the Mudjatik River (Schreiner, 1984a, b).

Bedrock in the area is generally concealed, with some relatively small, sporadic outcrops surrounding the lake (Pearson, 1977b). The nearest area with a significant extent of exposed bedrock is located approximately 10 km to the east of the site, across the Mudjatik River and south of Porter Lake.

3.2.2.3 Sub-Region 2.3

Dipper Rapids IR Area

The Dipper Rapids area is located on the west shore of Dipper Lake where the Churchill River enters the lake. This area consists of a glaciofluvial outwash plain that has been eroded and redistributed by the Churchill River (Figure 2.6). A large delta has formed where the Churchill River enters into Dipper Lake. To the north of the outwash plain, the surficial geology is characterized by a veneer of morainal sediments and bog plains. Towards the west and south of the Churchill River, the surficial deposits consist of hummocky morainal deposits. Similar hummocky terrain is noted on the east side of Dipper Lake, towards Primeau Lake (Schreiner, 1984a, b, c).

The Dipper Rapids area is predominantly covered by overburden, with bedrock exposure increasing to the northeast. The available bedrock exposures in the area are relatively small and are concentrated at the south end of Dipper Lake. These include a 1 by 2 km area of bedrock outcrop to the south of the community (south of McEachern Lake), a 1 by 3 km outcrop at the south end of the lake, and a 2 by 2 km outcrop at the southeast corner of the lake (Scott, 1977b). Further south of these outcrops, the area becomes covered by bog plains (Schreiner, 1984a, b, c).

Primeau Lake IR Area

Primeau Lake is part of the Churchill River system and located immediately downstream of Dipper Lake. The sediments surrounding the lake consist of hummocky morainal deposits (Figure 2.6). Bog plains are dominant towards the south of the lake (Schreiner, 1984d).

Some relatively small (i.e., less than 2 km^2) areas of bedrock outcrop are located on the peninsula that juts into Primeau Lake from the south. More extensive bedrock exposure is found northeast of the lake, including an area of approximately 1 km wide by 8 km long (Scott, 1977b).

Knee Lake IR Area

Knee Lake is the next body of water along the Churchill River system downstream of Primeau Lake. Hummocky morainal deposits are found along the west and south shores of the lake (Figure 2.6). Bog plains are dominant beyond these morainal sediments further south of the lake. The north side of the lake is characterized by ridged bedrock beneath a veneer of morainal deposits. An elongated lobe of glaciofluvial deposits extends from Bentley Bay at the east end of the lake towards the south-southwest (Schreiner, 1984a, b, c). A delta has formed where the Haultain River enters the Churchill River at the east end of Knee Lake.

Exposed bedrock has been mapped to the north and northwest of the lake, towards Primeau Lake. Two outcrops on the order of 2 km wide by 7 km long are located north of Knee Lake (Scott, 1977b). A smaller 1.5 by 3 km outcrop is located along the south shore of the lake (Scott, 1977b).

Elak Dase IR Area

The Elak Dase area is located at the east end of Knee Lake near the outlet of the Churchill River. The confluence of the Haultain River and the Churchill River is situated immediately south of the area. A delta formed in this area as glacial melt water was transported along the Haultain River channel and into the Churchill River system (Figure 2.6). A glaciofluvial plain extends to the south, following the Churchill River and is associated with bog plains (Schreiner, 1984d). The Haultain River extends northeast of the area and presently follows a meandering path through the glaciofluvial sediments deposited in the channel.

The reserve is located on an area characterized by ridged bedrock beneath a veneer of morainal deposits. This type of terrain extends to the north of the area and Knee Lake. A large area of exposed bedrock (within the Wollaston domain) is located approximately 15 km to the northeast of the area, across the Haultain River (Munday, 1978b; Saskatchewan Industry and Resources, 2010).

3.2.3 Lineament Investigation

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

The lineament investigation interpreted brittle structures and ductile lineaments in the ERFN 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 in the lineament study by JDMA (2013b), while key aspects of the 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 two general lineament classes, including ductile and brittle lineaments. Consistent with the known bedrock geology of the ERFN area, no dyke lineaments were interpreted. The two lineament categories employed in the analysis are described in more detail below in the context of their 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. These features are included to provide context to our understanding of the tectonic history of the ERFN area, but were not included in the merged lineament sets or statistical analyses.
- ***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 dykes.

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

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

In addition, ductile lineaments were picked using the aeromagnetic geophysical survey data by an automated picking routine with confirmation by a single documented specialist observer. These features are presented to provide context to the tectonic history of the ERFN area, but were not included in the merged lineament sets or statistical analyses.

The SPOT and CDED datasets (Figures 2.1 and 2.5, respectively) were used to identify surficial lineaments expressed in the topography, drainage and vegetation. The SPOT dataset has a uniform resolution of 10 m (panchromatic) and 20 m (multispectral) over the entire ERFN area (JDMA, 2013b). The CDED dataset is at a 1:50,000 scale, with a uniform 20 m resolution over the entire ERFN area (JDMA, 2013b). The resolution of the SPOT and CDED datasets allowed for the identification of surficial lineaments as short as a few hundred metres in length and provided sufficient detail to reveal surficial structural patterns. Aeromagnetic datasets (Figures 3.8 and 3.9) 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 ERFN area. Two additional magnetic surveys obtained from the GSC provided higher resolution (~400 m line spacing) coverage over approximately 10% of the ERFN area (Figure 1.2). This includes an area in the northwest corner of the region and an area to the northeast within Sub-Region 2.1. The available geophysical coverage allowed for the identification of geophysical lineaments on the order of 2.5 km or longer in length.

Figure 3.11 shows the combined surficial lineaments (SPOT and CDED). The same data for each of the sub-regions are shown on Figures 3.11a, b and c. The lineaments shown on Figure 3.11 consist of a merged dataset from two different interpreters. That is, they are the results of reproducibility assessment 1 (RA_1) described by JDMA (2013b). The results shown on Figure 3.11 depict the results from the RA_1 analysis, binned into four length categories (<1 km, 1 to 5 km, 5 to 10 km, >10 km). The SPOT dataset yielded a total of 1,082 surficial lineaments, ranging from 500 m to 65.7 km in length, with a geometric mean length of 4.1 km, while the CDED dataset yielded a total of 1,808 lineaments, ranging from 271 m to 83.5 km long, with a geometric mean length of 2.9 km. The density and distribution of surficial lineaments (especially shorter <1 km lineaments) was seen to be influenced by the overburden coverage in the area (Figure 3.11). However, drift cover over much of the ERFN area is characterized by a morainal veneer that only minimally obscures the underlying bedrock structure. Thicker overburden is noted towards the south near the Churchill River and to the west of the Mudjatik River. Both the SPOT and CDED datasets offered advantages to characterize the surficial lineaments. The higher resolution of the 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 SPOT imagery.

Orientation data for the surficial lineaments show two dominant trends to the north-northeast to northeast and to the northwest to north-northwest. The rose diagram on Figure 3.11 depicts strong north-northeast to northeasterly trends between 20º and 45º and northwest to north-northwesterly trends between 320º and 340º.

The aeromagnetic dataset yielded a total of 3,427 lineaments, 547 of which were interpreted as brittle features (Figure 3.12). The same data for each of the sub-regions are shown on Figures 3.12a, b and c. Again, the lineaments are categorized according to the length bins mentioned above. As described above, Figure 3.12 consists of a merged dataset from two different interpreters (i.e., RA_1 described by JDMA (2013b)). The length of the brittle geophysical lineaments ranged from 2.4 to 126.8 km, with a geometric mean length of 18.6 km. The density and distribution of brittle geophysical lineaments is influenced by the resolution of the geophysical coverage to some degree. The density of geophysical lineaments is slightly higher in areas of high resolution such as in the northwest and northeast corners of the ERFN area. This observation suggests that the southern portions of these areas may have a similar geophysical lineament density if higher resolution aeromagnetic data was available. In addition, shorter lineaments could be present in areas other than those covered by high resolution aeromagnetic data but remain undetectable due to the low resolution aeromagnetic coverage.

Azimuth data for the brittle geophysical lineaments exhibit prominent orientations to the northwest to north-northwest at 325º to 340º and to the north at 5º to 15º and 345º to 355º. There is also a diffuse trend to the east-northeast at 60º to 70º as well as a sharp peak trending east-southeast.

The geophysical data have advantages over surficial data in that they are minimally affected by overburden cover, which may partially or completely mask surficial lineaments. Importantly, brittle aeromagnetic lineaments may be indicative of features present at depth.

Aeromagnetic features interpreted as ductile lineaments have been mapped separately and are shown on Figure 3.13. A total of 2,880 lineaments were interpreted as ductile features (out of the 3,427 lineaments mentioned above). Such features are particularly useful in identifying the degree of deformation within the felsic gneiss and metasedimentary rocks. For example, the dome-and-basin structures are locally evident in the Mudjatik domain and the more linear fold pattern is visible in the Wollaston domain.

It should also be noted that the disparity between the number of identified ductile features (n = 2,880) versus brittle features (n = 547) in the aeromagnetic dataset is a result of the interpretation of the strongly linear magnetic character in the Wollaston domain as representing the ductile shear zone fabric. It is likely, although hard to quantify at the remote desktop stage of the investigation, that brittle reactivation of the ductile fabric also occurred in the Wollaston domain. This understanding would suggest that the density of brittle structures interpreted in areas with a strongly developed magnetic (ductile) character should be considered as minimum estimates of the *in situ* brittle lineament density.

Figure 3.14 shows the distribution of brittle lineaments from the merged surficial and geophysical datasets, classified by length. The merged lineament dataset yielded a total of 2,872 lineaments, ranging from 271 m to 126.8 km in length, with a geometric mean length of 3.6 km. The lineaments shown on Figure 3.14 are the product of reproducibility assessment 2 (RA_2) which examines the coincidence of lineaments between the different data sets (JDMA, 2013b). As such, Figure 3.14 combines coincident lineaments into one mapped feature, which is reflected in the total number of lineaments. JDMA (2013b) noted the following trends in the final merged lineament dataset:

- Longer lineaments generally have a higher certainty and reproducibility.
- Areas defined by higher lineament density tend to correspond to areas with better bedrock exposure.
- There is a much greater coincidence between surficial lineaments (18% coincidence between CDED and SPOT) than between geophysical lineaments and surficial lineaments (less than 7% of geophysical lineaments are observed in surficial datasets), presumably since surficial lineaments interpreted from CDED and SPOT are expressions of the same bedrock feature. A total of 582 lineaments (18%) were coincident with a lineament from one other dataset (RA_2 = 2) and 102 lineaments (3%) were identified and coincident between all three datasets (RA_2 = 3). Several factors may contribute to the low degree of coincidence observed among the different datasets in this area. The lack of coincidence between surficial lineaments appears to be the result of low coincidence among the shorter lineaments. When only lineaments longer than 5 km are considered, the coincidence increases significantly to 40%. Another notable observation is that the geophysics identified strong north and east trends that were not mapped from the surficial datasets.
- 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 also 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 as recognizable as in the available surveys with 400 m line spacing.

A rose diagram of length-weighted orientations of brittle lineaments is provided on Figure 3.14. There are several dominant lineament trends in the merged lineament dataset based on length-weighted frequency. The most prominent trend is toward the north-northwest. The north-northwest-trending lineaments correspond to known regional brittle faults (Figure 3.14). The spacing of these lineaments ranges from 1 km, up to approximately 10 km. There is also a prominent, wide-ranging north to east-northeasterly trend. This trend is especially prominent in the surficial dataset interpretation. Many of these interpreted lineaments occur in the Wollaston domain and are oriented parallel to both the regional foliation and the Needle Falls shear zone. They also tend to be tightly spaced, ranging from several hundreds of metres to one kilometre in separation distance. Another notable lineament trend is east-west. This east-west trend primarily comprises aeromagnetic lineaments with less agreement with the surficial lineaments. They are relatively sparsely populated with spacings in the range of 2 to 14 km. Lineament trends for the individual sub-regions in the ERFN area are presented on Figure 3.15 and further discussed in the subsections below.

Figure 3.16 shows that lineament density is relatively low across the sub-regions, with a maximum value of about 2.5 km per square km. As noted above, higher densities correspond with areas with better bedrock exposure such as the Haultain area (i.e., all of Sub-Region 2.1), near the Porter Lake area (in Sub-Region 2.2) and around the Elak Dase area (towards the east of Sub-Region 2.3). Correspondingly, variation in density was not influenced by geophysical data resolution (Figure 3.12). Overall, the highest lineament densities are observed over Sub-Region 2.1, the northeast third of Sub-Region 2.2 and the east-central portion of Sub-Region 2.3. Comparing the sub-regions, the largest area of relatively high lineament density is within Sub-Region 2.1, followed by Sub-Region 2.3 and then Sub-Region 2.2. It should be noted (as discussed below) that the areas between the sub-regions were mapped at a lower scale, focusing on lineaments longer than 5 km.

In order to gain insight into the influence of lineament length on lineament density, Figures 3.17 to 3.19 illustrate how lineament density varies across the ERFN area when lineaments are progressively “filtered” by length (i.e., plots showing only lineaments longer than 1 km, >5 km and >10 km). The shorter lineaments that are filtered out are less likely to be features that extend to repository depth and tend to be sensitive to the degree of overburden cover. The figures show that filtering out the shorter lineaments greatly increases the spacing between lineaments, including within areas having more exposed bedrock and higher resolution aeromagnetic data. For example, Figure 3.19 shows that there are areas within all of the sub-regions that contain relatively few lineaments that are longer than 10 km, leaving large volumes of rock between interpreted long lineaments. Also, filtering out the shorter lineaments appears to reduce the effects of both variable overburden cover (in the case of surficial lineaments) and low resolution aeromagnetic data on the lineament density. For example, the northeast corner of the ERFN area, with well-exposed bedrock and a high resolution aeromagnetic survey (i.e., on the east side of Sub-Region 2.1), exhibits increased lineament densities when all lineaments are shown but, when the shorter lineaments are filtered out, the lineament density is greatly reduced and becomes more comparable to the area north of Haultain Lake (with greater overburden cover and lower geophysical resolution).

As mentioned above, more detailed lineament interpretation (i.e., interpretation of lineaments <5 km long) was conducted within the three sub-regions only. Outside of those sub-regions, the analysis focused on lineaments greater than 5 km. This is reflected on Figures 3.16 and 3.17 which include lineaments less than 5 km long. In these two figures, there are areas, such as at the north boundary of Sub-Region 2.2, which show artificially abrupt changes in lineament density due to this change in mapping resolution. This issue is filtered out on Figures 3.18 and 3.19 which include only the lineaments greater than 5 km long. As such, these figures represent a consistent scale of lineament mapping across the boundaries of the sub-regions and are not affected by more detailed mapping within the sub-regions.

The final step of the filtering process provided on Figure 3.19 (>10 km lineaments) is a map that is useful for assisting with the identification of potential general siting areas. The effects of variable overburden cover and lower resolution aeromagnetic data are leveled out, while significant structures are still identifiable. For example, the filtered and combined surficial and geophysical lineaments consistently identified the long mapped regional faults in the ERFN area. Figure 3.20 shows the combined datasets (i.e., mapped regional faults, brittle lineaments, major shear zones and ductile features) which helps provide a structural understanding of the ERFN area. The long mapped regional faults are likely some of the more important structural features in the ERFN area. As mentioned above, most of these faults are oriented to the north-northwest, but there is a sub-set of faults oriented approximately east. The most reliable parameter in identifying these faults through the lineament analysis appears to be coincidence amongst datasets. A significant amount of these faults were observed in all three datasets (RA_2 = 3). This is a fairly unique identifier in the available dataset for these structures. Lineament length also assists in the identification of these features. Many of the mapped regional faults are represented by lineaments greater than 10 km long over most of their mapped length. However, length is somewhat less unique in its ability to highlight the mapped faults as many of the longer geophysical lineaments did not correspond to these features.

In summary, the lineament investigation was successful in identifying the mapped features in the area by considering length and reproducibility. The following subsections describe the characteristics of the interpreted lineaments for each of the sub-regions in the area, as well as the relative age of the lineaments identified in the ERFN area.

3.2.3.1 Sub-Region 2.1 (Haultain)

A total (RA_2) compilation of 472 brittle lineaments were mapped over Sub-Region 2.1 (Figure 3.14), which covers an area of 1,550 km^2. Lineaments over the area range in length from 436 m to 126.8 km and have a geometric mean length of 4.2 km (from the combined surficial and geophysical datasets). Orientations of these lineaments were weighted by length and plotted on a rose diagram (Figure 3.15), which shows three dominant orientations within the area including north-northwest broadly north-northeast to east-northeast, and east. The density of the combined brittle lineaments is relatively consistent across the sub-region with some small areas with lower density being associated with areas of thicker overburden.

Interpreted surficial lineaments (Figure 3.11a) range in length from approximately 436 m to 80.5 km, and are distributed in two main orientations, trending north-northwest and north-northeast to east-northeast. The surficial lineament density is generally consistent across the sub-region. This is likely due to the relatively uniformly lower percentage of overburden over the sub-region (Figure 2.6).

Interpreted geophysical lineaments (Figure 3.12a) range in length from approximately 3 km to 126.8 km, and show three main orientations including the dominant north-northwest trend as noted above for the surficial lineaments. Notably, the prominent north and east-northeasterly oriented lineaments are present in this dataset. The geophysical lineament density is comparatively high in this sub-region, including an area with low resolution aeromagnetic data to the west of Haultain Lake.

Coincidence between the interpreted lineaments and mapped structures is observed for two north-northwest-trending faults in the sub-region. One of these faults is located to the southwest of Haultain Lake (Figure 3.5) and was interpreted using all three datasets (RA_2 = 3) over almost its entire length (approximately 17 km long). Another longer (36 km) mapped fault, located at the southwest corner of the sub-region (Figure 3.5), was also mapped by all three datasets (RA_2 = 3) and extends beyond the boundaries of the sub-region. Lineaments with a consistent orientation to these faults are noted throughout Sub-Region 2.1. Further, the most RA_2 = 3 lineaments with a north-northwest orientation occur in this sub-region (Figure 3.20). The north-northwest-oriented lineaments represent one of two dominant lineament trends in the Haultain area that are observed in the SPOT, CDED and aeromagnetic datasets. Longer lineaments (>10 km) and lineaments with reproducibility between two or more independent datasets with this orientation (i.e., RA_2≥2) are interpreted to be representative of potentially important structures. Spacing of these structures ranges from approximately 1 to 4 km in the Haultain area. By focusing on lineaments that meet these criteria, the longer lineaments identified by the geophysical interpretation are included and many of the short ductile features are excluded. This method of interpretation allows for consistent treatment between areas that have varying degrees of overburden cover by including potentially important structures that may be obscured by overburden (i.e., long aeromagnetic lineaments) and putting less weight on short lineaments related to ductile features that can only be observed in areas with good bedrock exposure. This approach was used in the interpretation of the sub-regions presented below.

Several east-striking lineaments over 10 km long and lineaments with reproducibility between two datasets are also noted in Sub-Region 2.1 (Figure 3.20). Spacing of these structures ranges from 1 to 4 km in the Haultain area. Combined with the north-northwest-striking lineaments, several blocks of rock with a surface expression measuring approximately 3 by 3 km are noted in the area.

3.2.3.2 Sub-Region 2.2 (Porter Lake and Flatstone Lake)

A total of (RA_2) compilation 421 brittle lineaments were mapped over Sub-Region 2.2 (Figure 3.14), which covers an area of 2,324 km^2. Lineaments over the area range in length from 274 m to 126.8 km and have a geometric mean length of 4.0 km. Orientations of these lineaments were weighted by length and plotted on a rose diagram (Figure 3.15), which shows three dominant orientations within the area including north-northwest, broadly north-northeast to northeast, and east. The highest density of the combined brittle lineaments is noted in northeast corner of the sub-region. This is mostly influenced by the surficial lineaments and areas with better bedrock exposure.

Interpreted surficial lineaments (Figure 3.11b) range in length from approximately 274 m to 45.1 km, and show a prominent north-northwest trend. The surficial lineament density is notably variable across the sub-region with significantly less mapped lineaments over the western half of the sub-region. This appears to be due to the relatively thick overburden that covers the western half of the sub-region, to the west of the Mudjatik River.

Interpreted geophysical lineaments (Figure 3.12b) range in length from approximately 4.5 to 126.8 km, and show three main orientations including the dominant north-northwest trend noted for the surficial lineaments. As noted for Sub-Region 2.1, the prominent north and east-northeasterly oriented lineaments are present in this dataset. The geophysical lineament density is comparatively low in this sub-region, with a generally uniform distribution.

One north-northwest-trending fault is located in the sub-region, to the northeast of Porter Lake. This long fault was mapped using all three datasets (RA_2 = 3) over a small part of its total length at the north end of the sub-region. Further south, all three datasets recognize the feature but the geophysical lineament becomes offset beyond the buffer zone used to define coincidence. As such, the feature is mapped as an RA_2 = 2 feature for most of its length. The geophysical lineament remains parallel to the mapped fault but located slightly to the west. The offset suggests the fault dips steeply to the southwest.

Two more sub-parallel faults are noted by Pearson (1977b), spaced approximately 12 km further to the northeast beyond the boundary of Sub-Region 2.2. One of these mapped regional faults extends approximately 120 km through Holt Lake and Fault Lake and was mapped as an RA_2 = 3 lineament over a significant portion of its length. Based on the above, the lineament investigation was able to recognise the mapped faults in the area. Other lineaments with a consistent orientation to these faults are noted in the area (Figure 3.20). Spacing of these lineaments ranges from 1 to 6 km in the sub-region.

Several east-west-striking lineaments over 10 km long and lineaments with reproducibility between two or more datasets are also noted in the area (Figure 3.20). Spacing of these structures also ranges from 1 to 6 km in the sub-region.

3.2.3.3 Sub-Region 2.3 (Dipper, Primeau and Knee Lakes and Elak Dase)

A total (RA_2) compilation of 484 brittle lineaments were interpreted over Sub-Region 2.3 (Figure 3.14), which covers an area of 2,892 km^2. Lineaments over the area range in length from 535 m to 126.8 km and have a geometric mean length of 5.5 km. Orientations of these lineaments were weighted by length and plotted on a rose diagram (Figure 3.15), which shows three dominant orientations within the area including north, north-northeast to northeast and north-northwest to northwest. The highest density of the combined brittle lineaments is noted in the east-central portion of the sub-region. This is mostly influenced by the surficial lineaments and areas with better bedrock exposure.

Interpreted surficial lineaments (Figure 3.11c) range in length from approximately 535 m to 83.5 km, and are distributed in two main orientations, trending north-northwest and north-northeast. The surficial lineament density is notably lower near the Churchill River, especially on the south side. This is likely due to the thicker overburden cover present near the river and towards the contact with the Western Canada Sedimentary Basin.

Interpreted geophysical lineaments (Figure 3.12c) range in length from approximately 3.3 to 126.8 km, and show three main orientations including the same prominent north-northwest trend noted for the surficial lineaments. As for the other two sub-regions, the prominent north and east-northeasterly oriented lineaments are also observed in this sub-region. The geophysical lineament density displays a notable increase immediately west of the Mudjatik-Wollaston contact north of Knee Lake. The lowest density of geophysical lineaments generally appears to be to the west of Knee Lake and to the southeast of Elak Dase.

Coincidence between the interpreted lineaments and mapped structures is observed for several of the north-northwest-trending faults in the east end of the sub-region. One of these faults is the same 120 km long fault mentioned above and extends across the eastern end of Sub-Region 2.3. This fault is classified as an RA_2 = 2 feature for most of its length within Sub-Region 2.3, with over 10 km being coincident among all three datasets. Based on the above, the lineament investigation was able to recognize the mapped faults in the area. A number of long lineaments with a similar trend to the mapped faults, some with coincidence among two or more datasets, are noted in the sub-region. Spacing of these structures is in the range of about 1 to 5 km in the sub-region.

No faults have been mapped in the immediate surroundings of Dipper and Primeau Lake (Scott, 1977a). This is likely due to the limited bedrock exposure in the area, especially to the south of the Churchill River. The nearest mapped fault is located approximately 5 km east of the northernmost point of mapped alaskite granite and is oriented generally east and corresponds to an RA_2 = 2 lineament. Several north-northeast- to east-trending lineaments are noted in the area with coincidence amongst the three datasets. This includes a 40 km long lineament that runs through the center of the alaskite granite surrounding Primeau Lake. Several other (RA_2 = 3) lineaments with similar orientations appear to correspond with the Mudjatik-Wollaston contact near Knee Lake. These lineaments have spacings ranging from approximately 1 to 5 km in the area. The geophysical lineaments in the area suggest that these east-northeast- to east-trending lineaments are cross cut by the north-northwest-trending lineaments in this area.

3.2.3.4 Relative Age Relationships of Lineaments

As discussed in Section 3.1.3, there are a number of mapped structural features in the ERFN area with established relative age relationships. This section integrates the observed lineaments with the structural history of the area, based on the available information and the coincidence of lineaments with mapped structure. This interpretation, which may be refined as more information becomes available, was used at this stage to assist with the understanding of which lineaments are important with respect to the identification of potentially suitable siting areas.

Although they have been recognized in the field, structures related to the D_1 and D_2 episodes presented in Section 3.1.3 could not be assigned to any of the lineaments identified in this assessment.

Tight folding in the Wollaston Domain defines the D_3 event. These folds are represented by north-northeast-trending foliation, roughly parallel to the contact between the Mudjatik and Wollaston domains and to the Needle Falls shear zone. The dominant north-northeast-trending lineaments throughout the regional area are interpreted to be mostly stratigraphic features corresponding to the D_3 event. They are more prominent towards the east in the ERFN area and are especially pronounced in the Wollaston Domain (Figure 3.20). These lineaments were evident in both SPOT and CDED imagery (Figure 3.11), and mapped as ductile features using the geophysical data (Figure 3.13). The azimuth of these lineaments ranges from 20º to 40º. Many of the lineaments that were interpreted to be related to D_3-related foliation appear as relatively short features which are important in terms of defining anisotropy of rock mass properties. Mapping of the D_3-related lineaments is strongly dependent on the degree of bedrock exposure as higher densities of lineaments associated with this deformation event occur where they are not obscured by overburden. Lineament filtering by length was effective in de-emphasizing the importance of the numerous short lineaments with this north-northeast orientation (Figures 3.17 to 3.19).

The ductile dome-and-basin structures developed locally in the Mudjatik Domain were created by interference between the D_3 event and an orthogonal D_4 event. Many of the short, curvilinear lineaments in the Mudjatik Domain appear to correspond with these ductile features which represent segments of the regional (S_1) gneissosity. This is supported by the aeromagnetic features which also match the dome-and-basin structures (Figure 3.13). Figure 3.20 illustrates the coincidence of these lineaments with many of the dome-and-basin structures in the Mudjatik Domain. These features were not identified as brittle structures in the aeromagnetic dataset. As for the tighter, more linear ductile features in the Wollaston Domain, the lineaments associated with these structures are interpreted to be less likely to be significant features at repository depth. In contrast, the associated foliation patterns may add some predictability to anisotropic rock properties within a given dome, if selected as a potential siting area.

The above interpretation suggests that the sets of lineaments associated with D_5 reactivation of the fabrics developed during the D_3 and D_4 deformation events are less likely to be representative of structures that penetrate to repository depth and the density of these lineaments should not necessarily be used to preclude an area from further consideration as a potential general siting area.

The long, north-northwest-trending brittle faults define the D_5 deformation event in the area and are observed to crosscut foliation in the Wollaston Domain and the dome-and-basin structures in the Mudjatik Domain. They appear as prominent lineaments in the SPOT imagery, CDED and aeromagnetic data and display the best reproducibility and coincidence within the ERFN area. These north-northwest-striking lineaments are interpreted to correspond to D_5 brittle structures and therefore are tentatively interpreted to be contemporaneous with activation of the Tabbernor fault system. Each of the datasets used in this assessment expressed these features over various portions of their length and both interpreters identified those with the longest lengths. Most of these mapped faults are represented by lineaments with coincidence among two datasets (RA_2 = 2) with a significant proportion being interpreted in all three datasets (RA_2 = 3) (Figure 3.20). Spacing of these longer structures with higher ranking reproducibility generally ranges from 2 to 10 km.

A less prominent, but potentially important series of mapped faults are oriented in a northeast to east-southeasterly direction. These structures are also interpreted to be D_5 brittle faults, possibly related to reactivation of the regional north-northeast- to northeast-trending shear zones. Most of these mapped faults are represented by lineaments with coincidence among two datasets (RA_2 = 2) with some being mapped in all three datasets (RA_2 = 3) (Figure 3.20). As for the north-northwest-trending faults, the longer lineaments (>10 km) with agreement between two or more datasets, are interpreted to be more representative of features that may be associated with fracture zones at depth. The geophysical lineaments suggest that these lineaments are cross-cut by the more prominent north-northwest-trending lineaments. However, field investigation would be required to confirm this.

In summary, the mapped faults, with established age relationships, have been identified through the lineament analysis. They are defined by longer (>10 km) lineaments generally with greater coincidence amongst datasets. This allows the known age relationships to be provisionally extended to the other identified lineaments with similar orientations, placing more importance on the longer coincident lineaments and recognizing the probable occurrence of lineament sets that cannot be correlated to published deformation events. Based on the analysis, potentially important features are identified by the long north-northwest-trending lineaments. All three datasets used to map lineaments identified these mapped features (RA_2 = 3).

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

Saskatchewan is one of the most seismically stable regions in North America (NRCan, 2012). Historically, very few earthquakes of magnitude m_N greater than 3 (Nuttli magnitude) have been recorded within Saskatchewan and none in the ERFN area, as shown on Figure 3.21. The largest earthquake ever recorded in Saskatchewan occurred in 1909 in the southern portion of the province near the USA border, and measured a magnitude of 5.5 (NRCan, 2012). This event occurred at a location approximately 800 km south of Patuanak.

A significant portion of the seismicity measured in Saskatchewan is due to mining activities near Wollaston Lake, Esterhazy and Saskatoon (Gendzwill and Unrau, 1996). Of the 43 seismic events with a magnitude greater than m_N 1.8 in the period between 1985 and 2008 in Saskatchewan, 30 of those are identified as anthropogenic (man-made) resulting from caving within potash mines of southern Saskatchewan. The remaining 13 have been documented by Natural Resources Canada as natural earthquakes (NRCan, 2012). A query of the Geological Survey of Canada’s National Earthquake Database found no earthquakes in the areas where the English River First Nation reserves are located for their period of active monitoring, 1985 through present.

In summary, the available literature and recorded seismic events indicate that Saskatchewan is located within an area of very low seismicity. Specifically, there were no earthquakes recorded in the English River First Nation reserve areas from 1985 through 2011 and no evidence of historical earthquakes prior 1985 from available sources. However, this could be the result of scarcity of seismic monitoring stations in the region. Atkinson and Martens (2007) calculated the annual earthquake probability for stable Canadian craton to be in the order of 10^{-4} to 10^{-3}.

3.3.2 Neotectonic Activity

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

The movement and interaction of tectonic plates creates horizontal stresses that result in the compression of crustal rocks. The mean orientation of the current major principal stress orientation in central North America based on the World Stress Map (Heidbach et al., 2009) is northeast (63° ± 28°). This orientation coincides roughly with both the absolute and relative plate motions of North America (Baird and McKinnon, 2007; Heidbach et al., 2009), 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).

Possible evidence of neotectonic activity preserved in Phanerozoic rocks above the Tabbernor fault has been noted by a number of researchers (Elliot, 1996; Davies, 1998; Kreis et al., 2004). The Tabbernor fault is located approximately 150 km east of the ERFN area (Figure 3.1), but may be related to the mapped north-northwest-trending and east-northeast-trending faults located in the ERFN region. Any neotectonic activity might be expected to occur as reactivation of such faults, since these features are existing planes of weakness. However, no cases of neotectonic evidence have been documented for the immediate ERFN area, and the absolute timing of post-Paleoproterozoic fault movement is only constrained by the observation that Cretaceous rocks exhibit some brittle deformation. The current average major principal stress orientation is at a high angle to the Tabbernor fault system and the regional north-northwest-trending faults, which is favourable in terms of conditions that would minimize movement along these and related features. There are, however, a number of features such as the east-northeast-oriented faults that are at a low angle to the current estimated principal stress orientation. Given that 90° rotations of the major principal stress orientation have been observed in similar locations of the Canadian Shield (Martino et al., 1997), site-specific testing would be required to characterize the current stress state in the ERFN area.

The geology of the ERFN 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 motions are therefore overprinted by post-glacial isostasy in the northern portion of the North America plate. During the last glaciation (Wisconsinan), most of Saskatchewan was covered by the Laurentide ice sheet that flowed from Hudson Bay, located to the northeast. The thickness of the Laurentide ice sheet across Saskatchewan is unknown, although it likely thinned to the southwest at the edges of the flow. The thickness of ice that covered the ERFN area is unknown. At 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 ERFN area would have been somewhat greater, due to its closer proximity to the main center of glaciation located over Hudson Bay.

The area where the ERFN area is located has been ice free for approximately 8,200 years (Shackleton et al., 1990; Peltier, 2002). Since the regression of the Laurentide ice sheet, isostatic rebound has been occurring. The amount of depression of the Earth's crust in these areas, and the rate of rebound are unknown due to lack of data from the continental interior, but generally both are thought to diminish with distance from Hudson Bay (Lambert et al., 1998). Crustal uplift models suggest that the rate of rebound across the Prairie Provinces may be as much as 5 mm/year (Lambert et al., 1998). As a result of the glacial unloading, horizontal stresses are created locally in shallow bedrock. Natural stress release features include elongated compressional ridges or pop-ups, such as those described in White et al. (1973) and McFall (1993). Further analysis would also be required to assess the potential for movement to occur along any of the mapped faults as a result of isostatic rebound.

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

Under the appropriate conditions, glaciolacustrine deposits may preserve neotectonic features indicative of paleo-seismic activity (JDMA, 2013a). Existence of such features can be used to extend the seismic record for a region well into the past. As shown on Figure 2.6, glaciolacustrine terrain in the ERFN area is limited. An area of glaciolacustrine deposits is located in the northwest corner of the ERFN area. This area may allow for the investigation of the presence of neotectonic features in subsequent stages of the evaluation process.

4.0 HYDROGEOLOGY AND HYDROGEOCHEMISTRY

4.1 Groundwater Use

Information regarding groundwater use in the ERFN area was obtained from the Saskatchewan Watershed Authority (SWA) Water Well Record (WWR) database. The Haultain Lake IR, Porter Lake Island IR, Flatstone Lake IR, Dipper Rapids IR, Primeau Lake IR, Knee Lake IR and Elak Dase IR have no population registered with Statistics Canada (2010) and there are no groundwater wells in these areas.

There are no groundwater wells in the selected ERFN sub-regions. The nearest wells are within the Western Canada Sedimentary Basin approximately 25 km west of the Dipper Rapids IR. These wells are located within the village of Patuanak where the underlying bedrock consists of sedimentary rocks of the Western Canada Sedimentary Basin, which is not included as part of the selected ERFN sub-regions (Figure 4.1). The wells are recorded as withdrawal wells and are completed in the overburden.

4.2 Overburden Aquifers

There is no available information on the presence, extent or other characteristics of overburden aquifers in the ERFN area. In general, the main Quaternary deposits of ERFN area include morainal, glaciofluvial, and glaciolacustrine plains, although the thickness of these deposits is unknown. It is expected that any overburden aquifers in the ERFN area will be quite localized in extent and are currently not used as a waters source. There is little interest in developing these small aquifers as a significant groundwater resource given the abundance of surface water in the area. The groundwater table is expected to be shallow in low-lying areas, and it is expected that shallow unconfined groundwater flow generally parallels surface water drainage patterns.

4.3 Bedrock Aquifers

There are no known shallow or deep (~500 m) bedrock aquifers that are being utilized in the English River First Nation reserves or other communities located on the Canadian Shield. Precambrian rock of the Canadian Shield is not commonly developed as a significant aquifer primarily due to the low frequency of fractures that are capable of producing sufficient quantities of water. Water wells drilled into Precambrian rock are likely to be for small domestic supply purposes and are not likely to extend deeper than 100 m in most cases. At greater depths, water quality generally decreases to conditions that preclude potable water use. As such, the Precambrian bedrock in the ERFN area is not expected to be a significant groundwater resource. There are currently no existing bedrock wells in the area, and it is unlikely to be used for such purposes in the future.

4.4 Regional Groundwater Flow

In many shallow groundwater flow systems, the water table is generally a subdued replica 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. 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 is 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.

With the general concept in mind and with reference to the drainage features in the ERFN area shown on Figure 2.7, it is inferred that shallow groundwater flow in the overburden and shallow bedrock (e.g., upper 50 to 100 m of bedrock) will mimic the surface water flow systems. The ERFN area is located in the Churchill River Basin. The three sub-regions are each situated within a different sub-basin. The ERFN area includes two sub-basins in the north and one sub-basin in the south (Figure 2.7). The divide between the two northern sub-basins runs generally in a north-south direction, between Haultain Lake and Porter Lake. The third sub-basin is situated immediately below the two northern sub-basins.

The Haultain Lake area (Sub-Region 2.1) is situated in the easternmost sub-basin in the north end of the ERFN area. This sub-basin is drained by the Haultain River, which flows generally south-southwest near the contact between the Mudjatik and Wollaston domains and then drains into the Churchill River (just downstream of Knee Lake). It is expected that the regional groundwater flow in the overburden and shallow bedrock will follow this southerly flow trend, discharging to the Churchill River.

The Flatstone and Porter Lakes areas (Sub-Region 2.2) are situated in the westernmost sub-basin in the north end of the ERFN area. This sub-basin is drained by the Mudjatik River, which flows south and drains into the Churchill River just south of Little Flatstone Lake. It is expected that the regional groundwater flow in the overburden and shallow bedrock will also be south in this area, discharging to the Churchill River.

The Dipper Rapids, Primeau Lake, Knee Lake and Elak Dase areas (Sub-Region 2.3) are situated in the southernmost sub-basin. This basin drains the two sub-basins to the north. Once groundwater enters this sub-basin, the regional groundwater flow in the shallow bedrock is expected to be southeast, following the flow direction of the Churchill River. Locally, it is expected that the groundwater flow direction in the overburden around the chain of lakes comprising the Churchill River will be radially towards the nearest lake.

No information was found in the available literature regarding groundwater recharge rates and temporal patterns in the ERFN 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. Recharge patterns will be a function of local conditions with the highest rates generally occurring in elevated areas underlain by permeable sand or gravel deposits or by fractured bedrock in areas where it is exposed or covered by thin overburden. Lowland areas, especially muskeg, store substantial amounts of water and may act simultaneously as discharge and recharge areas according to seasonal variations. On the surfaces of the upland regions, it is expected that groundwater recharge will occur through the small lakes and wetlands situated on top of these topographic highs and may flow towards topographic lows as runoff in areas of exposed rock. Where thin layers of overburden cover the rock, discharge to the topographic lows may occur via interflow through the overburden or the shallow bedrock groundwater system itself.

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

There is little known about the hydrogeologic properties of the deep bedrock in the ERFN area, as no deep boreholes have been advanced for this purpose. Experience from other areas in the Canadian Shield with similar types of rock 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. For example, in Manitoba's Lac du Bonnet batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth (Everitt et al., 1996). The low topographic relief of the Canadian Shield tends to result in low hydraulic gradients for groundwater movement in the shallow active region (McMurry et al., 2003). In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures, thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell and Atikokan research areas range from approximately 10^{-15} to 10^{-10} ms^{-1} (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 east of Elliot Lake, Ontario, decreases from an average near surface value of 10^{-8} ms^{-1} to less than 10^{-12} ms^{-1} below a depth of 400 to 500 m.

Many of the faults and shear zones mapped in the ERFN area coincide with topographic lows. These topographic lows are often the location of wetlands and lakes. Major faults and shear zones can extend to depths that are likely greater than repository depth. If topographic highs in the area are hydraulically connected to the faults or shear zones at depth (e.g., via fractures or joint systems), flow can be expected to occur from recharge at topographic highs to discharge at topographic lows associated with a fault or shear zone. The orientation of fracture zones that facilitate this general pattern will be variable and site specific. Further, the hydraulic properties along these flow paths can be expected to vary over several orders of magnitude over very short distances.

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 Churchill and Superior Provinces. A 90° change in azimuth of the maximum compressive stress axis was identified in the near surface in the Whiteshell area and Ruttan Mine of Manitoba (Brown et al., 1995; Kaiser and Maloney, 2005) 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 ERFN area without site-specific data. The exact nature of deep groundwater flow systems in the ERFN area would need to be evaluated at later stages of the site evaluation process.

4.5 Hydrogeochemistry

No information on hydrogeochemistry was found for the ERFN 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 et al., 1987; Gascoyne, 2000 and 2004). Gascoyne et al. (1987) investigated the saline brines within Precambrian plutons and identified a chemical transition at around 300 m depth marked by a uniform and rapid rise in total dissolved solids (TDS) and chloride. This was attributed to advective mixing occurring above 300 m with a shift to diffusion-controlled flow below that depth. It was noted that major fracture zones within the bedrock can, where present, extend the influence of advective processes to greater depths, and hence, lower the transition to the more saline conditions characteristic of deeper, diffusion-controlled conditions.

At greater depths, 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 and 2004). Groundwater research carried out in AECL's Whiteshell Underground Research Laboratory (URL) in Manitoba found that crystalline rocks from depths of 300 to 1,000 m have TDS values ranging from 3 to 90 g/L (Gascoyne et al., 1987; Gascoyne, 1994, 2000 and 2004). TDS values exceeding 250 g/L, however, have been reported in some regions of the Canadian Shield at depths below 500 m (Frape et al., 1984).

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

5.0 NATURAL RESOURCES – ECONOMIC GEOLOGY

The primary source of information on past and present mining activities is the Saskatchewan Energy and Resources (2012) Mineral Deposit Index. There is no record of current or past mineral production in the ERFN area being considered in this assessment. Current mining claims and recorded mineral showings are shown on Figure 5.1. These are primarily concentrated along the Mudjatik-Wollaston domain contact, the mafic gneiss bands in the uplands around Complex and Holt Lakes, and the mafic and psammopelitic gneiss bands southeast of Black Birch Lake. The mining dispositions are actively held by five main owners. Along the Haultain River, the owners include Forum Uranium Corp. (16 claims covering 70,809 ha), Sunny Resources Inc. (seven claims covering 30,791 ha), and Uracan Resources Ltd. (two claims covering 10,439 ha). The claims held southeast of Black Birch Lake are owned by the Iron Ore Corporation of Canada (five claims covering 25,382 ha). Canadian Platinum Corp. holds six claims (covering 25,461 ha) in the center of the ERFN area, encompassing the Dot Lake Iron Formation occurrence. The remaining ten claims are spread over three owners, each with less than 5,000 ha of claimed land.

5.1 Metallic Mineral Resources

There is no record of economic metallic mineral production in the ERFN area being considered in this assessment. Past exploration has occurred in the areas of Dipper and Porter Lakes, but only on a reconnaissance level (Munday, 1978a). Mineral showings are concentrated primarily along the Mudjatik-Wollaston contact in the metasedimentary rocks of the Wollaston domain, associated with some of the regional faults (in the case of uranium), and within narrow bands of mafic gneiss within the Mudjatik domain (Figure 5.1). The economic value of these showings has not been proven. The basement rocks composed of felsic gneiss are generally considered devoid of economically exploitable metallic mineral resources.

Gold, Precious Metals, Iron and Base Metals

All gold, iron and base metal occurrences within the Canadian Shield rocks in the ERFN area occur within metasedimentary and metavolcanic rocks. These metasedimentary rocks can carry minor amounts of base metals associated with iron sulphides (Munday, 1977a). The mafic gneissic rocks of the Mudjatik domain in the Ithingo Lake (southeast of Black Birch Lake), and the Holt Lake and Complex Lake area have also been prospected for copper, nickel and gold.

Gold occurrences have been associated with mafic granulites and ultramafic metasedimentary rocks in the Porter Lake area. Approximately 40 km to the north of the Porter Lake, near Ithingo Lake, there is a mineral disposition with developed gold mineral prospects hosted within the mafic metasedimentary rock. In this area, gold mineralization is also associated with silver and metal sulphides like copper, nickel, minor zinc, and lead (Harper, 1988b). However, there are no occurrences within the area of Porter Lake that are currently economically proven.

Iron occurrences are found within a metasedimentary banded iron formation within the western extent of the Mudjatik domain, and can be found in the areas of Porter Lake and Ithingo Lake. However, no occurrences appear to be economically viable (Pearson, 1977a; Gilboy, 1985).

Discontinuous showings of galena (lead) have been identified over a 70 m distance between Birch and Segment Lakes. The maximum width of the showing over this span is 3 m (Pearson, 1977a). Further prospecting determined the area is not economically significant, and the staked claim was returned to Crown land in 1972.

Molybdenum occurrences have been found on an island in May Bay within Primeau Lake, occurring in the alaskite-rich rock (Scott, 1977a). An iron occurrence has also been found in alaskite rock to the north of the Primeau Lake IR, and a copper occurrence associated with amphibolite is located along the eastern edge of the Primeau Lake IR. Based on a rock chip sampling program, copper concentrations ranged from 4 to 92 parts per million (ppm), while molybdenum concentrations ranged from 0 to 40 ppm (Scott, 1977a). Neither occurrence is economically significant.

The 1970 Pinehouse Project located approximately 25 km northeast of Elak Dase near Zaharik Lake indicated 0.01% or less of each lead, molybdenum, silver, thorium, vanadium and cobalt; between 0.01 and 0.1% copper, nickel, zinc, and manganese; and 5 to 15% iron, within a shallow quartzose calcareous biotite gneiss containing 5 to 10% pyrite and pyrrhotite. Buff pegmatite and weakly radioactive quartzose chloritic bands were also noted. A calc-silicate pegmatite containing less than 5% combined pyrite and pyrrhotite contained cobalt, lead, and nickel at 0.01% or less; manganese between 0.01 and 0.5%; titanium at 0.05 to 0.5%; copper, vanadium and zirconium at less than 0.1%; and iron between 5 and 15%.

Other base metal occurrences in the ERFN area include pyrrhotite, and nickel, although there is no information available to indicate whether these occurrences have been recently explored or have any economic potential.

Rare Metals and Rare Earths

Rare metals include Li, Rb, Cs, Be, Nb, Ta and Ga and the lanthanide elements (rare earth elements or REE) which are often associated with minerals such as spodumene, lepidolite, beryl and columbite-tantalite in highly fractionated phases of peraluminous granite suites.

The only known rare earth metal showing in the ERFN area occurs approximately 20 km to the north of the Elak Dase reserve near Cup Lake (Figure 5.1). This occurrence has not been proven economical to date.

Uranium

Within the rocks of the Canadian Shield, uranium occurrences have been found within granitoids, leucogranitoids and granitic pegmatites (Harper, 1988b). Uranium is generally associated with metasedimentary rocks throughout the Mudjatik and Wollaston domains. The main focus of exploration for uranium within rocks of the Canadian Shield in the ERFN area has been along the transition zone between the Mudjatik and Wollaston domains, in the area generally east of Haultain Lake (Figure 5.1). An extensive portion of this area is covered by active claims.

Pegmatites associated with the Mudjatik domain area are anomalously enriched in uranium, thorium and molybdenum (Munday, 1977a). Radioactive pegmatites are noted in the Peak Lake, Keller Lake, Cup Lake, Key Lake and See Lake areas.

Adjacent to the Needle Falls shear zone, metasedimentary rocks appear to have economic potential for uranium mineralization (Munday, 1978a). Conglomerates at the base of the metasedimentary rocks are anomalously radioactive.

To date, no active uranium mining has occurred in the area being considered in this assessment. However, the area north of the ERFN area in the Athabasca basin around Key Lake is actively mined for uranium. Active uranium exploration in the ERFN area is focused on the Mudjatik-Wollaston contact in the northeast portion of the area, to the southeast of Haultain Lake. Based on the geological conditions and alteration features mentioned in Section 3.2.1.1, it is possible that the Mudjatik-Wollaston contact in that area is similar to the non-conformable uranium deposits in the Athabasca Basin and may have potential for an economical uranium deposit.

5.2 Non-Metallic Mineral Resources

Known non-metallic mineral resources within the ERFN area include building stone, sand and gravel, and peat.

Sand, Stone and Gravel

Sand and gravel consists of deposits related to the most recent glaciations. These resources occur in abundance, and are important sources of aggregate for infrastructure projects. There is approximately one small sand and gravel prospect per 26 km^2 and one large prospect for every 2,600 km^2 throughout Saskatchewan (SGS, 2003). There are no recorded sand and gravel pits within the ERFN area.

Building stone is not currently exploited as a resource throughout Saskatchewan. Given the characteristics of the crystalline rocks (e.g., granite, amphibolites and gabbro-diorite rock types) in the ERFN area, there is a potential for building stone quality crystalline rock to be present. However, any development of this resource in the future would occur at shallow depths.

Peat

There are no peat deposits in the ERFN area. The major peat lands of Saskatchewan occur on the northern margin of the Western Canada Sedimentary Basin. Peatlands west of La Ronge contain a large quantity of well-humidified sedge fuel peat, generally with a sphagnum cover (SGS, 2003). Only one peat producer operates within Saskatchewan, near Carrot River, which is approximately 340 km to the southeast of the La Plonge IR (SGS, 2003). Although unknown at this time, there may be potential for expanding this industry in the future.

Diamonds

No kimberlites or lamproites that could be diamond bearing have been identified in the ERFN area, although the potential for the Canadian Shield to host economic diamond deposits has been demonstrated by a number of mines in the Northwest Territories, Nunavut and Ontario.

5.3 Petroleum Resources

The ERFN area is located in a crystalline geological setting where the potential for petroleum resources is negligible and where no hydrocarbon production or exploration activities are known to occur.

6.0 ROCK GEOMECHANICAL PROPERTIES

Geomechanical information including intact rock properties, rock mass properties and *in situ* stresses are needed to design stable underground openings and 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 limited information on the geomechanical properties of the felsic gneiss in the ERFN area. Table 6.1 summarizes all available geomechanical information available for the area and from sites elsewhere in the Canadian Shield with rock types similar to those of interest. 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, and the felsic gneiss beneath AECL's Chalk River Laboratories. The majority of the geomechanical characterization work for the URL was conducted on these rocks as part of AECL's Nuclear Fuel Waste Management Program in the 1990s.

6.1 Intact Rock Properties

Intact rock properties tabulated in Table 6.1 are based on laboratory testing of rock core specimens from boreholes. The table also includes basic rock properties such as density, porosity, elastic moduli, 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 (Young's Modulus required to back-calculate *in situ* stress around an overcoring specimen).

Limited information is available regarding the intact rock properties of the felsic gneiss in the ERFN area. Fowler et al. (2005) presented a database of rock properties from the Trans-Hudson Orogen. Samples of Mudjatik gneiss were collected from the northwest corner of the ERFN area, south of Baker Lake. Between 20 and 23 samples were tested for saturated density, porosity, magnetic susceptibility, P-wave velocity and S-wave velocity. For other important properties, the data available from the comparatively well-studied Lac du Bonnet batholith, Eye-Dashwa pluton and Chalk River gneiss are provided. At this early stage of the site evaluation process, it is reasonable to assume that the geomechanical properties of intact rock in the ERFN area may resemble those of the Lac du Bonnet batholith, Eye-Dashwa pluton and Chalk River gneiss.

Table 6.1 summarizes the available rock properties data available for gneiss of the Mudjatik domain, compared to information available from these other Canadian Shield sites. Note that some important geomechanical parameters are not available for the Mudjatik gneiss and would require a drilling and testing program designed to provide that information. In general, the available information indicates typical property values compared to other rocks of the Canadian Shield. The limited data available for the Mudjatik gneiss are suggestive of high compressive strength (180 MPa) and bulk densities in keeping with the generally granitic character of the rock. Site specific geotechnical assessment would be conducted during later stages of site evaluation process. The rock property values presented in Table 6.1 are consistent with the values selected for numerical modeling studies conducted to evaluate the performance of hypothetical repository designs in a similar crystalline rock environment (SNC-Lavalin Nuclear Inc., 2011; Golder, 2012a,b).

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

Property	Mudjatik Gneiss	Lac du Bonnet Granite	Eye-Dashawa Granite	Chalk River Gneiss
Uniaxial compressive strength (MPa)	NA	185 ±24[b]	212 ±26[b]	216 ±33[c] 121 ±44[e] 189 ±51[f]
Tensile Strength (MPa)	NA	4 to 9[c]	NA	7 to 14[e,f]
Porosity (%)	0.6±0.3[a]	0.35[b]	0.33[b]	0.1 to 3 0.5 average[d]
P-wave velocity (km/s)	6.07±0.31[a]	4.89±0.19 to 3.22±0.10[g]	NA	3.8 to 6[e,f]
S-wave velocity (km/s)	3.35±0.21[a]	2.16±0.06 to 3.03±0.12[g]	NA	2.1 to 3.5[e,f]
Density (Mg/m^3)	2.73±0.19[a]	2.65[b]	2.65[b]	2.6 to 3[e,f]
Young's Modulus (GPa)	NA	66.8[b]	73.9[b]	76[c]
Poisson's Ratio	NA	0.27[b]	0.26[b]	0.26[c]
Thermal Conductivity (W/(m°K))	2.3[a]	3.4[b]	3.3[b]	NA
Coef. Thermal Expansion ($x10^{-6}/^{o}C$)	NA	6.6	15	NA

NA = Not Available

[a] Fowler et al., 2005

[b] Stone et al., 1989

[c] Annor et al., 1979

[d] Thomas and Hayles 1988

[e] Gorski et al., 2009

[f] Gorski and Conlon, 2010

[g] Eberhardt et al., 1999

6.2 Rock Mass Properties

Fracture spacing, orientation and condition of the fractures tend to dominate the overall mechanical response of the rock mass. There is no information available on rock mass properties of the felsic gneiss in the ERFN area. However, it is known that crystalline rock of the Canadian Shield can have a spectrum of fracture conditions at a given site.

In general, there will be a downward decreasing fracture density from highly fractured rocks in shallow horizons (ca. < 300 mbgs) to sparsely fractured intact rock at greater depths as observed at other sites on the Canadian Shield (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 sites on the Canadian Shield (e.g., Everitt, 2002) and stress measurement data (e.g., Maloney et al. 2006), one could infer that a shallowly-dipping to sub-horizontal fracture set may exist as a result of either strain releasing during the rebound from the last glacial cycle or the presence of pre-existing fabric anisotropy (e.g., bedding, tectonic foliation) in the rock structure. Rock mass properties for the ERFN area will need to be investigated at later stages of the assessment.

6.3 *In situ* Stresses

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

No site-specific information is available regarding the *in situ* stress conditions within the ERFN area. The nearest *in situ* stress measurements were taken at the Ruttan Mine (Churchill Province/Lynn Lake Sub-province) located approximately 400 km to the east of the ERFN area. At a depth of 661 m in the Ruttan Mine, the minimum principal stress ranges from 14 MPa to 27.5 MPa (with an average value of 22 MPa) and dips at an angle of 59° (Kaiser and Maloney, 2005). As a check, vertical *in situ* stresses may also be estimated using the unit weight of the rock measured on intact core specimens. Assuming a rock density of 2.8 Mg/m^3, and a corresponding unit weight of 27.5 kN/m^3, the approximate magnitude of the *in situ* vertical stress at a depth of 500 m at the Ruttan Mine would be 14 MPa.

Horizontal stress conditions are more difficult to estimate. However, over-coring or hydraulic fracturing methods can be used to determine the stresses on a plane at depth and resolve the horizontal *in situ* stress conditions (or resolve inclined principal stresses). A large set of such horizontal stress measurements is available from various locations in the Canadian Shield (Kaiser and Maloney, 2005; Maloney et al., 2006). These data are presented on Figure 6.1. A review of the data available for the Ruttan Mine area indicates that the maximum principal stress in that area is 52 MPa (on average) and oriented in the north-northwest to south-southeast direction. It should be noted that this maximum principal stress direction was provided for only one measurement. The World Stress Map which indicates a dominant west-southwest direction of the maximum principal stress within the central portion of the Canadian Shield (Heidbach et al., 2009). However, a significant number of measurements in the database (e.g., at Thompson Manitoba, the URL in southeastern Manitoba, and the Campbell Mine in northwestern Ontario) indicated a maximum principal stress direction approximately 90° to the dominant trend which would agree with the measurement taken at the Ruttan Mine (Brown et al., 1995).

The observation that the stress state is neither constant nor linear (Maloney et al., 2006) suggests that variability should be expected in the Canadian Shield. Based on the available stress measurement data, Maloney et al. (2006) developed a conceptual model that describes the variable stress state in the upper 1,500 m of the Canadian Shield. The conceptual model identifies a shallow stress released zone from surface to a depth of 250 m, a transition zone from 250 to 600 m and an undisturbed stress zone below 600 m. The undisturbed stress zone can be expected to be representative of far-field boundary stress conditions whereas stresses within the shallow zone tend to be lower as they have been disturbed through exhumation and influenced by local structural weaknesses such as faults (Maloney et al., 2006). Typical repository depths of approximately 500 m fall within the transition zone, where the maximum principal stress may range from approximately 20 to 50 MPa.

Local stress relief features such as faults and shear zones can be expected to locally affect stress regime. For example, thrust faults at AECL's URL facility 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) (Heidbach et al., 2009). Below the same thrust fault, the stress magnitudes are much higher than the average data for the

Canadian Shield, and the maximum principal stress rotates approximately 90° to a southeast orientation (Martino et al., 1997). This orientation is consistent with the data presented by Herget (1980) for the area which indicates maximum compression clustered in the southwest and southeast for the Canadian Shield.

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

6.4 Thermal Conductivity

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

There are little site-specific thermal conductivity values or detailed quantitative mineral compositions available for the ERFN area. Fowler et al. (2005) provides an average thermal conductivity value of 2.3 W/(m˚K) for gneiss of the Mudjatik domain, based on measurements taken on three samples (Table 6.1). For the purposes of comparison, typical values of thermal conductivity for similar rock types are presented in Table 6.2. The mineralogy of the felsic gneiss is described in Section 3.2.1. Available information indicates that the composition of the felsic gneiss ranges from granite to granodiorite and tonalite. The quartz mineral content of these rock types can range from approximately 20% to 60% by volume (Streckeisen, 1976).

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]Kukkonen et al., 2007

Although no thermal conductivity values are available for the ERFN area, some useful comparisons are provided by Stone et al. (1989) in their summary of thermal conductivity values for two late Archean granitic intrusions of the Superior Province of the Canadian Shield, the Lac du Bonnet batholith and the Eye-Dashwa pluton (Table 6.1). Both intrusions were described as having similar mineralogical compositions, 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. For comparison, a value of 3 W/(m˚K) was selected for numerical modeling studies conducted to evaluate the thermo-mechanical performance of hypothetical repository designs in a similar crystalline rock environment (Golder, 2012a,b).

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

7.0 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE ENGLISH RIVER FIRST NATION AREA

7.1 Approach

The objective of the Phase 1 desktop geoscientific preliminary assessment is to assess whether the ERFN area contains general areas that have the potential to satisfy the NWMO's geoscientific site evaluation factors. For Phase 1 of the preliminary assessment Region 2 was further subdivided to encompass the reserves and to understand the local geoscientific characteristics. At this stage of the preliminary assessment, the intent is to assess whether there are areas within the ERFN area that have the potential to satisfy the geoscientific evaluation factors and safety functions defined in the site selection process document (NWMO, 2010). The location and extent of 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 by 550 m for the main buildings and about 100 by 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 at the preferred site, 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 repository would require a footprint in the order of 2 by 3 km. Therefore, general siting areas would need to have a surface area of approximately 2 by 3 km or more.

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 of the ERFN area described below. The second step (Section 7.3) was to verify that identified general areas have the potential to meet all of 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 (Golder, 2011) were not considered. The pelitic and psammitic metasedimentary rocks and mafic gneiss were considered unfavourable rock units for siting a deep geological repository because these rocks typically occur in thin, complexly folded bands with uncertain geometry at depth. The alaskite rock in the Primeau Lake area is potentially suitable, but was considered unfavourable for reasons listed below. The felsic gneiss of the Mudjatik and Wollaston domains was considered a potential host rock. This rock has predominantly a granitic to tonalitic composition and has the potential for favourable rock properties (e.g., permeability, fracture conditions, homogeneity). The geological setting of the main potentially suitable areas is further discussed in Section 7.2.

- ***Structural Geology***: The spatial distribution, character and history of local and regional scale mapped faults and domain boundaries in the ERFN area were considered. The most prominent structural features in the ERFN area are the shear zones and brittle faults that overprint these shear zones (Figure 3.4). The Needle Falls shear zone is a north-northeast to northeast-trending regional scale shear located just outside the southeast corner of the ERFN area. This shear zone imparts a preferred north-northeast to northeast brittle structure to the rocks that increases in intensity towards the shear zone. The ERFN area also contains a series of mapped long, north-northwest-trending brittle faults. Potential host rock thicknesses were considered, noting that the felsic gneiss in the ERFN area is estimated to range from 5 to 10 kilometres in thickness, which is sufficient for the purpose of the repository. The potential for groundwater movement at repository depth within an area is in part controlled by the fracture frequency, their degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of infilling. At this stage of the assessment, current stress conditions, fracture aperture orientation and frequency, and tectonic lensing that could affect groundwater movement at depth were not included in the assessment, due to lack of site specific information. Factors potentially influencing groundwater movement at repository depth are addressed at a generic level in Section 7.3.

- ***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. Geophysical lineaments were particularly considered as relevant as they are not significantly affected by overburden. The presence of a higher number of surface lineaments in a particular area was not considered as an indication of poor suitability, as surface features may not all extend to repository depth and may not be structural discontinuities. There may be under-identification of brittle lineaments within Sub-Regions 2.1 and 2.3 due to high ductile strain associated with the Needle Falls shear zone (Section 3.2.3). The lineament filtering process, as described in Section 3.2.3 and presented on Figures 3.17 to 3.19, helped the identification of potentially suitable areas. The removal of shorter lineaments through the filtering process also helped compensate for bias in lineament density due to overburden cover (in the case of surficial lineaments) and low resolution aeromagnetic surveys (in the case of geophysical lineaments).

- ***Overburden:*** The distribution and thickness of overburden cover is an important factor to consider when assessing amenability to site characterization of a general potential 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).

  Areas of exposed bedrock or a thin veneer of overburden were generally favoured when selecting general potential areas. The thickness and distribution of overburden within the ERFN area is defined at a regional (1:250,000 scale) level. Based on the terrain analysis conducted for the ERFN area (JDMA, 2013a), areas characterized by morainal veneer appear to have sufficiently thin cover to allow for generally un-obscured mapping of the underlying bedrock structure. This is further supported by bedrock geology maps (Munday, 1977b, c; Munday, 1978b), which provide detailed definition of areas with thick overburden (shown on Figures 7.1, 7.2 and 7.3). Within Sub-Region 2.1, bedrock exposure is generally good. Thicker overburden deposits are noted toward the north of Haultain Lake. Sub-Region 2.2 displays good bedrock exposure in the Porter Lake Area. However, to the west of the Mudjatik River towards Flatstone Lake, the overburden thickness increases and the bedrock in the western half of this sub-region is largely obscured by overburden. In the south, Sub-Region 2.3 contains the Churchill River lowlands. Much of this southern area is largely covered by relatively thick overburden and bog plains (e.g., the Dipper Rapids, Primeau Lake and Knee Lake areas). The alaskite rock in the Primeau Lake area is mostly covered by overburden. Bedrock exposure improves toward the east of this sub-region.

- ***Protected Areas:*** All provincial and federal parks were excluded from consideration in the selection of general potentially suitable areas. There are no provincial or national parks within ERFN area. As such, this was not a major factor in evaluating the ERFN area for general potentially suitable areas. The nearest recreation area is the Gordon Lake Recreation Site, which is located along the southern boundary of the ERFN area, approximately 15 km southeast of the Elak Dase IR (Figure 2.8). This recreational site is small and covers less than 4 km^2. The absence of locally protected areas would need to be confirmed in discussion with the community and Aboriginal peoples in the area during subsequent site evaluation stages.

- ***Natural Resources:*** Areas associated with known and exploitable natural resources were excluded from further consideration. Readily available information on the past and potential future occurrence of natural resources such as oil and gas, metallic and non-metallic mineral resources indicates that there is no evidence of past or present exploration or development activities associated with oil and gas or coal resources at or near ERFN area. There are also no currently operating or past producing mines within the area of the ERFN area. There are several metallic mineral occurrences within the area such as gold, copper and iron. These occurrences and the current mining claims are shown on Figure 5.1. However, none of these are known to be economically exploitable. Mineral occurrences in the area appear to be primarily associated with inferred fault traces, and metasedimentary rocks, both of which are excluded based on geoscientific evaluation factors discussed above. Uranium dispositions are present to the east and south of the Haultain Lake IR at the Mudjatik-Wollaston contact. Based on recent exploration activity in this area, these occurrences represent the highest likelihood of mineral potential in the area. This further supports the exclusion of the rocks along this contact, which were previously excluded on the basis of unfavourable geometry and properties, as well as the potential for shearing and possible low angle faults. At this stage of the assessment, areas of active mining claims were not systematically excluded if the claims were located in geological environments judged to have low mineral resource potential, particularly where the claims were of short tenure. The review of known mineral deposits, exploration activity and mineral potential indicates that the felsic gneiss of the ERFN area has a generally low economic mineral potential. As such, this was not a major factor in the identification of potentially suitable areas within the felsic gneiss. These areas will be assessed in more detail during subsequent site evaluation stages.

- ***Surface Constraints***: Areas of obvious topographic constraint (high density of steep slopes), and large water bodies (wetlands, lakes) were considered during the identification of potential siting 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. There are no significant topographic features in the ERFN area that would make site investigation or construction exceptionally difficult. As discussed in Section 2, topography is moderately variable with the most relief occurring as bedrock ridges covered by a thin veneer of glacial moraine (Figure 2.2), and low lands with marshy areas. The most extensive areas containing wetlands are to the south of the Churchill River. The Churchill River itself consists of a chain of relatively large lakes at the south end of the ERFN area. These lakes are considered unfavourable in terms of surface conditions. However, the area has largely been excluded on the basis of unsuitable geology and thick overburden. The ERFN area is largely undeveloped, with no major infrastructure present. The closest infrastructure is Highway 914, located approximately 9 km west of the Haultain Lake IR. At present, none of the English River First Nation reserve areas within Sub-Regions 2.2 and 2.3 are directly accessible by all season roads, although seasonal access to some areas may be available via Highways 914 and 918.

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above key geoscientific evaluation factors revealed that the ERFN area contains three general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. These general areas are located within the felsic gneiss in each of the sub-regions. Figures 7.1 to 7.3 show features illustrating some of the key characteristics and constraints used to identify general siting areas, including bedrock geology, protected areas, areas of thick overburden cover, surficial and geophysical lineaments, the existing road network, the potential for natural resources and mining claims for each sub-region. The legend of each figure includes a 2 by 3 km box to illustrate the approximate surface area of potentially suitable rock that would be needed to host a repository.

The following sections describe how the key geoscientific factors and constraints discussed above were applied to the various geological units within the ERFN area to assess whether they contain general areas that have the potential to satisfy the NWMO's geoscientific site evaluation factors. At this stage of the assessment, the boundaries of these general areas are not yet defined. The location and extent of general potentially suitable siting areas would be further refined during subsequent site evaluation stages.

7.2.1 Felsic Gneiss in Central Sub-Region 2.1

As discussed in Section 3.2.1, the approximately 2.7 Ga felsic gneiss in Sub-Region 2.1 is 5 to 10 km thick, granitic to tonalitic in composition, has the potential for favourable rock properties (e.g., hydraulic conductivity, fracture conditions, homogeneity) and is extensive in the ERFN area. Most of the felsic gneiss within Sub-Region 2.1 has low potential for natural resources, and is free of protected areas and surface constraints (i.e., topography and large water bodies). Therefore, the differentiating factors for selecting potentially suitable areas within the felsic gneiss in Sub-Region 2.1 were considered to be mainly geology, overburden thickness and structural geology.

The felsic gneiss in the central part of Sub-Region 2.1, immediately south of Haultain Lake, was identified as containing siting areas that have the potential to meet NWMO's geoscientific site evaluation factors. It is away from pelitic and psammitic metasedimentary gneisses and amphibole gneiss that were considered unfavourable for siting a deep geological repository (Figures 3.5 and 7.1). It appears to be away from the influence of the Needle Falls shear zone and is also within a magnetically quiescent area (Figure 3.8), which may suggest relative homogeneity in the rock. However, there is some uncertainty in the homogeneity of the felsic gneiss as discussed in Section 3.2.1.1.

Approximately 66% of the central part of Sub-Region 2.1, south of Haultain Lake, is exposed bedrock or covered by relatively thin overburden (less than 2 m). Areas to the north and northeast in Sub-Region 2.1 have thicker overburden deposits. The central part of Sub-Region 2.1 is also away from the mapped fault and the contact between the Mudjatik and Wollaston domains in the eastern side of the sub-region (Figures 3.4 and 7.1).

The general potential area in the central part of Sub-Region 2.1 was further refined using the distribution and orientation of interpreted lineaments. Figures 3.12a and 7.1 show that geophysical lineament density is low over Sub-Region 2.1 and does not appear to vary much, despite differences in the geophysical data resolution (800 m and 400 m spacing in the west and east of the sub-region, respectively). The orientation of geophysical lineaments in Sub-Region 2.1 (Figures 3.12a and 3.15) is somewhat complex with several directions indicated. The distribution of geophysical lineaments within the central part of Sub-Region 2.1 includes long northwest lineaments spaced between 1 and 4 km and east-west lineaments with spacing between 1 and 4 km, suggesting a potential for identifying suitable volumes of rock for siting a repository between the longer lineaments. Also, there is good agreement between interpreted geophysical lineaments and the mapped fault within Sub-Region 2 (Figures 3.5 and 7.1). Geophysical lineaments are particularly relevant as they are not significantly affected by overburden. However, there is a potential for under-identification of lineamnets due to the low resolution of available geophysical data.

Figures 3.11a and 7.1 show the surficial lineament density to be generally low throughout Sub-Region 2.1, with higher density of lineaments associated with areas of exposed bedrock. The orientation of surficial lineaments in Sub-Region 2.1 (Figures 3.11a and 3.15) is somewhat complex with several directions indicated. At the desktop stage of the assessment, it is uncertain if surficial lineaments represent real bedrock structure, the nature of that structure, and how far they extend to depth, particularly for the shorter lineaments.

The distribution of lineament density as a function of lineament length over Sub-Region 2.1 is shown on Figures 3.17 to 3.19 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 throughout Sub-Region 2.1) as shorter lineaments are filtered out. The central part of Sub-Region 2.1, south of Haultain Lake, exhibits intermediate lineament density relative to the rest of Sub-Region 2.1. There are lower lineament density areas to the southwest and to the northwest, but these are in areas of thick overburden cover or where amphibole and psammitic gneiss is present. When only lineaments longer than 10 km are considered, the density in the central part of Sub-Region 2.1 becomes approximately 1 to 1.5 km/km^2. Geophysical lineaments in the central part of Sub-Region 2.1 longer than 10 km are typically spaced on the order of 1 to 4 km.

Sub-Region 2.1 is predominantly Crown land (Figure 2.8), and does not contain any protected areas. A small portion of the sub-region is designated as Crown Reserve. The lands have no known exploitable mineral resources and are free of mineral showings and active mining claims (Figures 5.1 and 7.1). Adjacent claims are not found to impact the potential suitability of the central part of Sub-Region 2.1 because they are located in the pelitic to psammitic gneiss and psammitic to meta-arkosic gneiss of the Wollaston domain, along the boundary between the Mudjatik and Wollaston domains.

Access to the central part of Sub-Region 2.1 is good via Highway 914. The area has well drained, higher land with moderate to high relief with numerous blocky bedrock knobs characterizing the terrain. Drainage is good throughout the area with total lake/wetland cover being approximately 16%. The area falls entirely within the Haultain watershed which drains to the Haultain River.

In summary, the central part of Sub-Region 2.1, south of Haultain Lake, was identified as a general potentially suitable area based on its favourable geology, overburden cover and structural geology. The geological setting consists of early felsic gneiss; good bedrock exposure with interpreted favourable lineament spacing, and low potential for economically exploitable natural resources. The area is also outside of protected areas and is accessible via the nearby road network.

7.2.2 Felsic Gneiss in Eastern Sub-Region 2.2

Given the similarity with Sub-Region 2.1, the differentiating factors for selecting potentially suitable areas within the felsic gneiss in Sub-Region 2.2 were considered to be mainly geology, overburden thickness and structural geology.

The general area in the eastern part of Sub-Region 2.2 was identified as containing siting areas that have the potential to meet NWMO's geoscientific site evaluation factors. There are several repository-sized areas within the general area that are away from pelitic and psammitic metasedimentary gneisses and amphibole gneiss that were considered unfavourable for siting a deep geological repository (Figures 3.5 and 7.2). This general area is away from the regional Needle Falls shear zone and the mapped fault on the boundary of the eastern side of Sub-Region 2.2 (Figures 3.6 and 7.2). Much of it is also within a low to moderate aeromagnetic response area (Figure 3.8), which may suggest relative homogeneity in the rock. However, there is some uncertainty in the homogeneity of the felsic gneiss as discussed in Section 3.2.1.1. Approximately 80% of the eastern part of Sub-Region 2.2 is exposed bedrock or covered by relatively thin overburden (less than 2 m). Most of the western half of Sub-Region 2.2 has thicker overburden deposits.

The general potential area in the eastern part of Sub-Region 2.2 was further refined using the distribution and orientation of interpreted lineaments. Figures 3.12b and 7.2 show that geophysical lineament density is low over Sub-Region 2.2 and does not appear to vary greatly. The low density is likely due to the low resolution of the magnetic data across this sub-region (805 m line spacing). The orientation of geophysical lineaments in Sub-Region 2.2 (Figures 3.12b and 3.15) is somewhat complex with several directions indicated. The distribution of geophysical lineaments within the eastern part of Sub-Region 2.2 includes long north-northwest lineaments spaced between 1 and 6 km and east-west lineaments with spacing between 1 and 6 km, suggesting a potential for identifying suitable volumes of rock for siting a repository between the longer lineaments. Also, there is good agreement between interpreted geophysical lineaments and the mapped fault on the boundary of the eastern side of Sub-Region 2.2 (Figures 3.6 and 7.2). Geophysical lineaments are particularly relevant as they are not significantly affected by overburden. However, as mentioned earlier, there is a potential for under-identification of lineamnets due to the low resolution of available geophysical data.

Figures 3.11b and 7.2 show the surficial lineament density to be generally low throughout Sub-Region 2.2, with higher density of lineaments associated with areas of exposed bedrock. The orientation of surficial lineaments in Sub-Region 2.2 (Figures 3.11b and 3.15) is somewhat complex with several directions indicated. At the desktop stage of the assessment, it is uncertain whether surficial lineaments represent real bedrock structure and how far they extend to depth, particularly the shorter lineaments.

The distribution of lineament density as a function of lineament length over Sub-Region 2.2 is shown on Figures 3.17 to 3.19 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 throughout Sub-Region 2.2 as shorter lineaments are filtered out. The eastern part of Sub-Region 2.2 exhibits low to intermediate lineament density relative to most of Sub-Region 2.2. There are lower lineament density areas to the west, but these are in areas of thick overburden cover or where amphibole, pelitic gneiss and psammitic gneiss is present. When only lineaments longer than 10 km are considered the total lineament density in the eastern part of Sub-Region 2.2 becomes approximately 0.5 to 1.5 km/km^2. Geophysical lineaments in the eastern part of Sub-Region 2.2 longer than 10 km are typically spaced on the order of 1 to 6 km.

Sub-Region 2.2 is predominantly Crown land (Figure 2.8), and does not contain any protected areas. There are no known exploitable mineral resources in the eastern part of Sub-Region 2.2 and it is largely free of mineral showings and active mining claims (Figures 5.1 and 7.2). There are a few isolated mineral showings, but these are not known to be economically significant and are associated with the amphibole gneiss, pelitic gneiss and psammitic gneiss.

Access to Sub-Region 2.2 is poor, with only winter road access. The closest year-round access road is Highway 914, located approximately 50 km to the east. The general potentially suitable area is well drained, intermediate elevation land with low to moderate relief and with large, domal bedrock outcrops characterizing the terrain. The total lake/wetland cover is approximately 16%. A tertiary drainage divide is located in the southeastern portion of Sub-Region 2.2 between the Mudjatik watershed in the north-west and the Upper Churchill watershed in the southeast. Both these watersheds discharge into the Churchill River.

In summary, the eastern part of Sub-Region 2.2 was identified based on its favourable geology, overburden cover and structural geology. The geological setting consists of early felsic gneiss, very good bedrock exposure with interpreted favourable lineament spacing, and low potential for economically exploitable natural resources within the felsic gneiss. The area is also outside of protected areas but is not easily accessible by a year-round road network.

7.2.3 Felsic Gneiss in Eastern Sub-Region 2.3

Given the similarities with the two other Sub-Regions, the differentiating factors for selecting potentially suitable areas within the felsic gneiss in Sub-Region 2.3 were considered to be mainly geology, overburden thickness and structural geology.

The general area in the eastern part of Sub-Region 2.3, north of Gordon Lake was identified as containing siting areas that have the potential to meet NWMO's geoscientific site evaluation factors. Much of the area is away from pelitic and psammitic metasedimentary gneisses and amphibole gneiss that were considered unfavourable for siting a deep geological repository (Figures 3.7 and 7.3). However, the eastern part of Sub-Region 2.3 contains number mapped faults in the south-eastern side and may be influenced by the proximity of the Needle Falls shear zone (approximately 40 kilometres to the southeast). Much of the felsic gneiss in the eastern part of Sub-Region 2.3, north of Gordon Lake is within a moderate aeromagnetic response area (Figure 3.8), except where the pelitic to psammitic gneiss and amphibole gneiss are present. However, there is some uncertainty in the homogeneity of the felsic gneiss as discussed in Section 3.2.1.1.

Approximately 80% of the felsic gneiss in the eastern part of Sub-Region 2.3, north of Gordon Lake is exposed bedrock or covered by relatively thin overburden (less than 2 m). Most of the western and southwestern parts of Sub-Region 2.3 have overburden deposits. The general potentially suitable area in the eastern part of Sub-Region 2.3 contains mapped faults in the southeastern side (Figures 3.7 and 7.3) and may be influenced by the proximity of the Needle Falls shear zone (approximately 40 km to the southeast).

The general potential area in the eastern part of Sub-Region 2.3, north of Gordon Lake, was further refined using the distribution and orientation of interpreted lineaments. Figures 3.12c and 7.3 show that geophysical lineament density over Sub-Region 2.3 does not appear to vary greatly. As for the other sub-regions, the low lineament density is likely due to the low resolution of the magnetic data across this sub-region (805 to 1,609 m line spacing). The orientation of geophysical lineaments in the eastern part of Sub-Region 2.3 (Figures 3.12c and 3.15) is simpler, likely due to the strong northeast fabric of the rock in this area that is related to the Needle Falls shear zone. The distribution of geophysical lineaments within the eastern part of Sub-Region 2.3, north of Gordon Lake, includes long north-northwest lineaments spaced between 0.5 and 3 km and east-west lineaments with spacing between 0.5 and 3 km, suggesting a potential for identifying suitable volumes of rock for siting a repository between the longer lineaments. Also, there is good agreement between interpreted geophysical lineaments and the mapped fault on the eastern side of Sub-Region 2.3 (Figures 3.7 and 7.3).

Figures 3.11c and 7.3 show the surficial lineament density to be generally low throughout Sub-Region 2.3, with higher density of lineaments associated with areas of exposed bedrock. The orientation of surficial lineaments in the eastern part of Sub-Region 2.3 is simpler, likely due to the strong northeast fabric of the rock in this area. At the desktop stage of the assessment, it is uncertain whether surficial lineaments represent real bedrock structure and how far they extend to depth, particularly the shorter lineaments.

The distribution of lineament density as a function of lineament length over Sub-Region 2.3 is shown on Figures 3.17 to 3.19 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 throughout Sub-Region 2.3 as shorter lineaments are filtered out. The eastern part of Sub-Region 2.3, north of Gordon Lake, exhibits overall low lineament. There are lower lineament density areas to the west and north, but these are in areas of thick overburden cover or where amphibole, pelitic gneiss and psammitic gneiss is present. When only lineaments longer than 10 km are considered, the density in the eastern part of Sub-Region 2.3, north of Gordon Lake, becomes approximately 0.5 to 1 km/km^2. Geophysical lineaments in the eastern part of Sub-Region 2.3, north of Gordon Lake, longer than 10 km are typically spaced on the order of 1 to 5 km.

Sub-Region 2.3 is Crown land (Figure 2.8), and does not contain any protected areas. The Gordon Lake Recreational Site occurs at the periphery of Sub-Region 2.3, but does not occur within the general siting area. There are no known exploitable mineral resources in Sub-Region 2.3 and it is largely free of mineral showings and active mining claims (Figures 5.1, and 7.3). There are a few isolated mineral showings, but these are not known to be economically significant and are usually associated with the amphibole gneiss, pelitic gneiss and psammitic gneiss.

Access to the eastern part of Sub-Region 2.3, north of Gordon Lake, is good via Highway 914, which runs past the Gordon Lake recreational area. The area is well drained, higher elevation land with moderate relief and with long, outcrop ridges characterizing the terrain. Drainage is good throughout the area with total lake/wetland cover being approximately 8%. The eastern part of Sub-Region 2.3, north of Gordon Lake, straddles the Haultain and Central Churchill watershed.

In summary, the eastern part of Sub-Region 2.3, north of Gordon Lake, was identified based on its favourable geology, overburden cover and structural geology. The geological setting consists of early felsic gneiss, very good bedrock exposure with interpreted favourable lineament spacing and low potential for economically exploitable natural resources. The area is accessible by Highway 914.

7.2.4 Other Areas

No prospective general potentially suitable areas were identified within the amphibolites gneiss, pelitic gneiss and psammitic gneiss, as these rock types were considered unfavourable rock units for siting a deep geological repository. General potentially suitable areas were identified within the felsic gneiss using overburden cover and structural geology to further refine the extent of the areas. Given the very large geographic extent of the ERFN area, it may be possible to identify additional general potentially suitable areas. However, the three general areas identified are those judged to best meet the preferred geoscientific characteristics outlined in Table 7.1, based on available information.

7.2.5 Summary of Characteristics of Felsic Gneiss in Sub-Regions of ERFN

Table 7.1 provides a summary of the key geoscientific descriptive characteristics of the three general areas in each sub-region of the ERFN area.

Table 7.1: Summary of Characteristics of Areas in Sub-Regions – English River First Nation Area

Geoscientific Descriptive Characteristic	Felsic Gneiss in Central Part of Sub-Region 2.1	Felsic Gneiss in Eastern Part of Sub-Region 2.2	Felsic Gneiss in Eastern Part of Sub-Region 2.3
Rock Type	Felsic gneiss of the Mudjatik domain	Felsic gneiss of the Mudjatik domain	Felsic gneiss of the Wollaston domain
Age	*ca*. 2.7 Ga	*ca*. 2.7 Ga	*ca*. 2.7 Ga
Inferred host rock thickness	5 to 10 km	5 to 10 km	5 to 8 km
Extent of rock unit within the Sub-Region of ERFN area	1,565 km^2	2,327 km^2	2,861 km^2
Relative proximity to mapped geological features (fault zones, shear zones, geological sub-province boundaries, etc.)	Needle Falls shear zone – approximately 75 km	Needle Falls shear zone – approximately 100 km	Needle Falls shear zone – approximately 40 km
Structure: faults, foliation, dykes, joints	Low apparent surface lineament density Low apparent geophysical lineament density >10 km long NNW trending fault to the SW	Low apparent surface lineament density Low apparent geophysical lineament density >10 km long NNW trending fault to the NE	Low apparent surface lineament density Low apparent geophysical lineament density >10 km long NW trending faults to the east
Aeromagnetic characteristics and resolution	Quiescent , low resolution on W side, high resolution on E side	Moderately noisy, quiet within domes, low resolution	Relatively noisy, NNE foliation apparent, low resolution
Terrain: topography, vegetation	Moderate to high relief	Moderate to high relief, some steep slopes	Moderate to high relief, some steep slopes
Access	Good, Hwy 914 access	Poor, no all-season road access	Good, Hwy 914 access
Resource Potential	Low, Moderate at Mudjatik-Wollaston contact to the east	Low	Low
Bedrock Exposure	Generally moderate to high	Generally high	Generally moderate to high
Drainage	Generally good, draining to Haultain and Churchill Rivers	Good, draining to Mudjatik and Churchill Rivers	Generally good, draining to Haultain and Churchill Rivers

7.3 Evaluation of the General Potentially Suitable Areas in the ERFN 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 indicate that the identified siting areas would fail to satisfy the safety functions.

An evaluation of the three identified general potentially suitable areas in terms of the safety functions is provided in the following subsections.

7.3.1 Safe Containment and Isolation of Used Nuclear Fuel

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

This requires that:

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

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

As discussed in Section 3 and summarized in Table 7.1, available geophysical information indicates that the estimated thicknesses of the felsic gneiss is potentially greater than 5 km (Figure 3.2). Based on this, the thicknesses of the rock in the three general areas (Figures 7.1, 7.2 and 7.3) 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 lineaments interpreted during this preliminary assessment (Section 3.2.3) indicate that the three general areas in the ERFN area have the potential to contain structurally-bounded rock volumes of sufficient size to host a deep geological repository. The distribution of lineament density as a function of lineament length over the potentially suitable host rocks shows that the variable density and spacing of shorter brittle lineaments is influenced by the amount of exposed bedrock. By classifying the lineaments according to length, this local bias is reduced and the general areas exhibit geophysical lineament spacing on the order of less than 0.5 to 5 km and geophysical lineament spacing between longer lineaments (i.e., those longer than 10 km) on the order of 1 to 6 km, suggesting there is a potential for there to be sufficient volumes of structurally favourable rock at typical repository depth. All three general areas are located away from mapped major deformation zones or faults. The two areas in the Mudjatik domain within Sub-Regions 2.1 and 2.2 are located away from major deformation zones or faults. The one area in the Wollaston domain within Sub-Region 2.3 has a strong north-northeast ductile fabric to the rock that may be related to the Needle Falls shear zone, located 40 km away to the southeast. There is a potential for under-identification of lineaments in this sub-region as discussed in Section 3.2.3.

The hydrogeological regime at repository depth should exhibit low groundwater velocities and retard the movement of any potentially released radioactive material. There is limited information on the hydrogeological properties of the deep bedrock in the ERFN 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 areas. The potential for groundwater movement at repository depth is in part controlled by the fracture frequency, the degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of mineral infilling. Experience from other areas in the Canadian Shield indicates that ancient faults, similar to those in the ERFN 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 need to be investigated at later stages in the site evaluation process through site characterization activities that include drilling and testing of deep boreholes.

As discussed in Section 4.4, available information for other granitic intrusions and gneisses within the Canadian Shield indicates that active groundwater flow within structurally-bounded blocks tends to be generally limited to shallow fracture systems, typically less than 300 m. In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the

Whiteshell Research Area and Atikokan range from approximately 10^{-15} to 10^{-10} ms^{-1} (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} ms^{-1} to less than 10^{-12} ms^{-1} below a depth of 400 to 500 m.

Information on other geoscientific characteristics relevant to the containment and isolation functions of a deep geological repository, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, the thermal and geomechanical properties of the rock are not available, or very limited at this stage of the site selection process. 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 felsic gneiss rocks characterizing the three general potentially suitable areas identified within the ERFN area. Site-specific mineralogical and hydrogeochemical characteristics, including pH, Eh and salinity, would need to be assessed during subsequent site evaluation stages. Similarly, it is expected that the geomechanical and thermal characteristics of the felsic gneiss within the ERFN area may resemble those of the Lac du Bonnet batholith and Eye-Dashwa pluton with no obvious unfavourable conditions known at present. These properties would need to be assessed during subsequent site evaluation stages, provided the community remains interested and is selected by the NWMO to advance in the site selection process.

In summary, the review of available information, including completion of a lineament analysis and geophysical interpretation of the area, did not reveal any geological or hydrogeological conditions that would indicate that any of the three identified general areas would be unable to satisfy the containment and isolation function. Potential suitability of these areas would have to be further assessed during subsequent site evaluation stages.

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

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

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

- Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term;
- The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository;
- The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository; and
- The repository should be located at a sufficient distance from geological features such as zones of deformation or faults that could be potentially reactivated in the future.

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

The ERFN area is located within the Canadian Shield, where large portions of land have remained tectonically stable for more than 1.6 Ga. Historically, very few earthquakes of magnitude greater than 3 (Nuttli magnitude) have been recorded within Saskatchewan and none in the ERFN area over the last 25 years. As discussed in Section 5.2, fault zones have been identified in the ERFN area. These brittle features were probably created in the area approximately 1.8 Ga as part of the last significant deformation event known to have occurred in the area (D_5). There is some evidence suggesting periods of reactivation along a fault system (Tabbernor fault) approximately 150 km to the east of the ERFN area. This fault initially formed approximately 1.8 Ga (Davies, 1998), but likely experienced more recent periods of reactivation (Elliot, 1996). However, there is no evidence of recent movement in the ERFN area and the majority of the movement along any related faults is inferred to have occurred 1.8 to 1.6 Ga. The three identified general areas are away from these fault zones.

The geology of the ERFN 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 in the future. However, findings from studies conducted in other areas of the Canadian Shield suggest that deep crystalline rocks have remained largely unaffected by past perturbations such as glaciation. Findings of a comprehensive paleohydrogeological study of the fractured crystalline rock at the Whiteshell Research Area, located within the Manitoba portion of the Canadian Shield (Gascoyne, 2004) 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 approximately 300 m have 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. These various studies found that fractures below a depth of several hundred metres in the rock were typically ancient features. Subsequent geological processes such as plate movement and continental glaciations have caused reactivation of existing zones of weakness rather than the formation of large new zones of fractures.

Land in the ERFN 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 to 2 mm/yr) south of the Great Lakes. Present day rebound rates in the ERFN should be on the order of 5 mm/yr (Lambert et al., 1998, Sella et al., 2007). There is no site-specific information on erosion rates for the ERFN 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 areas in the ERFN area have the potential to meet the long-term stability factor. The review did not identify any obvious geological or hydrogeological conditions that would cause the performance of a repository to be substantially altered by future geological and climate change processes, or prevent the identified areas from remaining stable over the long term. The long-term stability factor would need to be further assessed through detailed multidisciplinary 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 ERFN area. The areas are characterized by moderate to high relief and each contains enough surface land outside 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 felsic gneiss in the ERFN area. However, there is abundant information at other locations of the Canadian Shield with similar types of rock that could provide insight into what should be expected for the ERFN area in general. As discussed in Section 6, available information suggests that granitic crystalline rock units within the Canadian Shield generally possess good geomechanical characteristics that are amenable to the type of excavation activities involved in the development of a deep geological repository for used nuclear fuel (Arjang and Herget, 1997; Everitt, 1999; McMurry et al., 2003; Chandler et al., 2004). The conceptual model developed by Kaiser and Maloney (2005), based on available stress measurement data, describes the variable stress state in the upper 1,500 m of the Canadian Shield. Although this model can be used as an early indicator of average stress changes with depth, significant variations such as the principal horizontal stress rotation and the higher than average stress magnitudes found at typical repository depth (500 m) at AECL's URL (Martino et al., 1997) could occur as a result of local variations in geological structure and rock mass complexity.

The general potentially suitable areas have generally low overburden cover. At this stage of the site evaluation process, it is not possible to determine the exact thickness of the overburden deposits in these areas. Figure 2.6 shows these areas to be dominated by exposed bedrock and a thin (<2 m) till veneer. These conditions are geotechnically suitable in terms of bearing capacity and stability for the construction of surface infrastructure associated with a repository.

In summary, the three general potentially suitable areas in the ERFN area have good potential to meet the requirements for safe construction, operation and closure.

7.3.4 Isolation of Used Fuel from Future Human Activities

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

This requires that:

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

Some metallic mineral occurrences have been identified in the ERFN area and exploration of these occurrences, particularly uranium has occurred in the recent past. However, these occurrences are within geological settings that were excluded in the process of identifying areas (e.g., thin bands of metasedimentary rocks, faults near the Mudjatik-Wollaston contact). Further, no mining has occurred to date in the ERFN area.

The review of available information did not identify any groundwater resources at repository depth for the ERFN area. As discussed in Section 4.3, the Saskatchewan Watershed Authority (SWA) Water Well Record database shows that there are no water wells known in the Canadian Shield portion of the ERFN area. Experience from other areas with similar rock types in the Canadian Shield has shown that active groundwater flow in crystalline rocks is generally confined to shallow fractured localized systems. SWA Water Well Records indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the ERFN area or anywhere else in northern Saskatchewan. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits potential yield, even if suitable water quality were to be found.

In summary, the potential for groundwater resources and economically exploitable natural resources at repository depth is considered low in the three identified general areas within the ERFN area, although this conclusion will be subject to further confirmation.

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

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

Factors affecting the amenability to site characterization include geological heterogeneity, structural and hydrogeological complexity, accessibility, and the presence of lakes or overburden with thickness or composition that could mask important geological or structural features. As described in Section 3, the felsic gneiss in the general areas identified ERFN area has the potential to be relatively homogeneous. The lithological homogeneity of the felsic gneiss would need to be further assessed during subsequent stages of the site evaluation process through the acquisition of higher resolution geophysical surveys and detailed geological mapping.

As discussed in Section 7.1, interpreted lineaments represent the observable two-dimensional expression of three-dimensional features. The ability to detect and map such lineaments is influenced by topography, the character of the lineaments (e.g., their width, orientation, age, etc.), the thickness of overburden, and the underlying resolution of the data used for the mapping. The orientation of lineament features in three dimensions represents another degree of structural complexity that will require assessment through detailed site investigations in future phases of the site selection process. The entire ERFN area is characterized by low total lineament density. The density of lineaments in the eastern part of Sub-Region 2.2 (Wollaston domain) would need to be further assessed during subsequent stages of the site evaluation process because of the strong north-northeast fabric of the rock in this area that is related to the Needle Falls shear zone.

The identification and mapping of geology and structure is strongly influenced by the extent and thickness of overburden cover and the presence of large lakes. The ERFN area is dominated by a thin veneer of morainal sediments or exposed bedrock. Thicker overburden deposits occur over the western (toward Flatstone Lake) and southern (toward the Churchill River) lowland portions of the ERFN area.

Provincial Highway 914 provides nearby access to the general potentially suitable areas in Sub-Regions 2.1 and 2.3. Currently there is no all-season road access to the general area in Sub-Region 2.2.

The review of available information did not indicate any obvious conditions which would make the rock mass in the three general potentially suitable areas unusually difficult to characterize. Outcrop locations are available for site characterization purposes at all of the identified general potentially suitable areas.

8.0 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

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

The preliminary geoscientific assessment built on the work previously conducted for the initial screening (Golder, 2011) and focused on the three sub-regions within the ERFN area as shown on 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. The key geoscientific characteristics considered relate to: geology, structural geology and distribution of lineaments, distribution and thickness of overburden deposits, surface conditions, and the potential for economically exploitable natural resources. Where information for the ERFN area was limited or not available, the assessment drew on information and experience from other areas with similar types of rock in 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 and radiometric);
- Lineament studies using available satellite imagery, topography and geophysical surveys to provide information on the characteristics such as location, orientation and length of interpreted structural bedrock features;
- Terrain analysis studies to help assess factors such as overburden type and distribution, bedrock exposures, accessibility constraints, watershed and subwatershed boundaries, groundwater discharge and recharge zones; and
- The identification and evaluation of general potentially suitable areas based key geoscientific characteristics and the systematic application of NWMO's geoscientific site evaluation factors.

The desktop geoscientific preliminary assessment showed that the ERFN area contains at least three general areas that have the potential to satisfy NWMO's site evaluation factors.

The bedrock (felsic gneiss) in the three identified potentially suitable areas appears to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. It has a sufficient depth and extends over a large area at surface. It also appears have the potential to be lithologically homogeneous, with low potential for natural resources and limited surface constraints. One of the three identified areas has poor access compared to the two others.

While the ERFN area appears 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 for the ERFN area include the low resolution of available geophysical data over most of the potentially suitable areas, the lithological homogeneity of the felsic gneiss, the complexity of structures (as shown by complex lineament orientations) and the potential influence of the Needle Falls shear zone.

Interpreted lineaments suggest that all three identified general areas have the potential to contain structurally bounded rock volumes of sufficient size to host a deep geological repository. However, this would need to be further assessed during future site evaluation stages as the observed low geophysical lineament density is likely due the low resolution of available geophysical data and the difficulty in recognizing brittle structures due to high ductile strain associated with the Needle Falls shear zone. The potential impact of the Needle Falls shear zone on the lithological and structural homogeneity of the bedrock within the three potentially suitable areas is also uncertain and would need to be further assessed.

Should the community of ERFN be selected by the NWMO to advance to Phase 2 of the 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 ERFN 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, field geological mapping and the drilling of deep boreholes.

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Report Signature Page

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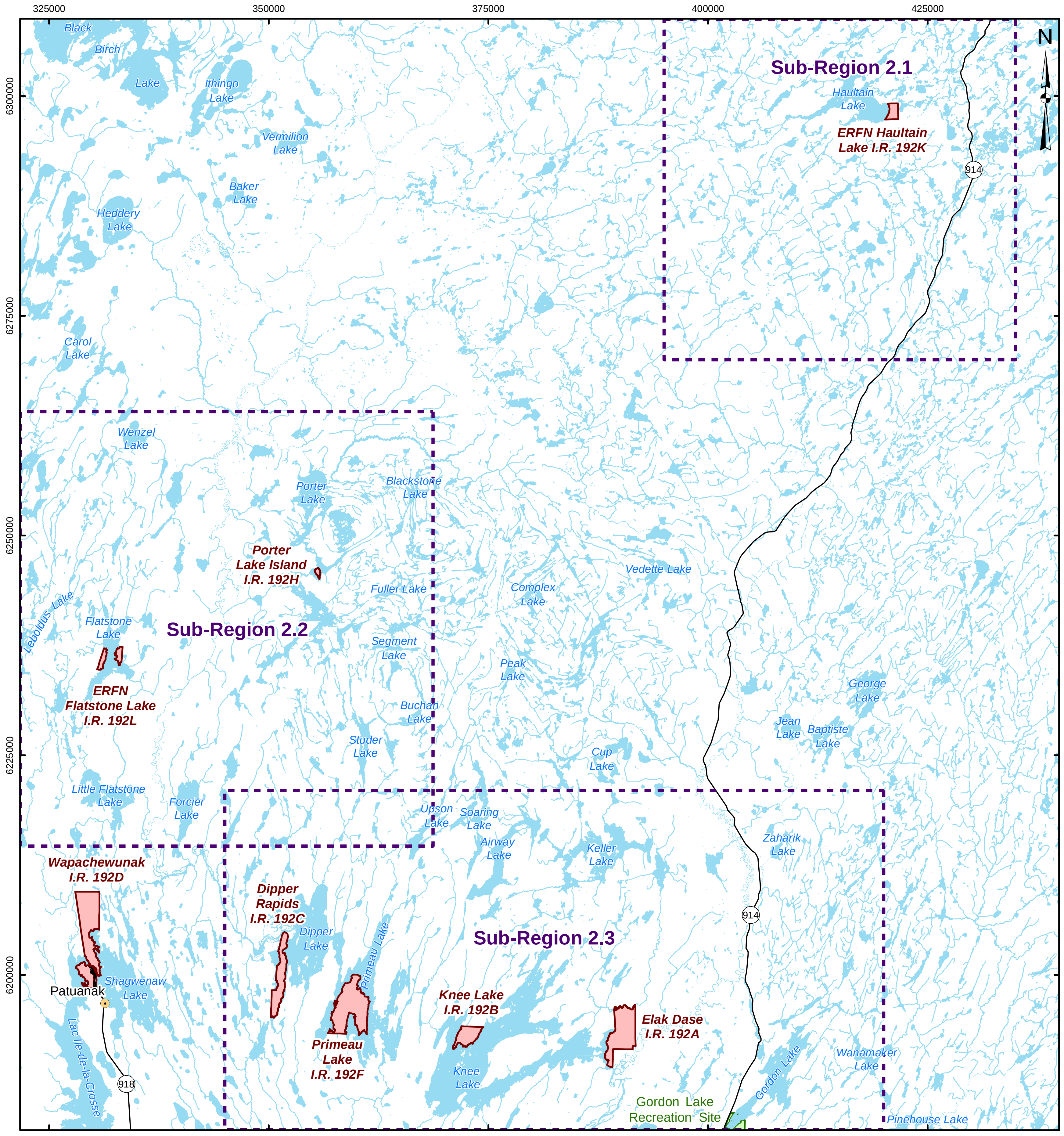
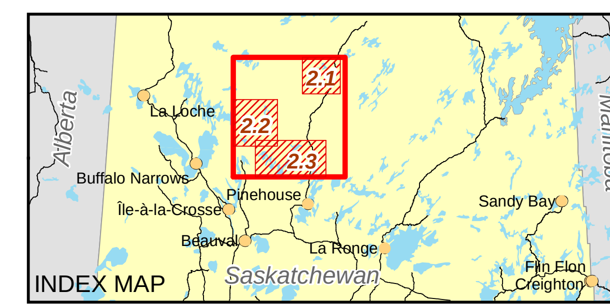
FIGURES



LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Park and Recreation Area



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

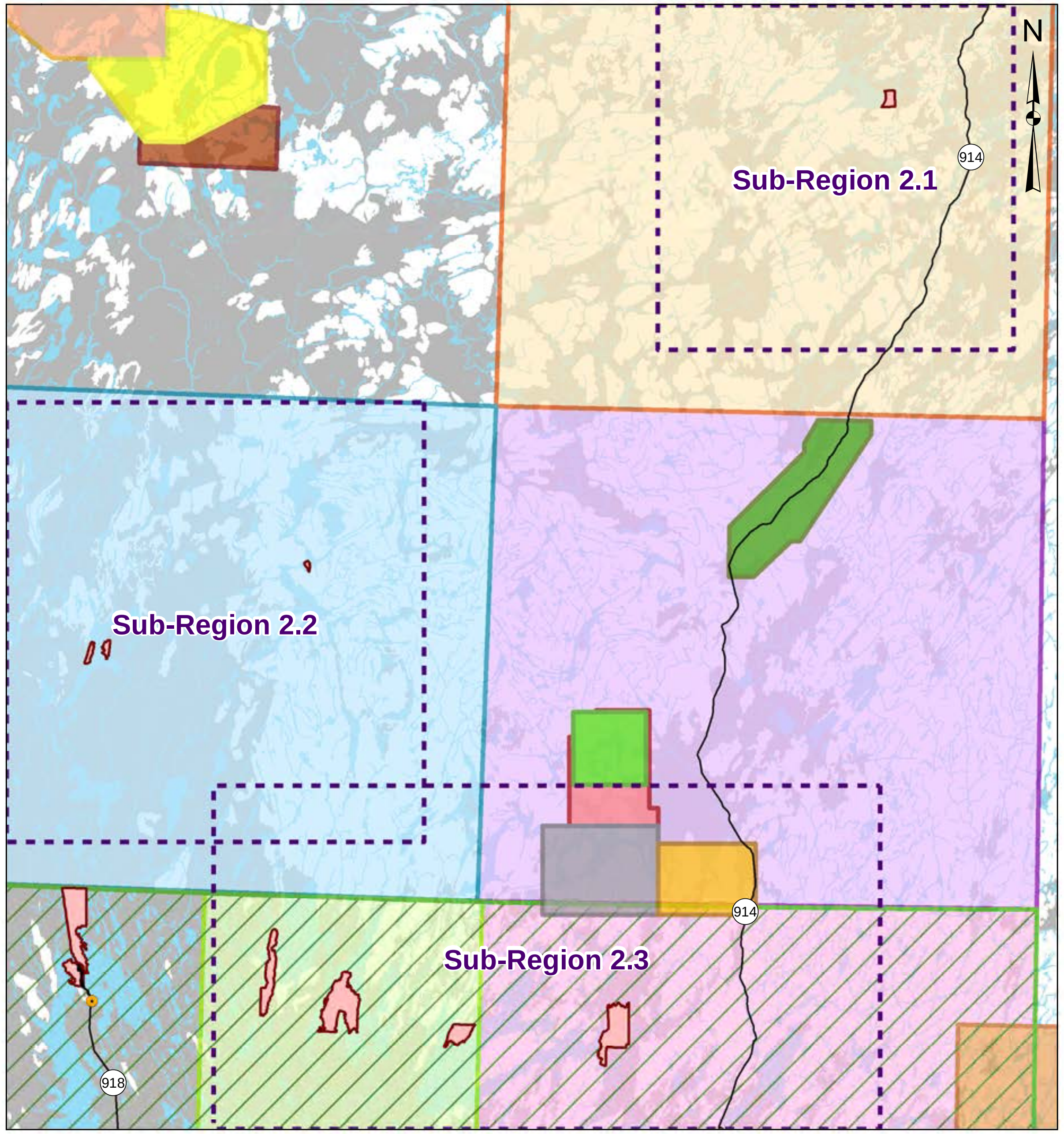
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
English River First Nation
and Surrounding Area

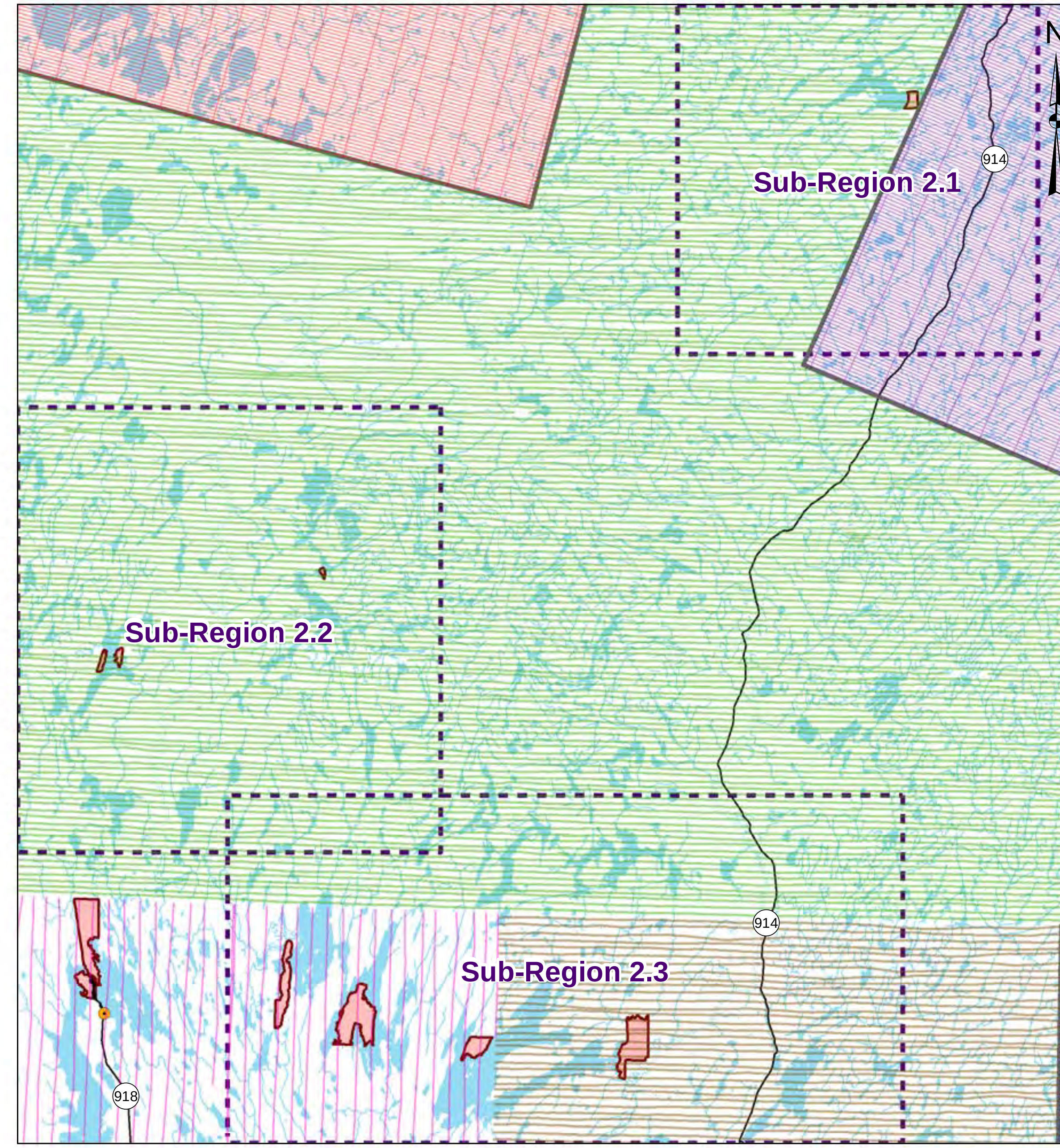
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 1.1	
GIS	PM/JB	18 Sep. 2013		
CHECK	AM	18 Sep. 2013		
REVIEW	GWS	18 Sep. 2013		

Geology Mapping Coverage



Geophysics Mapping Coverage



LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Overburden Cover

Detailed Geology Extent

- Pearson 1972, 1977b Map 166A
- Scott 1977b Map 183A
- Munday 1977b Map 168B
- Munday 1972, 1977c Map 168A
- Munday 1978b Map 189A
- Thomas and Slimmon 1985 Map 245A
- Coombe 1994
- Thomas 1978 Map 78-10-10
- Harper 1988b Map 88-4-7
- Tran 1999a Map 99-4.2-(6.1)
- Tran 1999b Map 99-4.2-(6.2)
- Tran 1999c Map 99-4.2-(6.3)
- Tran and Yeo 1999 Map 99-4.2-(7)
- Card et al 2008a Map 08-4.2-(1.2)
- Card et al 2008b Map 08-4.2-(1.3)

Full Geology Coverage

Saskatchewan Industry and Resources, 2010

LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve

Geophysical Survey Flightpaths

- Cree Lake South
- Upper Foster Lake
- Saskatchewan #5
- Saskatchewan #7
- Saskatchewan #8
- Saskatchewan #9
- Saskatchewan #10

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

15 7.5 0 15 30 45
SCALE 1:750,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geoscience Mapping and Geophysical Coverage of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM/JB	19 Nov. 2012	FIGURE: 1.2	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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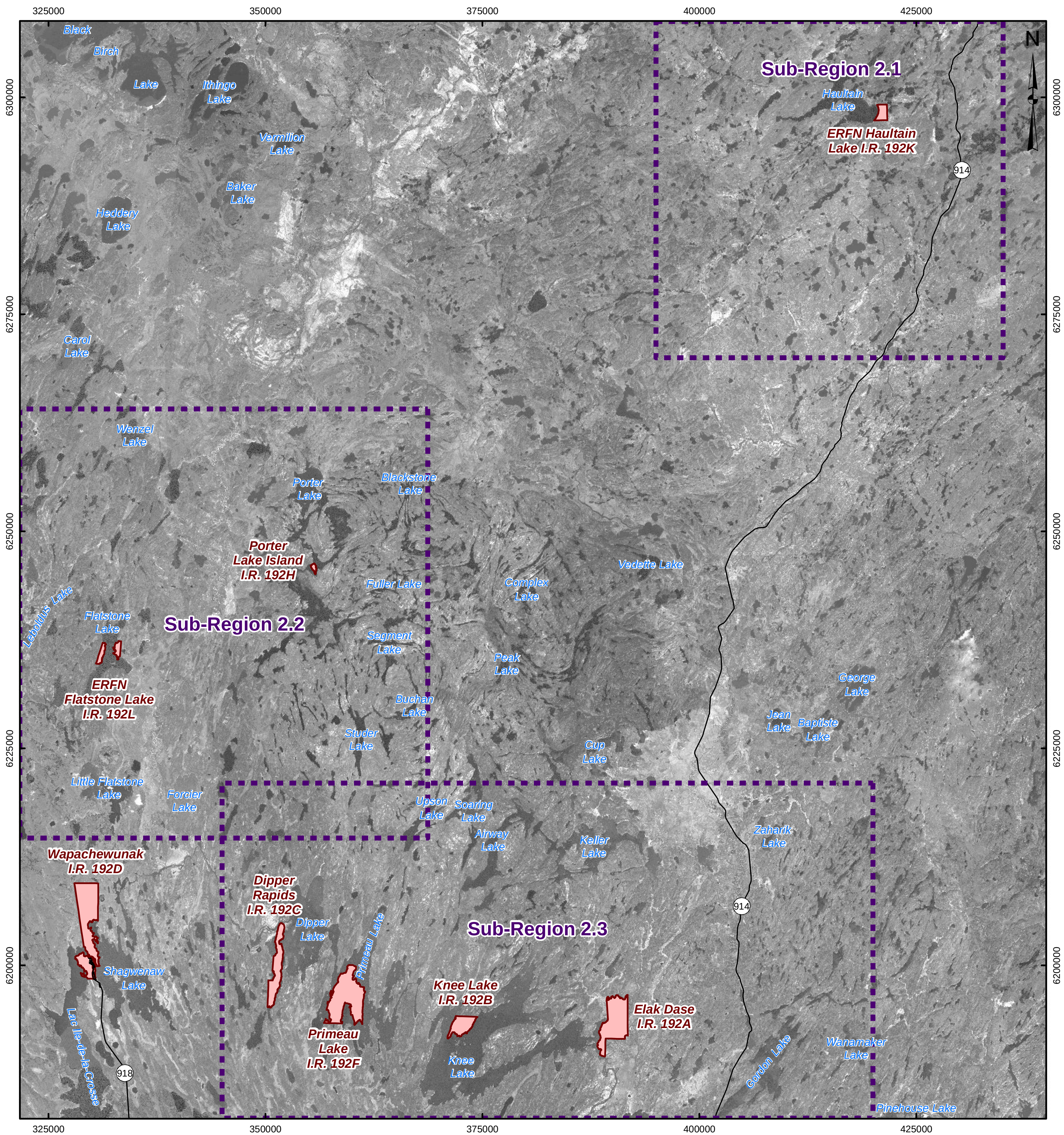
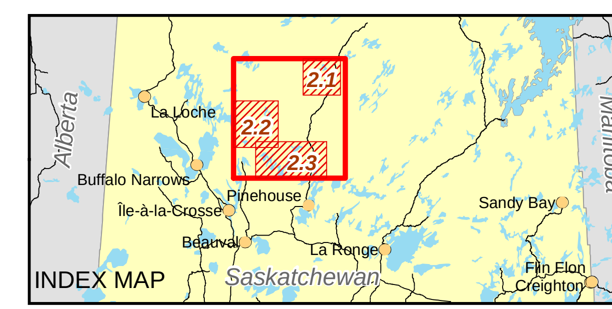


LEGEND

- English River First Nation Detailed Area
- Highway
- Federal Land - Indian Reserve



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Imagery - SPOT obtained from GeoBase (2005, 10m resolution)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Satellite Imagery of the
English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 2.1	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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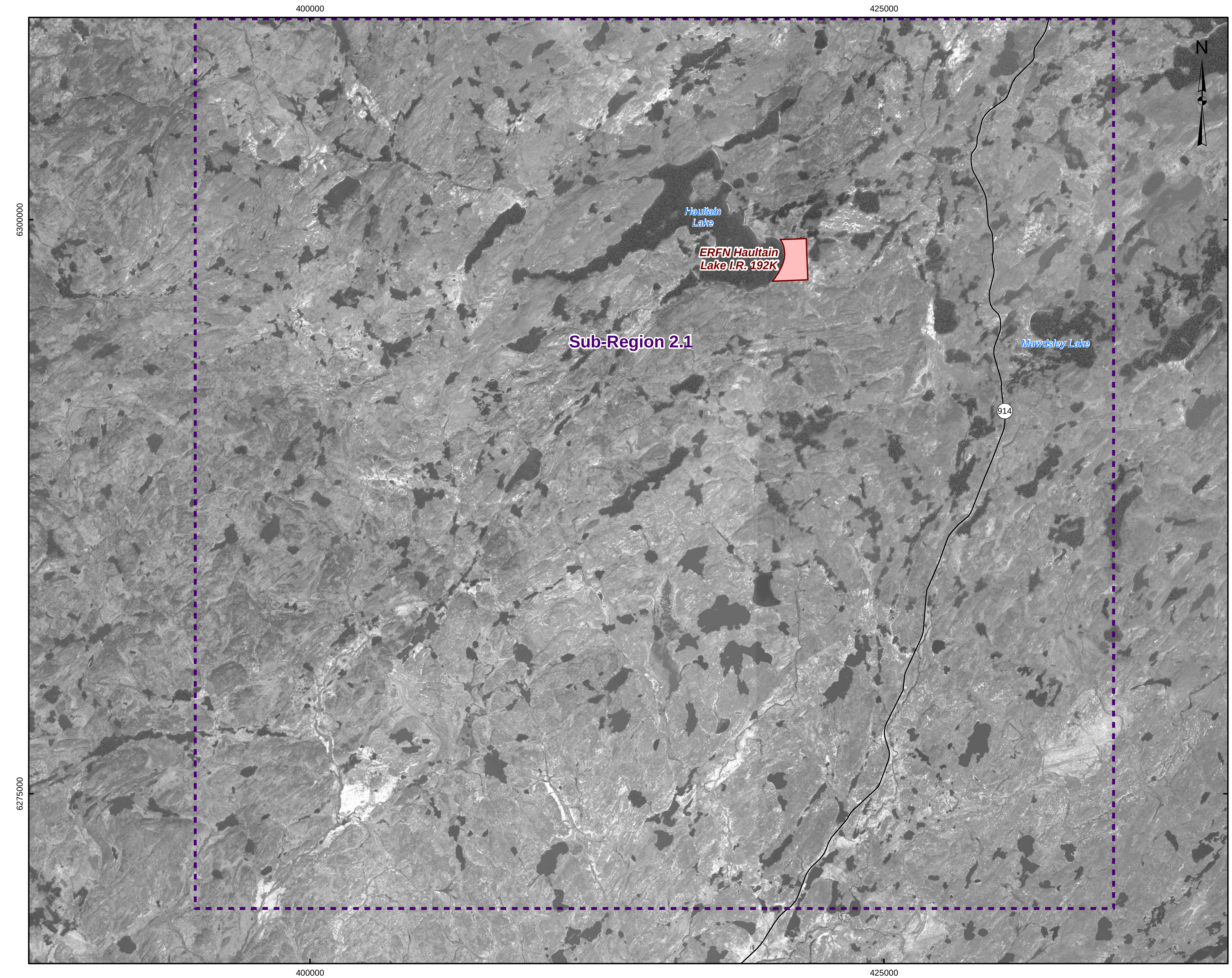
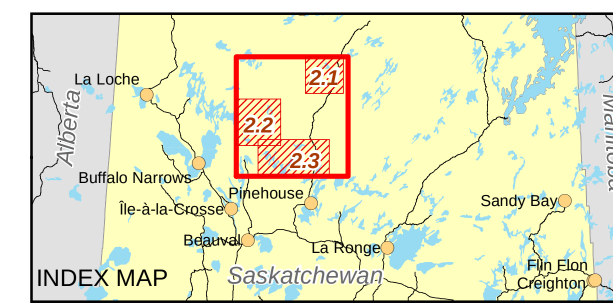


LEGEND

- English River First Nation Detailed Area
- Highway
- Federal Land - Indian Reserve



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Imagery - SPOT obtained from GeoBase (2005, 10m resolution)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

3 1.5 0 3 6 9
SCALE 1:175,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Satellite Imagery of the English River First Nation Area - Sub-Region 2.1

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012		
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013	FIGURE: 2.2	
REVIEW	GWS	19 Sep. 2013		

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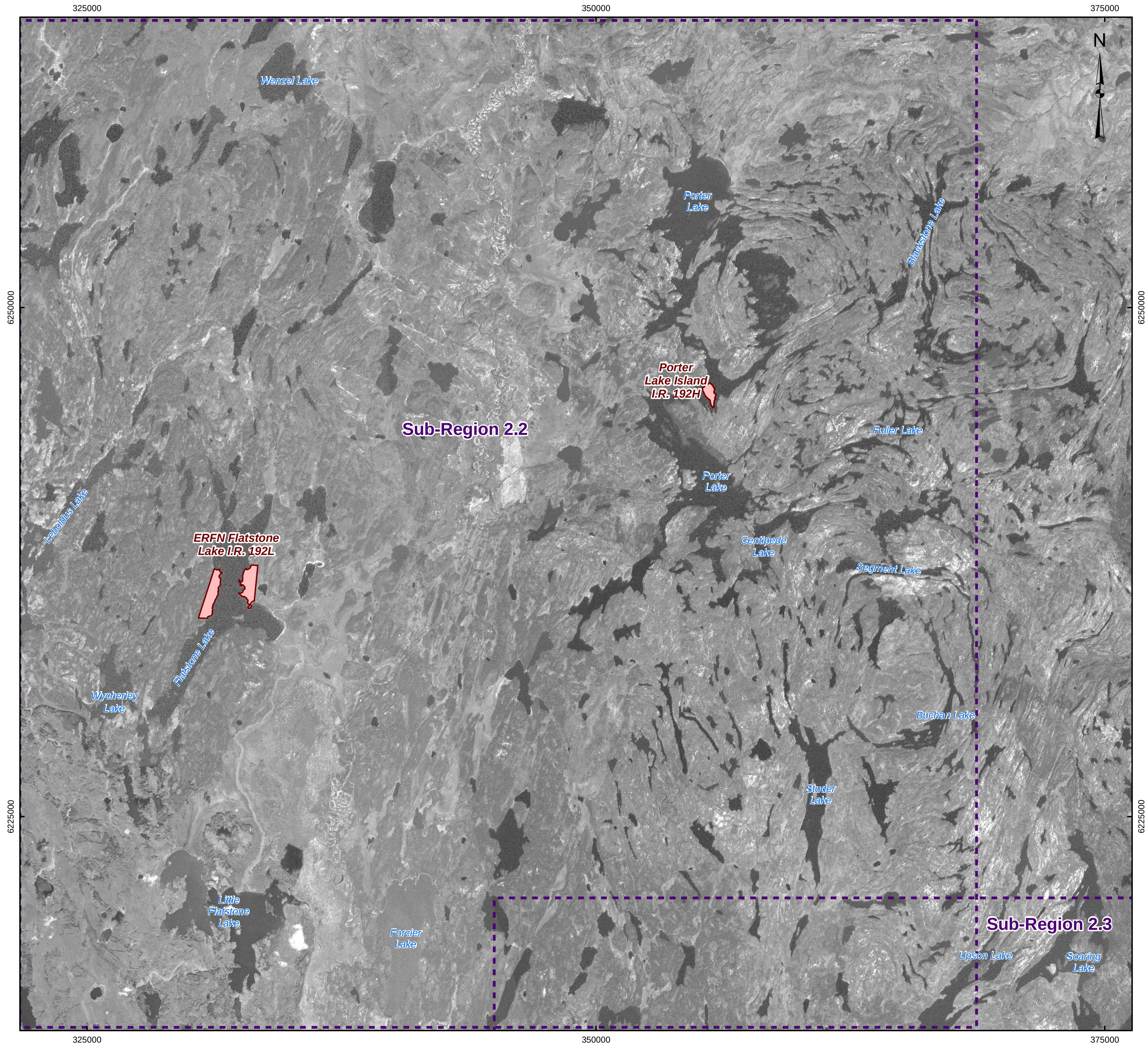
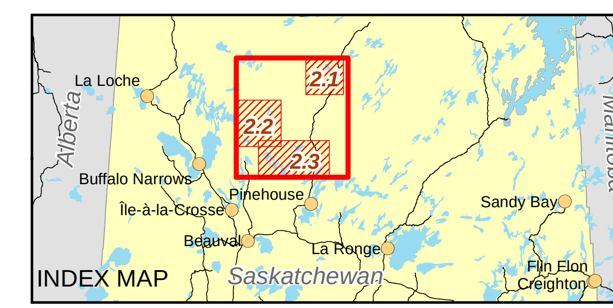


LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Imagery - SPOT obtained from GeoBase (2005, 10m resolution)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

4 2 0 4 8 12
KILOMETERS
SCALE 1:200,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Satellite Imagery of the English River First Nation Area - Sub-Region 2.2

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012		
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

Golder Associates
Mississauga, Ontario

FIGURE: 2.3

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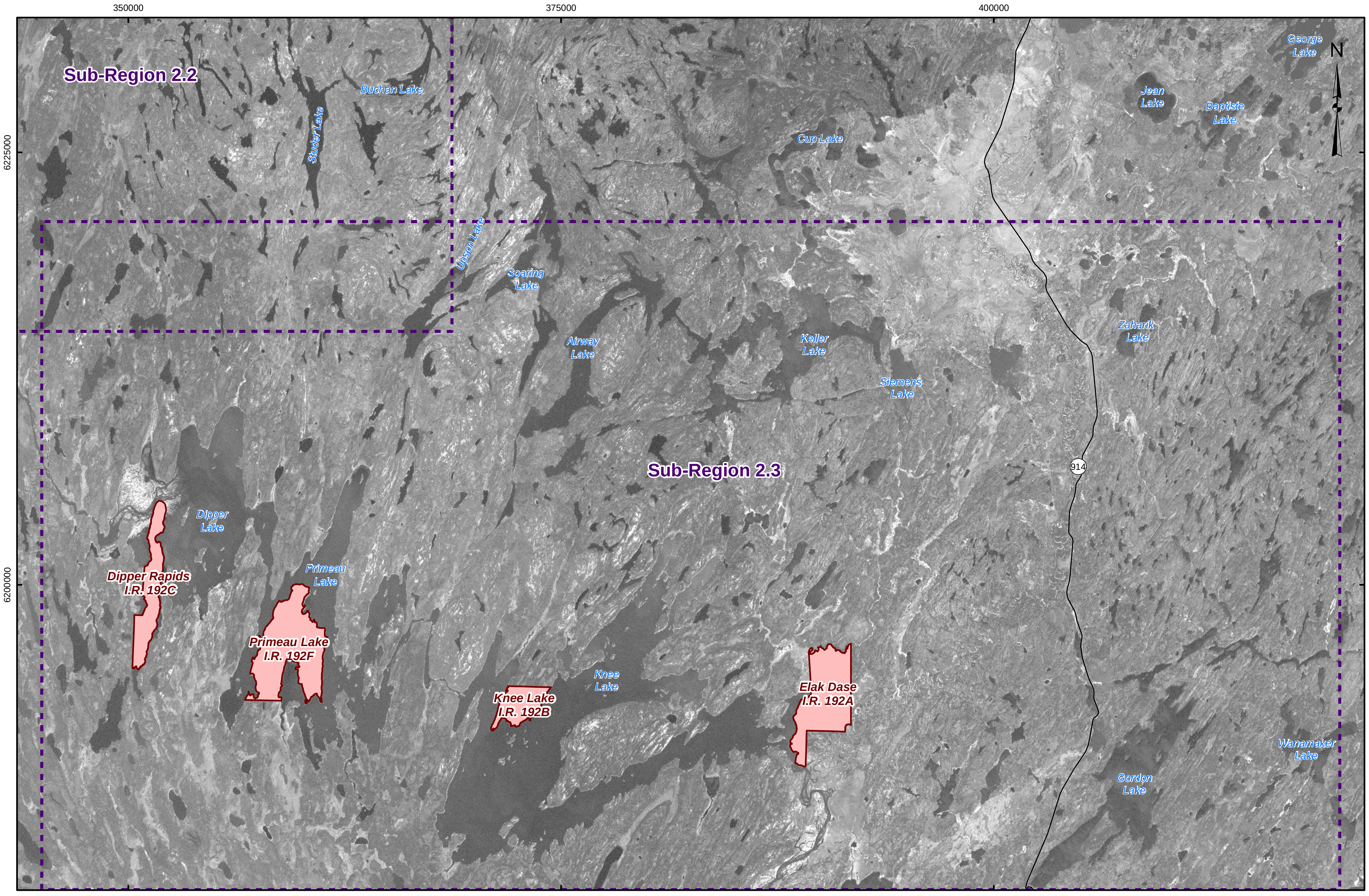
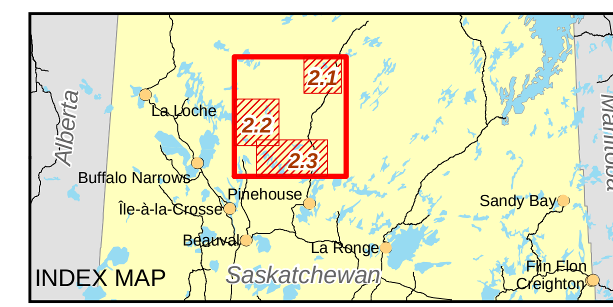


LEGEND

- English River First Nation Detailed Area
- Highway
- Federal Land - Indian Reserve



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Imagery - SPOT obtained from GeoBase (2005, 10m resolution)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10 15
SCALE 1:250,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Satellite Imagery of the
English River First Nation Area - Sub-Region 2.3

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 2.4	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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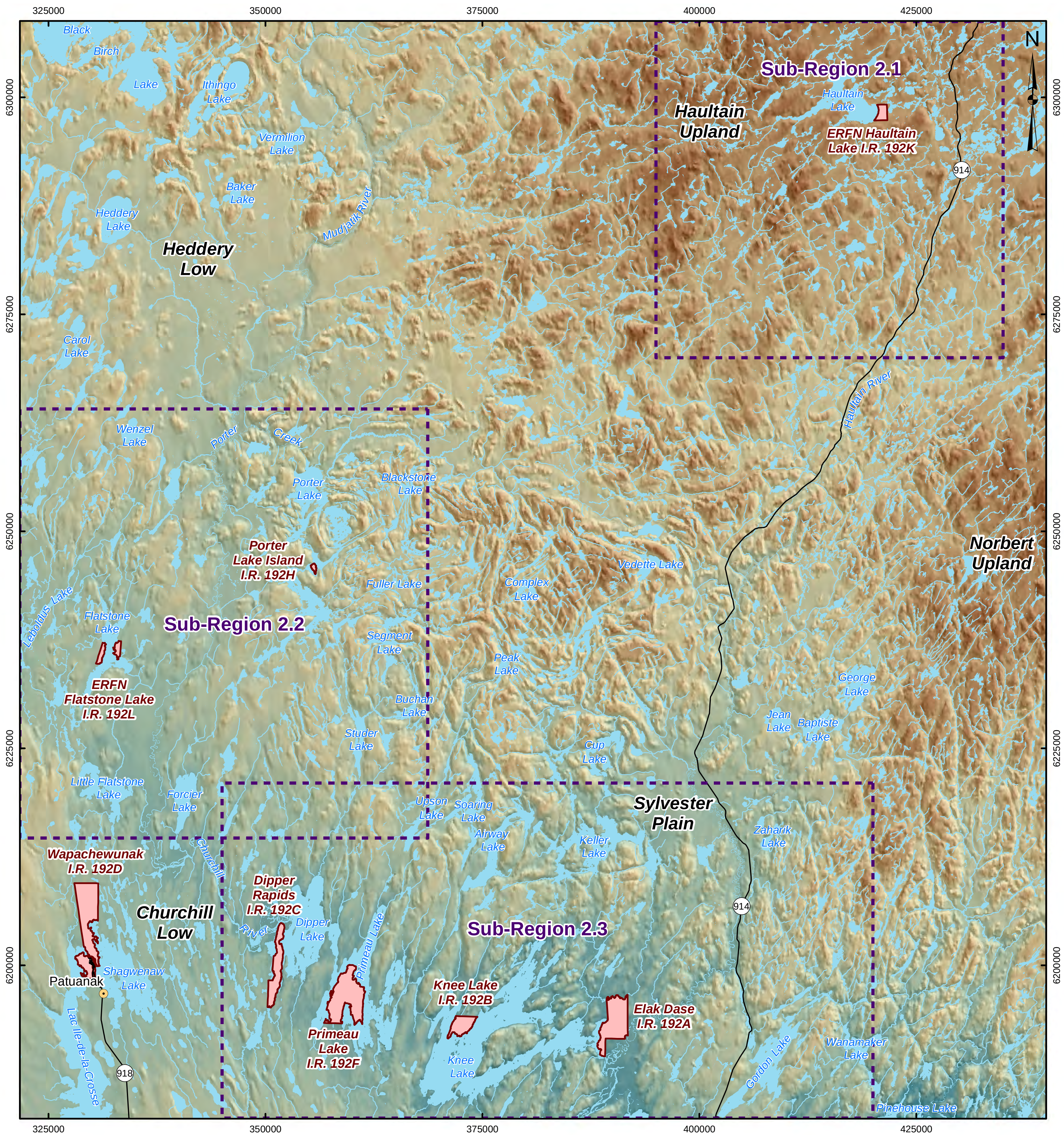
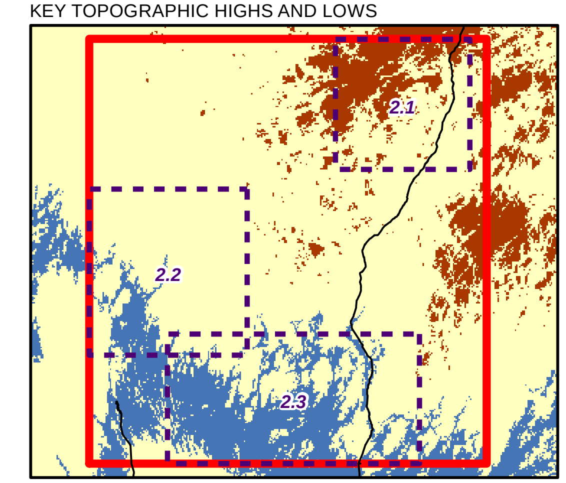


LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve

Elevation (masl)
631
575
525
475
425
375

KEY TOPOGRAPHIC HIGHS AND LOWS



Elevation (m)
202 - 425
426 - 550
551 - 745

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Digital Elevation Model - CDED slope and elevation raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Elevation and Major Topographic Features of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	6 Dec. 2012	FIGURE: 2.5	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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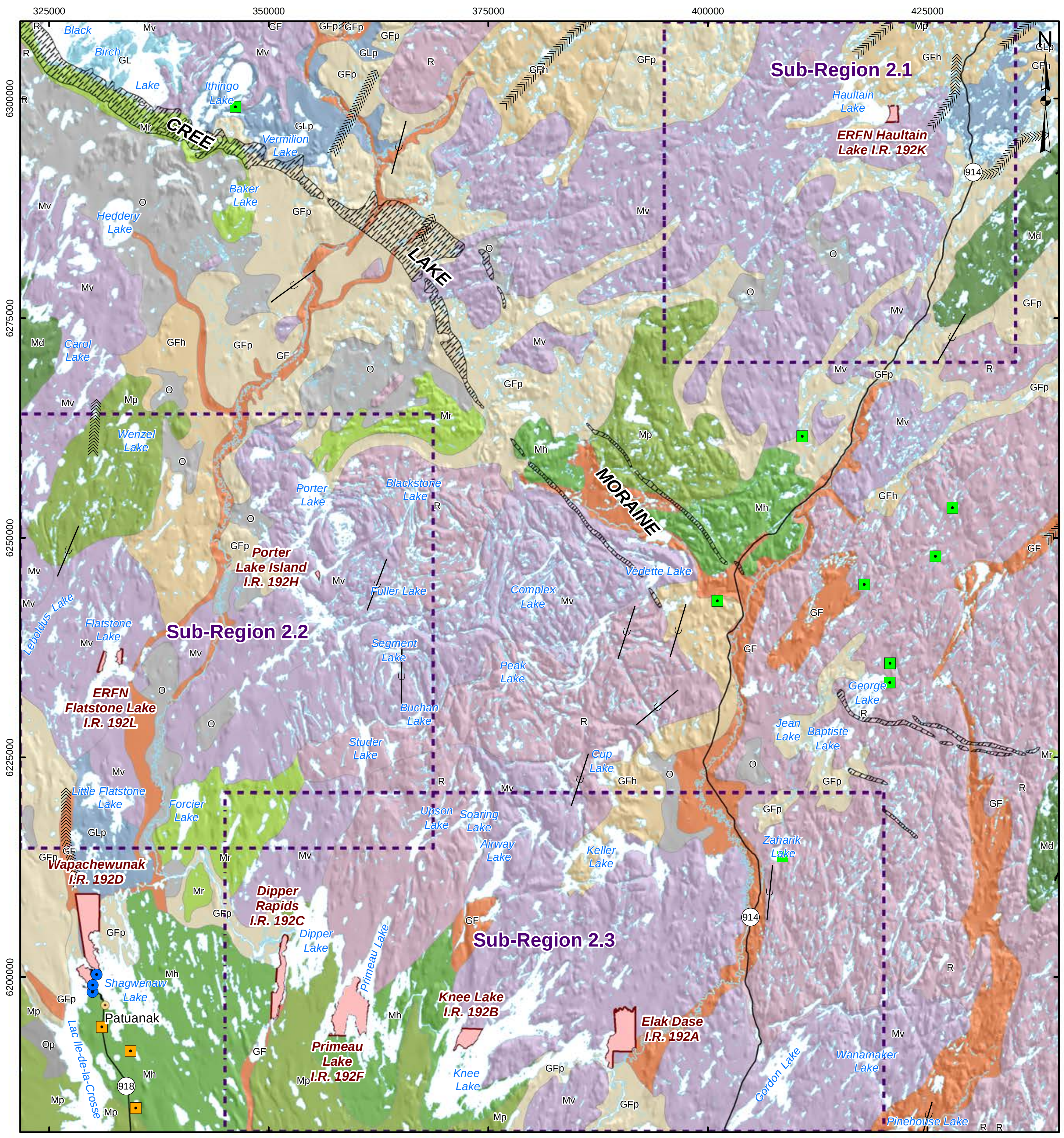


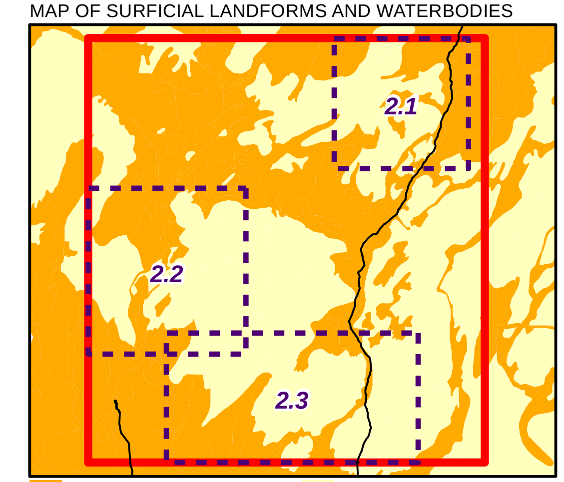
LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Waterbody
- Federal Land - Indian Reserve
- Water well
- Drill hole (Regina databse)
- Drill hole (La Ronge database)
- Drumlin
- Striation
- Esker
- Moraine

Surficial Geology

- O - Organic
- Op - Organic plain
- GF - Glaciofluvial
- GFh - Glaciofluvial hummocky
- GFp - Glaciofluvial plain
- GL - Glaciolacustrine
- GLp - Glaciolacustrine plain
- Md - Morainal drumlinoid
- Mh - Morainal hummocky
- Mp - Morainal plain
- Mr - Morainal ridged
- Mv Morainal veneer
- R - Rock

MAP OF SURFICIAL LANDFORMS AND WATERBODIES



Surficial or water (roughly 50%) Rock or morainal veneer (roughly 50%)

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Quaternary Geology - Saskatchewan Geological Atlas (1:250,000)
Drill holes - Sask Geological Atlas
Wells - Saskatchewan Watershed Authority Water Well Database
Hillshade - CDED slope rater: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Terrain Features of the
English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 2.6	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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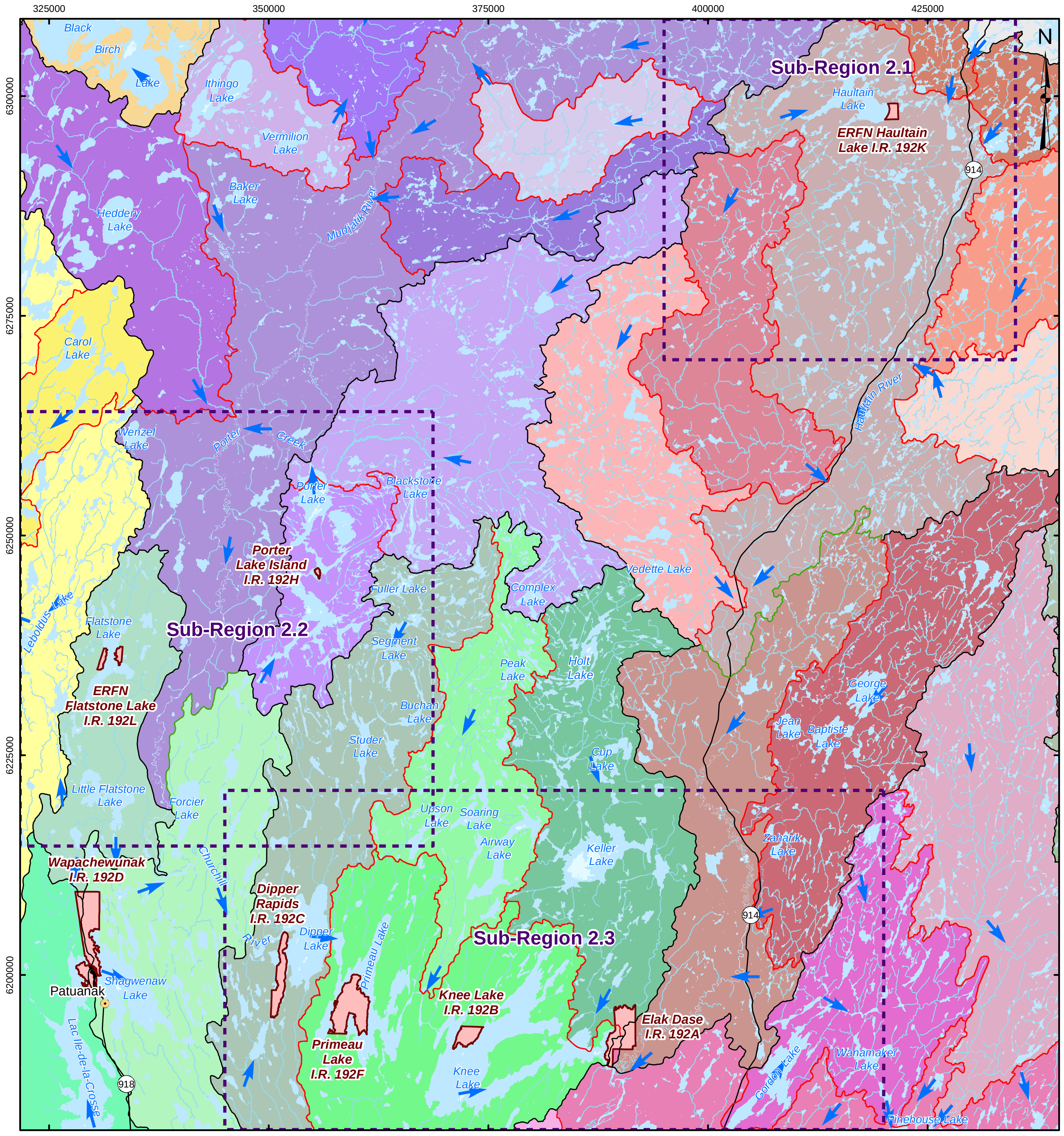


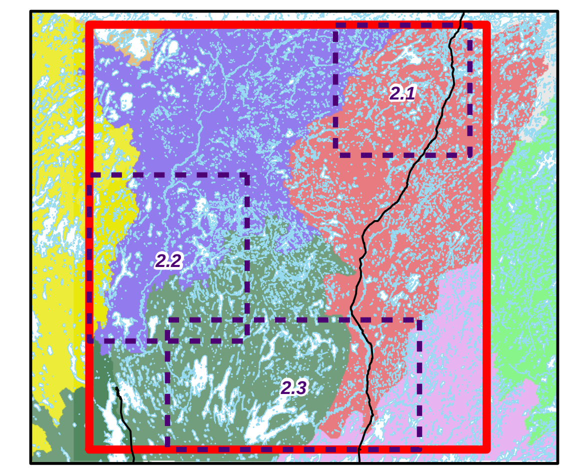
LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Federal Land - Indian Reserve
- Flow Direction

Drainage Divide

- Delineated by PFRA (Confirmed by JDMA)
- Delineated by JDMA
- Delineated by PFRA
- Watercourse
- Waterbody
- Wetland

MAP OF TERTIARY WATERSHEDS



Tertiary Watershed

- Mudjatik
- Haultain
- Upper Churchill
- Central Churchill
- Churchill Lake
- Clearwater
- Foster
- Cochrane

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30

SCALE 1:525,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Drainage Features of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 2.7	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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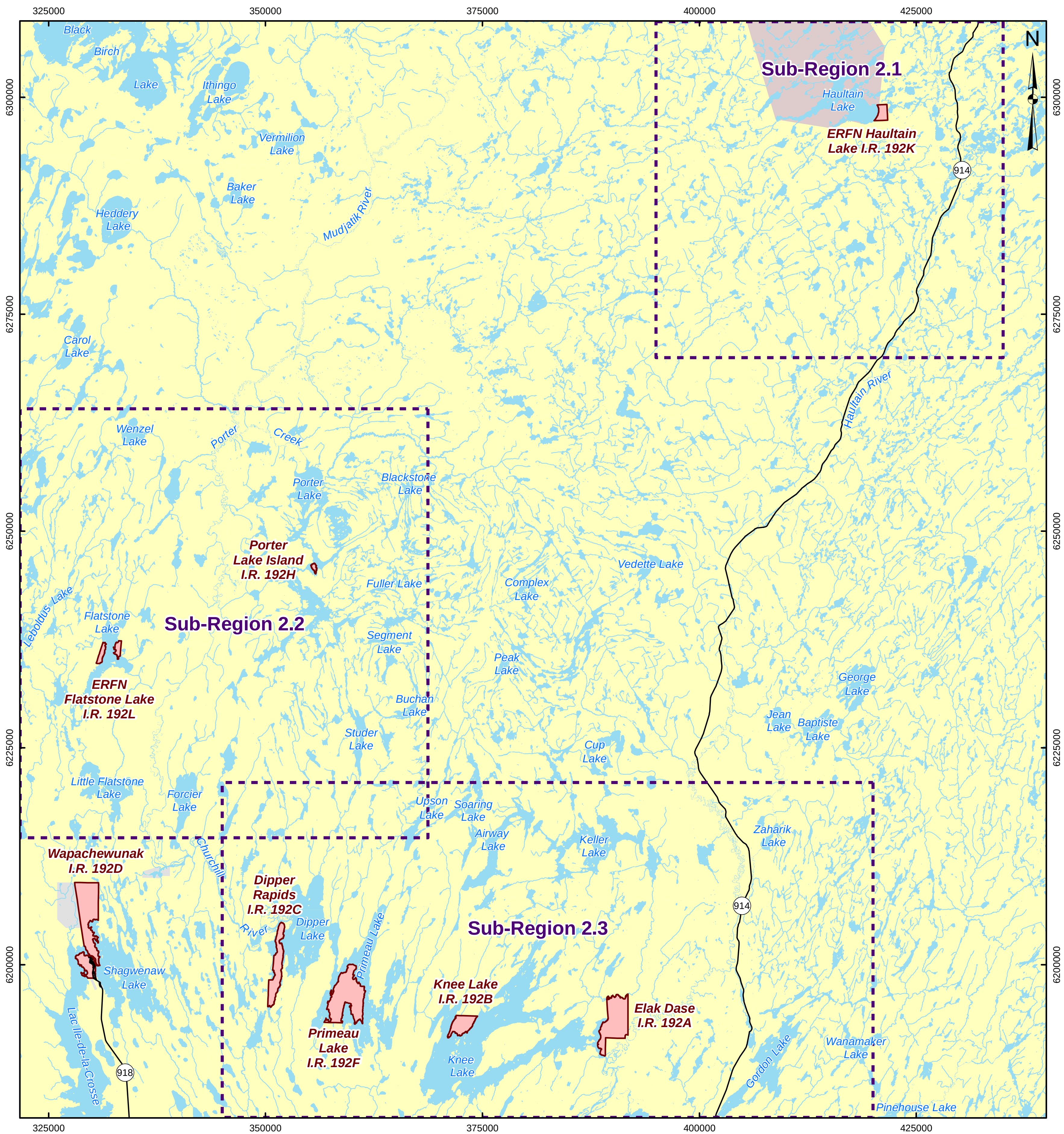
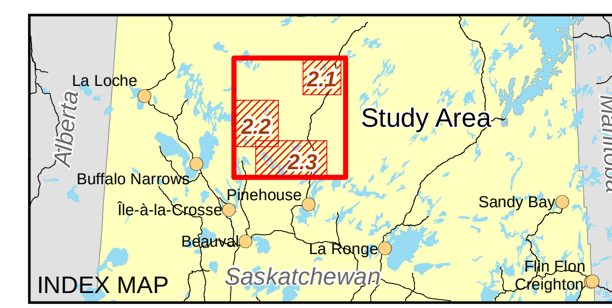


LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Park and Recreation Area
- Crown Land
- Private Land
- Unclassified Land
- Crown Reserves



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Cadastral Data - Information Services Corporation of Saskatchewan, 2008
Crown Reserves - Saskatchewan Geological Atlas
Projection: Universal Transverse Mercator Datum: NAD 83
Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Land Disposition and Ownership
within the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 2.8	
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

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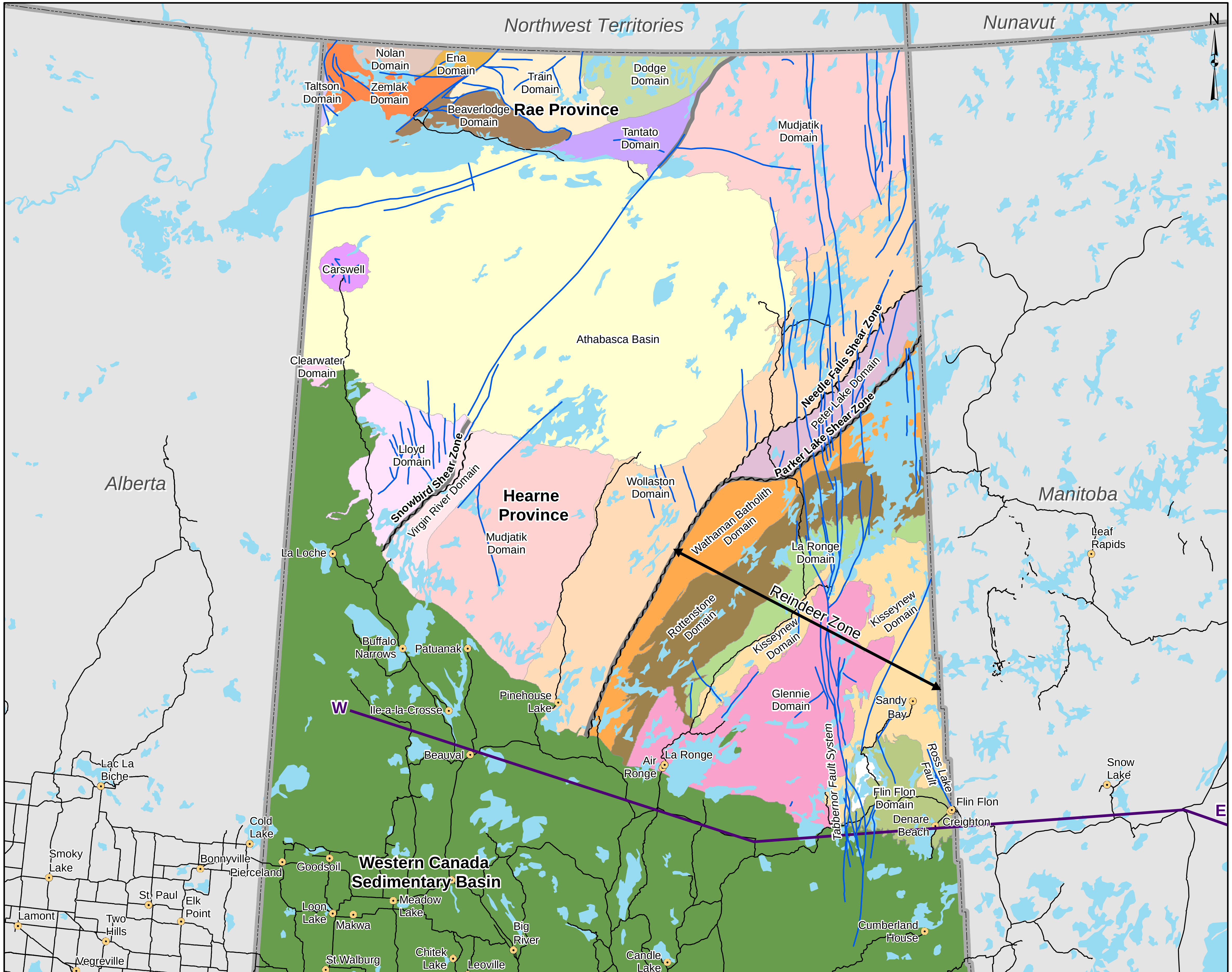


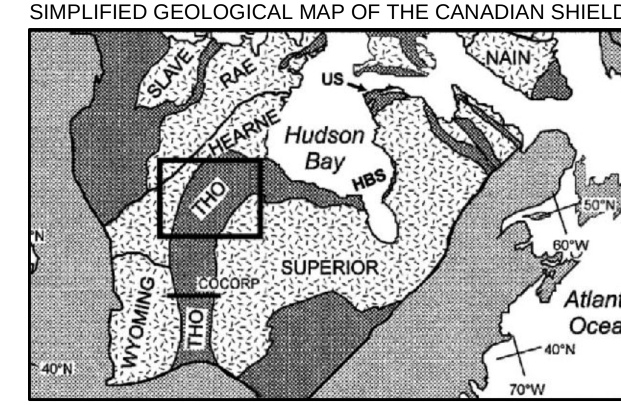
LEGEND

- Provincial Boundary
- Community
- Highway
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Geological Cross Section (see Figure 3.2)
- Precambrian Geological Province

Lithotectonic Domain

- Athabasca Basin
- Beaverlodge Domain
- Carswell Domain
- Clearwater Domain
- Dodge Domain
- Ena Domain
- Flin Flon Domain
- Glennie Domain
- Kisseynew Domain
- La Ronge Domain
- Lloyd Domain
- Mudjatik Domain
- Nolan Domain
- Peter Lake Domain
- Rottenstone Domain
- Taltson Domain
- Tantato Domain
- Train Domain
- Virgin River Domain
- Wathaman Batholith Domain
- Wollaston Domain
- Zemlak Domain
- Western Canada Sedimentary Basin

SIMPLIFIED GEOLOGICAL MAP OF THE CANADIAN SHIELD



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Government of Canada, Natural Resources Canada, Centre for Topographic Information, 2001
Corrigan et al., "The Palaeoproterozoic Trans-Hudson Orogen: a prototype of modern accretionary processes", *Geological Society, London, Special Publications* 2009; v. 327; p. 457-479.
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13N

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SCALE 1:3,000,000 KILOMETRES

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Lithostructural Domains of
Northern Saskatchewan

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	JB	8 Nov. 2012	FIGURE: 3.1	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GS	19 Sep. 2013		

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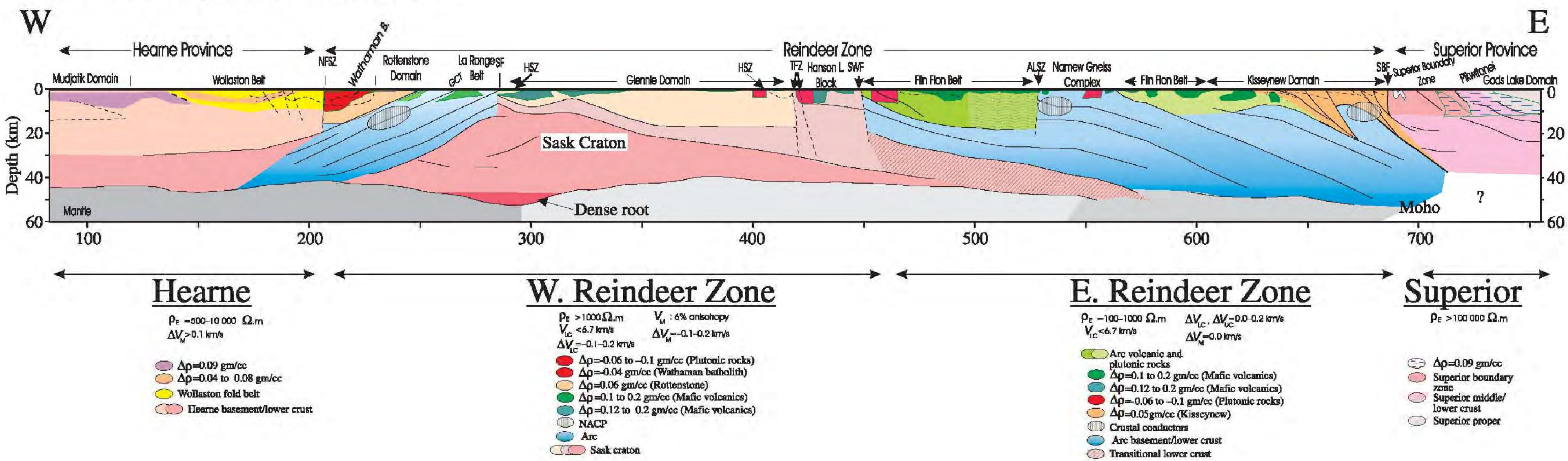


REFERENCE

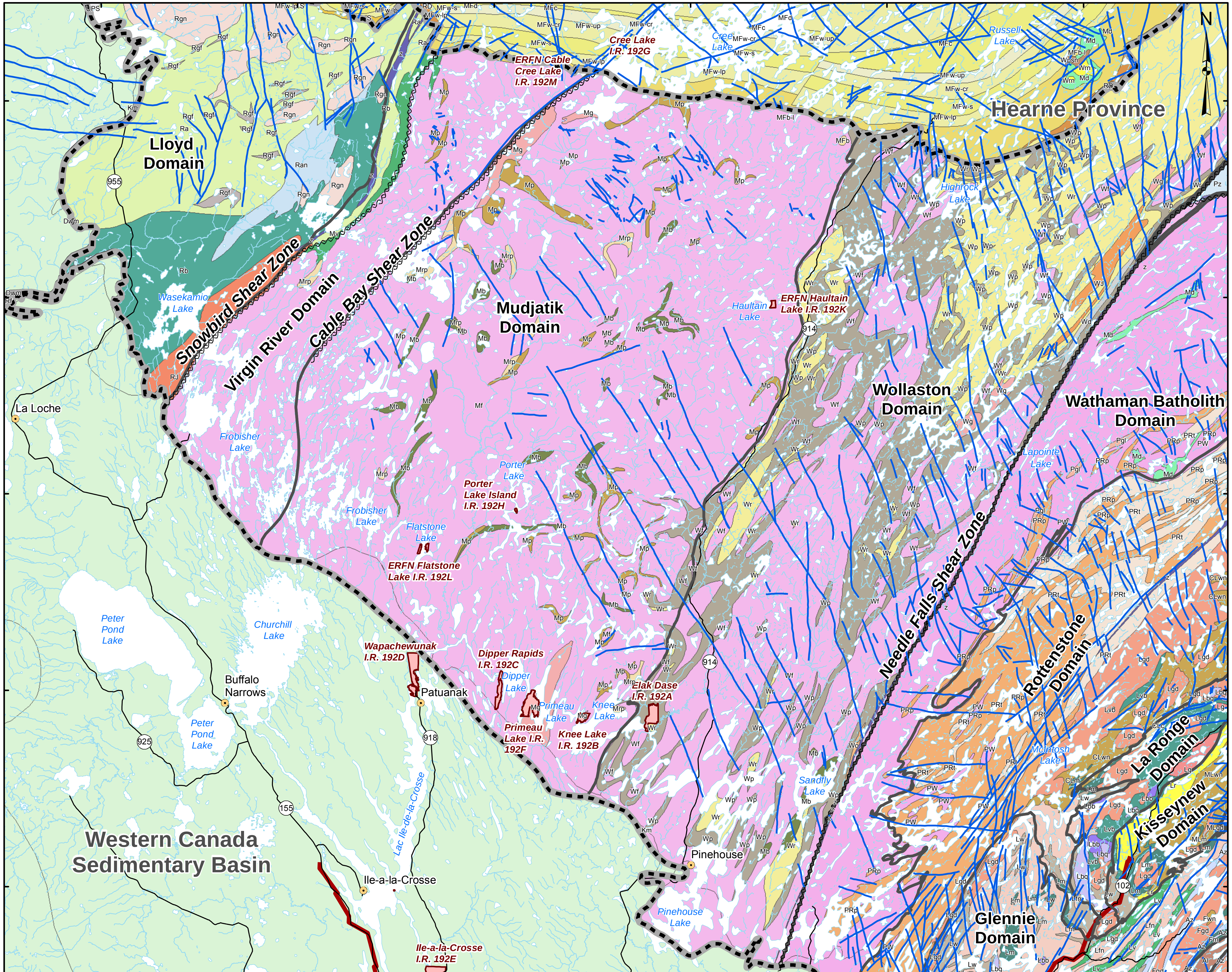
White, D.J., M.D. Thomas, A.G. Jones, J. Hope, B. Németh and Z. Hajnal, 2005, Geophysical transect across a Paleoproterozoic continent-continent collision zone; The Trans-Hudson Orogen. Canadian Journal of Earth Sciences, 42, pp. 385-402.

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geological Cross Section Through Northern Saskatchewan

Golder Associates
Saskatoon, Saskatchewan

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	JB	8 Nov. 2012	FIGURE: 3.2	
GIS	BDS	18 Sep. 2013		
CHECK	AM	18 Sep. 2013		
REVIEW	GWS	18 Sep. 2013		



LEGEND

- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Mapped Shear Zone
- Lithoprobe Line
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin
- Western Canada Sedimentary Basin

Athabasca Basin
- MFb-l - Manitou Falls: Lower conglomeratic quartzarenite
- MFc - Manitou Falls: Quartzarenite
- MFd - Manitou Falls: Clay-intraclast-rich quartzarenite
- MFw-cr - Manitou Falls: Clay-intraclast-rich quartzarenite
- MFw-lp - Manitou Falls: Lower conglomeratic quartzarenite
- MFw-s - Manitou Falls: Quartzarenite
- MFw-up - Manitou Falls: Upper quartz-pebbly quartzarenite
- Md - Mackenzie diabase dykes and sills
- RD - Read: Quartzarenite, conglomerate, local pebbly mudstone
- S - Smart: Quartzarenite, local pebbly mudstone
- Wpsn - Pelitic, psammopelitic gneiss
- Wr - Calcareous arkose, arkose, psammopelite, calc-silicate
- Wm - Psammitic meta-arkosic gneiss

Lloyd Domain
- MFw-lp - Manitou Falls: Lower conglomeratic quartzarenite
- MFw-s - Manitou Falls: Quartzarenite
- RD - Read: Quartzarenite, conglomerate, local pebbly mudstone
- RJ - Megacrystic granite
- Ra - Felsic-mafelsic gneiss (plutonic)
- Ran - Anorthosite
- Rb - Mafic-mafelsic gneiss (volcanic)
- Rf - Quartzofeldspathic gneiss
- Rgf - Garnet-feldspar gneiss
- Rgn - Granite-granodiorite gneiss
- S - Smart: Quartzarenite, local pebbly mudstone
- UPS - Unexposed Precambrian Shield

Virgin River Domain
- MFb-l - Manitou Falls: Lower conglomeratic quartzarenite
- Mf - Felsic gneisses, mainly plutonic
- Mp - Pelitic gneiss
- Mrp - Psammitic/psammopelitic gneiss
- Mv - Metavolcanics, mainly basic
- RJ - Megacrystic granite
- Ra - Felsic-mafelsic gneiss (plutonic)
- Rb - Mafic-mafelsic gneiss (volcanic)
- z - Mylonitic gneiss

Mudjatik Domain
- MFb - Manitou Falls: fluviatile conglomerate
- MFb-l - Manitou Falls: Lower conglomeratic quartzarenite
- Mb - Mafic Gneiss
- Mf - Felsic gneisses, mainly plutonic
- Mg - Late granitoids
- Mp - Pelitic gneiss
- Mrp - Psammitic/psammopelitic gneiss
- Wf - Felsic orthogneiss
- Wp - Pelitic gneiss
- Wr - Calcareous arkose, arkose, psammopelite, calc-silicate

Wollaston Domain
- Mb – Mafic Gneiss
- Mf - Felsic gneisses, mainly plutonic
- Mrp - Psammitic/psammopelitic gneiss
- Pz - Peter Lake Complex deformed rocks
- WJ - Janice Lake Formation: fanglomerate, conglomerate, arkose
- Wd - Slate, phyllite,, mica schist
- Wf - Felsic orthogneiss
- Wg - Late granitoids
- Wo - Needle Falls Group basal assemblage: conglomerate, arkose, volcanics
- Wp - Pelitic gneiss
- Wr - Calcareous arkose, arkose, psammopelite, calc-silicate
- z - Mylonitic gneiss

Wathaman Batholith Domain
- Md - Mackenzie diabase dykes and sills
- PRp - Biotitic and hornblenitic gneiss
- PRt - Trondjhemite-tonalite
- PW - Wathaman granite
- Pgl - Late granitoids
- z - Mylonitic gneiss

Rottenstone Domain
- CLc - Crew Lake Calc-silicate rocks
- CLm - Metabasite/amphibolite (volcanic)
- CLwn - Crew Lake pelitic-psammitic gneiss
- Lfn - Felsic orthogneiss
- Lgd - Granite-granodiorite-tonalite
- Lm - Metabasite/amphibolite (volcanic)
- Lvb - Basic to intermediate volcanic
- Lw - Greywacke, local conglomerate
- PRp - Biotitic and hornblenitic gneiss
- PRt - Trondjhemite-tonalite
- PW - Wathaman granite
- z - Mylonitic gneiss

Glennie Domain
- Az - Mylonitic gneiss
- Fgd - Granite-granodiorite-tonalite
- Fm - Metabasite/amphibolite (volcanic)
- Fwn - Gneissic greywacke, psammopelite to pelite, conglomerate
- Lbb - (Diorite)-gabbro(ultramafite)
- Lbq - Tonalite-diorite
- Lfn - Felsic orthogneiss
- Lgd - Granite-granodiorite-tonalite
- Lm - Metabasite/amphibolite (volcanic)
- Lv - Undivided volcanics
- Lw - Greywacke, local conglomerate
- MLwn - Gneissic greywacke, psammopelite to pelite, conglomerate
- PRp - Biotitic and hornblenitic gneiss

La Ronge Domain
- CLc - Crew Lake Calc-silicate rocks
- CLwn - Crew Lake pelitic-psammitic gneiss
- Lbb - (Diorite)-gabbro(ultramafite)
- Lbq - Tonalite-diorite
- Lfn - Felsic orthogneiss
- Lg - Granite to tonalite
- Lgd - Granite-granodiorite-tonalite
- Lm - Metabasite/amphibolite (volcanic)
- Lvb - Basic to intermediate volcanic
- Lw - Greywacke, local conglomerate

Kisseynew Domain
- Lbq - Tonalite-diorite
- Lfn - Felsic orthogneiss
- Lgd - Granite-granodiorite-tonalite
- Lm - Metabasite/amphibolite (volcanic)
- Lr - Arkose, conglomerate, psammitic gneiss
- Lvb - Basic to intermediate volcanic
- Lw - Greywacke, local conglomerate
- MLgd - Granite-granodiorite-tonalite
- MLm - Metabasite/amphibolite (volcanic)
- MLwn - Gneissic greywacke, psammopelite to pelite, conglomerate

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:1,000,000)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

20 10 0 20 40 60
KILOMETERS
SCALE 1:1,000,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

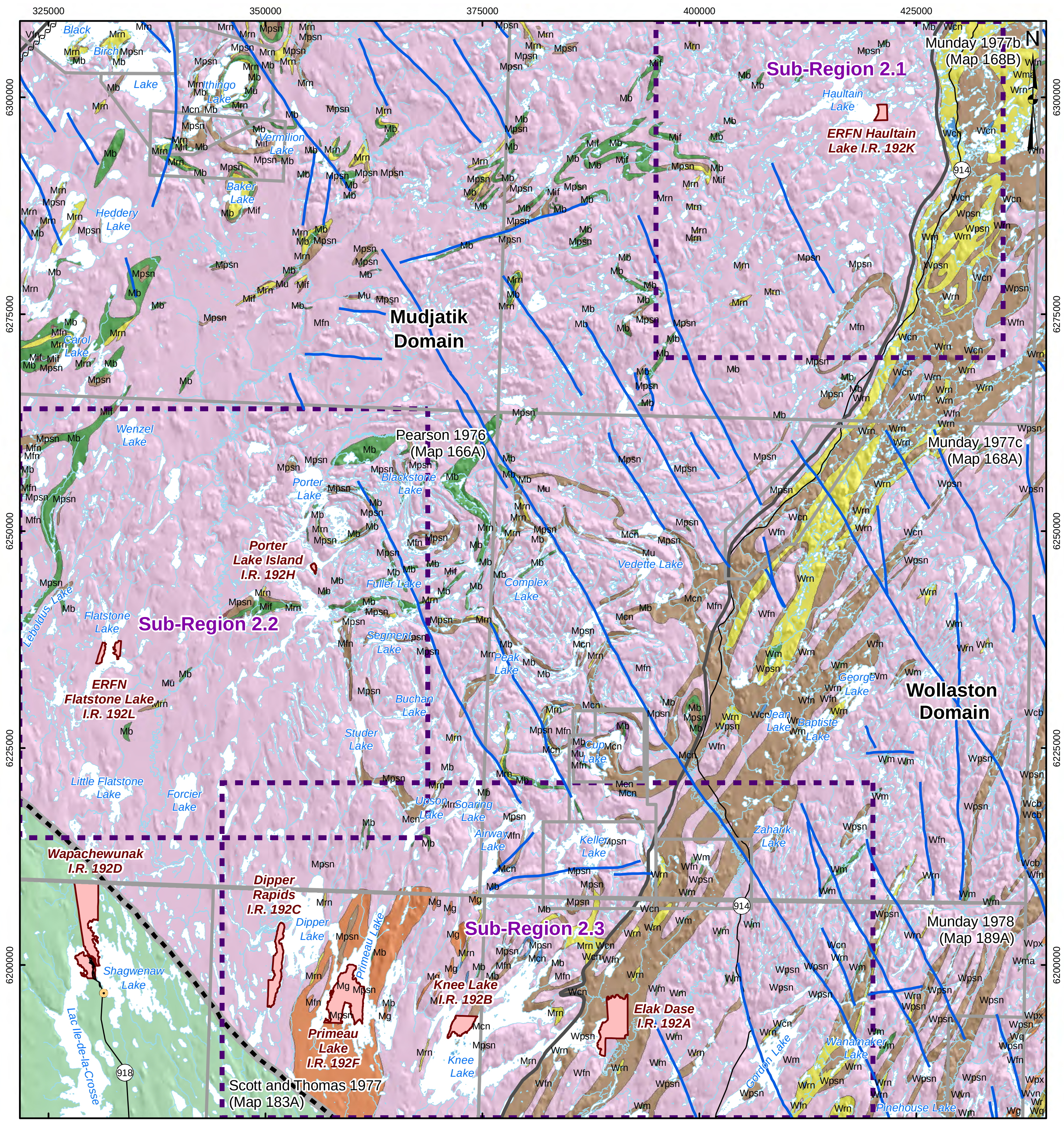
TITLE
Regional Geology of the
English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026		SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	
GIS	PM/JB	19 Sep. 2013	
CHECK	AM	19 Sep. 2013	
REVIEW	GWS	19 Sep. 2013	

FIGURE: 3.3

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\ERFN\Draft_Integrated_Report\RegionalBedrockGeologyERFNArea.mxd



LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Cable Bay Shear Zone
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Detailed Geology Extents

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Virgin River Domain

- Vfn - Felsic gneiss

Wollaston Domain

- Wcb - Massive coarse grained calc-silicate
- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wg - Leucogranite, granite, monzogranite, granodiorite
- Wm - Amphibolite
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wpx - Migmatized supracrustal rocks
- Wq - Metaquartzite
- Wr - Meta-arkose
- Wm - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss

Pearson 1976 (Map 166A)
Munday 1977c (Map 168A)
Munday 1977b (Map 168B)
Scott and Thomas 1977 (Map 183A)
Munday 1978 (Map 198A)

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

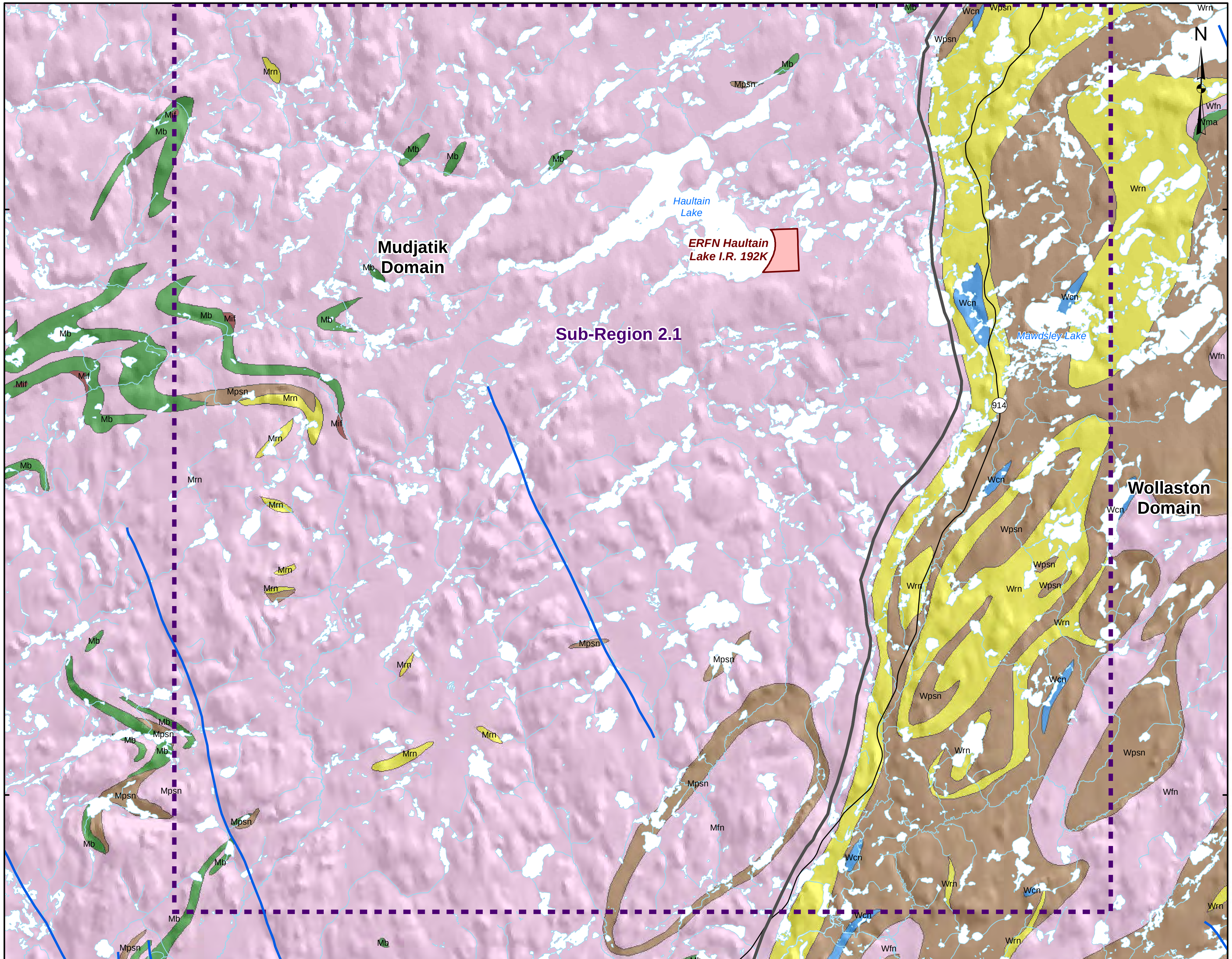
10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Local Bedrock Geology of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.4	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		



LEGEND

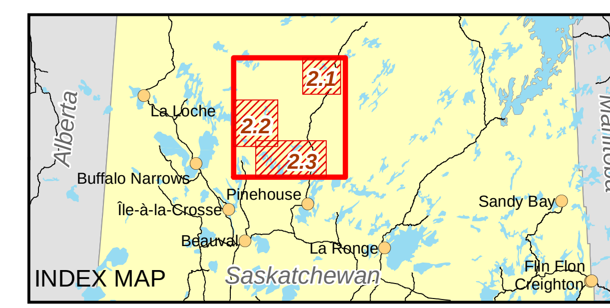
- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mfn - Felsic gneiss
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss

Wollaston Domain

- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wm - Psammitic to meta-arkosic gneiss



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

3 1.5 0 3 6 9
KILOMETERS
SCALE 1:175,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Local Bedrock Geology of the
English River First Nation Area - Sub-Region 2.1

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.5	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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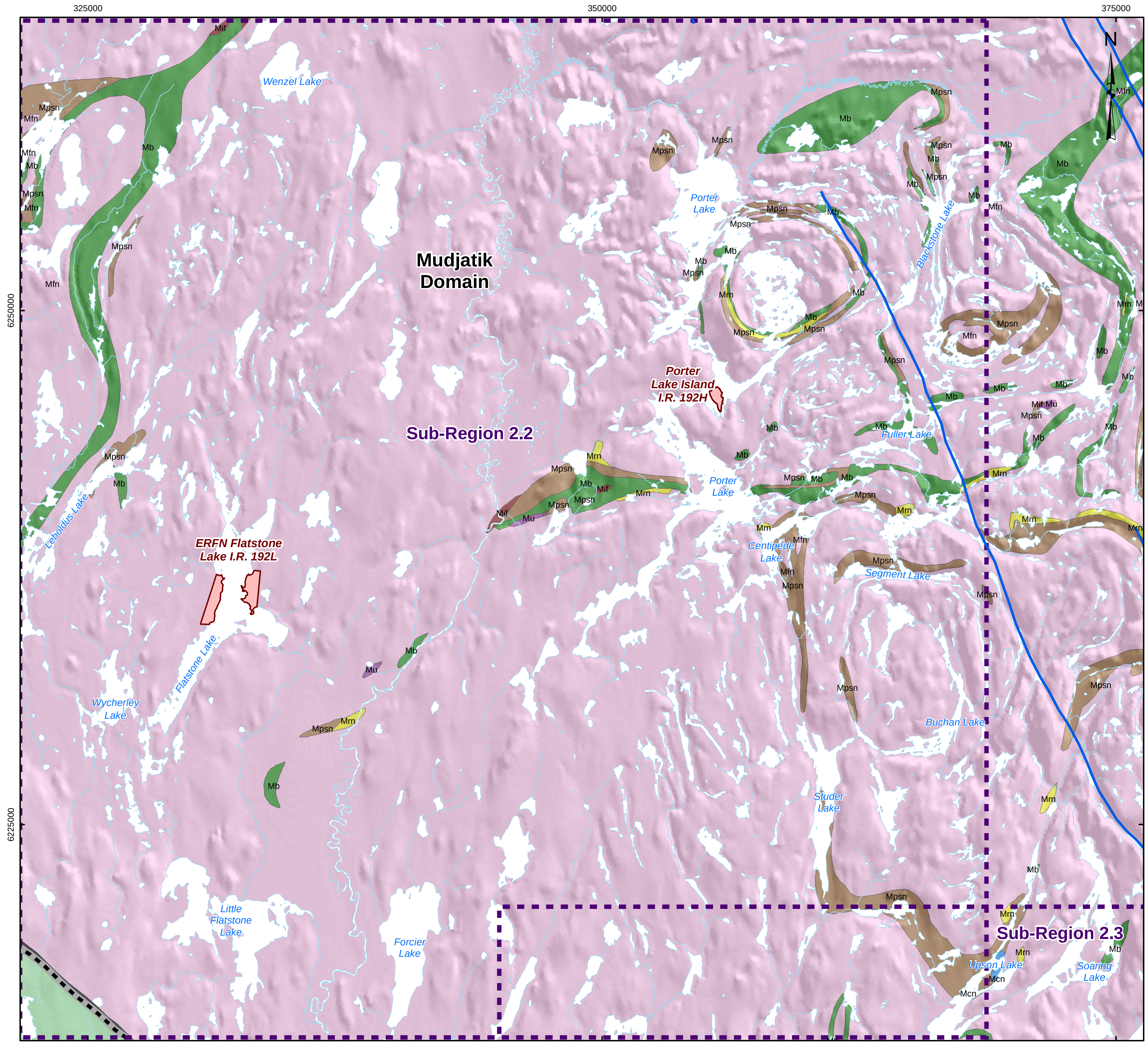


LEGEND

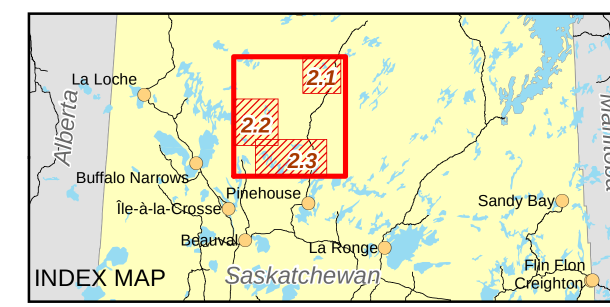
- English River First Nation Detailed Area
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

4 2 0 4 8 12
KILOMETERS
SCALE 1:200,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Bedrock Geology of the
English River First Nation Area - Sub-Region 2.2

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.6	
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

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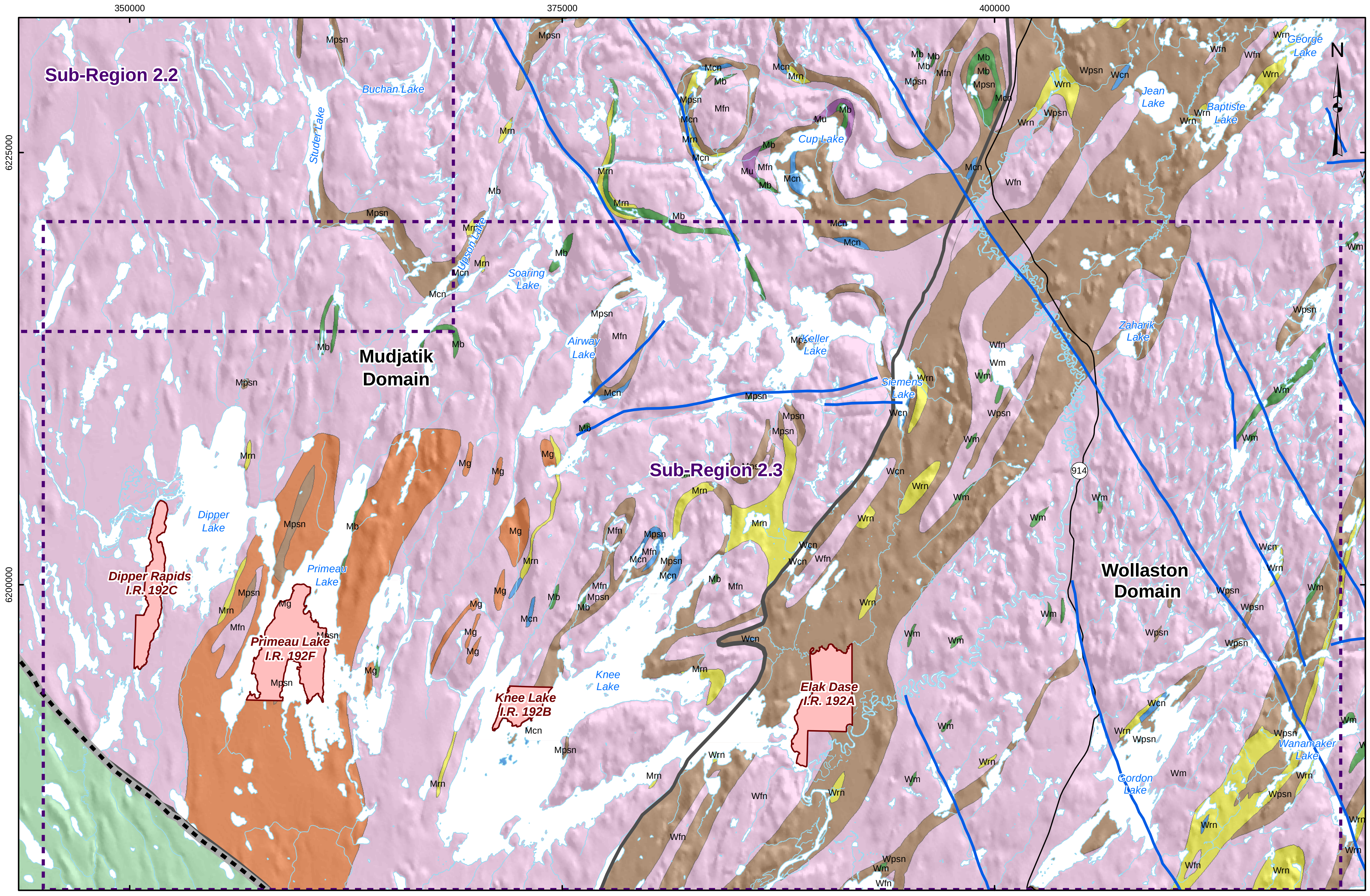


LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

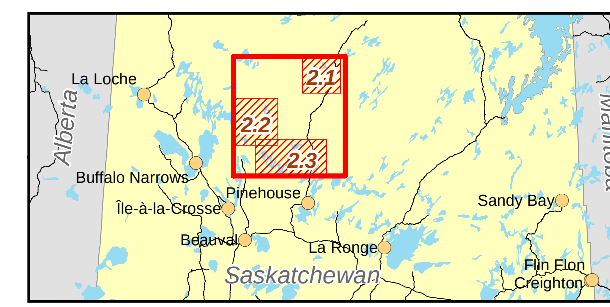
- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Wollaston Domain

- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wm - Amphibolite
- Wpsn - Pelitic, psammopelitic gneiss
- Wm - Psammitic to meta-arkosic gneiss



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10 15
SCALE 1:250,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Local Bedrock Geology of the
English River First Nation Area - Sub-Region 2.3

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.7	
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

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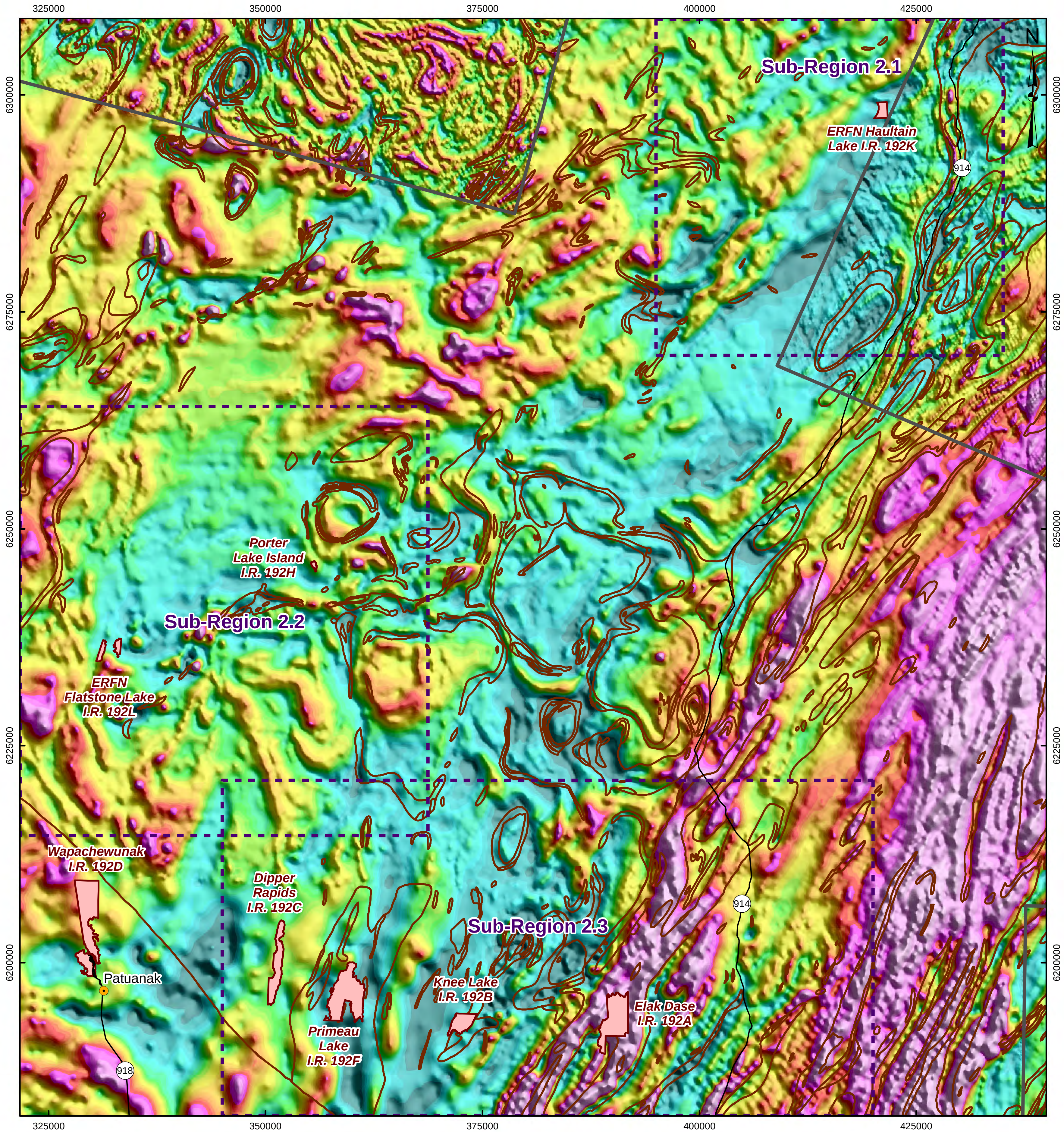
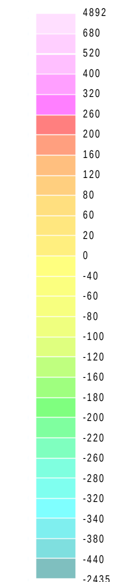


LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Federal Land - Indian Reserve
- Geological Contact
- Higher Resolution Geophysical Surveys

Residual Total Magnetic Field (nT)



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Geophysics - GSC Canada - 200m - Magnetic - Residual Total Field, 2008;
Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30

SCALE 1:525,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Total Magnetic Field (Reduced to Pole) of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026		
DESIGN	PM	3 May. 2012
GIS	PM/JB	18 Sep. 2013
CHECK	BT	18 Sep. 2013
REVIEW	GWS	18 Sep. 2013

SCALE AS SHOWN | REV. 0.0

FIGURE: 3.8

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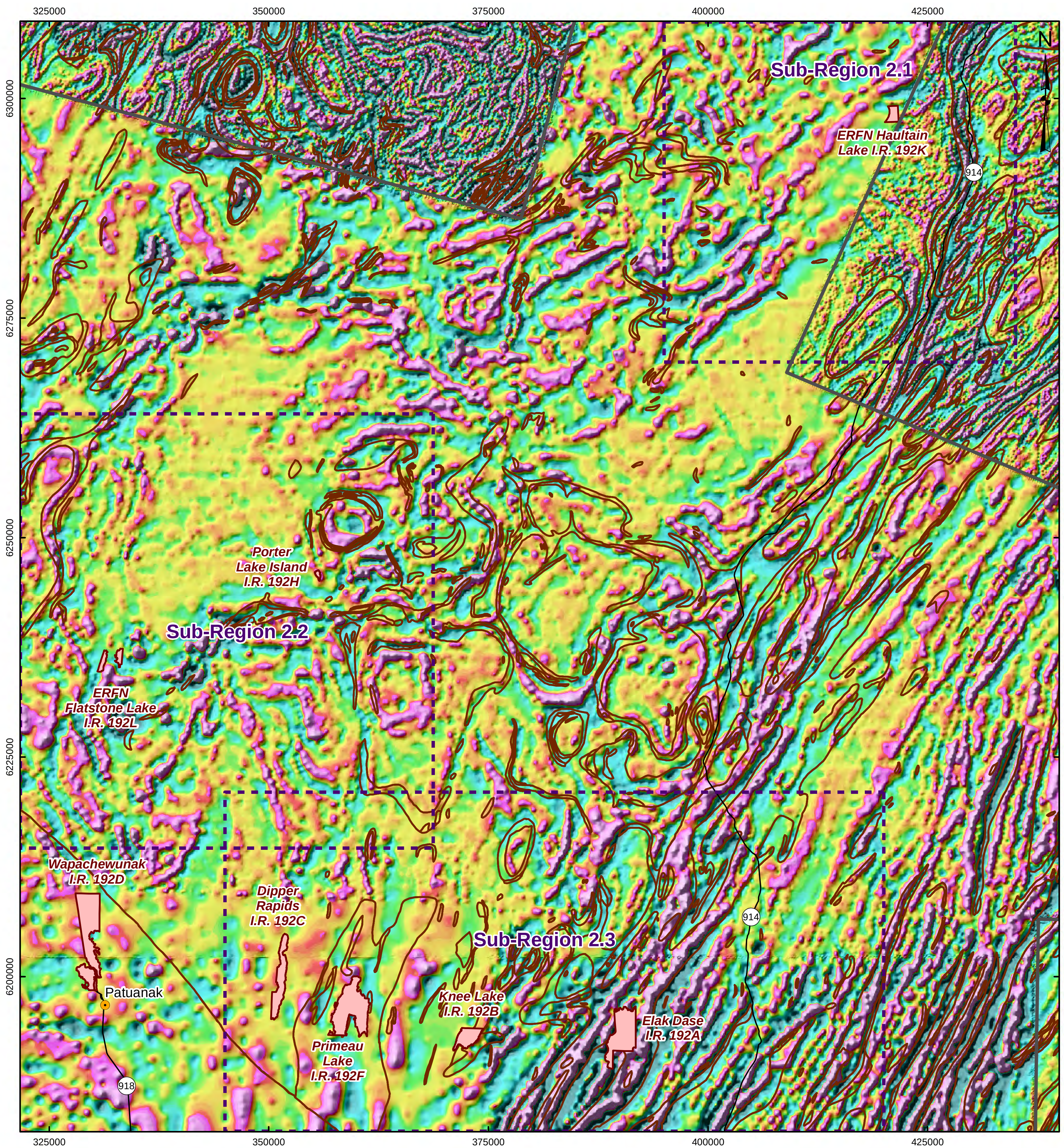

LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Federal Land - Indian Reserve
- Geological Contact
- Higher Resolution Geophysical Surveys

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

29.35
0.58
0.36
0.26
0.2
0.16
0.12
0.1
0.08
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
-0.1
-0.12
-0.14
-0.16
-0.18
-0.22
-0.26
-0.32
-0.46
-21.27

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan,
Administrative Boundary Overlays (2012)
Geophysics - GSC Canada - 200m - Magnetic - Residual Total Field, 2008;
Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
First Vertical Derivative (Reduced to Pole) of the
Magnetic Field of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.9	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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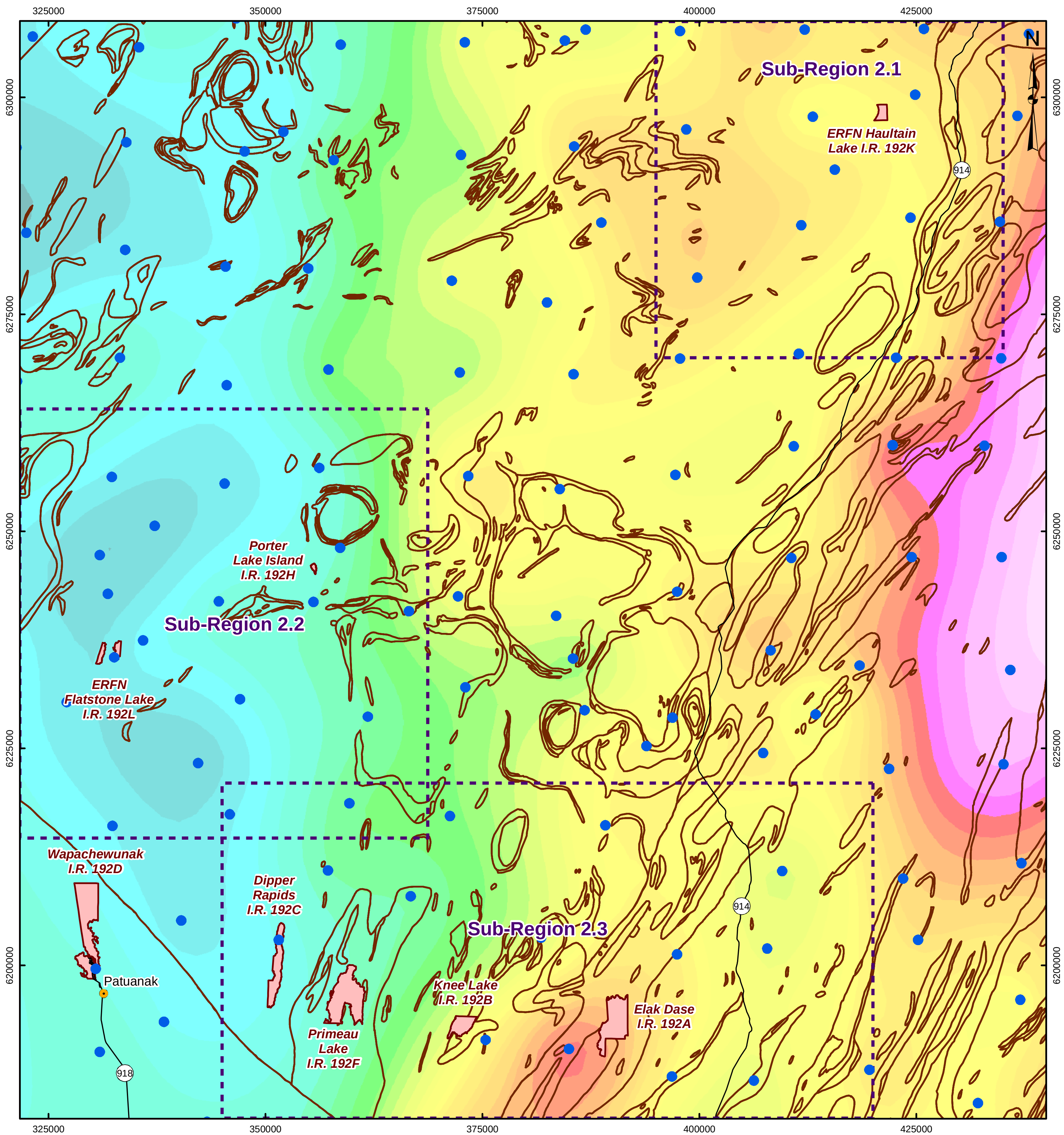

LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Federal Land - Indian Reserve
- Gravity Station
- Geological Contact

Gravity Anomaly (mGal)

-45.6
-48.5
-50.0
-51.5
-53.0
-54.0
-55.0
-56.0
-57.0
-57.5
-58.5
-59.0
-60.0
-60.5
-61.0
-62.0
-62.5
-63.5
-64.5
-65.5
-66.5
-68.0
-69.5
-71.0
-73.0
-74.5
-76.5
-79.0
-82.0
-93.7

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Geophysics - GSC Canada - 2km - Gravity Anomalies, 2010;
Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Bouguer Gravity of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.10	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Cable Bay Shear Zone
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Overburden Cover

Surficial Lineaments (SPOT and CDED)

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

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

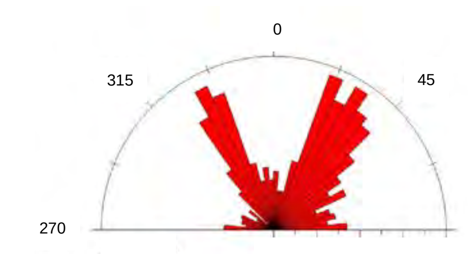
Virgin River Domain

- Vfn - Felsic gneiss

Wollaston Domain

- Wcb - Massive coarse grained calc-silicate
- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wg - Leucogranite, granite, monzogranite, granodiorite
- Wm - Amphibolite
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wpx - Migmatized supracrustal rocks
- Wq - Metaquartzite
- Wr - Meta-arkose
- Wm - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss

ENGLISH RIVER FIRST NATION SURFICIAL LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Admin. Boundaries - Information Services Corporation of Sask., Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Overburden - Munday, R.J.C., 1978b. The Shield Geology of the Ile-a-la-Crosse (East) Area Saskatchewan. Part of the NTS Area 73-0. 1:100,000 Sheet 1, Map 189A, SGS; Munday, R.J.C., 1977b. The Geology of the Mudjatik (East) Area Saskatchewan. 1:100,000 North Sheet. Map 168B to accompany Report 168, SGS; Scott, B.P., 1977b. Geology of the Dipper Lake Area (NTS 73-0-14) Saskatchewan. 1:63,360 Map 183A to accompany Report No. 183, SGS; Pearson, D.E., 1977b. Geology of the Mudjatik (Southwest) Area. 1:100,000 Map 166A to accompany Report No. 166, SGS
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30

SCALE 1:525,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Surficial Lineaments
of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.11	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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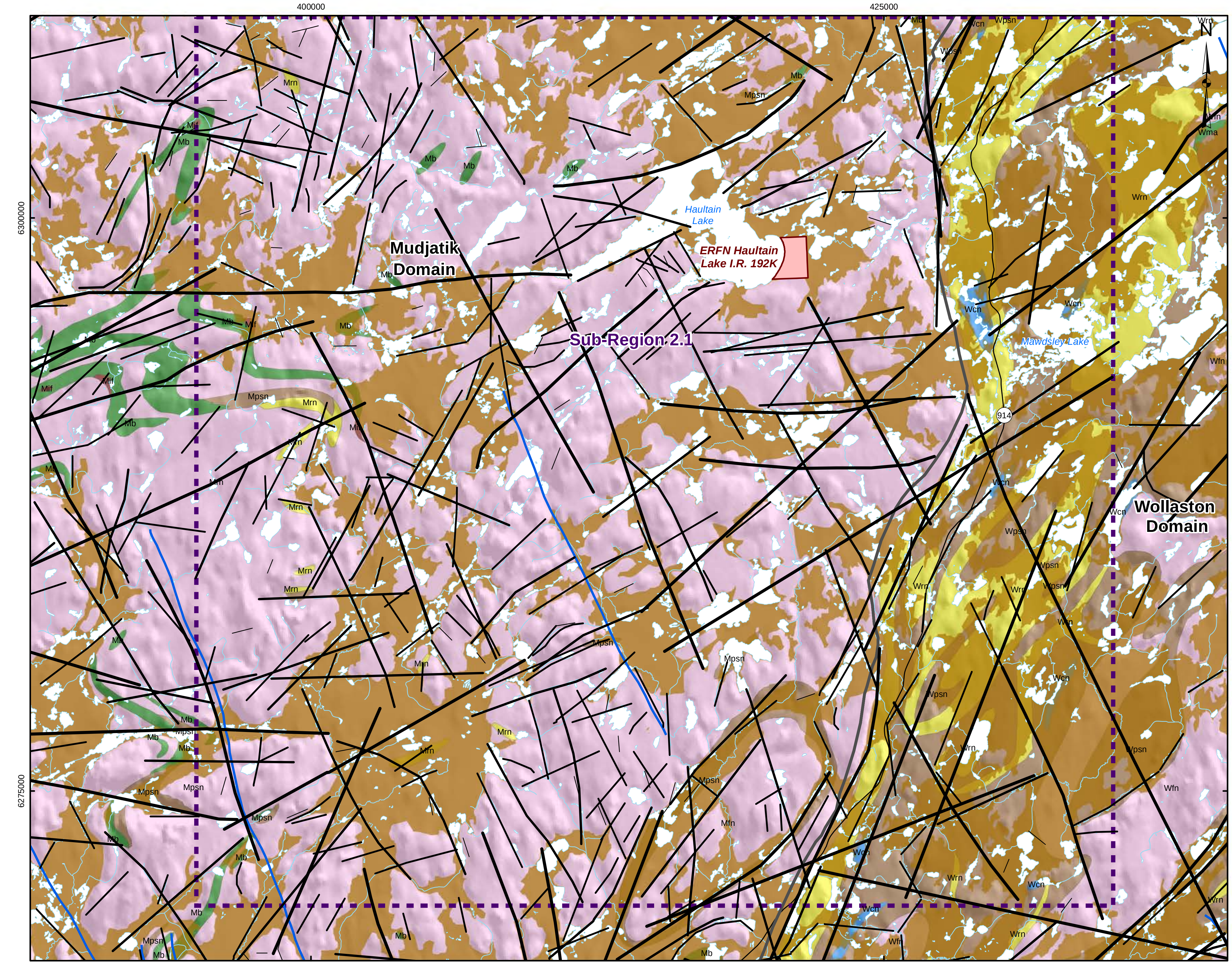


LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Overburden Cover

Surficial Lineaments

(SPOT and CDED)

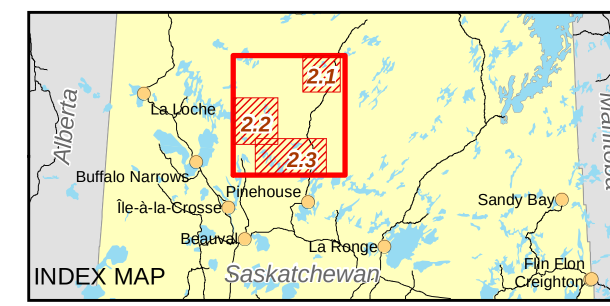
- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km

Mudjatik Domain

- Mb - Mafic gneiss
- Mfn - Felsic gneiss
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss

Wollaston Domain

- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wm - Psammitic to meta-arkosic gneiss



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Overburden - Munday, R.J.C., 1977b. The Geology of the Mudjatik (East) Area Saskatchewan. 1:100,000 North Sheet. Map 168B to accompany Report 168, SGS
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

3 1.5 0 3 6 9
KILOMETERS
SCALE 1:175,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Surficial Lineaments of the
English River First Nation Area - Sub-Region 2.1

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.11a	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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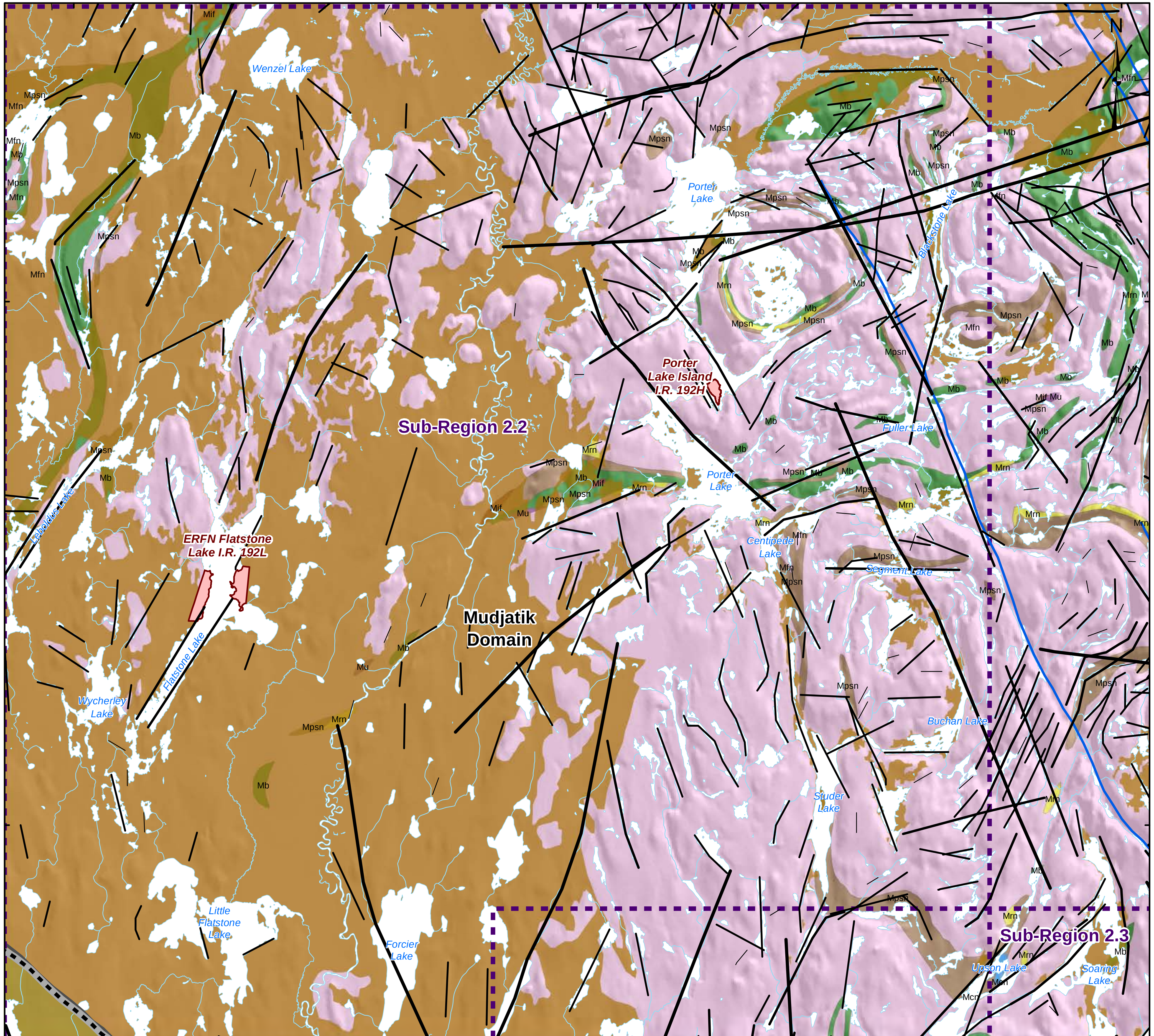


LEGEND

- English River First Nation Detailed Area
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Overburden Cover

Surficial Lineaments

(SPOT and CDED)

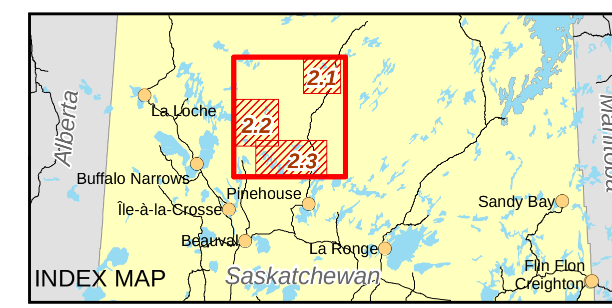
- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Overburden - Pearson, D.E., 1977b. Geology of the Mudjatik (Southwest) Area. 1:100,000 Map 166A to accompany Report No. 166, SGS
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

4 2 0 4 8 12
KILOMETERS
SCALE 1:200,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Surficial Lineaments of the
English River First Nation Area - Sub-Region 2.2

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.11b	
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

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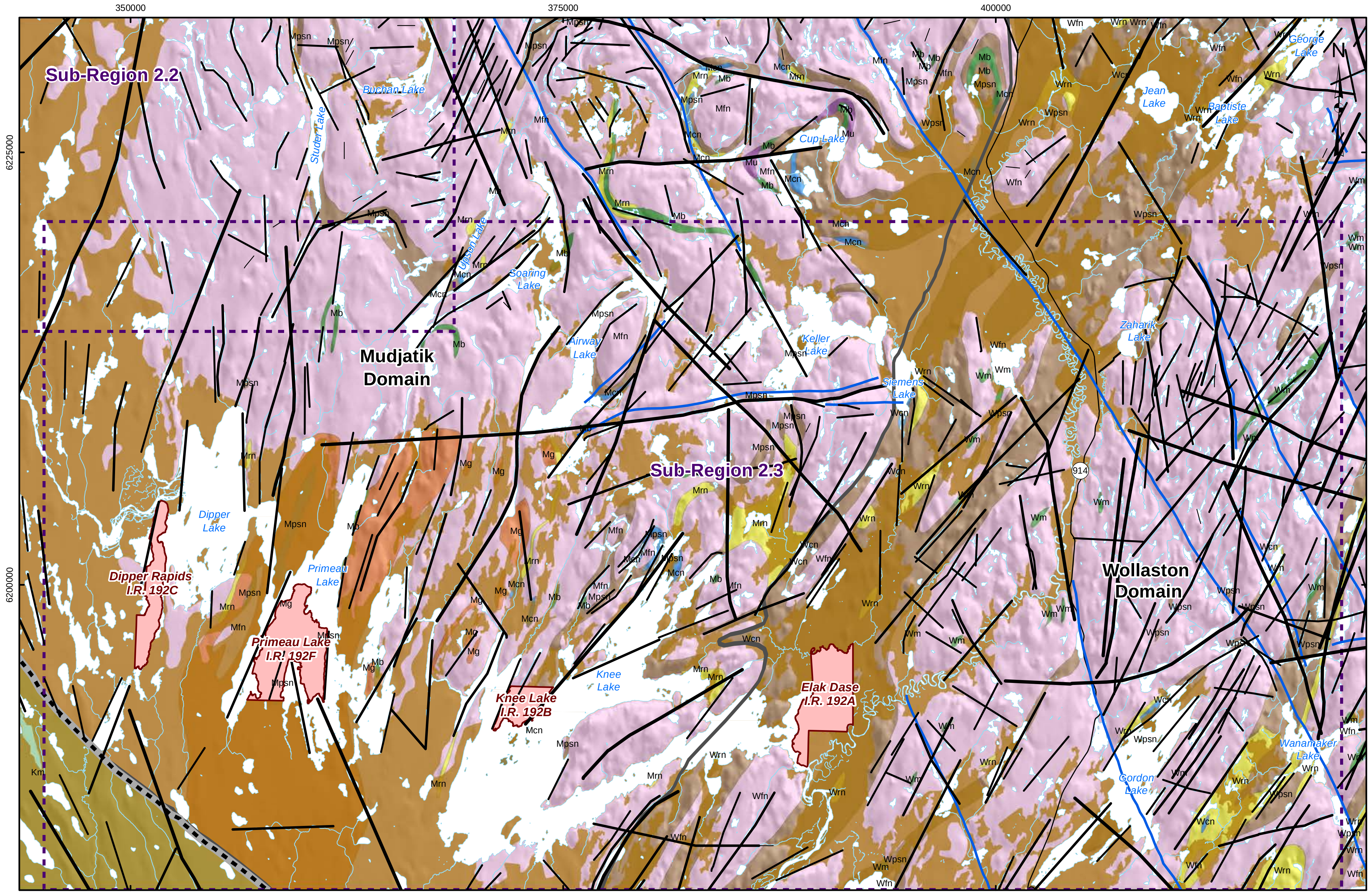


LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Overburden Cover

Surficial Lineaments

(SPOT and CDED)

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

Western Canada Sedimentary Basin

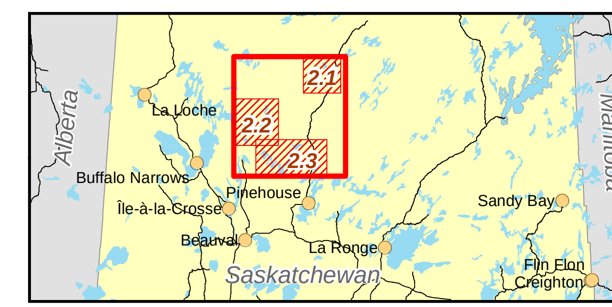
- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Wollaston Domain

- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wm - Amphibolite
- Wpsn - Pelitic, psammopelitic gneiss
- Wm - Psammitic to meta-arkosic gneiss



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Admin. Boundaries - Information Services Corporation of Sask., Admin. Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Thick Overburden - Munday, R.J.C., 1978b. The Shield Geology of the Ile-a-la-Crosse (East) Area Saskatchewan. Part of the NTS Area 73-0. 1:100,000 Sheet 1, Map 189A, SGS and Scott, B.P., 1977b. Geology of the Dipper Lake Area (NTS 73-0-14) Saskatchewan. 1:63,360 Map 183A to accompany Report No. 183, SGS
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10 15

SCALE 1:250,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Surficial Lineaments of the
English River First Nation Area - Sub-Region 2.3

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.11c	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Cable Bay Shear Zone
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Higher Resolution Geophysical Surveys

Geophysical Lineaments

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

Western Canada Sedimentary Basin

- Wester Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

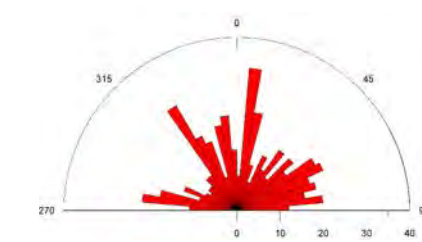
Virgin River Domain

- Vfn - Felsic gneiss

Wollaston Domain

- Wcb - Massive coarse grained calc-silicate
- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wg - Leucogranite, granite, monzogranite, granodiorite
- Wm - Amphibolite
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wpx - Migmatized supracrustal rocks
- Wq - Metaquartzite
- Wr - Meta-arkose
- Wm - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss

ENGLISH RIVER FIRST NATION GEOPHYSICAL LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geophysical Lineaments
of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.12	
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

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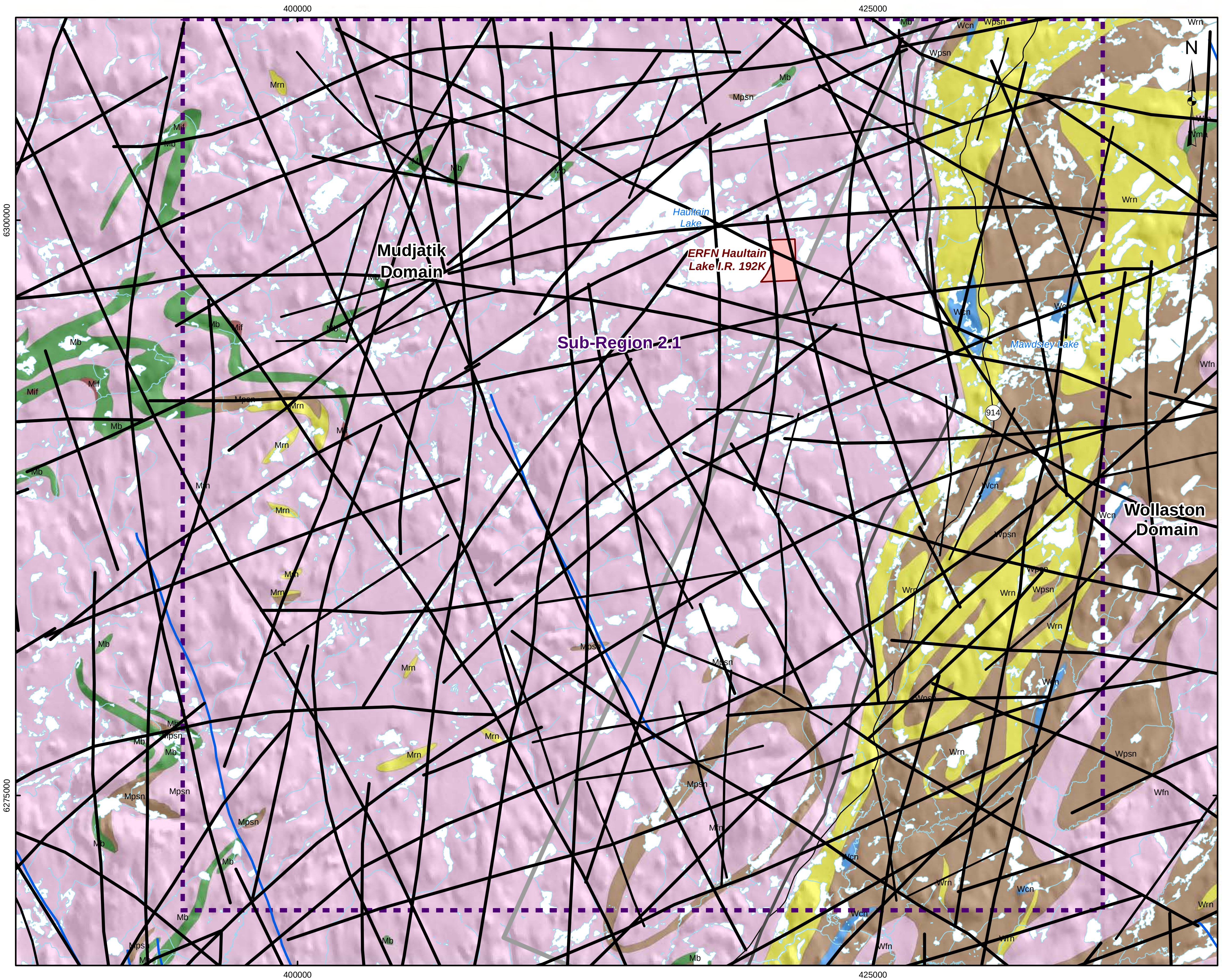


LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Higher Resolution Geophysical Surveys

Geophysical Lineaments

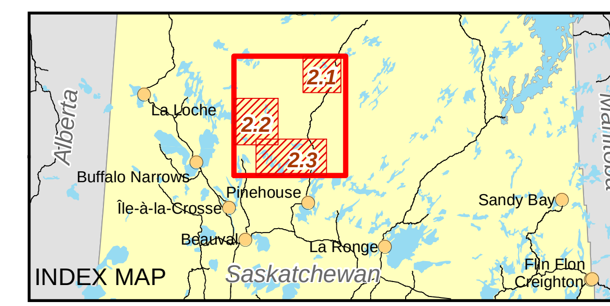
- > 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km

Mudjatik Domain

- Mb - Mafic gneiss
- Mfn - Felsic gneiss
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss

Wollaston Domain

- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wm - Psammitic to meta-arkosic gneiss



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

3 1.5 0 3 6 9

SCALE 1:175,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Geophysical Lineaments of the
English River First Nation Area - Sub-Region 2.1

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.12a	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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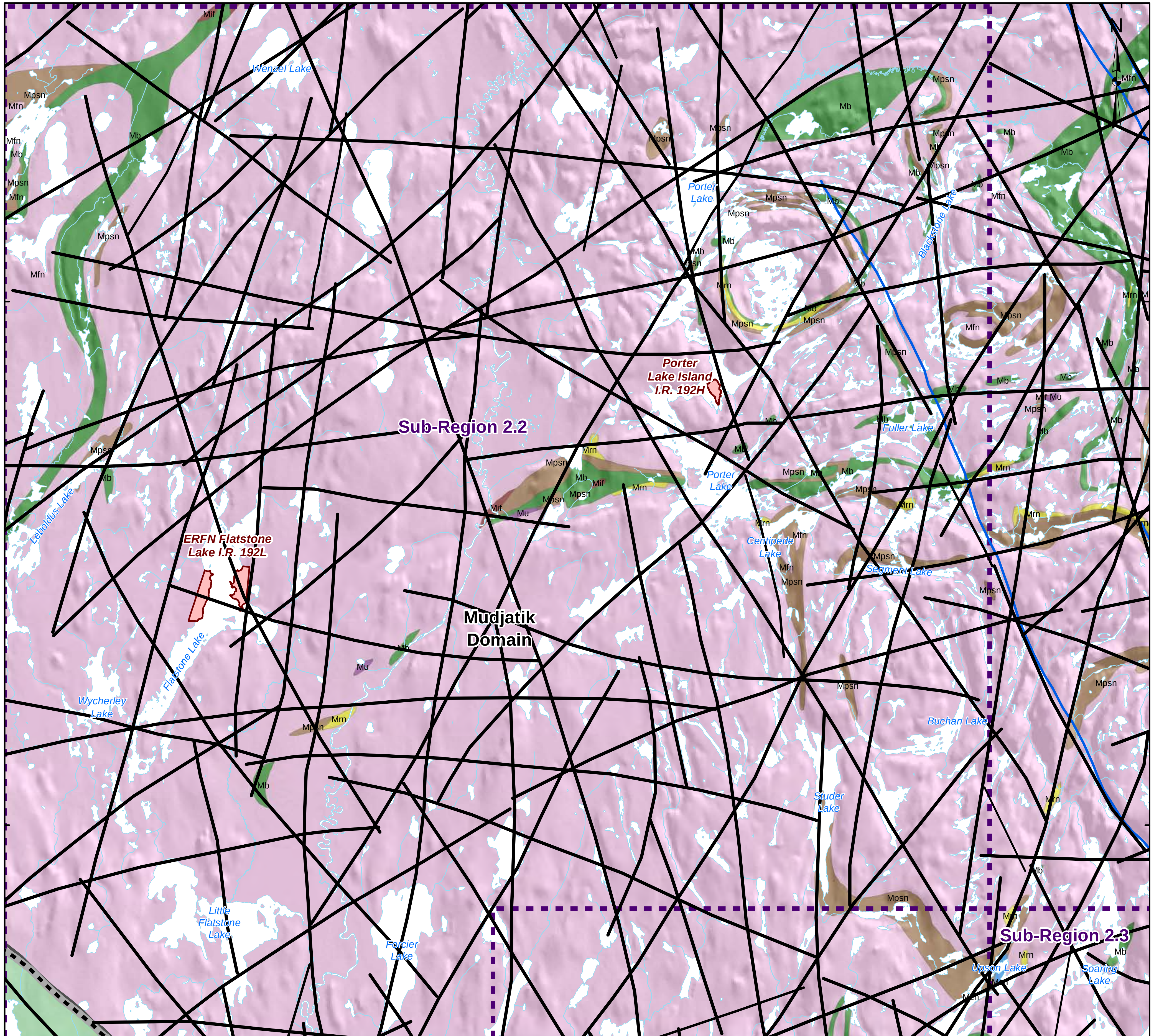


LEGEND

- English River First Nation Detailed Area
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Geophysical Lineaments

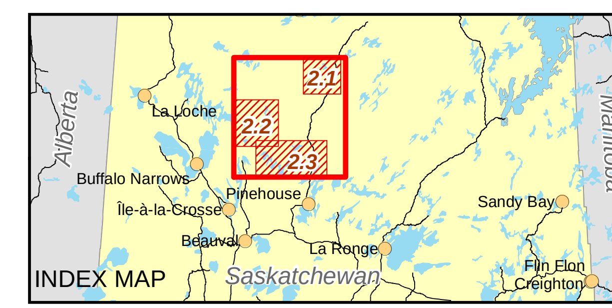
- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

4 2 0 4 8 12
KILOMETERS
SCALE 1:200,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geophysical Lineaments of the
English River First Nation Area - Sub-Region 2.2

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012		
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013	FIGURE: 3.12b	
REVIEW	GWS	20 Sep. 2013		

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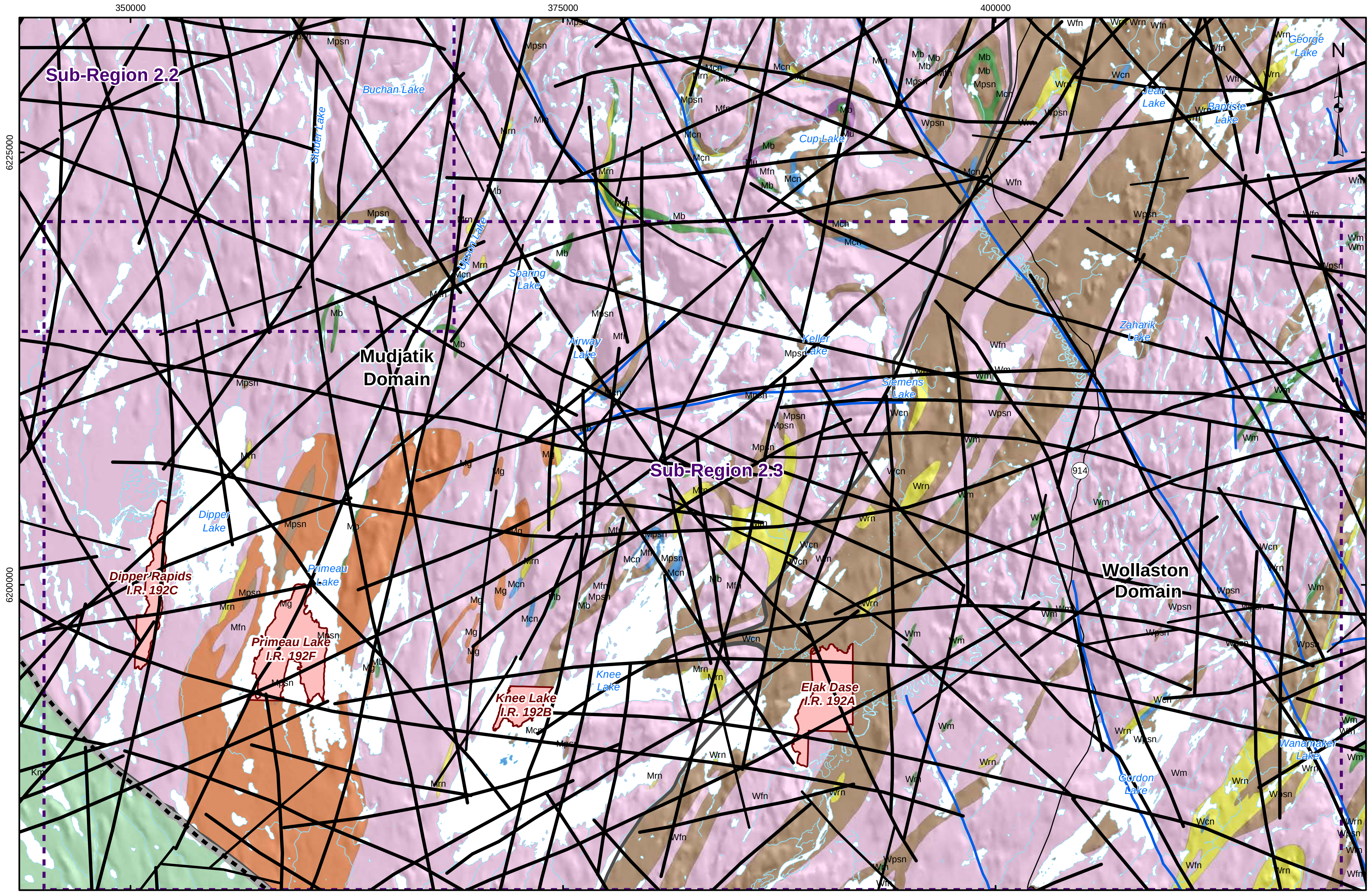


LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Geophysical Lineaments

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

Western Canada Sedimentary Basin

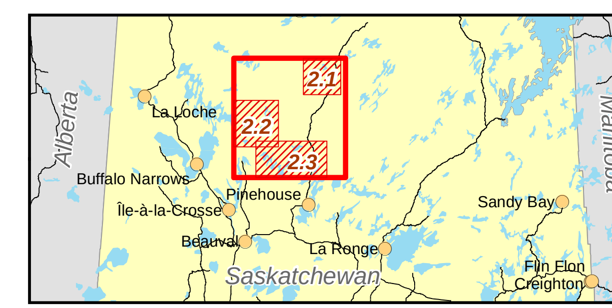
- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Wollaston Domain

- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wm - Amphibolite
- Wpsn - Pelitic, psammopelitic gneiss
- Wm - Psammitic to meta-arkosic gneiss



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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SCALE 1:250,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Geophysical Lineaments of the
English River First Nation Area - Sub-Region 2.3

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.12c	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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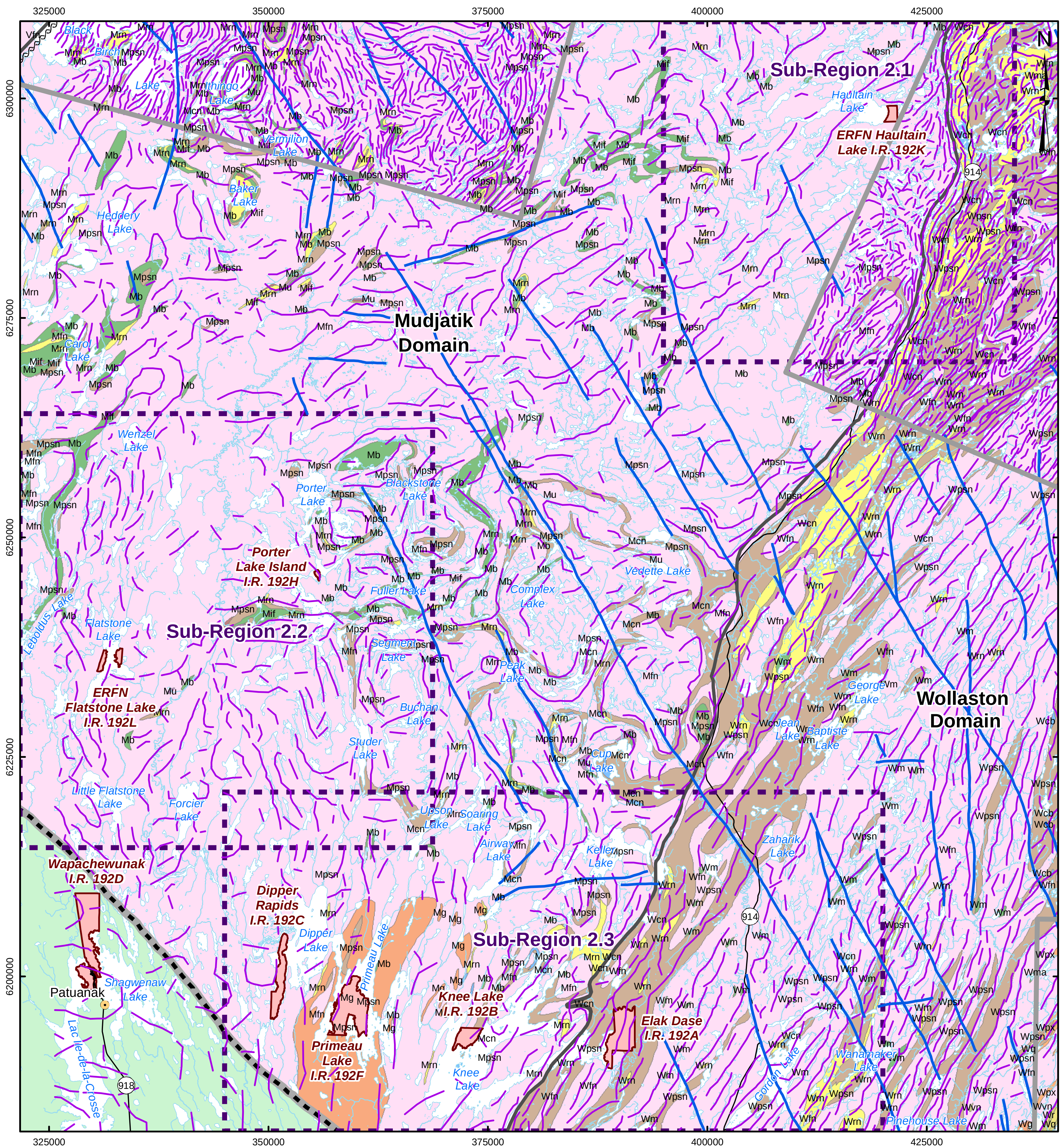

LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Cable Bay Shear Zone
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Ductile Lineaments
- Higher Resolution Geophysical Surveys

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Virgin River Domain

- Vfn - Felsic gneiss

Wollaston Domain

- Wcb - Massive coarse grained calc-silicate
- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wg - Leucogranite, granite, monzogranite, granodiorite
- Wm - Amphibolite
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wpx - Migmatized supracrustal rocks
- Wq - Metaquartzite
- Wr - Meta-arkose
- Wm - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Ductile Lineaments
of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.13	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Cable Bay Shear Zone
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Domain Boundary

Brittle Lineaments
(Surficial and Geophysical)

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

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

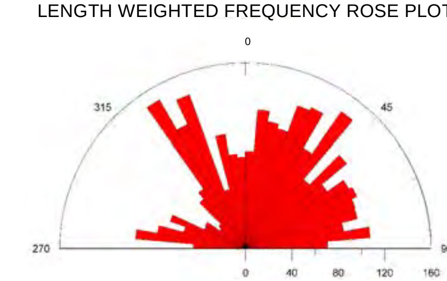
Virgin River Domain

- Vfn - Felsic gneiss

Wollaston Domain

- Wcb - Massive coarse grained calc-silicate
- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wg - Leucogranite, granite, monzogranite, granodiorite
- Wm - Amphibolite
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wpx - Migmatized supracrustal rocks
- Wq - Metaquartzite
- Wr - Meta-arkose
- Wm - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss

ENGLISH RIVER FIRST NATION ALL LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineaments
of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.14	
GIS	PM/JB	19 Sep. 2013		
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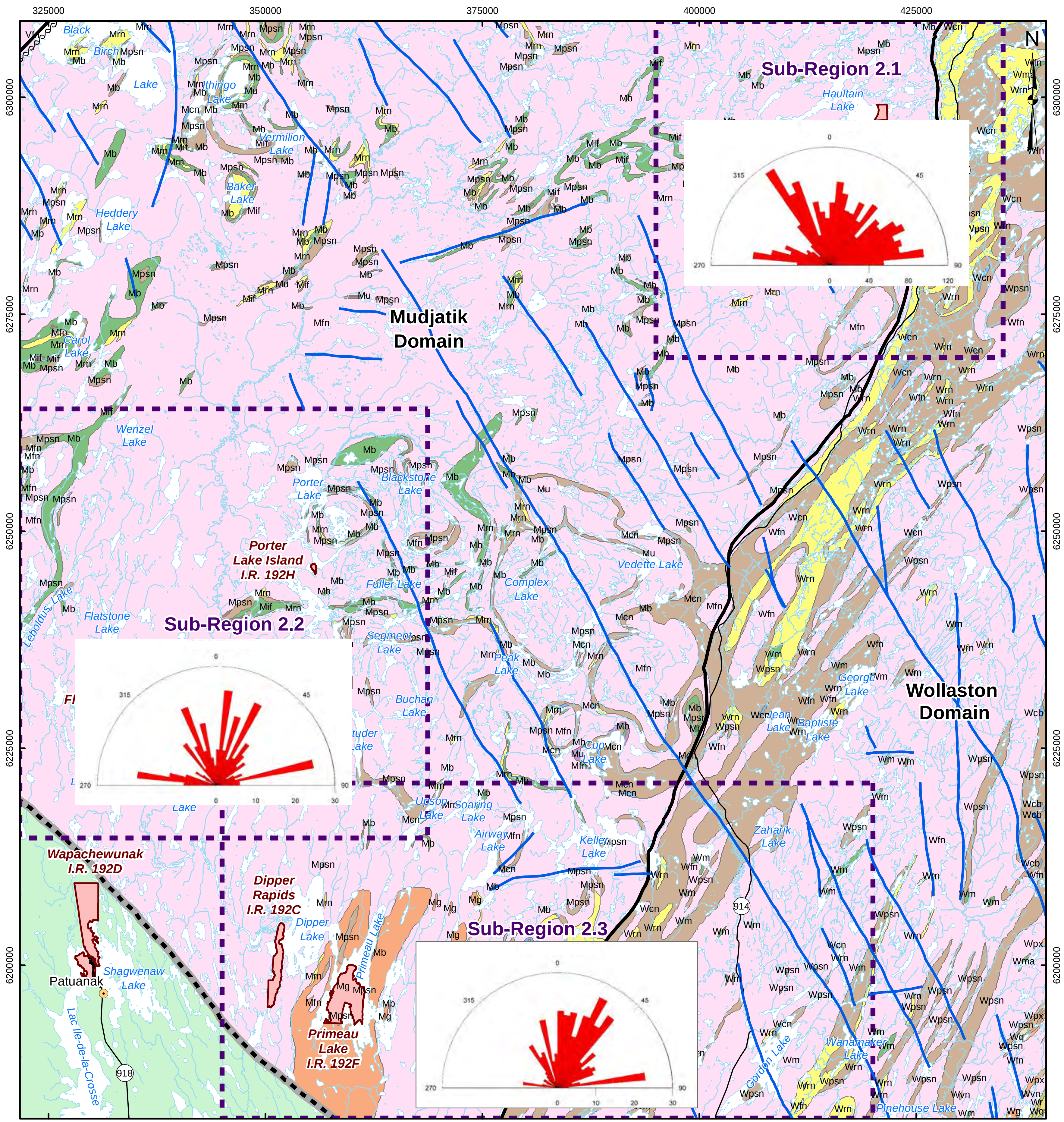


LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Cable Bay Shear Zone
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Virgin River Domain

- Vfn - Felsic gneiss

Wollaston Domain

- Wcb - Massive coarse grained calc-silicate
- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wg - Leucogranite, granite, monzogranite, granodiorite
- Wm - Amphibolite
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wpx - Migmatized supracrustal rocks
- Wq - Metaquartzite
- Wr - Meta-arkose
- Wm - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

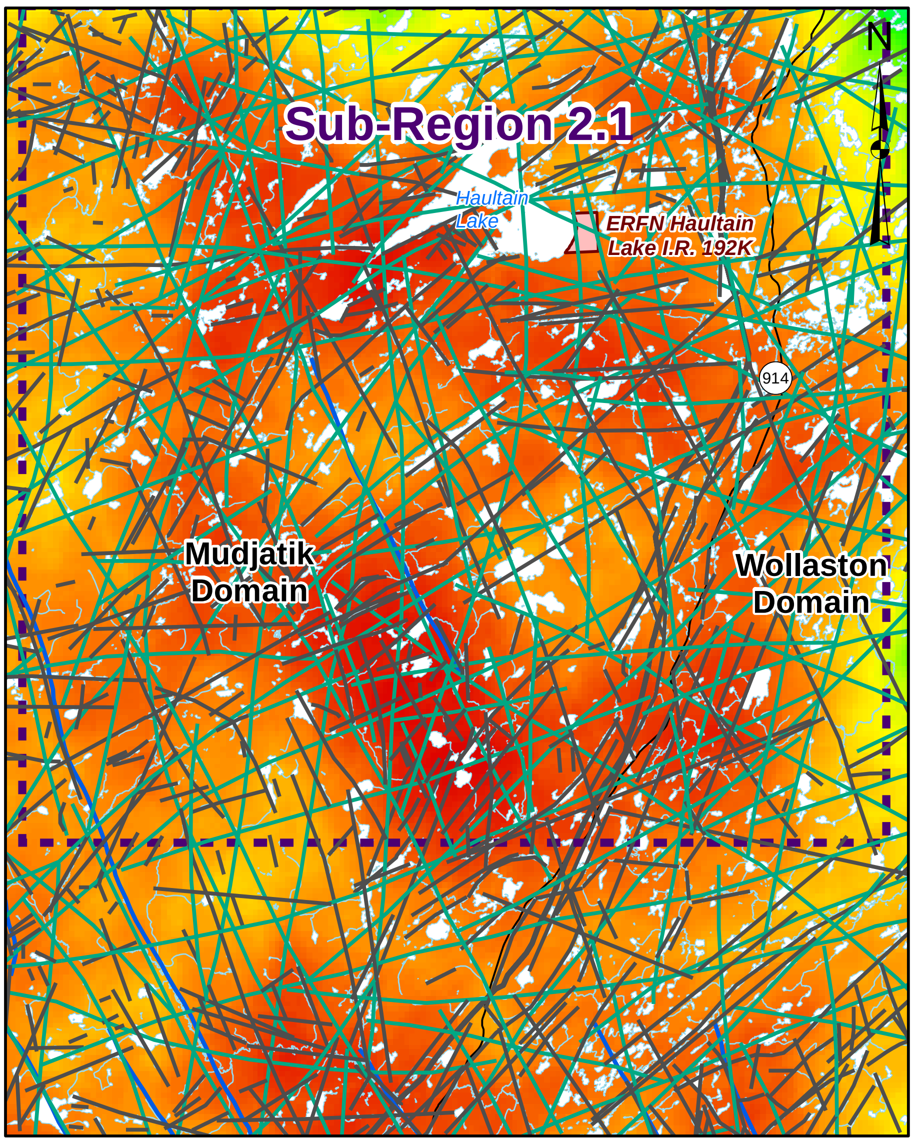
10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

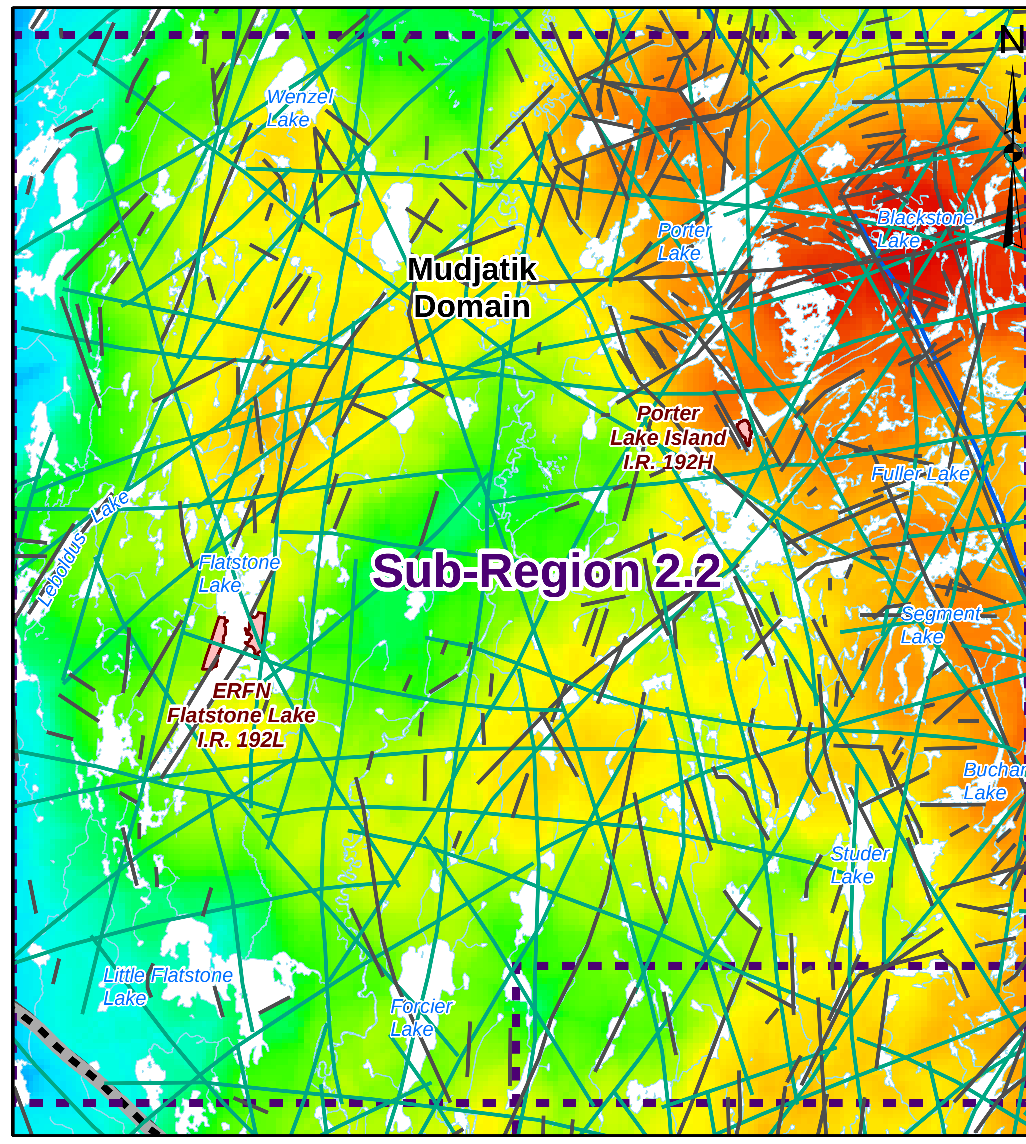
TITLE
Lineament Orientations in Sub-Regions of the English River First Nation Area

Golder Associates
Mississauga, Ontario

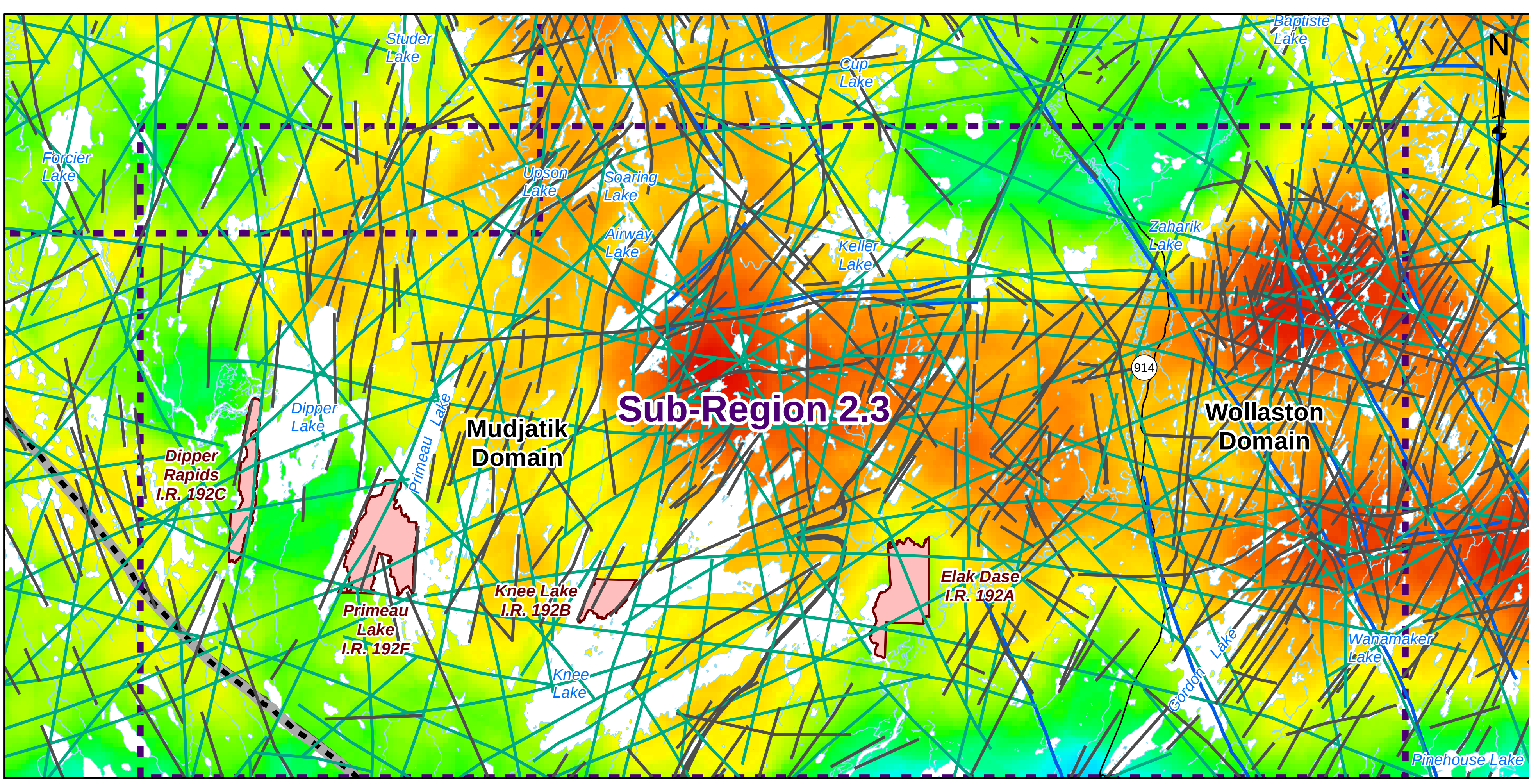
PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.15	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		



Sub-Region 2.1



Sub-Region 2.2



Sub-Region 2.3

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LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Geophysical Lineament
- Surficial Lineament
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Lineament Density (km/km²)

High : 2.5

Low : 0

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20

SCALE 1:350,000 KILOMETERS

PROJECT

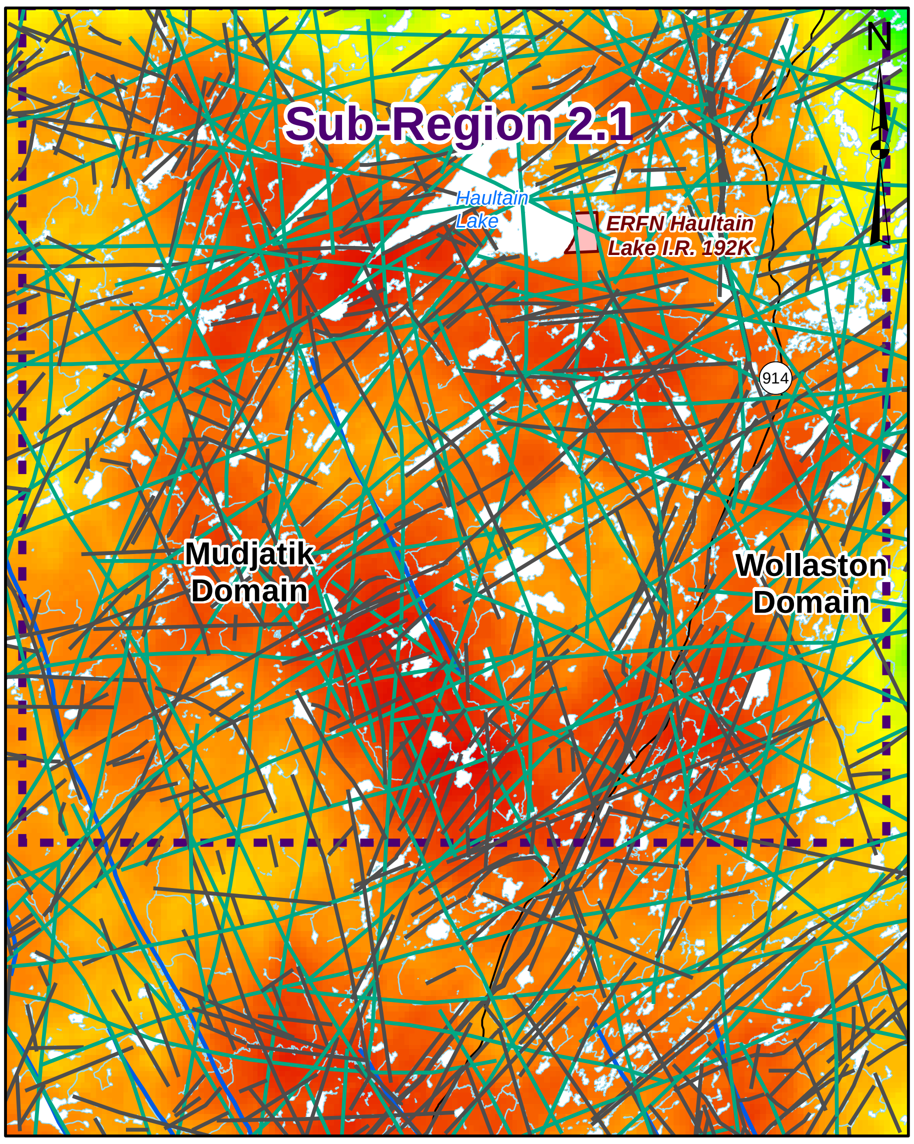
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

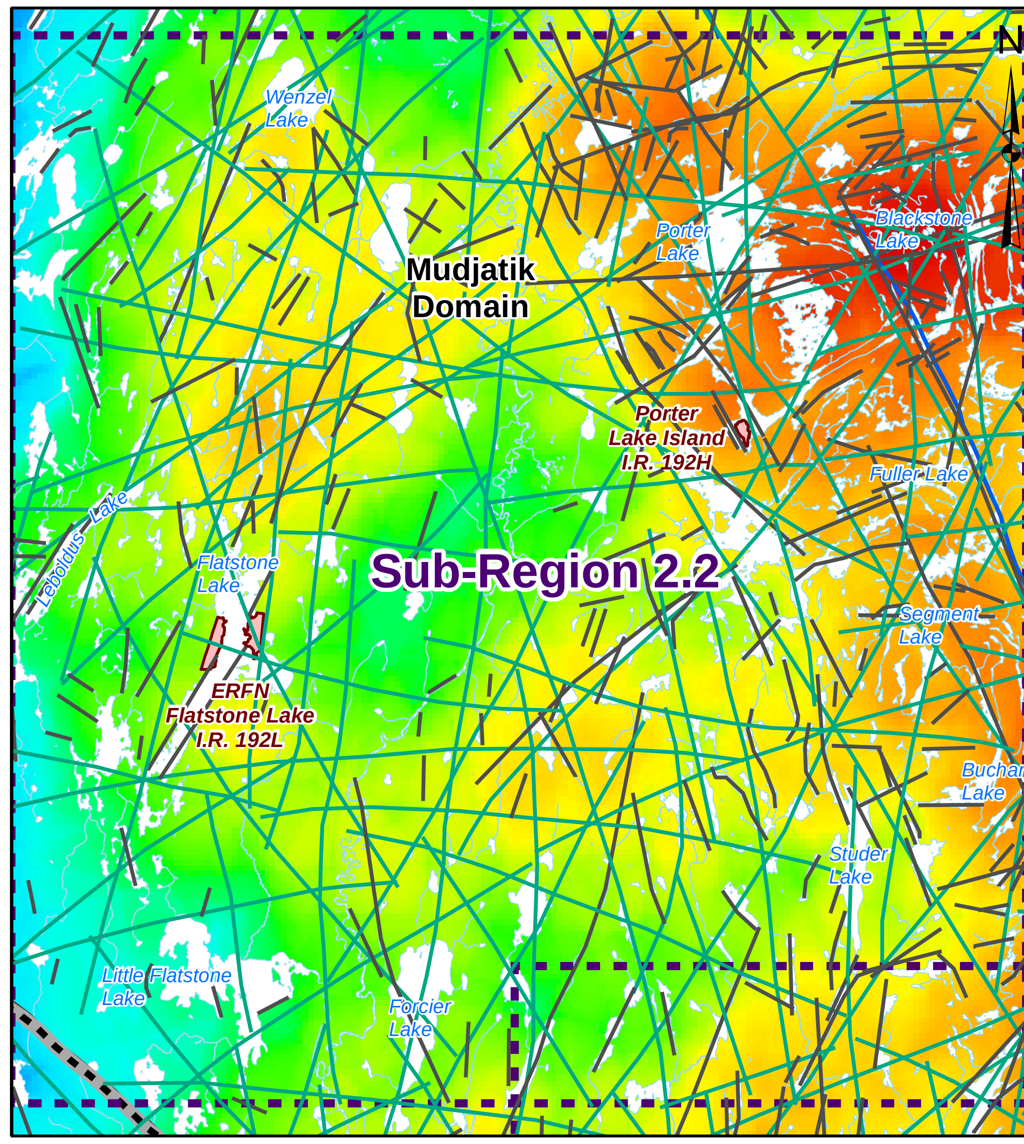
TITLE

Brittle Lineament Density Calculated for Lineaments in the English River First Nation Area

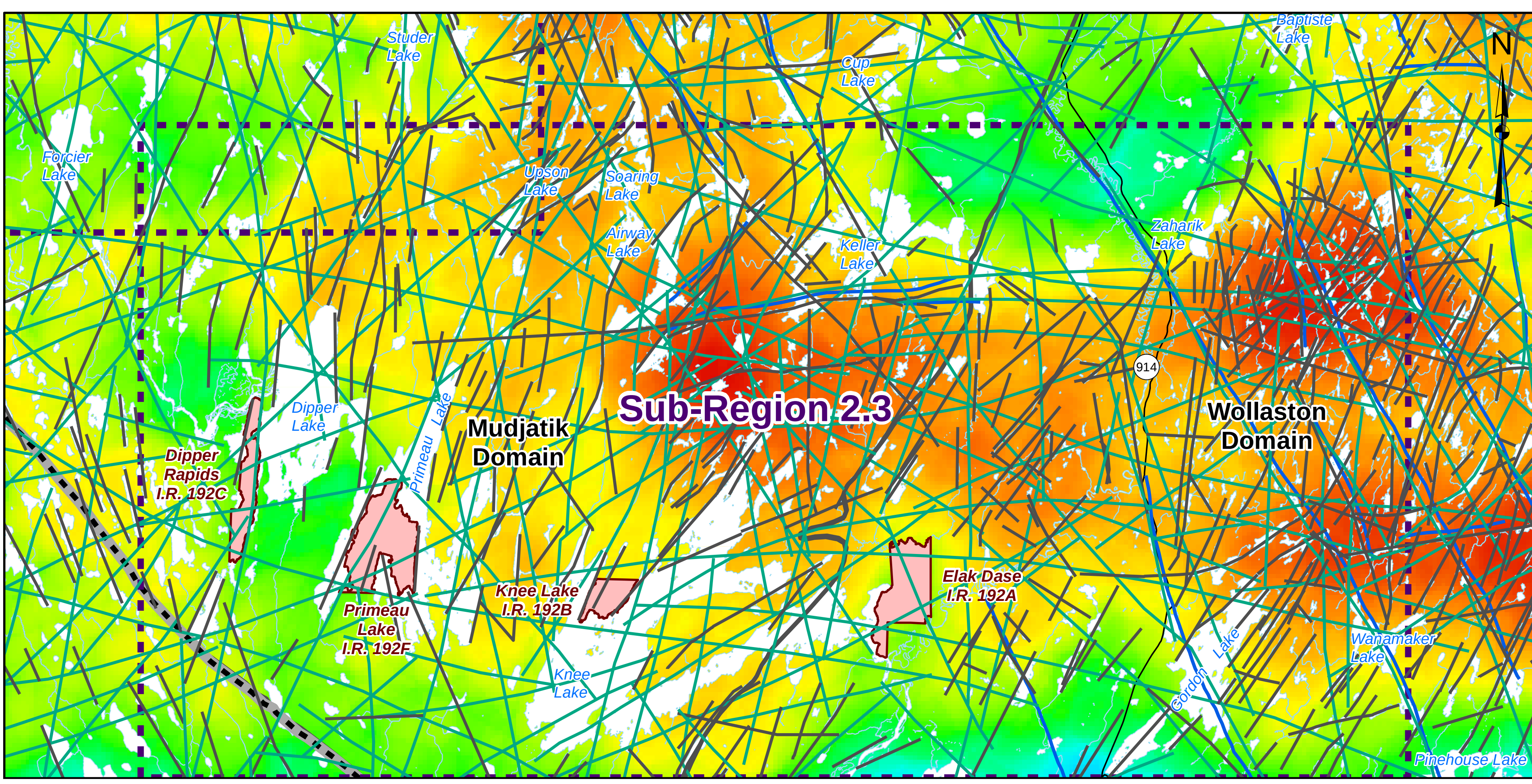
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	11 Feb. 2013	FIGURE: 3.16	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		





Sub-Region 2.1 **Sub-Region 2.2**



Sub-Region 2.3

LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Geophysical Lineament (>1 km)
- Surficial Lineament (>1 km)
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Lineament Density (km/km²)
High : 2.5
Low : 0

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20
SCALE 1:350,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineament Density Calculated for Lineaments >1 km in the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	11 Feb. 2013	FIGURE: 3.17	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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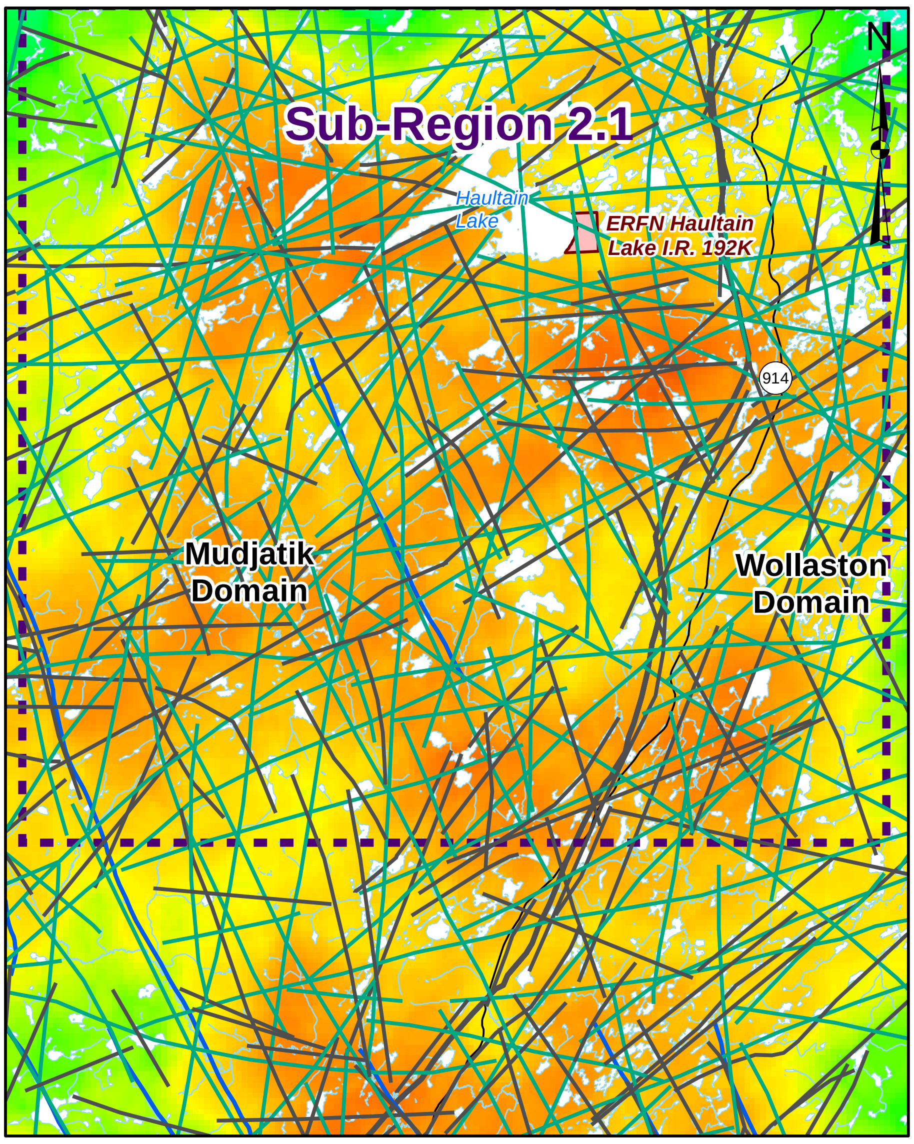
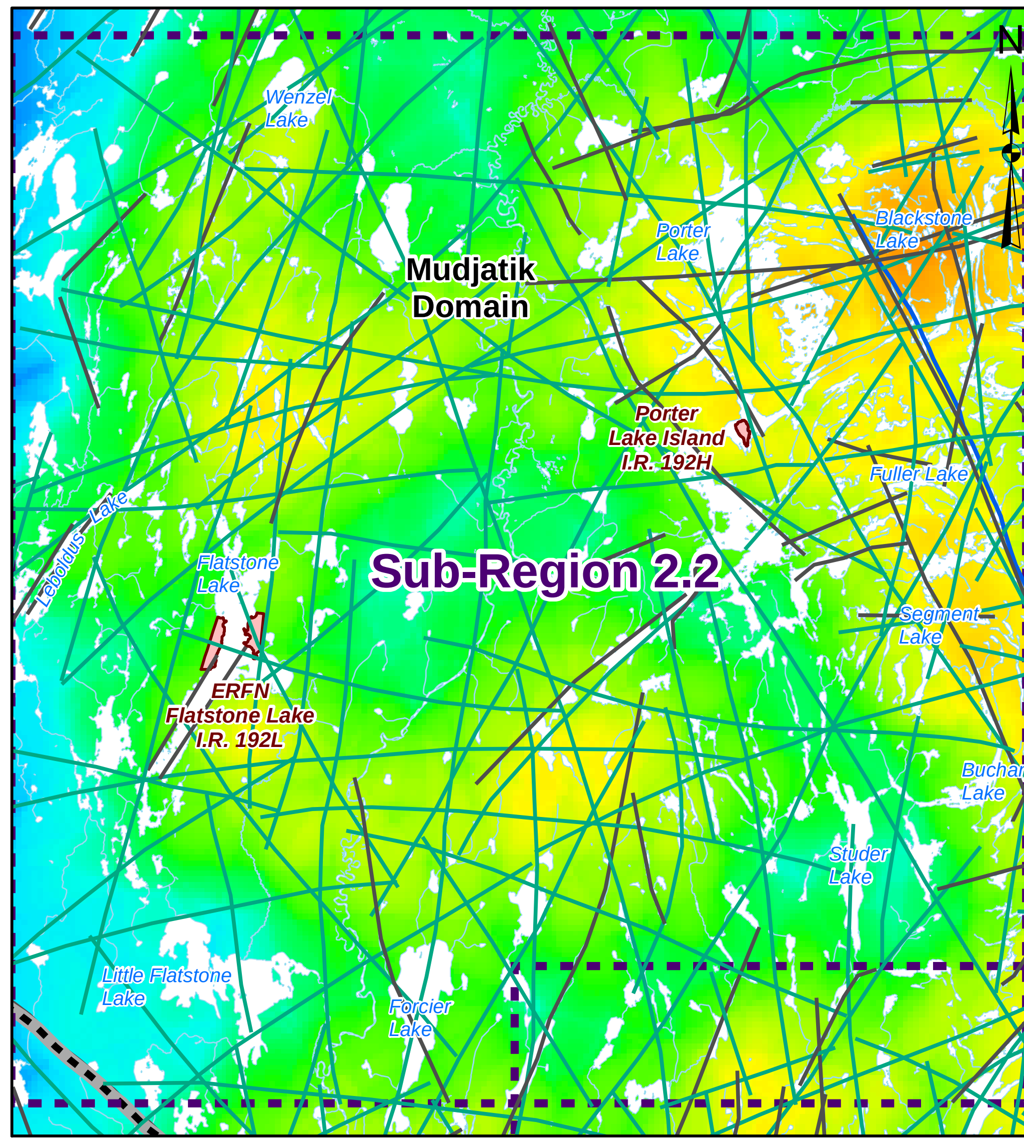
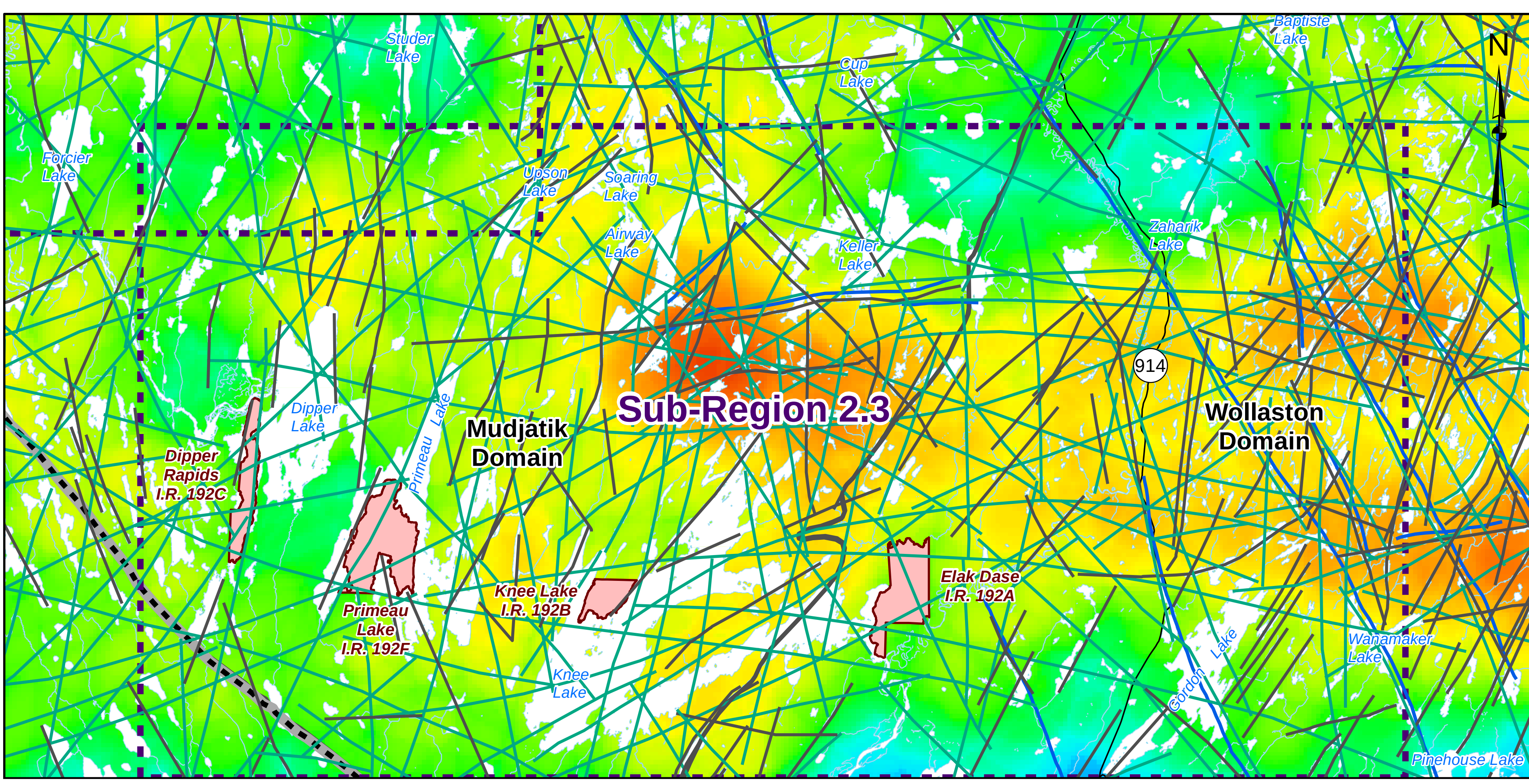


Sub-Region 2.1



Sub-Region 2.2



Sub-Region 2.3

LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Geophysical Lineament (>5 km)
- Surficial Lineament (>5 km)
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Lineament Density (km/km²)
High : 2.5
Low : 0

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

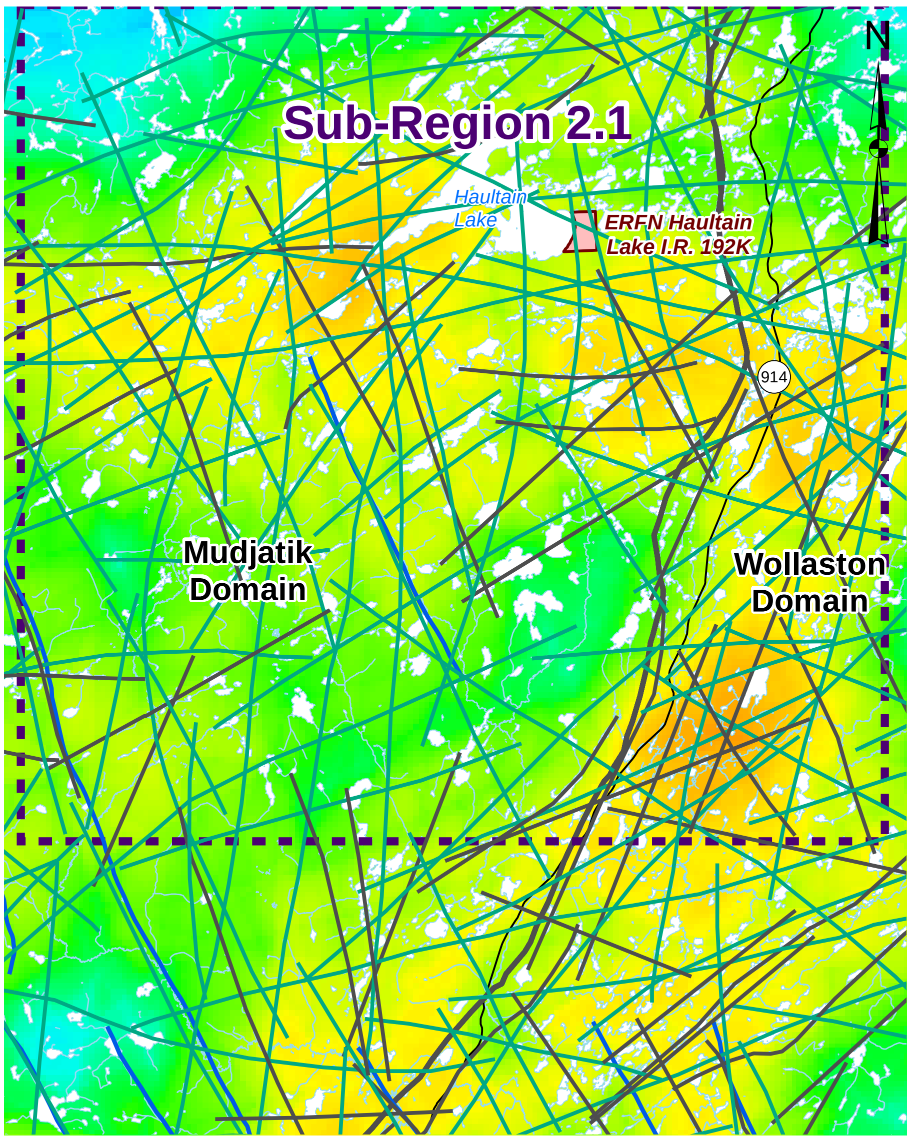
10 5 0 10 20
SCALE 1:350,000 KILOMETERS

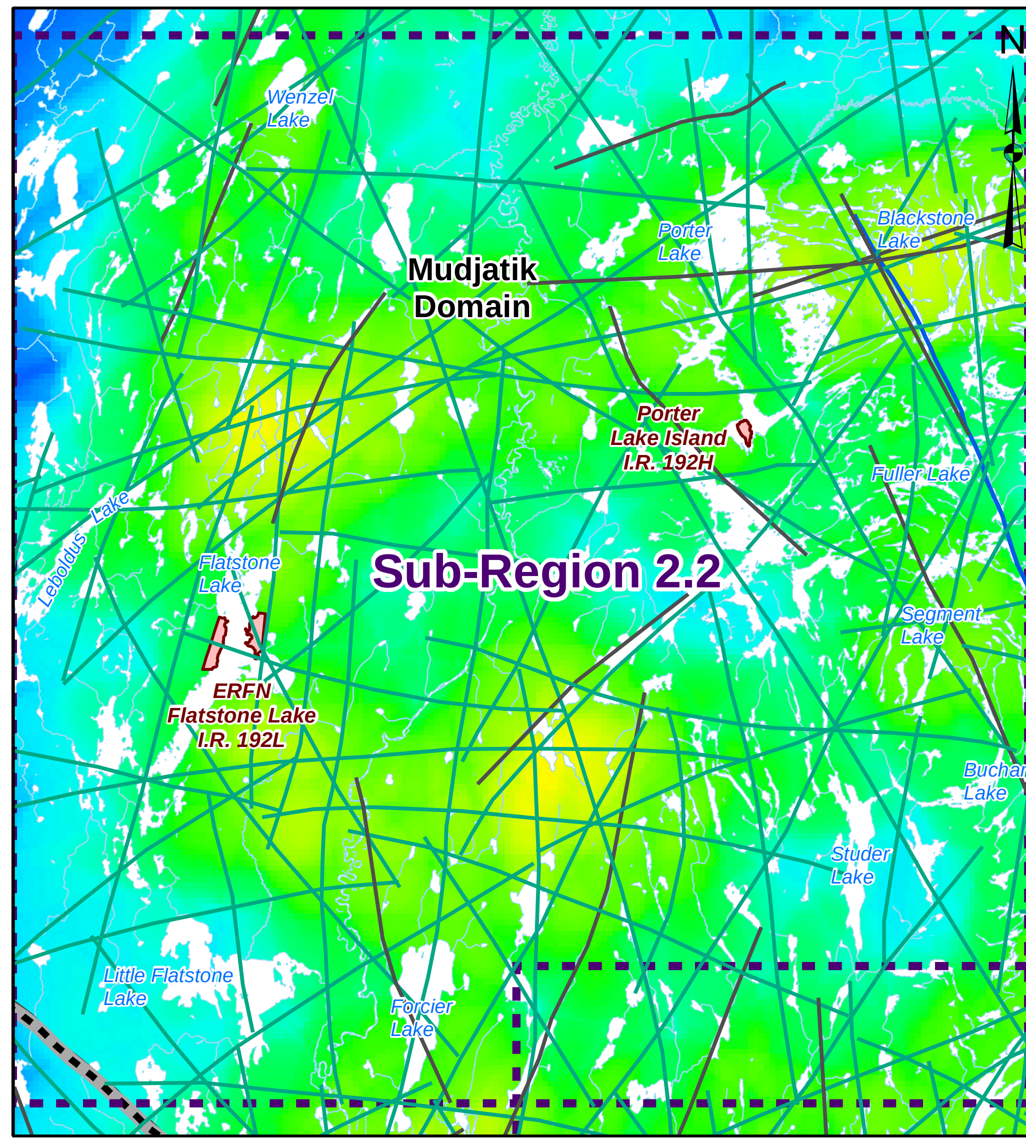
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineament Density Calculated for Lineaments >5 km in the English River First Nation Area

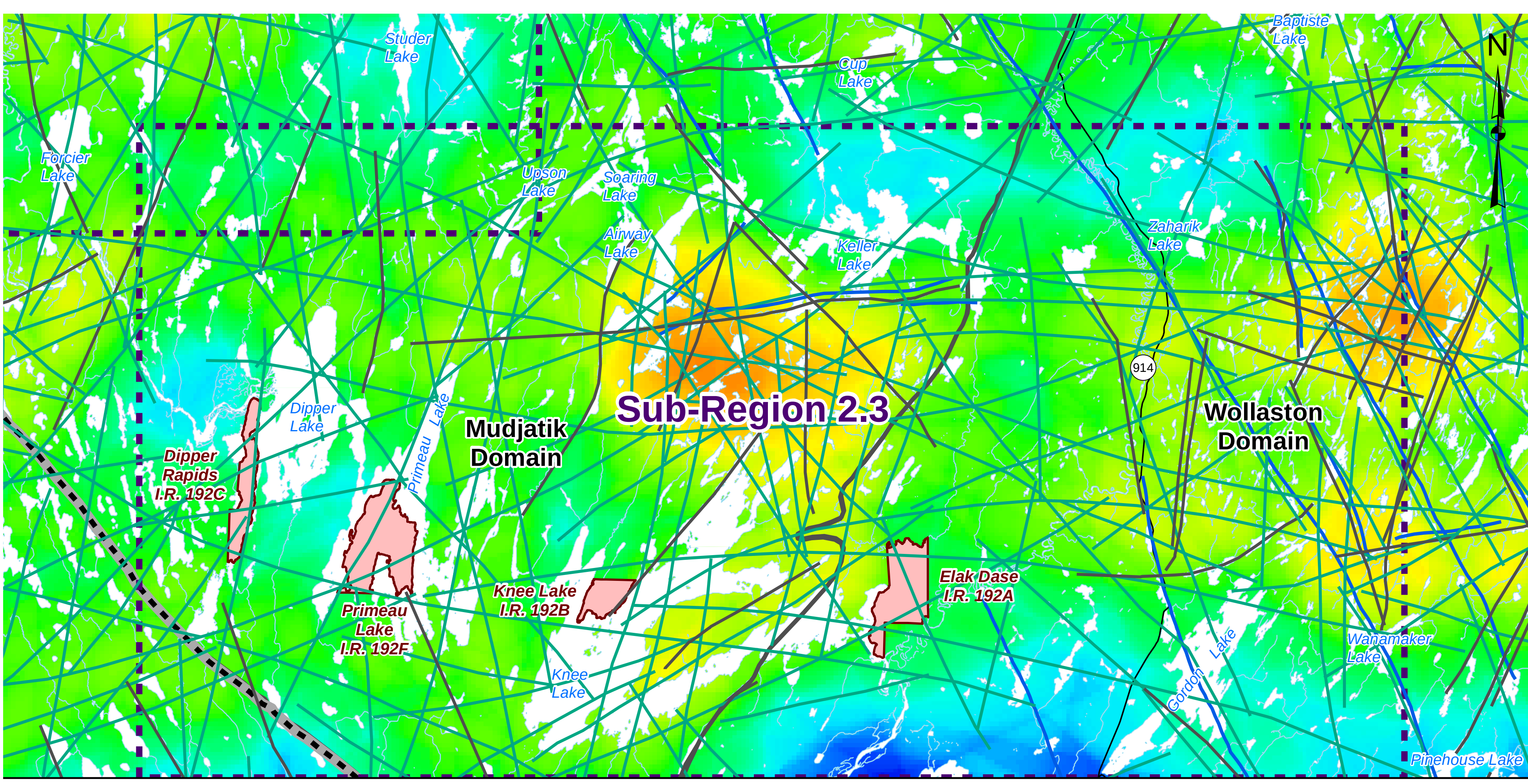
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	11 Feb. 2013	FIGURE: 3.18	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		





Sub-Region 2.1 **Sub-Region 2.2**



Sub-Region 2.3

LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Geophysical Lineament (>10 km)
- Surficial Lineament (>10 km)
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Lineament Density (km/km²)
High : 2.5
Low : 0

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20
SCALE 1:350,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineament Density Calculated for Lineaments >10 km in the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	11 Feb. 2013	FIGURE: 3.19	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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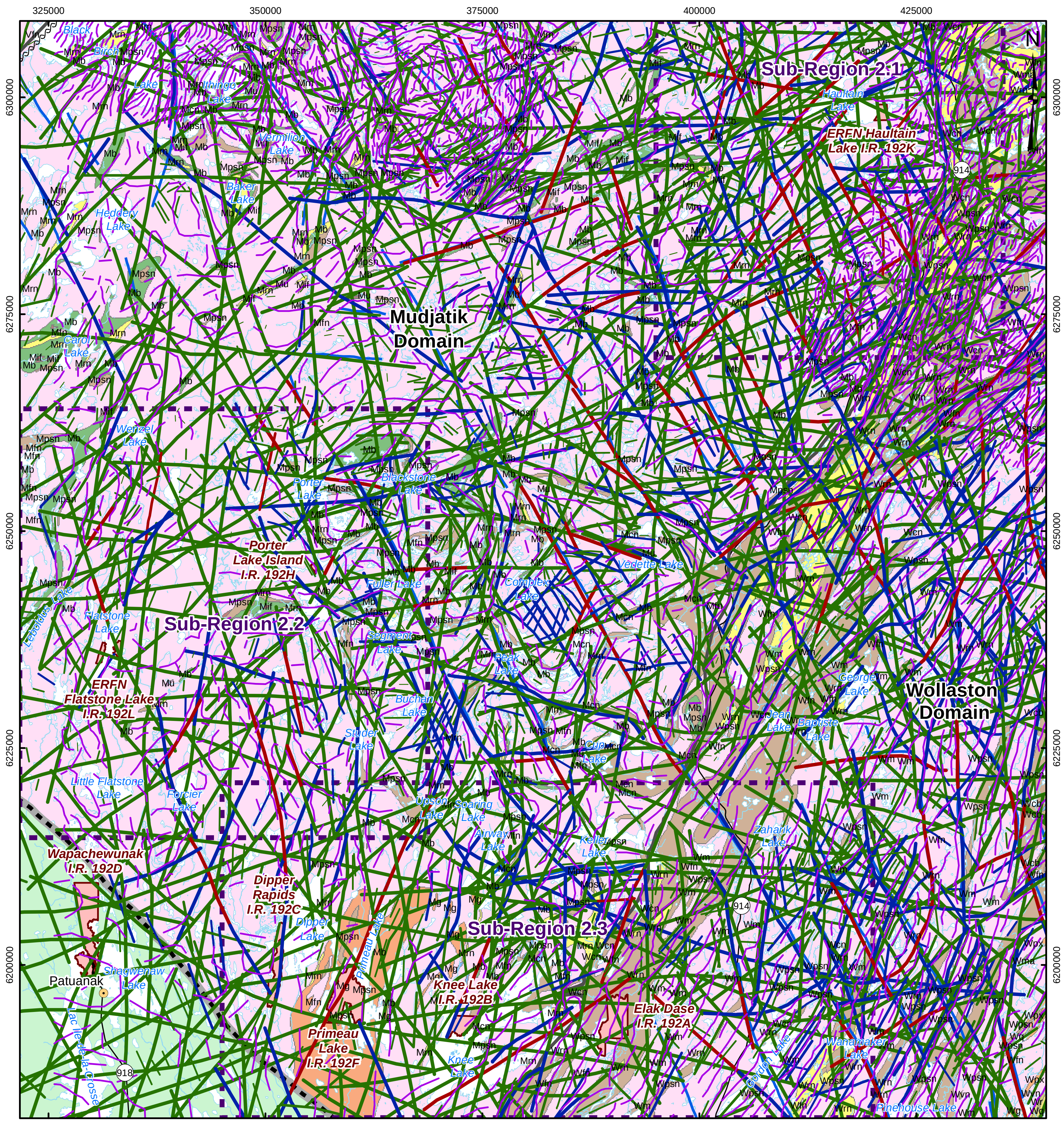


LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Mapped Fault
- Cable Bay Shear Zone
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Ductile Lineaments

Lineament Reproducibility

- 1
- 2
- 3

Lineament Length

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

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

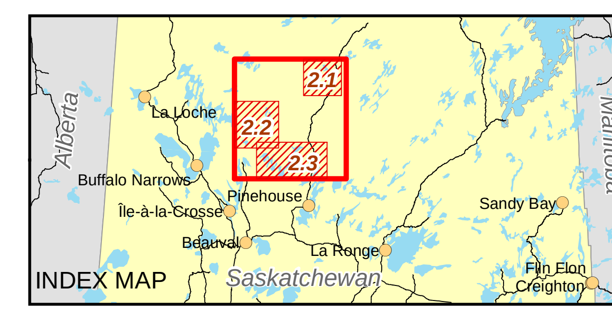
- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Virgin River Domain

- Vfn - Felsic gneiss

Wollaston Domain

- Wcb - Massive coarse grained calc-silicate
- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wg - Leucogranite, granite, monzogranite, granodiorite
- Wm - Amphibolite
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wpx - Migmatized supracrustal rocks
- Wq - Metaquartzite
- Wr - Meta-arkose
- Wm - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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SCALE 1:525,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Combined Structural Features of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.20	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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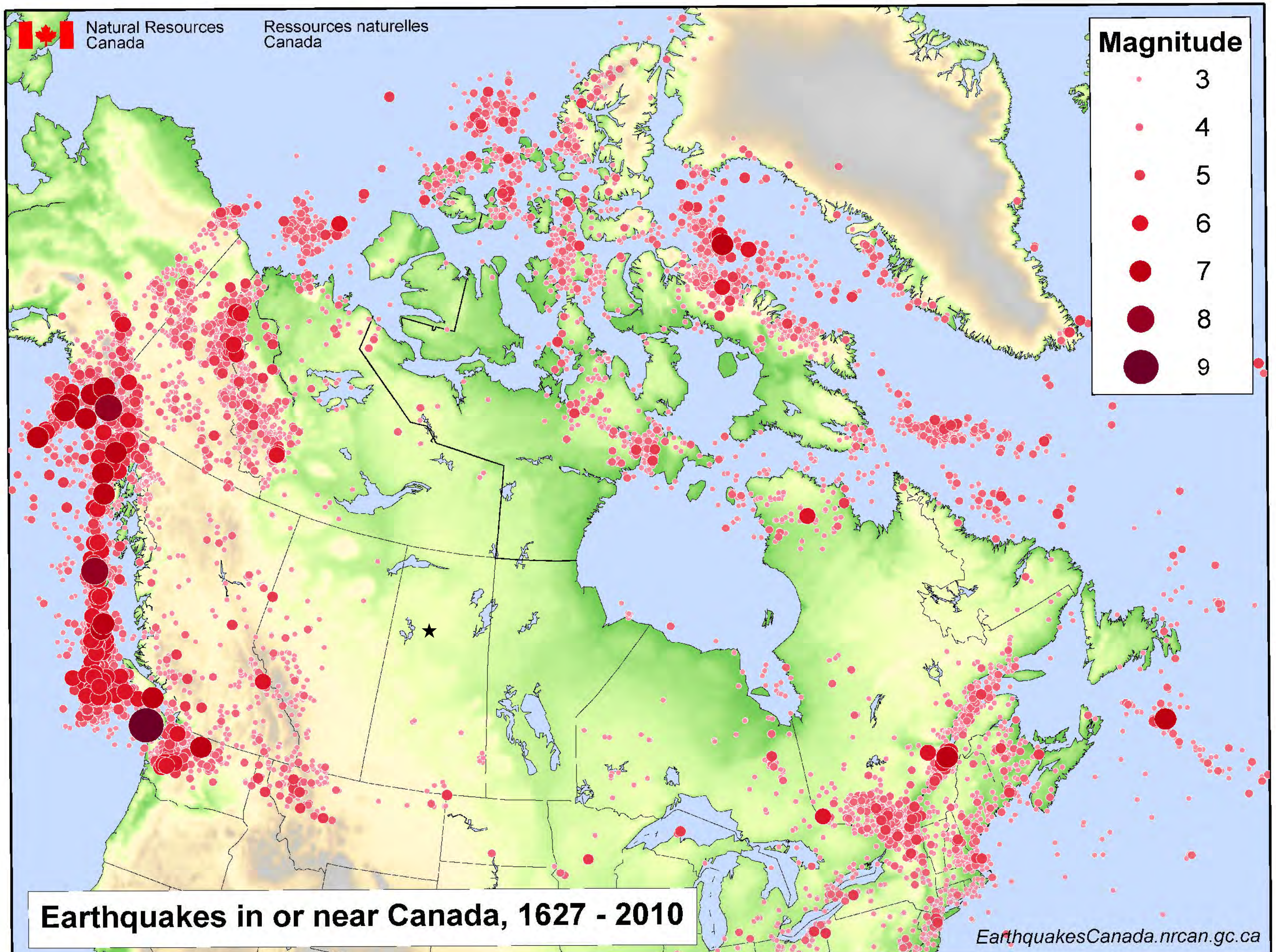

LEGEND

★ English River First Nation

REFERENCE

Seismic - Resources Canada (NRC). Earthquakes Canada Website. http://earthquakescanada.nrcan.gc.ca

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Earthquakes Map of Canada 1627-2010

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.21	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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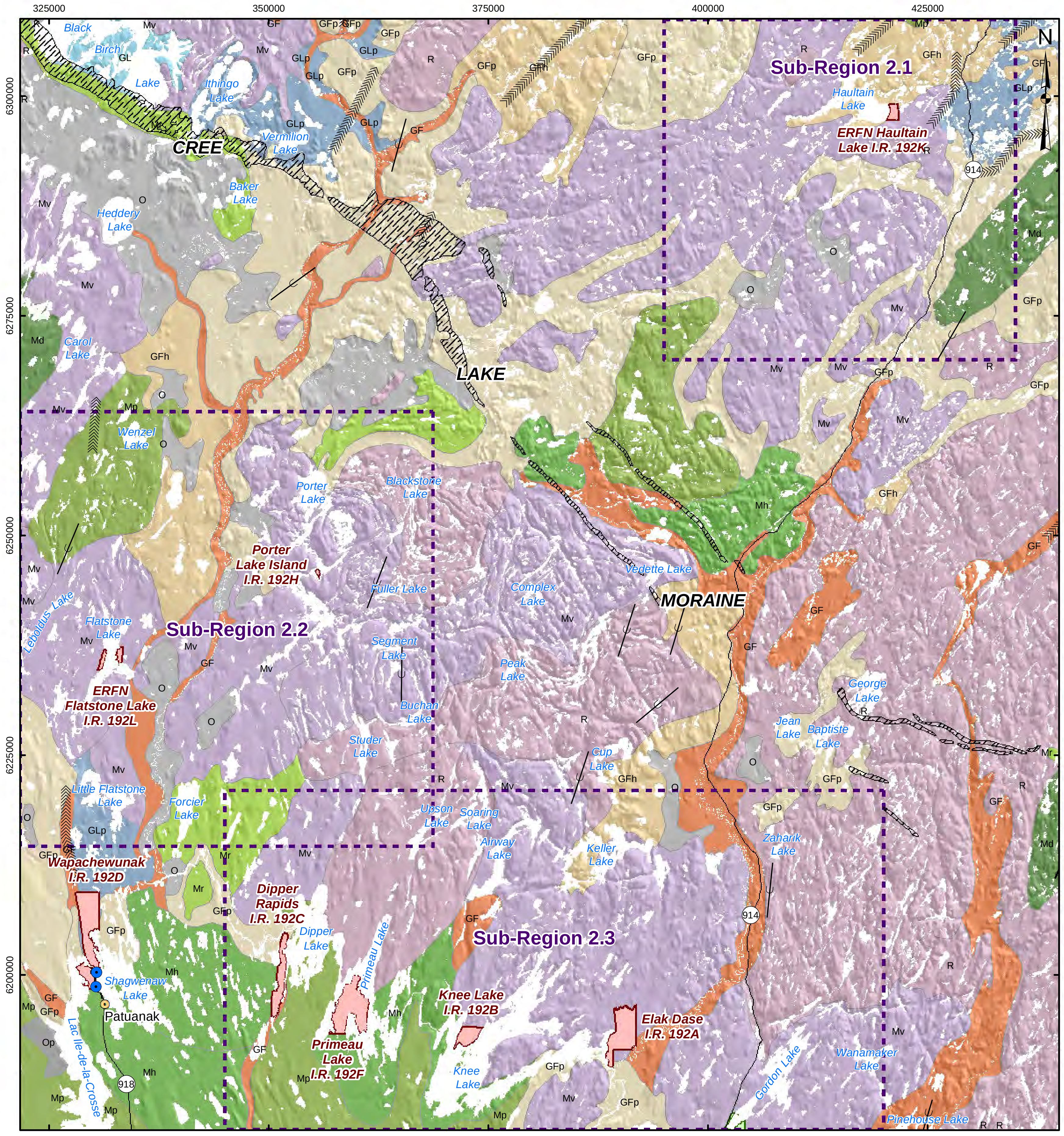
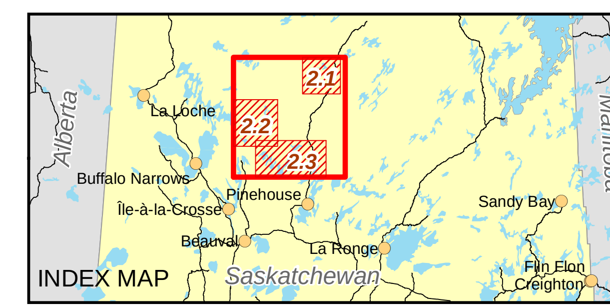


LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Waterbody
- Federal Land - Indian Reserve
- Park and Recreation Area
- Groundwater Well
- Drumlin
- Striation
- Esker
- Moraine

Surficial Geology

- O - Organic
- Op - Organic plain
- GF - Glaciofluvial
- GFh - Glaciofluvial hummocky
- GFp - Glaciofluvial plain
- GL - Glaciolacustrine
- GLp - Glaciolacustrine plain
- Md - Morainal drumlinoid
- Mh - Morainal hummocky
- Mp - Morainal plain
- Mr - Morainal ridged
- Mv Morainal veneer
- R - Rock



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Quaternary Geology - Saskatchewan Geological Atlas (1:250,000)
Drill holes - Sask Geological Atlas
Wells - Saskatchewan Watershed Authority Water Well Database
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

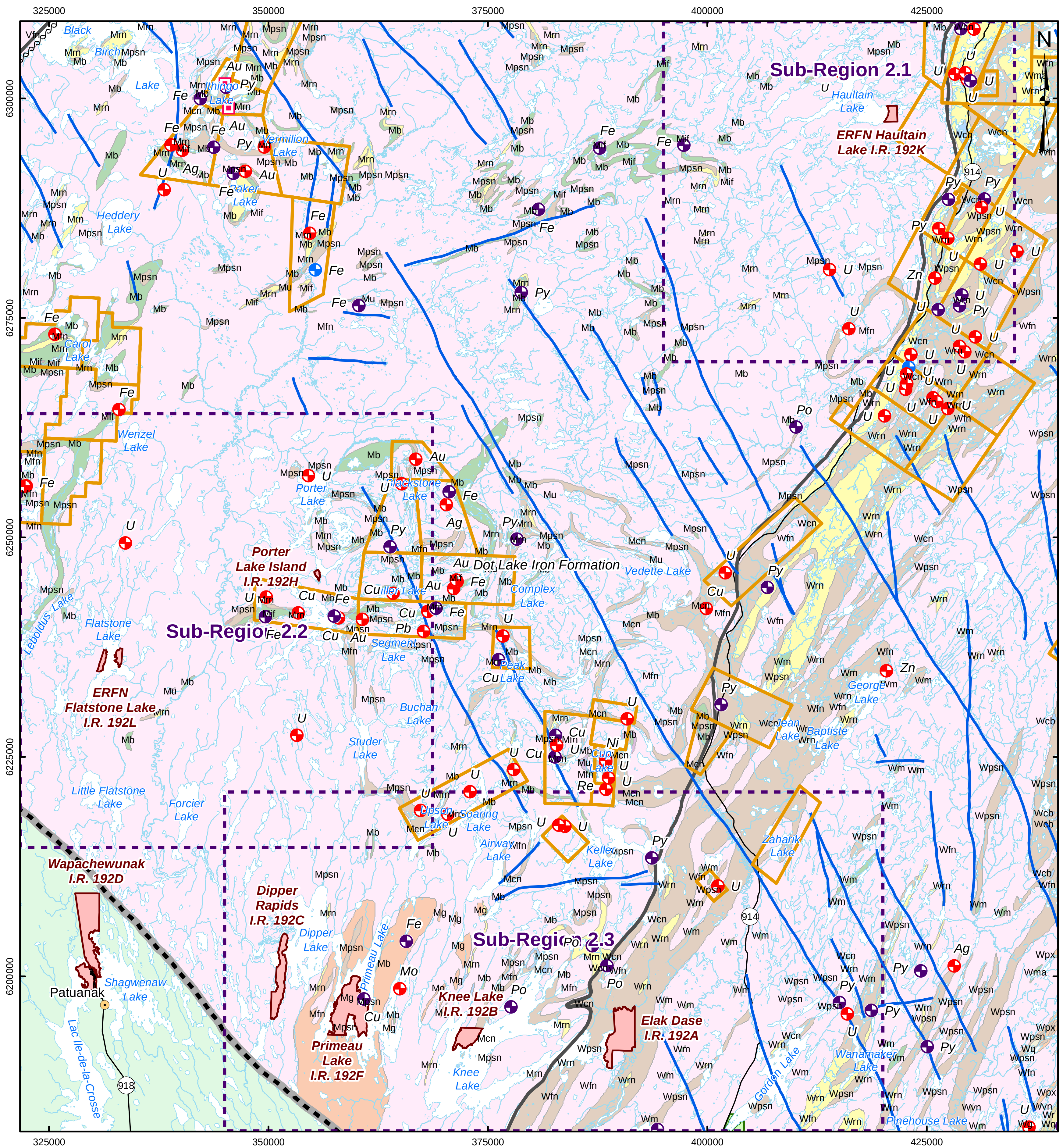
10 5 0 10 20 30
SCALE 1:525,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Groundwater Wells within the
English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 4.1	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		



LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Park and Recreation Area
- Developed Mineral Prospect
- Showing Mineral Potential
- Showing Mineral Potential - Reserve
- Showing Mineral Potential - No Assays
- Mapped Fault
- Cable Bay Shear Zone
- Mining Dispositions
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Virgin River Domain

- Vfn - Felsic gneiss

Wollaston Domain

- Wcb - Massive coarse grained calc-silicate
- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wg - Leucogranite, granite, monzogranite, granodiorite
- Wm - Amphibolite
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wpx - Migmatized supracrustal rocks
- Wq - Metaquartzite
- Wr - Meta-arkose
- Wm - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Mining Claims - Geological Atlas of Saskatchewan (Nov. 2012)
Projection: Universal Transverse Mercator Datum: NAD 83
Coordinate System: UTM Zone 13

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KILOMETERS
SCALE 1:525,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Mineral Showings and Dispositions
of the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT No. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012		
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

FIGURE: 5.1

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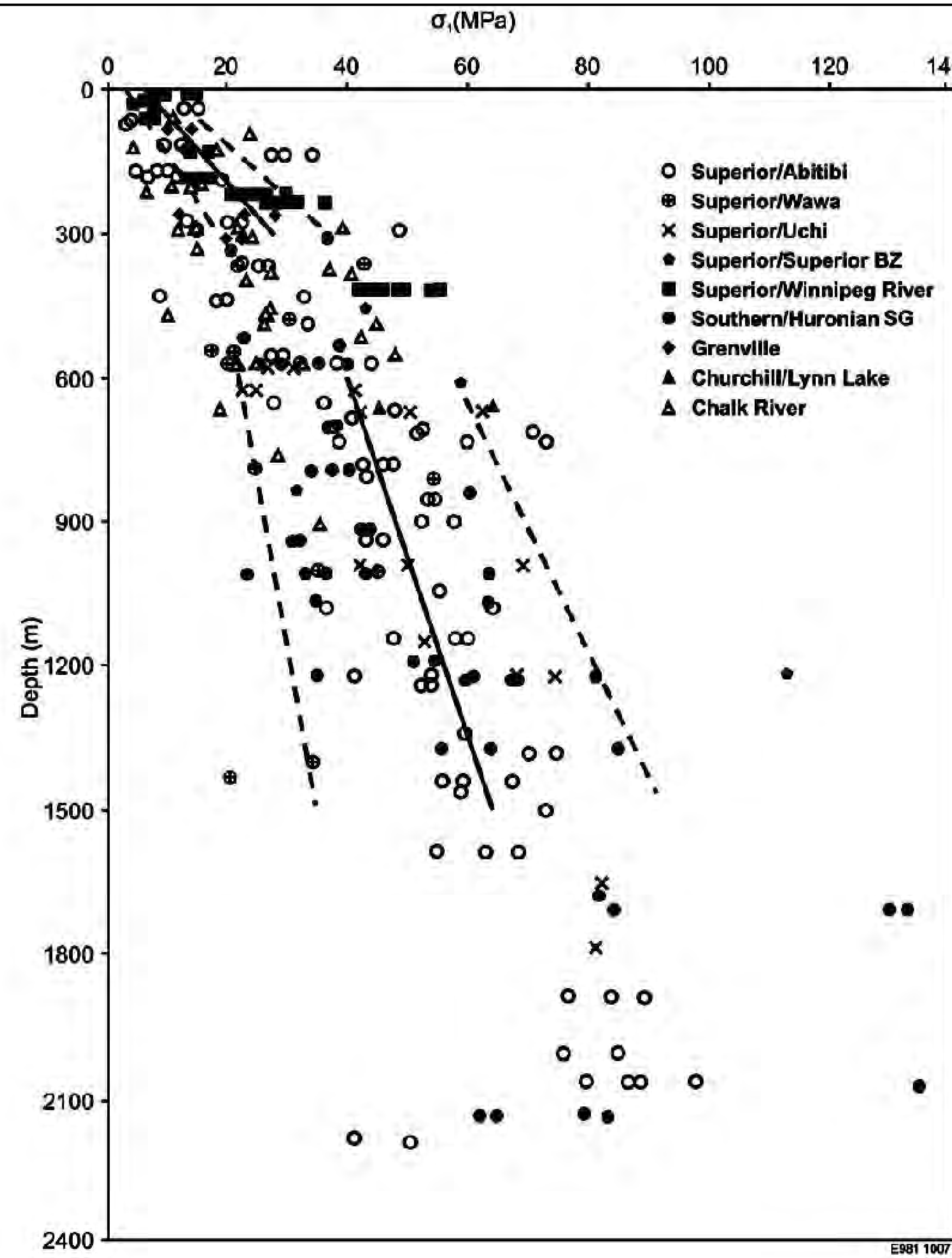


REFERENCE

Maximum Horizonal In Situ Stresses Measured in the Canadian Shield: After Maloney, Kaiser, and Vorauer, 2006.

PROJECT

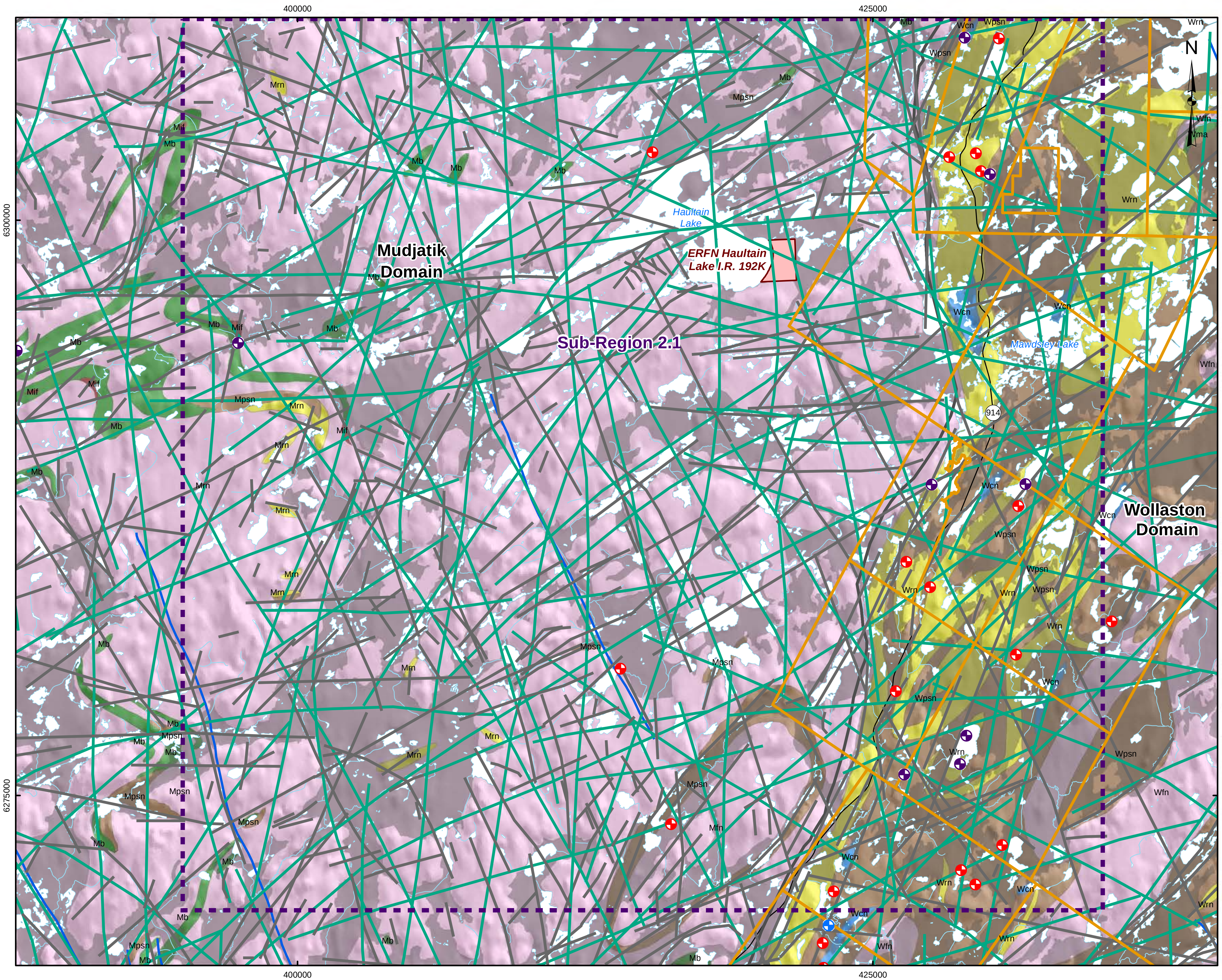
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

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

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	6 Nov. 2012	FIGURE: 6.1	
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		



LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Showing Mineral Potential
- Showing Mineral Potential - Reserve
- Showing Mineral Potential - No Assays
- Mapped Fault
- Geophysical Lineament
- Surficial Lineament
- Mining Dispositions
- Overburden Cover
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mfn - Felsic gneiss
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss

Wollaston Domain

- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wma - Amphibolite (Archean)
- Wpsn - Pelitic, psammopelitic gneiss
- Wm - Psammitic to meta-arkosic gneiss

Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Overburden - : Munday, R.J.C., 1977b. The Geology of the Mudjatik (East) Area Saskatchewan. 1:100,000 North Sheet. Map 168B to accompany Report 168, SGS
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Mining Claims - Geological Atlas of Saskatchewan (Nov. 2012)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

3 1.5 0 3 6 9

KILOMETERS

SCALE 1:175,000

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY PHASE 1 DESKTOP STUDY

TITLE

Key Geoscientific Characteristics of Sub-Region 2.1 in the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 7.1	
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013		
REVIEW	GWS	19 Sep. 2013		

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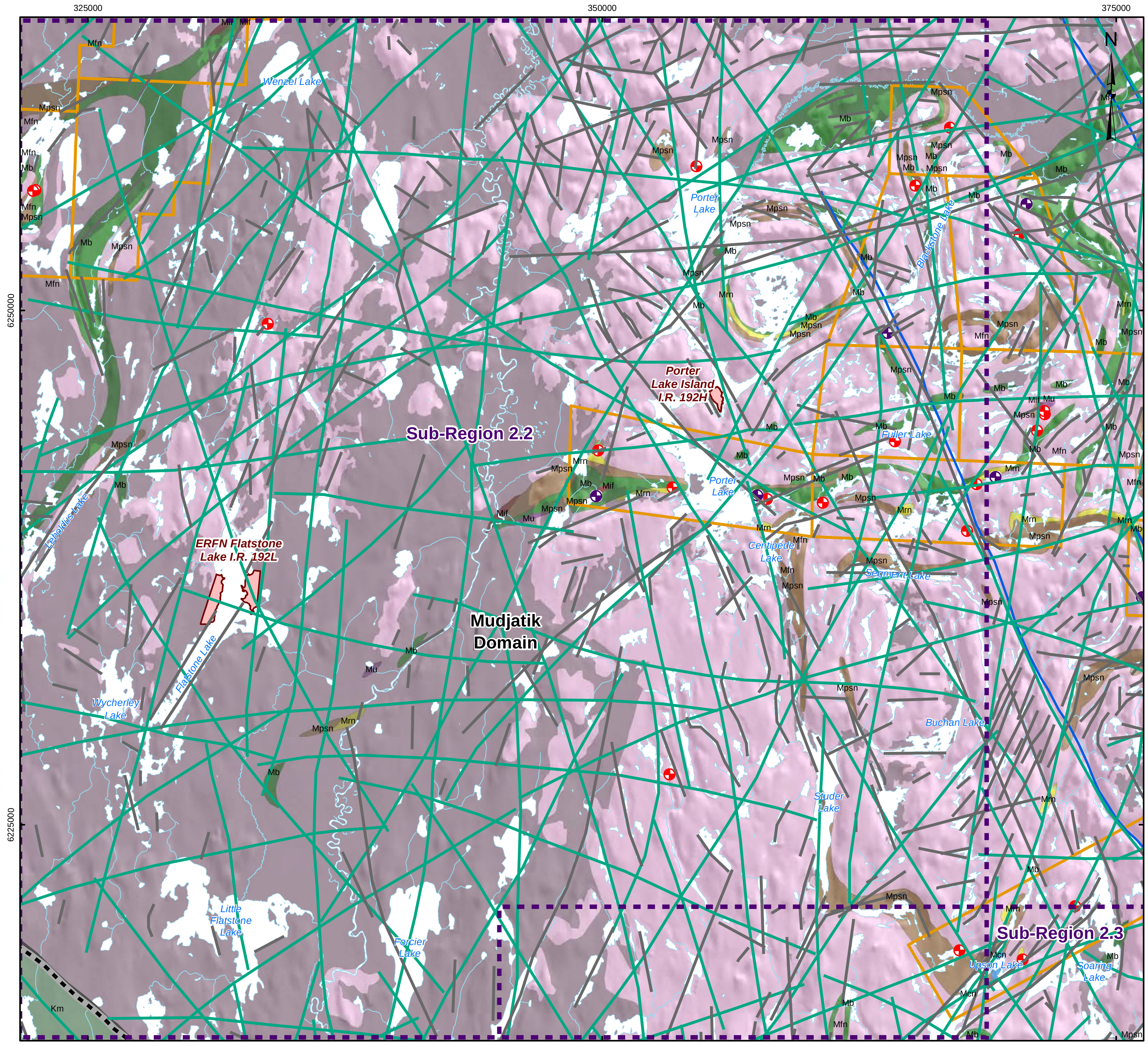


LEGEND

- English River First Nation Detailed Area
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Showing Mineral Potential
- Showing Mineral Potential - No Assays
- Mapped Fault
- Geophysical Lineament
- Surficial Lineament
- Mining Dispositions
- Overburden Cover
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mif - Banded iron formation
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Approximate Size of Repository Footprint

3 km
2 km

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Overburden - Pearson, D.E., 1977b. Geology of the Mudjatik (Southwest) Area. 1:100,000 Map 166A to accompany Report No. 166, SGS
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Mining Claims - Geological Atlas of Saskatchewan (Nov. 2012)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

4 2 0 4 8 12
SCALE 1:200,000 KILOMETERS

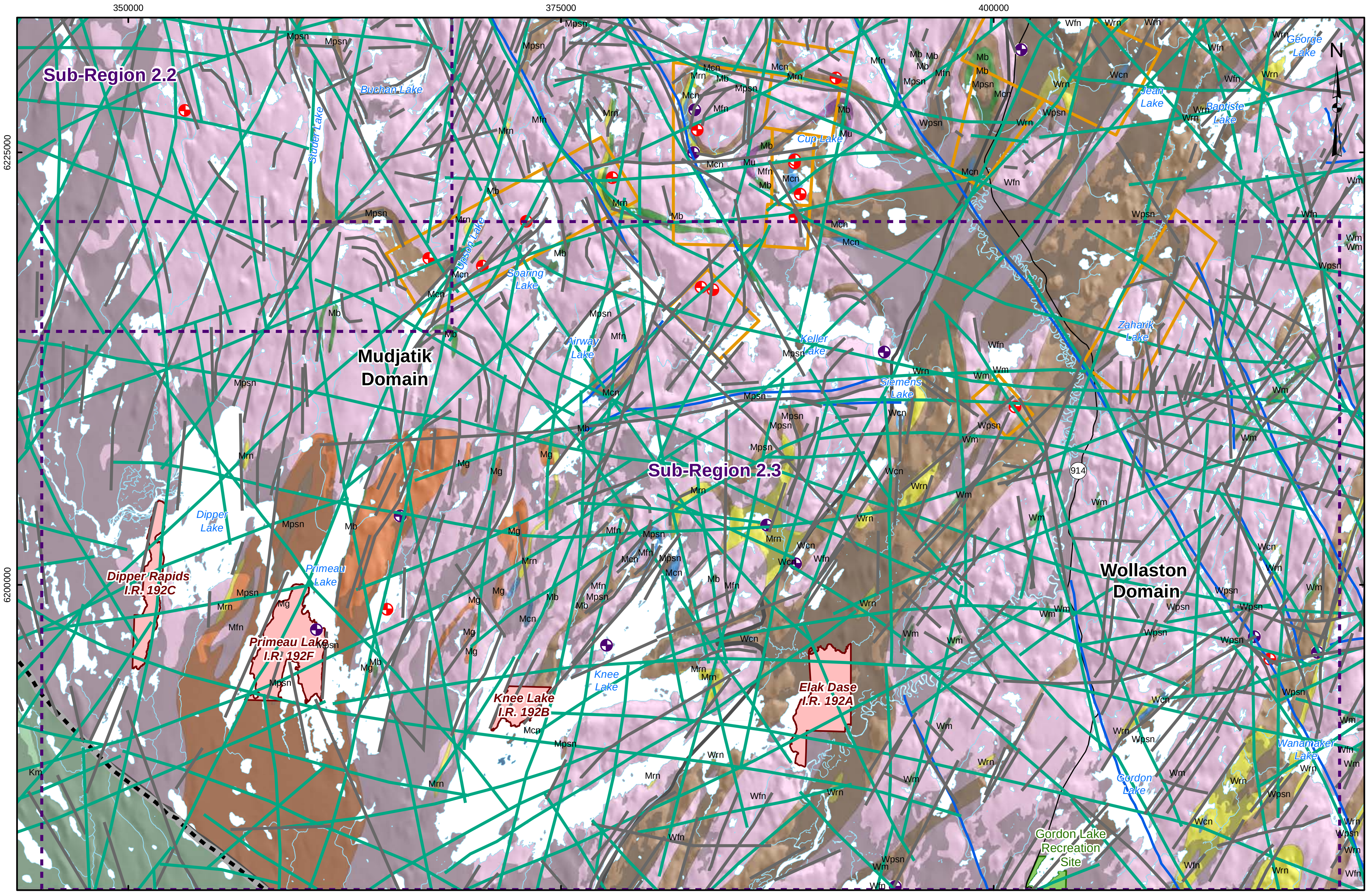
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Key Geoscientific Characteristics of Sub-Region 2.2 in the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT No. 12-1152-0026		SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	
GIS	PM/JB	19 Sep. 2013	
CHECK	AM	19 Sep. 2013	
REVIEW	GWS	19 Sep. 2013	

FIGURE: 7.2



LEGEND

- English River First Nation Detailed Area
- Highway
- Watercourse
- Waterbody
- Federal Land - Indian Reserve
- Protected Area
- Showing Mineral Potential
- Showing Mineral Potential - No Assays
- Mapped Fault
- Geophysical Lineament
- Surficial Lineament
- Mining Dispositions
- Overburden Cover
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mb - Mafic Gneiss
- Mcn - Calc-silicate rock, marble
- Mfn - Felsic gneiss
- Mg - Leucogranite
- Mpsn - Pelitic, psammopelitic and psammitic gneisses
- Mm - Psammitic to meta-arkosic gneiss
- Mu - Ultramafic rock

Wollaston Domain

- Wcn - Calc-silicate rock, marble
- Wfn - Felsic gneiss
- Wm - Amphibolite
- Wpsn - Pelitic, psammopelitic gneiss
- Wm - Psammitic to meta-arkosic gneiss

Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Lineaments - Lineament Interpretation, ERFN, Saskatchewan (JDMA, 2013)
Overburden - Munday, R.J.C., 1978b. The Shield Geology of the Ile-a-la-Crosse (East) Area Saskatchewan. Part of the NTS Area 73-0. 1:100,000 Sheet 1, Map 189A, SGS and Scott, B.P., 1977b. Geology of the Dipper Lake Area (NTS 73-0-14) Saskatchewan. 1:63,360 Map 183A to accompany Report No. 183, SGS
Admin. Boundaries - Information Services Corporation of Sask., Admin. Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Mining Claims - Geological Atlas of Saskatchewan (Nov. 2012)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10 15

SCALE 1:250,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY PHASE 1 DESKTOP STUDY

TITLE

Key Geoscientific Characteristics of Sub-Region 2.3 in the English River First Nation Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012		
GIS	PM/JB	19 Sep. 2013		
CHECK	AM	19 Sep. 2013	FIGURE: 7.3	
REVIEW	GWS	19 Sep. 2013		

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.
Transportation	**6.** The site should have a route that exists or is amenable to being created that enables the safe and secure transportation of used fuel from existing storage sites to the repository site.	**6.1** The repository should be located in an area that is amenable to the safe transportation of used nuclear fuel. **6.2** The repository should be located in an area that allows appropriate security and emergency response measures during operation and transportation of the used nuclear fuel.

APPENDIX B

Geoscientific Data Sources

Table B-1: Summary of Geological Mapping Sources for the ERFN Area

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
Prelim. Map 74-B-SE	Geological Sketch Map of the Mudjatik Area (SE)	Munday, R.	SGS	1:126,720	1972	South of Haultain area	Hand-drawn precursor of Map 168A
Prelim. Map 74-B-SW	Preliminary Map 74-B-SW Mudjatik SW	Pearson, D.E.	SGS	1:100,000	1972	Porter Lake and Flatstone Lake areas	Hand-drawn precursor of Map 166A
Map 168B	Geology of the Mudjatik (East) Area North Sheet	Munday, R.	SGS	1:100,000	1977	Haultain area	Detailed bedrock lithology, mapped faults, structural measurements, areas with thick overburden
Map 168A	Geology of the Mudjatik (East) Area South Sheet	Munday, R.	SGS	1:100,000	1977	South of Haultain area	Detailed bedrock lithology, mapped faults showing offset, structural measurements, areas with thick overburden
Map 166A	Geology of the Mudjatik (Southwest) Area	Pearson, D.E.	SGS	1:100,000	1977	Porter Lake and Flatstone Lake areas	Detailed bedrock lithology, mapped faults, structural measurements, areas with thick overburden
Map 183A	Geology of the Dipper Lake Area	Scott, B.P.	SGS	1:63,360	1977	Dipper Lake, Primeau Lake and Knee Lake areas	Detailed bedrock lithology, mapped faults, structural measurements, areas with thick overburden
Map 189A	Shield Geology of the Ile-a-la-Crosse (East) Area	Munday, R.	SGS	1:100,000	1978	Knee Lake and Elak Dase to the Needle Falls shear zone	Detailed bedrock lithology, mapped faults, structural measurements, areas with thick overburden
Map 78-10-10	Uranium Metallogenic Studies: Cup Lake Area,	Thomas, D.J.	SGS	1:20,000	1978	Cup Lake, NTS Area 74B-2 (part)	Detailed bedrock geology
Map 221 A	Quaternary Geology of the Precambrian Shield, Saskatchewan	Schreiner, B.T.	SGS	1:1,000,000	1984	Full (SK)	Quaternary geology up to the Saskatchewan-Manitoba border
Open File 84-8	Quaternary Geology of the Mudjatik Area	Schreiner, B.T.	SGS	1:250,000	1984	North half of ERFN	Quaternary geology, areas with

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
						area	veneer
Open File 84-5	Quaternary Geology of the Ile-a-la-Crosse Area	Schreiner, B.T.	SGS	1:250,000	1984	South half of ERFN area	Quaternary geology, areas with veneer
Map 245A	Ile-a-la-crosse, NTS Area 73O	Thomas, M.W and W.L. Slimmon	SGS	1:250,000	1985	South area, Knee Lake to Elak Dase	Compilation bedrock geology series
Misc. Rep. 88-4, Fig. 1	Mudjatik Domain, Geology and Gold Studies: Porter Lake Area	Harper, C.T.	SGS	1:200,000	1988	900 km^2 centered around Porter Lake	Geological sketch map
Map 99-4.2-(6.1)	Geology of the Cup Lake – Keller Lake – Schmitz Lake Area	Tran, H.T.	SGS	1:20,000	1999	Peak Lake	Detailed bedrock geology
Map 99-4.2-(6.2)	Geology of the Cup Lake – Keller Lake – Schmitz Lake Area	Tran, H.T.	SGS	1:20,000	1999	Cup Lake West	Detailed bedrock geology
Map 99-4.2-(6.3)	Geology of the Cup Lake – Keller Lake – Schmitz Lake Area	Tran, H.T.	SGS	1:20,000	1999	Cup Lake East	Detailed bedrock geology
Map 99-4.2-(7)	Geology of the McKenzie Falls, Haultain River Area	Tran, H.T. and Yeo, G.	SGS	1:20,000	1999	South of Sub-Region 2.2 along Hwy. 914	Detailed bedrock geology
Map 08-4.2-(1.1)	Bedrock Geology of the Careen Lake Area	Card, C.D. and McEwan, B.	SGS	1:20,000	2008	Near NW corner of Area	Detailed bedrock geology
Map 08-4.2-(1.2)	Bedrock Geology of the Roe Lake and west Black Birch Lake Area	Card, C.D., Bosman, S.A. and McEwan, B.	SGS	1:20,000	2008	NW corner of Area	Detailed bedrock geology
Map 08-4.2-(1.2)	Bedrock Geology of the east Black Birch Lake and Ithingo Lake Area	Card, C.D., Bosman, S.A. and McEwan, B.	SGS	1:20,000	2008	NW corner of Area	Detailed bedrock geology
Rep 2010-7	Geological Atlas of Saskatchewan	SGS	SER	1:1,000,000	2010	Full (SK)	Regional mapping of Saskatchewan

SGS = Saskatchewan Geological Survey

SER = Saskatchewan Energy and Resources

Table B-2: Summary of Geophysical Mapping Sources for the ERFN Area

Product	Source	Type	Line Spacing/ Sensor Height	Line Direction	Coverage	Date	Additional Comments
Cree Lake South	GSC	Fixed wing magnetic / radiometric	400m / 127m	105°	Covers 877.6 km^2 in NW part of ERFN area	2007	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic and especially radiometric coverage.
Upper Foster Lake	GSC	Fixed wing magnetic / radiometric	400m / 147m	114°	Covers 1,074.5 km^2 in NE part of ERFN area	2005	The lower height, closer line spacing and vintage of this survey greatly improves standard GSC magnetic and especially radiometric coverage.
Saskatchewan #5	GSC	Fixed wing magnetic	805m / 305m	90°	North-central part of ERFN area	1964	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum.
Saskatchewan #7	GSC	Fixed wing magnetic	1609m / 305m	90°	Adjacent to SW corner of ERFN area	1952	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum.
Saskatchewan #8	GSC	Fixed wing magnetic	1609m / 305m	0°	SW part of ERFN area	1952	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum
Saskatchewan #9	GSC	Fixed wing magnetic	805m / 305m	90°	SE part of ERFN area	1969	Recorded on analog charts, navigation and flightpath based on photomosaics, digitized from the GSC contour maps, levelled to a nationwide magnetic datum
Saskatchewan #10	GSC	Fixed wing magnetic	402m / 305m	135°	Near SE corner of ERFN area	1958	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	10-15 km/surface	-	Entire ERFN area	1960-67	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	90°	Entire ERFN area	1975 1976	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. The compilation in the ERFN area was

Product	Source	Type	Line Spacing/ Sensor Height	Line Direction	Coverage	Date	Additional Comments
							prepared from the Foster Lake, Mudjatik River. Lac la Ronge, Ile-à-la-Crosse and Geikie River surveys.

Table B-3: Summary of Geoscientific Databases for the ERFN Area

Database	Description	Scale (Regional/Local)	Used? (Yes/No)
Geological Atlas of Saskatchewan	GIS maps and data for download. Includes all online geoscience data for Saskatchewan such as: surficial geology, bedrock geology, mine locations, mineral deposits index, crown dispositions, reserves, land claims, mineral assessment file maps, drill holes, EM conductors, kimberlite occurrences, lithogeochemistry, LITHOPROBE lines, aeromagnetic surveys, topographical base maps, dykes, faults. Surficial and bedrock geology is available at a scale of 1:250,000 and dyke and fault information is available at a scale of 1:1,000,000.	Regional and Local	Yes
SMAD, (MARS)	Saskatchewan Mineral Assessment Database (SMAD), after December 12, 2012 to be compiled in the Mineral Administration Registry Saskatchewan (MARS): contains active claims, alienations and dispositions. Data includes: links to available geological information. (http://www.er.gov.sk.ca/smad)	Regional	Yes
Drill Holes	SGS Diamond Drill Hole Database: 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 available drill hole records and/or reports.	Regional and Local	Yes
Earthquakes Canada	Geological Survey of Canada Earthquake Search (On-line Bulletin): http://www.earthquakescanada.nrcan.gc.ca/index-eng.php	Regional	Yes
Geoscience Publications	SGS Geoscience Publications Database. Includes: geophysical index maps, annual reports, base maps, cross-sections, economic information.	Regional and Local	Yes
Summary of Investigations	SGS Summary of Investigations Database. Consists of a summary of SGS field work from 1972 to the present.	Regional and Local	Yes
CDED	Geobase (http://www.geobase.ca) Canadian digital elevation data.	Regional	Yes
SPOT	Geobase (http://www.geobase.ca) Orthoimage.	Regional	Yes
SWA (Water Wells)	Saskatchewan Watershed Authority (SWA) Database containing water well records throughout Saskatchewan (https://gis.wsask.ca)	Regional	Yes

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