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Phase 1 Geoscientific Desktop Preliminary Assessment, Processing and Interpretation of Geophysical Data

ENGLISH RIVER FIRST NATION, SASKATCHEWAN

APM-REP-06144-0045

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PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT

PROCESSING AND INTERPRETATION OF GEOPHYSICAL DATA

English River First Nation, Saskatchewan

Prepared for

Golder Associates Ltd.
and
Nuclear Waste Management Organization (NWMO)

by

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EXECUTIVE SUMMARY

In January 2012, English River First Nation (ERFN), Saskatchewan expressed interest in continuing to learn more about the Nuclear Waste Management Organization's nine-step site selection process (NWMO, 2010), 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 the successful completion of an initial screening conducted during Step 2 of the site selection process.

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

This report presents the findings of a geophysical data interpretation assessment completed as part of the desktop geoscientific preliminary assessment of the ERFN area (Golder, 2013). The purpose of this assessment was to perform a detailed interpretation of all available geophysical data for the ERFN area (e.g., magnetic, gravity and radiometric) to identify additional information that could be extracted from the data, in particular regarding the coincidence of geophysical features with mapped lithology and structural features in the ERFN area.

The geophysical data covering the ERFN area show variability in dataset resolution. Medium to low-resolution magnetic, gravity and radiometric data were obtained from the Geological Survey of Canada (GSC) for the entire ERFN area. Two additional higher resolution magnetic/radiometric surveys were obtained from the GSC for approximately 15% of the ERFN area to the northeast and northwest. No electromagnetic data were available for the ERFN area.

The coincidence between the geophysical data and the mapped lithology and structural features were interpreted using all available geophysical data sets (e.g., magnetic, gravity and radiometric). In general, the coincidence between the geophysical interpretations and the published geological maps is in good agreement, but in some locations the geophysical data provided new interpretations.

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1 INTRODUCTION

In January 2012, English River First Nation (ERFN), Saskatchewan expressed interest in continuing to learn more about the Nuclear Waste Management Organization's nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the English River First Nation (ERFN) area for safely hosting a deep geological repository (Step 3). 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 (NWMO, 2013).

This report presents the findings of a geophysical data processing and interpretation completed by Paterson, Grant & Watson Limited (PGW) as part of the desktop geoscientific preliminary assessment of the ERFN area (Golder, 2013). The objective of the desktop geoscientific preliminary assessment is to determine whether the English River First Nation area contains general areas that have the potential to satisfy the geoscientific evaluation factors outlined in the NWMO site selection process. The assessment focused on ERFN and its periphery, referred to throughout the report as the "English River First Nation area" or "ERFN area".

1.1 Objective

Geophysical data forms an important component of assessing a region for its potential suitability to host a deep geological repository, and to assist in the identification of potentially suitable areas.

The purpose of this assessment was to perform a review of available geophysical data for the ERFN area, followed by a detailed interpretation of all available geophysical data (e.g., magnetic, gravity and radiometric) to identify additional information that could be extracted from the data, in particular regarding the coincidence of geophysical features with mapped lithology and structural features in the ERFN area.

The primary role of geophysics is to extrapolate the surface analysis applied using geological maps, topography and satellite imagery into the subsurface. Drillholes, wells and other underground information may be available at individual points to supplement geological data acquired on surface. However, where these individual data points are limited (or non-existent), such as for the ERFN area, the critical advantage of airborne geophysical data is that it provides a basis for interpreting the subsurface physical properties across the area. This is particularly important in areas where bedrock exposure is limited by surface water bodies and/or overburden cover such as glacial sediments, such as in the ERFN area. A secondary role of geophysics is that it often elucidates certain characteristics of geological formations and structures that may not be easily discerned from surface mapping and analysis. Thirdly, it highlights tectonic and regional-scale features that may not be easily extracted from studies of a particular area on a more detailed scale.

1.2 English River First Nation Area

The ERFN area is a rectangular area measuring 119 km by 126 km, and covering an area of about 15,000 km^2 situated in north-central Saskatchewan (Figure 1). 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. The southern boundary of the area is located 67 km north of Beauval, 88 km northwest of La Ronge, and 237 km north of Prince Albert, Saskatchewan. 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. The ERFN area has been further divided into sub-regions that were reviewed in greater detail.

Sub-region 2.1 – Haultain Area 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 (SR 2.1): This reserve area covers 2 km^2 and is located on the east shore of Haultain Lake, approximately 9 km west of Provincial road 914.

Sub-region 2.2 – Porter and Flatstone Lake Area located in the west-central ERFN area, covering an area of about 2,324 km^2. This sub-region includes the following reserve (IR) areas:

- Flatstone Lake IR (SR 2.2): This reserve area covers 2.3 km^2 and is another remote site located 37 km north of the community of Patuanak; and
- Porter Lake Island IR (SR 2.2): This reserve area covers 0.425 km^2 and is a remote site located north of the Churchill River, near the winter road route leading to Cree Lake.

Sub-region 2.3 – Dipper, Primeau, Knee Lakes and Elak Dase Area located at the south end the ERFN area, covering an area of about 2,892 km^2. This sub-region includes the following reserve (IR) 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; and
- Elak Dase IR: This reserve area covers 14 km^2 and is located 51 km east of Patuanak along the Churchill River system.

1.3 Qualifications of the Geophysical Interpretation Team

The team responsible for the geophysical review, processing and interpretation investigation component of the Phase 1 Desktop Geoscientific Preliminary Assessment of Potential Suitability for the ERFN area consisted of qualified experts from Paterson, Grant & Watson Limited (PGW). The personnel assigned to this assessment were as follows:

Dr. D. James Misener, Ph.D., P.Eng. – geophysical interpretation, report preparation

Dr. Misener is President of PGW and a senior geophysicist with 37 years of experience in all aspects of geophysics and geophysics software applications. Dr. Misener founded Geosoft Inc. and led its development of world-leading geosciences software applications until he succeeded Dr. Paterson as President of PGW. He has directed implementation of geophysical data processing systems; initiated and managed major continental scale compilations of aeromagnetic/marine magnetic data in North America and worldwide including interpretation of aeromagnetic, radiometric, gravity and electromagnetic surveys in Algeria, Brazil, Cameroon, Niger, Ivory Coast, Zimbabwe, Malawi, Kenya, China, Suriname and Ireland.

Stephen Reford, B.A.Sc., P.Eng. – project management, report preparation

Mr. Reford is a senior consulting geophysicist and Vice-President of PGW. Mr. Reford has 31 years of experience in project management, acquisition and interpretation of airborne magnetic, electromagnetic, radiometric, gravity and digital terrain data for clients throughout Canada and around the world. Projects include management of the geophysical component of Operation Treasure Hunt for the Ontario Ministry of Northern Development and Mines as well as a similar role for the Far North Geoscience Mapping Initiative (2006-2009). Mr. Reford has served as a consultant to the International Atomic Energy Agency (IAEA) in gamma-ray spectrometry and is co-author of two books on radioelement mapping.

Edna Mueller, M.Sc. – data processing and map preparation

Ms. Mueller is a senior consulting geophysicist for PGW. She has 18 years of experience in project management, acquisition, processing and modelling of airborne magnetic, electromagnetic, radiometric, gravity and digital terrain data throughout and gamma-ray spectrometer surveys for clients throughout Canada and around the world. In recent years, she has provided management and quality control for a number of OGS magnetic, gravity and electromagnetic surveys, and has reprocessed numerous industry surveys published by OGS.

Winnie Pun, M.Sc. – data processing and map preparation

Ms. Pun will soon complete her first year as a consulting geophysicist for PGW after completing her M.Sc. in geophysics at the University of Toronto. She has prepared hundreds of geophysical maps for publication by government agencies in Nigeria and Botswana, and most recently has carried out several 2D/3D magnetic and gravity modelling studies on several iron ore projects.

Nikolay Paskalev, M.Sc. – GIS preparation

Mr. Paskalev has been the Manager, Geomatics and Cartography for Watts, Griffis and McOuat Limited (geological consultants) since 2006 and has been with the company since 2001. His work there has included a nationwide GIS of geology, ores and industrial minerals for Egypt, a GIS compilation of geological maps for a large part of Saudi Arabia and a Radarsat and DEM study for gold exploration in Sumatra. He has also worked part-time for PGW for the last 12 years, and most recently prepared a nationwide GIS for the geophysical interpretation of Nigeria. In 2011, he incorporated World GeoMaps Inc. for consulting in geomatics, cartography and GIS.

2 SUMMARY OF PHYSICAL GEOGRAPHY AND GEOLOGY

A detailed discussion of the geological setting of the ERFN area is provided in a separate report (Golder, 2013). The following sections on Physical Geography, Bedrock Geology, Structural History and Quaternary Geology, present the information from Golder (2013) and JDMA (2013a,b) and PGW (this report) where applicable, in order to provide the necessary context for discussion of the results of this geophysical assessment (Section 5.0).

The ERFN area lies on rocks of 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. 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; Corrigan et al., 2007; Corrigan et al., 2009; Hajnal et al., 2005; Whitmeyer and Karlstrom, 2007). 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). A cross section through the Trans-Hudson Orogen in the ERFN area 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 (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 south-east corner near Knee Lake and the north-east corner east of Haultain Lake (Figure 2). 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,b, 1978a,b; 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, and 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. 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 on the south and overlain by Phanerozoic rocks of the Western Canada sedimentary basin, in the southwest corner of the ERFN area (Figure 2), whereas to the north rocks of the Hearne Province are overlain by sedimentary rocks of the Athabasca Group, within the Athabasca basin.

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., 2008).

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 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.

2.1 Physical Geography

A detailed discussion of the physical geography of the ERFN area is provided in a separate terrain analysis report by JDMA (2013a). The physical geography of the ERFN area exhibits topography and drainage that are characteristic of the Canadian Shield, a low-relief, dome-like, gently undulating land surface. Ground surface elevation ranges from about 631 metres above sea level (masl) near Norbert Lake to 385 masl on the Churchill River in the south-east near Sandfly Lake. Elevations and relief are lowest in the south and southeast of the ERFN area along the Churchill River. The low relief in the southwest of the ERFN area results from the cover of Phanerozoic rocks and Quaternary surficial materials. Between the Haultain and Mudjatik Rivers, the topography is very rugged with deeply incised valleys that express the underlying bedrock structures (Figure 4 in JDMA, 2013a). The highest elevations are found in the northeastern and eastern portions of the ERFN area.

Two major topographic highs are present within the ERFN area, informally referred to by JDMA (2013a) as the Haultain and Norbert highs, named after lakes situated on the highlands within the ERFN area. The two highlands are divided by the lowland surrounding the Haultain River. The Haultain high extends southwest from near Haultain Lake into the center of the ERFN area. The Norbert high represents a prominent northeast trending highland in the east-central part of the ERFN area. The tops of these bedrock-controlled uplands exceed 600 m in elevation, representing 150 to 175 m of relief above the surrounding lowlands.

The major topographic lows in the ERFN area are informally referred to by JDMA (2013a) as the Heddery and Churchill lows. The Churchill low represents the area of lowermost elevation within the ERFN area where the Mudjatik and Haultain rivers empty into the Churchill River, which traverses along the southern fringe of the Precambrian Shield. The Heddery low is the low-relief outwash plain south of where the Cree Lake Moraine is best expressed within the ERFN area, from its junction with the Mudjatik River to Black Birch Lake. The Heddery low forms a discontinuous plain extending eastward into the Haultain high thereby rendering the craggy upland surrounding Complex Lake as an isolated summit. It can be argued that the Heddery low represents the most prominent Quaternary landform in the ERFN area, rather than the Cree Lake Moraine as suggested by Schreiner (1984a and 1984b). It makes up a much larger area than the moraine and the strong contrast provided by the rock ridges extending like tiny islands from the vast outwash plain forms a distinctive appearance. There is also a smaller outwash plain located at the southern limit of the depression between the Haultain and Norbert highs, at the intersection of Sylvester Creek and the Haultain River, here referred to for convenience as the Sylvester Plain (JDMA, 2013a).

Surface water covers a total area of 1,907 km^2, which represents coverage of approximately 13% of the ERFN area. All of the surface flow within the ERFN area drains through the Churchill River into Hudson Bay, except for a small area around Black Birch Lake, which drains into the Arctic Ocean through the Athabasca River. Sub-basins

within the ERFN area are drained by the Churchill, Clearwater, Haultain, Mudjatik, and Wheeler Rivers.

2.2 Bedrock Geology

The reader is directed to Golder (2013) for a detailed description and discussion of the bedrock and structural geology of the ERFN area. The ERFN area features three main geological units, including felsic gneiss in the Mudjatik domain, supracrustal rocks with a dominantly sedimentary protolith in the Wollaston domain, and felsic gneiss in the Wollaston domain (Figure 2). Exposed bedrock (including thin, <1 m, morainal veneer) covers 7,735 km^2 or roughly 52% of the ERFN area. Golder (2011) identifies the felsic gneiss in the Mudjatik and in the Wollaston domain as being potentially suitable for hosting a deep geological repository in the ERFN area. There are no mapped dykes in the ERFN area.

2.2.1 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 (White et al., 2005; Hajnal 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 (1988 a, 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 origin 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 quartzofeldespathic, 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 porphyritic 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 relicts. Finally, pink granite pegmatite intrudes all rocks other gneissic rocks. Their occurrence occurring as irregular veins in the granites, suggest they are the last phase related to the formation of the granite.

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 toward 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.

2.2.2 Metasedimentary and Metavolcanic Rocks

Metasedimentary and metavolcanic rocks of the Mudjatik domain are dominated by psammopelitic to pelitic rocks and amphibolite that unconformably overlie the Archean felsic gneiss (Card and Bosman, 2007). These supracrustal rocks range from Archean to Paleoproterozoic in age, and they may correlate to the basal groups of the Wollaston Supergroup (Card et al., 2008). The supracrustal rocks occur in narrow, arc shaped bands throughout the Archean felsic gneiss, defining a dome and basin pattern (SGS, 2003). Near the mapped boundary, between the Mudjatik and Wollaston domains, is a complexly deformed and highly metamorphosed area where the metasedimentary and minor metavolcanic rocks are interspersed with migmatites and felsic gneiss (Munday, 1978a).

The Wollaston Supergroup consists mainly of arkose, quartzite, pelite, orthoquartzite, psammopelite, calc-silicate and psammite (Yeo and Delaney, 2007). Pelitic to psammopelitic gneisses found in the region are fine to coarse grained, generally well foliated to gneissic in texture, commonly porphyroblastic and biotite rich. These gneisses can include cordierite, garnet, sillimanite, graphite and magnetite (Thomas and Slimmon, 1985). Metasedimentary psammitic to meta-arkosic gneiss consist of fine to medium grained, massive to foliated rocks, which can be locally colour-banded and may include quartz, feldspar, biotite, muscovite, sillimanite, cordierite, garnet, diopside, epidote,

andalusite, interbanded calc-silicates and pelitic gneiss. Slivers of metavolcanic rocks are also evident in the supracrustal package (Thomas and Slimmon, 1985).

The predominance of metasedimentary gneisses of the Wollaston Supergroup in the north and central parts of the Wollaston domain declines towards the south, where they become discontinuous in bands intercalated with Archean felsic (ortho) gneiss and younger granitoid rocks.

2.2.3 Faults and Shear Zones

The most prominent structural features in the ERFN area are the domain-bounding shear zones and brittle faults of various orientations that overprint these shear zones.

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 sub-vertical to steeply northwest-dipping 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 ERFN 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 (pers. comm. Card, 2012).

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 (Figure 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 Orogen, 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 Orogen (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 faults that are sub-

horizontal to low-dipping to the east at depths of about 5 km and 13 km beneath the Mudjatik domain. 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 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 are noted at the east end of the Wollaston domain, close to the Needle Falls shear zone (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. 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 is a north-south trending topographical, geophysical and geological lineament 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). The Tabbernor fault is indicated, on the regional bedrock compilation map of Saskatchewan, to have overprinted the Paleozoic sedimentary rocks located along its southern extension. 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).

2.2.4 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 of which the Churchill structural province was subjected to. The metamorphic overprint of the Trans-Hudson Orogeny (THO) on the Superior Province was primarily focused within a restricted zone along the western border of this craton. Conversely, the metamorphic effects of the THO 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) posed that all metamorphic fabrics observed in the Hearne craton were the result of a single thermotectonic cycle caused by the THO. This view has been disputed by other authors (e.g., Bickford et al., 1994; Tran, 2001; Card et al., 2007) 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 THO.

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 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 THO during the approximate period 1.84 to 1.80 Ga, and later outlasted it (Tran, 2001). 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.

2.3 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 2. It is understood that there are potential problems in applying a regional D_x numbering system into a local geological history. Nonetheless, the summary below represents an initial preliminary interpretation for the ERFN area, which may be modified after site-specific information has been collected, if the community is selected by the NWMO and remains interested in continuing with the site selection process.

The 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 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., 2008; Whitmeyer and Karlstrom, 2007; Corrigan et al., 2009).

Table 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.

Time Period (Ga)	Geological Event
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 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 (re-activation?) 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 (re-activation?) 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., 2007).

Later deformation involved the development of regional-scale brittle structure, including the Tabbernor fault zone (ca. 1.80 Ga) and the steeply-dipping brittle faults observed within the Wollaston domain (Figure 2). 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 brittle deformation events that overprinted the entire region. The dominant feature associated with D_6 is the large-scale Tabbernor fault system which has a long history of re-activation 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 centre 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. The present day zero thickness erosional edge of the basin trends northwesterly across the province and the southwest corner of the ERFN area (Figure 2). 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, it can be suggested 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.

2.4 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 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 if the community is chosen by the NWMO and they decide to remain in the siting 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 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) note 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 2). These features have likely had a long history of re-activation consistent with the interpretation that they are related to the Tabbernor fault system located about 150 km to the east of the ERFN area. The orientations of D_5-related lineaments are dominantly north-northwest and minor east-northeast sets (Figure 2), 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 (Elliot, 1996; Davies, 1998; Hajnal et al., 2005).

2.5 Quaternary Geology

Quaternary geology of the ERFN area is described in detail in a separate terrain analysis report by JDMA (2013a). Quaternary surficial deposits cover a total of 6,224 km^2 or roughly 42% of the ERFN area (Figure 3), which does not include areas covered by a thin (<1 m thick) veneer of till or glaciolacustrine deposits. This surficial cover comprises different types of glacial deposits that accumulated with the progressive retreat of the ice sheet during the end of the Wisconsinan glaciation. Regionally, the main Quaternary deposits include morainal plains, and glaciofluvial plains, with sparse occurrences of glaciolacustrine plains. Glaciofluvial plains mainly consist of outwash plains that were incised through the morainal deposits as the glacier receded and melt waters drained. 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.

Ground moraine represents the most common glacial landform in northern Saskatchewan, typically represented as veneers and blankets of sandy ablation till distributed amongst lakes, muskegs, and bedrock outcrops (Schreiner, 1984b). Within the areas mapped as ground moraine, the area underlain by till is typically equalled by that made up of lakes, muskeg, and bedrock exposures.

Bedrock topography is only minimally obscured in areas of morainal veneer. The surface expression of faults, shear zones and other geological structures are displayed clearly in these areas. Schreiner (1977) suggested that south of the Cree Lake Moraine within the ERFN area, sandy till is so thin that the underlying bedrock structure is detectable. Preferential deposition of till in low areas between bedrock ridges and hills can mask the relief of the bedrock terrain. Areas of thicker more continuous ground moraine are generally represented as moraine plains and drumlinoid moraine (Schreiner, 1984b). In some areas, ground moraine occurs in association with glaciolacustrine silts and clays typically deposited in depressions.

Schreiner (1984b) describes drumlins north of the ERFN area that are approximately 30 m thick from the top of the drumlin to the bedrock surface. Flutings are restricted to areas of thicker drift. They represent smoothly rolling ridges and troughs with relief on the order of 10 m.

Sand and gravel are found mainly along the Mudjatik and Haultain Rivers within the ERFN area, which functioned as major melt water channels (Schreiner et al., 1976). Schreiner (1984b) suggests that of the Mudjatik, Haultain, Foster and Paull Rivers, the Mudjatik and Haultain were the more substantial melt water channels, as indicated by the

wide sand plains bordering these rivers, especially south of the Cree Lake moraine. The floor of the spillway cut along the Mudjatik River south of this moraine is at least 20 m below the surface of the sand plain, indicating a minimum depth of the stratified sand deposit if the floor of the spillway is within the outwash deposit.

Larger glaciofluvial deposits have the potential to represent significant regional aggregate or groundwater supplies. The good foundation conditions and abundance of suitable borrow and granular materials make these landforms ideal for transportation routes, building sites, and airport locations.

Schreiner et al. (1976) indicated a scarcity of glaciolacustrine deposits in the southern part of the ERFN area, and suggested that Lake Agassiz did not extend this far westward. Some isolated glaciolacustrine deposits were mapped within the ERFN area north of the Cree Lake Moraine.

Estimates of overburden thickness within the ERFN area were extracted from descriptions in the available SGS reports. The Cree Lake moraine represents a significant Quaternary landform in the ERFN area. Its thickness outside of the ERFN area can reach 45 to 74 m, as indicated by its relief above the surrounding landscape, but within the ERFN area the moraine is represented by a discontinuous band of hummocky debris probably less than 30 m. Glacial deposits in areas mapped as ground moraine are characterized as veneers and blankets of sandy ablation till distributed amongst lakes, muskegs, and bedrock outcrops, with deposit thicknesses typically less than one metre to many tens of metres. Outwash deposits in northern Saskatchewan are typically 5 to 10 m thick. Thin organic deposits are common in low-relief areas of thick drift, whereas they can reach much greater thicknesses where they fill high relief basins formed between bedrock ridges and knobs or in kettle holes.

One of the reasons for locating the Highway 914 route along the Haultain River valley (Mollard et al., 1977) was that the organic deposits in the outwash plains along the valley were suspected to be much thinner than those confined between bedrock highs along the alternate route to the east, which traversed through the bedrock terrain. That is, organic terrain is less common in bedrock terrain, but where present, the peat usually fills deep basins between bedrock knobs and ridges. The material present in organic terrain is peat and muck and within most organic terrain, stagnant drainage or wet surface conditions are common. Large areas of organic terrain are located in the Heddery Lake low and the Sylvester plain.

Exceptionally poor engineering characteristics can be found within areas mapped as organic terrain. Peat and muck have very low shear strength and high compressibility. Groundwater tables are at, or near, the surface in organic terrain. Flooding is common in organic terrain, and this forms a significant constraint on most types of development. Although peat and muck deposits usually occur as relatively thin surficial layers, in places, these organic materials can be several metres thick, and the thickness can change drastically over very short distances. The deposits are generally thin where they overlie flat mineral soil terrain such as outwash and glaciolacustrine plains, whereas they are

thicker in high relief till deposits and where they fill bedrock depressions and deep kettle holes. The locations of deeper pockets of organic material are difficult to predict reliably without test drilling.

The Haultain Lake area contains many positively expressed landforms such as ridges and knobs where overburden thickness is low and bedrock exposure is good. The Highway 914 corridor provides access to several of these rock ridges. However, the vast majority of the areas of thin drift and good bedrock exposure are located ten or more kilometres west of the highway. Between these local bedrock highs, the largest wetlands are located in the southern half of the detailed area.

There is currently no road access to the Porter Lake area. Most of the best areas of thin drift and good bedrock exposure are located in the highlands in the northeast part of the area, which is furthest from the existing road (Highway 918). The outwash plains within the valley of the Mudjatik River within the Porter Lake area contain extensive wetlands, which is an unfavourable attribute for road routing. The intricate fabric of lakes and steep slopes within the uplands poses a different set of access constraints.

The best areas of thin drift and good bedrock exposure within the Primeau Lake area are concentrated north of the Churchill River in the central and east parts of the detailed area. Highway 918 provides direct access to some of these areas. The north-central part of the area has the best outcrop exposure, but road routing into this area would involve creek crossing and sections traversing through rugged bedrock-controlled terrain. The large water bodies associated with the Churchill River and the intricate pattern of lakes on the upland to the north pose additional constraints in this area.

2.6 Land Use

The ERFN area is within a remote part of northern Saskatchewan that is almost completely undeveloped. Uranium deposits discovered north of the ERFN area around Key Lake in the middle 1970s resulted in the routing Highway 914 through the valley of the Haultain River from Pinehouse to the prospective mill site at Key Lake (Mollard et al., 1977).

Five of the eight First Nations Reserves located within the ERFN area are positioned proximally to the Churchill River, which traditionally represented a major transportation corridor for the areas currently represented by the Provinces of Alberta, Saskatchewan to Manitoba. This was also an important transportation corridor during the fur trade starting with the Hudson's Bay Company in the early 1800s. The communities along the Churchill are the Wapachewunak, Dipper Rapids, Primeau Lake, Knee Lake, and Elak Dase Indian Reserves. Three relatively remote reserves are located along the Mudjatik and Haultain rivers. These are the Flatstone Lake and English River reserves and the Haultain Lake reserve, respectively.

Recreational lodges are located at Complex Lake and Holt Lake, with outfitters at George Lake, Cup Lake and along the Churchill River. The Gordon Lake Recreation Site is

located south of the ERFN area. Land use and cultural features in the ERFN area do not negatively impact on the geophysical interpretation.

3 DATA SOURCES AND QUALITY

For the ERFN, geophysical data were obtained from available public-domain sources, in particular the Geological Survey of Canada (GSC). The flightpath of the aeromagnetic surveys are shown in Figure 4.

The quality of the available data was assessed to determine which data sets are suitable for inclusion in this assessment. The geophysical surveys covering the ERFN area show variability in data set resolution. The quality of the data is mainly a function of the flight line spacing, the sensor height and equipment sensitivity. In particular, where more than one data set overlaps, the available data were assembled using the highest quality coverage. Various geophysical data processing techniques were applied to enhance components of the data most applicable to the current assessment. The integrity of the higher quality data was maintained throughout.

3.1 Data Sources

Medium-resolution magnetic and radiometric data obtained from the Geological Survey of Canada (GSC) cover the northeast and northwest portions of the ERFN area. Low-resolution GSC magnetic and radiometric data cover the remainder of the ERFN area. The gravity measurements tend to be evenly distributed throughout the ERFN area. There are no electromagnetic data available for the area. The geophysical data sets are individually discussed in more detail below and are summarized in Table 2. .

3.1.1 Magnetic Data

The magnetic data were collected during seven airborne geophysical surveys using different survey parameters outlined in Table 2. The magnetic data help in the understanding of geological and structural variations caused by different rock types associated with their content of magnetic minerals, such as magnetite and pyrrhotite. Magnetic maps show a distribution of magnetic and nonmagnetic geological bodies within the subsurface, particularly useful for delineating spatial geometry of bodies of rock, and the presence of faults and folds.

The quality and reliability of the retrieved magnetic datasets varies greatly within the ERFN area. Surveys were flown over a period of 56 years, over which time the quality and precision of the equipment as well as the quality of the processing has improved. In addition, variability in the density of the survey coverage has also influenced the ability of the magnetic data to identify geological structures of interest relevant to this assessment.

Lower resolution magnetic data from the GSC (Saskatchewan #5, #8, #9, and #10) provides coverage over approximately 86 percent of the southern and central portion of the ERFN area (Figure 4) (GSC, 2012). These surveys were all 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, and are provided in Geosoft database format by the GSC. In addition, these surveys have also been compiled by the GSC into a single GSC Regional Compilation of gridded data, which incorporates all regional airborne magnetic survey data from across Canada (GSC, 2012). Data from the Saskatchewan #5 survey within the ERFN area also forms a part of the GSC Northern Saskatchewan Compilation (Buckle et al., 2011), defining the southern margin of that data set in the ERFN area.

The Cree Lake and Upper Foster Lake surveys provide higher resolution coverage in the northeastern and northwestern portion of the ERFN area at a lower terrain clearance of 127 m and 147 m, respectively, 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. This compilation of data focused primarily on supporting ongoing and future geological mapping activities and mineral resource exploration in the Athabasca Basin.

3.1.2 Gravity Data

Gravity data provides complete coverage for the ERFN area (GSC, 2012) consisting of an irregular distribution of 107 station measurements within the ERFN area, comprising roughly a station every 10 to 15 km.

The retrieved gravity measurements comprise observed gravity data, as well as Bouguer, isostatic, and free-air corrected data. For the purpose of this report the Bouguer gravity data are presented, which compensates for the gravity effect of the material between the measurement station and the datum elevation and for the contribution to the measurement of the gravity effects of the surrounding topographic features.

Despite the fact that the individual gravity measurements are of good quality, the sparseness of the measurement locations in the ERFN area is such that the gravity data can only be used to provide information about large scale geologic features. The resolution of the acquired gridded data is 2 km by 2 km.

3.1.3 Radiometric Data

The GSC radiometric data coverage and the Cree Lake South and Upper Foster Lake surveys provide complete radiometric coverage of the ERFN area (GSC, 2012). Data acquired from the GSC radiometric coverage and the Cree Lake South and Upper Foster Lake surveys show the distribution of natural radioactive elements at surface: uranium (eU), thorium (eTh) and potassium (K), which can be interpreted to reflect the

distribution of mineralogical and geochemical information in the area. These surveys were all flown in an E-W orientation at 5000 m line spacing with a terrain clearance of 120 m above the surface.

In the northeastern and northwestern portion of the ERFN area, the lower resolution of GSC radiometric coverage was replaced with the Cree Lake South and Upper Foster Lake Surveys, which were flown at a much tighter line spacing of 400 m, and a lower terrain clearance of 127 m and 147 m, respectively. The retrieved radiometric data consisted of measurements of four variables:

- Potassium, K (%);
- Equivalent uranium, eU (ppm);
- Equivalent thorium, eTh (ppm); and
- Total Air Absorbed Dose Rate (nGy/h).

3.2 Data Limitations

The magnetic surveys that cover the ERFN area, with the exception of the northeast and northwest portions, consist of older regional low resolution coverage. Nevertheless, the magnetic data reflect quite coherent responses that elucidate the mapped geology, particularly in areas of limited bedrock exposure, as well as the main structural regimes.

All three data types considered, magnetic, gravity and radiometric, contribute to the interpretation. No electromagnetic or VLF-EM data were available for the ERFN area. The limitation in applying these data types to the ERFN area is governed mainly by the following factors:

- Coverage and quality of data – types available, density of the coverage, vintage and specifications of the instrumentation;
- Overburden – areal extent, thickness and physical properties; and
- Bedrock lithologies – physical properties and homogeneity.

The user of the geophysical information must bear in mind that each method relies on characterizing a certain physical property of the rocks. The degree to which these properties can be used to translate the geophysical responses to geological information depends mainly on the amount of contrast and variability in that property within a geological unit and between adjacent geological units. The usability of each data set also depends on its quality, especially resolution.

Table 2. Summary of the Characteristics for the Geophysical Data Sources in the English River First Nation 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 #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	10-15km/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 prepared from the Foster Lake, Mudjatik River. Lac la Ronge, Île-à-la-Crosse and Geikie River surveys.

GSC – Geological Survey of Canada

4 GEOPHYSICAL DATA PROCESSING

All data were processed and imaged using the Oasis montaj software package (Geosoft, 2012). Three additional magnetic grids were prepared using the Encom PA software package (Pitney Bowes, 2012). The grids that resulted from the various processing steps were also loaded in ArcMAP 10 (ESRI, 2012) using a Geosoft plug-in.

4.1 Magnetic

The acquired magnetic data located within the ERFN area and surrounding areas were processed using several common geophysical techniques in order to enhance the magnetic response to assist with interpretation. The magnetic data were upward or downward continued (if necessary) to a common elevation datum of 140 m, and were regridded to a smaller common grid cell size of 50 m to retain the resolution of the higher quality surveys in the area. Magnetic data from within the ERFN area were projected to the UTM13N/NAD83 coordinate system.

The GSC Northern Saskatchewan Compilation grid covered all but the southern part of the ERFN area. For the low resolution coverage, it was used in preference to the GSC regional compilation, due to the reprocessing that the GSC had carried out in preparing it. Magnetic data from the GSC regional compilation was downward continued 165 m and an 8th-order 800 m low pass Butterworth filter was applied to reduce noise introduced by the downward continuation and coarse data. The Northern Saskatchewan Compilation grid had an 8th-order 400 m low pass Butterworth filter applied. The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the pass band. The 800 m or 400 m wavelength did not reduce the geological signal due to the line spacing of 805 m and the coarse sampling of the digitized data along the flightlines. The remaining surveys were similar in flying height so that they were not downward (or upward) continued.

The surveys were knitted together using Oasis montaj (Geosoft, 2012), where the suture path between the grids was along the edge of the grid with the original higher resolution grid cell size so that the most detailed data was retained in the final product. The resultant grid was the residual magnetic intensity grid (i.e., total magnetic field after IGRF correction) and the basis for preparing the enhanced magnetic grids.

Reduction to the Pole (RTP)

The direction (inclination and declination) of the geomagnetic field varies over the Earth and influences the shape of the magnetic responses over geological sources. At the North Magnetic Pole the inducing magnetic field is vertical (i.e. inclination of 90° and declination of 0°), which results in the magnetic response being a symmetric positive magnetic peak over a source, in the absence of dip and magnetic remanence. Transforming the measured magnetic field to a pole reduced magnetic field simplifies the interpretation, particularly to determine the location and geometry of the sources (Baranov, 1957). For the ERFN area, the residual magnetic intensity grid was reduced to

the pole using a magnetic inclination of 79° N and magnetic declination of 15° E (Figure 5).

The RTP filter, computed from the residual magnetic field after it is transformed to the Fourier domain, is defined as follows:

$$L(\theta) = \frac{[\sin(I) - i \cdot \cos(I) \cdot \cos(D-\theta)]^2}{[sin^2(I_a) + cos^2(I_a) \cdot cos^2(D-\theta)] \cdot [sin^2(I) + cos^2(I) \cdot cos^2(D-\theta)]}$$

$$if\ (|I_a| < |I|), I_a = I \qquad \text{(eq. 4.1)}$$

Where:
$L(\theta)$ = pole-reduced magnetic field for wavenumber θ
I = geomagnetic inclination
I_a = inclination for amplitude correction (never less than I).
D = geomagnetic declination
i = imaginary number in the Fourier domain

First Vertical Derivative of the Pole Reduced Field (1VD)

The vertical derivative is commonly applied to the RTP magnetic field data in the Fourier domain to enhance shallower geologic sources in the data (Figure 6). This is particularly useful for lithologic mapping (e.g., the anomaly texture is revealed), locating contacts and mapping structure (Telford et al., 1990). It is expressed as:

$$1VD = {}^{dRTP}/_{dZ} \qquad \text{(eq. 4.2)}$$

where Z is the vertical offset.

Second Vertical Derivative of the Pole Reduced Field (2VD)

The second vertical derivative is commonly applied to the RTP magnetic field data the Fourier domain to further enhance shallower geologic sources in the data (Figure 7). This is particularly useful for lithologic mapping (e.g., the anomaly texture is revealed), locating contacts and mapping structure close to surface (Telford et al., 1990). It is expressed as:

$$2VD = {}^{d^2RTP}/_{dZ^2} \qquad \text{(eq. 4.3)}$$

where Z is the vertical offset.

One limitation of this filter is that the higher order derivatives tend to also enhance the high frequency noise in the data set. To reduce noise that resulted from aliasing during the minimum curvature gridding process, an 8th-order 200 m low-pass Butterworth filter was also applied.

Tilt Angle of the Pole Reduced Field

The tilt angle (Miller and Singh, 1994) has been applied to the RTP magnetic field data to preferentially enhance the weaker magnetic signals (Figure 8). This is particularly useful for mapping texture, structure and edge contacts of weakly magnetic sources. It is expressed as:

$$TILT = \tan^{-1}\left\{\frac{\frac{dRTP}{dZ}}{\sqrt{\left([\frac{dRTP}{dX}]^2+[\frac{dRTP}{dY}]^2\right)}}\right\} \qquad \text{(eq. 4.4)}$$

where *X* and *Y* are the horizontal offsets in the east and north directions. The first vertical derivative is computed in the Fourier domain whereas the horizontal derivatives in *X* and *Y* are computed in the space domain.

Analytic Signal Amplitude

The amplitude of the analytic signal (AS) (Figure 9) is the square root of the sum of the squares of the derivatives in the horizontal (*X* and *Y*), and vertical (*Z*) directions (i.e. the Fourier domain first vertical derivative and the space domain horizontal derivatives in the *X* and *Y* directions), computed from the total magnetic field (Nabighian, 1972):

$$AS = \sqrt{\left([\frac{dT}{dX}]^2 + [\frac{dT}{dY}]^2 + [\frac{dT}{dZ}]^2\right)} \qquad \text{(eq. 4.5)}$$

The analytic signal is useful in locating the edges of magnetic source bodies, particularly where remanence complicates interpretation. It is particularly useful to interpret the contacts of intrusions.

Depth to Magnetic Sources Using Source Parameter Imaging (SPI™)

The SPI method locates the depths of edges in the gridded magnetic data (Thurston and Smith, 1997). It assumes a 2D sloping contact or 2D dipping thin sheet model. The SPI solutions extracted from the pole reduced magnetic field grid are stored in a database. The SPI values calculated are depths between the magnetic source and the instrument height. If the survey was flown at a constant terrain clearance, then the drape height could be subtracted from the SPI value to result in a depth below surface. For certain surveys (Saskatchewan #5, #8, #9, and #10 surveys), only the average flying heights were known. For the remaining surveys (Cree Lake South and Upper Foster Lake), the radar altimeter data were included in the survey database and were consequently used to more accurately determine the distance between the magnetic sensor and the computed depth to the magnetic source. The radar altimeter channel was gridded at the original grid cell size and sampled back to the SPI database. Thus a more accurate depth to magnetic sources could be calculated. If the value of the depth to source is < 0, i.e. above ground, it is set to a value of zero. Thus, the SPI depth with respect to the ground surface is calculated as:

- SPI_depth = SPI_value – average flying height, if no radar data is available, or
- SPI_depth = SPI_value – radar value, if available.

The SPI depths were calculated for each individual data set in the ERFN area (Figure 10). Lower resolution grids are biased with deeper basement depths due to the reduced high frequency content. Thus, where a high resolution survey overlaps with a low resolution regional survey, the SPI depths from the low resolution grid were excluded. The depth grid was calculated with a grid cell size of 200 m.

Encom Magnetic Grids

A series of grids were created to highlight the edges of both shallow and deep sources and to categorize anomalous zones into different areas (Shi and Butt, 2004). These grids are:

- rtpzsedge – gradient filters applied to the pole reduced magnetic field to emphasize edges
- rtpzsedgezone – gradient filters and amplitude equalization filters applied to the pole reduced magnetic field to emphasize edges
- rtpzsplateau – gradient filters and amplitude equalization filters applied to the pole reduced magnetic field to emphasize homogeneous blocks bounded by edges.

Magnetic Peaks, Troughs and Edges

The semi-automated extraction of magnetic anomaly peaks, troughs and edges is useful for delineating structure, foliation, texture and contacts. Anomaly peaks typically trace the center of a source or the more magnetic horizons within a larger source. Anomaly troughs often complement the peaks, indicating a less magnetic horizon. They also may map a remanent (i.e. reversely) magnetized source, or magnetite depletions (e.g. along a fault) which are a less magnetic source in a more magnetic host rock. Anomaly edges mark geological contacts or the boundaries of horizons within a geological unit. Offsets and orientation changes in the peaks, troughs and edges are useful for mapping faults and shears. Lineament detection for peaks, troughs and edges was performed based on the CET (Centre for Exploration Targeting) Grid Analysis package in Oasis montaj (Geosoft, 2012).

The phase symmetry method, a frequency-domain approach based on axes of symmetry, is used to identify arbitrarily oriented line features. The 2D image is analyzed with 1D profiles in multiple orientations and varying scales. A line feature exhibits strong symmetry responses from profiles in all orientations not parallel to the line itself. Symmetry is closely related to periodicity: the symmetry point in the spatial domain corresponds to either a minimum or maximum of its local Fourier components. Thus, the detection is carried out by frequency analysis.

The frequency analysis is performed by wavelet transform, which estimates local frequency using complex valued log-Gabor filters. The filters are comprised of an even

symmetric (cosine) wavelet and an odd symmetric (sine) wavelet, each modulated by a Gaussian. These filters at different scales respond to particular bands of frequencies. The local frequency information is obtained from the convolution of the wavelet filters with the 2D data. An array of filter response vectors is generated for each point in the signal for each scale. Localized frequency representation is produced from these vectors. The frequency component is represented as a complex number; its real and imaginary parts are the outputs from the even and odd symmetry filter responses, respectively. At the point of symmetry, frequency components are at their amplitude extrema. This corresponds to where the absolute values of the outputs are high from even symmetry filter and low from odd symmetry filter, for all frequencies. This 1D analysis is performed in multiple orientations to extend to 2D analysis (Holden et al., 2008).

An amplitude threshold is then applied to the output symmetry grid, to distinguish cells that contain signal of interest from the background. A lower threshold value leads to the detection of more features, but may also introduce noise in the data. The resulting grid is binary: 1 for regions of interest and dummies for background. The grid is then skeletonized to trendlines. This process also sets the minimum valid line length.

The smallest filter wavelength used in this analysis for the ERFN area was four cells (equivalent to 200 m), over five scales. The filter sizes were therefore 200 m, 400 m, 800 m, 1,600 m and 3,200 m. All orientations were considered in the search for symmetry. A threshold value of 0.1 was applied, and a minimum line length of 3 cells (150 m) was set.

Edges were enhanced by computing the balanced horizontal gradient magnitude (TDX) (Cooper and Cowan, 2006) from the RTP grid, as modified by Fairhead and Williams (2006):

$$TDX = \tan^{-1}\left\{\frac{\sqrt{\left([\frac{dRTP}{dX}]^2+[\frac{dRTP}{dY}]^2\right)}}{\frac{dRTP}{dZ}}\right\} \qquad \text{(eq. 4.6)}$$

The first vertical derivative is computed in the Fourier domain whereas the horizontal derivatives in *X* and *Y* are computed in the space domain.

The TDX of the pole-reduced magnetic field is a more accurate locator of source edges and less susceptible to noise in the data than other forms of edge detectors. Pilkington and Keating (2009) confirmed that TDX and its analog, “theta mapping”, produce identical results and are the most robust of the edge detection techniques applicable to potential field data.

The standard deviation of the TDX grid was then computed to further improve lineament detection. This step is effective for data with large and/or continuous features. The standard deviation value of a cell is a measure of its variability with respect to its neighbouring cells within a square window. A window size of 5 by 5 cells (250 m by 250 m) was set for this analysis.

The positive peak values are extracted by applying an amplitude threshold to the TDX grid to identify cells of interest. The resulting grid is binary and is skeletonized to locate the source edges. In this project, a threshold value of 0.9 was used.

The peaks, troughs and edges generated using the CET methods were not submitted directly for further lineament analysis. The Encom grids and TDX images are not presented in this report. However, all of these maps and images were used as guides during the manual interpretation process. The accuracy and reliability of these products were greatly influenced by the resolution of the original magnetic data.

4.2 Gravity

The following four gravity grids and their gravity station locations were downloaded for the ERFN area, extracted from the GSC gravity compilation (GSC, 2012) at 2000 m grid cell size:

- Bouguer gravity field (Figure 11);
- First vertical derivative of the Bouguer gravity field (Figure 12);
- Total horizontal gradient of the Bouguer gravity field; and
- Isostatic residual gravity field.

All grids were reprojected to the ERFN area's coordinate system, UTM13N/NAD83. The first vertical derivative was computed by the GSC using the same methodology applied to the pole reduced magnetic field, as described in Section 4.1. The total horizontal gradient of the Bouguer gravity provided similar results as the first vertical derivative, and therefore was not presented in this report. The isostatic residual compensates for mass deficiencies at depth predicted from topography, preserving the shorter wavelength components of the field due to nearer surface sources. In the ERFN area, the isostatic residual field closely resembles the Bouguer gravity field due to the relatively gentle topography, and therefore was not presented in this report. The GSC applied standard gravity reduction methods to compute the free air and Bouguer gravity fields. A Bouguer correction density of 2.67 g/cm^3 was applied, the typical value for the Canadian Shield. As the data for the ERFN area were collected as far back as 1960, the elevations for the older survey stations were likely determined using barometric altimeters (much less accurate than GPS) and terrain corrections were not applied.

4.3 Radiometric

The following seven radiometric grids (radioelement concentrations and ratios) were downloaded for the ERFN area (GSC, 2012):

- Potassium (K %);
- Thorium (eTh ppm);
- Uranium (eU ppm);
- Total air absorbed dose rate (nGy/h);
- Thorium over potassium ratio (eTh/K);

- Uranium over potassium ratio (eU/K); and
- Uranium over thorium ratio (eU/eTh).

The grids were already a merge of low resolution surveys prepared by the GSC. As a part of this assessment, the higher resolution Cree Lake south and Upper Foster Lake radiometric surveys were merged with data from the GSC radiometric coverage. The determination of the radioelement concentrations, dose rate and ratios followed the methods and standards published by the International Atomic Energy Agency, many of which were developed at the GSC. All grids were reprojected to the ERFN area's coordinate system, UTM13N/NAD83. The dose rate is a calibrated version of the measured "total count", and reflects the total radioactivity from natural and man-made sources. The radiometric data are presented in Figure 13 as a ternary RGB image of the three radioelements, with the intensity of potassium (%) displayed in red, equivalent thorium (ppm) in green and equivalent uranium (ppm) in blue. Areas of highest intensity of all three radioelements show light colours and trend towards white. Areas of lowest intensity of all three radioelements are dark colours and trend towards black.

5 GEOPHYSICAL INTERPRETATION

5.1 Methodology

The coincidence of geophysical features with mapped lithology and structural features were identified and interpreted for the ERFN area using all available geophysical data sets. In particular, the pole reduced magnetic field and its first vertical derivative were the most reliable for mapping variations in geological contacts, identifying heterogeneity, and delineation and classification of structural lineaments (faults, dykes). The results from the structural lineament interpretations are presented in the lineament report for the ERFN area (JDMA, 2013b). The first and second vertical derivatives were used to trace quasilinear magnetic anomaly peaks that are interpreted to outline the ductile structure. These ductile features are interpreted as being associated with the internal fabric to the rock units and may include in places sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation. Enhanced grids of the magnetic field data were used to assist in the interpretation:

- Pole-reduced magnetic field – magnetic units (Figure 5);
- Pole-reduced first and second vertical derivatives – boundaries, texture, foliation (Figure 6 and Figure 7);
- Tilt angle – subtle magnetic responses (Figure 8); and
- Analytic signal – anomaly character, texture, boundaries (Figure 9).

Gravity data were of insufficient resolution to be used for detailed interpretation of geological units and boundaries (Figures 11 and 12). However, some general characterizations of the regional scale units were possible. Similar comments apply to the radiometric data (Figure 13), although two higher resolution surveys in the north provide some evidence of lithological variability.

The coincidence of the lithological units with the geophysical data was mainly recognized in the magnetic images from their anomaly amplitude, texture, width, and orientation characteristics. The automated peaks, troughs and edges generated from the magnetic data assisted in more accurate location of contacts. The magnetic anomaly characteristics and geophysical contacts were compared to the current mapped bedrock geology in order to identify similarities and/or changes in the lithological contact locations. In some cases, difference in the boundaries determined from the magnetic data and the mapped boundaries may reflect a subsurface response which may not match the mapped surface contacts (e.g. dipping unit) and/or a contact extended through locations with limited outcrop exposure (e.g. under overburden and drainage cover). Results of the coincidence between the geophysical interpretation and the mapped bedrock geology are presented in Figures 14 to 16 for the three sub-regions.

The geophysical data were evaluated against the following published geological maps (Figure 2):

- Geology of Mudjatik (East) Area – North Sheet (Munday, 1977b). Covers northeast corner of ERFN area;
- Geology of Mudjatik (Southwest) Area (Pearson, 1977b). Covers the southwest outcrop area – 56°N to 56°30'N;
- Shield Geology of the Île-à-la-Crosse (East) Area (Munday, 1978b). Covers the southeast corner of the ERFN area;
- Geology of the Dipper Lake Area (Scott, 1977). Extreme southwest corner, covered region; and
- Saskatchewan Energy and Resources, 2010. Geological Atlas of Saskatchewan. NTS Map Sheets 73O/P, 74 A/B.

5.2 Results

The following section presents a regional-scale description and interpretation of each geophysical data set in the ERFN area, followed by detailed interpretations of geophysical responses for the felsic gneisses within the three outlined sub-regions (Figure 2). Using the published regional bedrock geology maps as a starting point, the integration of all suitable geophysical information provides a preliminary interpretation of a subsurface distribution of geological units for the sub-regions of the ERFN area presented in Figure 14 to 16.

Some of the ERFN area is covered by moderate overburden (Figure 3) and therefore actual outcrop mapping is relatively sparse. Discrepancies in these areas between the published mapping and the geophysical interpretation are to be expected.

5.2.1 Magnetic

The ERFN area exhibits significant variability in the regional magnetic data associated with the complex distribution of felsic gneiss, pelitic and psammitic gneiss as well as minor amounts of arkosic gneiss rock units of the Wollaston and Mudjatik domains

(Figure 2). The magnetic field data for ERFN are presented as the reduced to pole magnetic field (Figure 5) reflecting changes in both bedrock geology and structure. Enhanced grids of the reduced to pole magnetic field are presented as the first (Figure 6) and second (Figure 7) vertical derivatives, tilt angle (Figure 8) and analytic signal (Figure 9), which emphasize the subtle magnetic responses associated with geological rock types and structure.

Within the Mudjatik domain in the ERFN area, the felsic gneiss unit is characterized by a low magnetic response, in terms of its low magnetic background and its overall low amplitude. The pelitic and psammitic gneiss rocks are sparsely dispersed throughout the Mudjatik domain, characterized by elevated magnetic responses forming a series of curvilinear ductile features located within the low magnetic background. The curvilinear features are consistent with extensive folding and the formation of dome and basin structures (Card and Bosman, 2007). The sharp contrast in the magnetic character is attributed locally to the location of the pelitic and psammitic gneiss adjacent to the felsic gneiss units. Locations that are dominated by these features likely reflect the extensive deformation history and more pronounced lithological heterogeneity of the rock units in which many of these observations correspond well to the locations of pelitic and psammitic gneiss rock units in bedrock geology maps.

The magnetic data also provide evidence for additional curvilinear magnetic high anomalies that may represent unmapped portions of potential pelitic and psammitic gneiss, and amphibolite rock units. These anomalies tend to be widespread through the center and northwestern parts of the ERFN area as broad zones of curvilinear anomalies together with elevated background responses. As a result, these areas may reflect a more extensive lithological heterogeneity which may be characterized by a mixture of the pelitic and psammitic gneisses and amphibolites.

Along the southern edge of the ERFN area sparse outcrops have indicated a plutonic alaskite (leucogranite) intruding the felsic gneiss. This unit displays a lower magnetic response than the surrounding rocks, with a north-northeast-striking foliation pattern. Noting that the data resolution is low, it is difficult to delineate the alaskite intrusion contacts with the host felsic gneiss as both show a relatively low magnetic susceptibility with isolated areas of higher curvilinear anomalies.

Within the southwestern corner of the ERFN area the Mudjatik domain is partially overlain by the sedimentary deposits of the Western Canada Sedimentary Basin. Magnetically, these sedimentary rocks are transparent so the magnetic interpretation reflects the underlying Mudjatik domain. More detail highlighting the deformation is evident in the northeast and northwest parts of the ERFN area, but this is at least partly a reflection of the slightly higher resolution of the magnetic data.

There is a clear difference in the magnetic pattern observed between the Mudjatik and Wollaston domains, although the predominant bedrock unit, felsic gneiss, is the same for both areas (Figure 2). The major contrast in the structural characteristics between the Wollaston and Mudjatik domains is especially evident on magnetic field maps (Figures 5

to 9). The Mudjatik domain exhibits a relatively consistent magnetic low pattern with curvilinear and concentric lineations over the felsic gneiss, which is truncated sharply to the east. In contrast, the Wollaston domain exhibits a strong northeast-trending linear magnetic high zone, which parallels the dominant tectonic fabric in the same area. The magnetic high anomaly may be a result of the penetrative fabric development, where these rocks are situated inside a major ductile high-strain belt that is several tens of kilometres wide, or from tight interfingering of the felsic gneiss, pelitic and psammitic gneiss, and amphibolite rocks in the strongly deformed zone leading to a more complex lithological heterogeneity within the felsic gneiss that has not been identified on the bedrock geology map (Figure 2). This belt has a strong, north-northeast-directed, ductile structural anisotropy which could be of major significance for later reactivation in the brittle regime.

5.2.2 Gravity

The Bouguer gravity data and gravity station locations across the ERFN area are presented in Figure 11, together with the first vertical derivative of the Bouguer gravity in Figure 12. White et al., (2005) attribute the regional Bouguer gravity slope, from high in the east to low in the west, to isostatic compensation that extends into the mantle. It forms part of an 800 km wide zone across Manitoba and Saskatchewan that shows an inverse relationship between gravity and topography. Within the Wollaston domain, the gravity data are characterized by a strong gravity response in the northeast part of the ERFN area, which corresponds well with the northeast strike of the domain boundary. Modelling by White et al. (2005) indicates a thickening of the gneiss from 5 km to 8 km in this area.

This gravity response shows an abrupt decrease along strike towards the southeastern corner of the ERFN area. Based on the mapped bedrock geology, this decrease may correspond to an area with fewer pelitic and psammitic gneiss and amphibolite rocks intermixed with the felsic gneiss. In the Mudjatik domain, the gravity field displays a more northerly trend in the responses. The felsic gneisses generally correlate with weak but recognizable gravity lows, possibly indicating a decrease in rock density to the west. The lowest gravity values (Figure 12) correspond to the felsic gneiss, and lesser amounts of pelitic and psammitic gneiss, and amphibolite units along the western boundary of the ERFN area.

5.2.3 Radiometric

The higher resolution radiometric surveys in the northern part of the area (Figure 13) demonstrate the method's capabilities in the Canadian Shield, despite limitations due to water cover and transported overburden. The continuity of regional signatures in the much sparser data to the south is also evident, particularly higher levels of potassium and thorium following the northeast orientation of the Wollaston domain and lower levels in all three radioelements in the Mudjatik domain. The latter area reflects the Heddery low annotated in the Quaternary geology (Figure 3), where the bedrock is obscured by organic, glaciofluvial and other overburden material. The dark spots almost invariably reflect the lack of responses over water (lakes) in the ERFN area. The somewhat higher

radioelement responses (whiter areas) in the southern half of the area (Figure 13) generally reflect the felsic gneiss where there is better bedrock exposure as opposed to the glacial cover elsewhere. In general, the Wollaston domain is slightly elevated in potassium and diminished in uranium relative to the Mudjatik domain. The structural patterns and foliation are evident in the higher resolution data, particularly in the Wollaston domain to the northeast.

For the radiometric grids within the ERFN area, the radioelement responses are summarized in Table 3.

Table 3: Radioelement Responses of the English River First Nation area

Radioelement	Minimum*	Maximum	Mean
Potassium (%)	-0.05	2.70	1.09
Uranium (ppm)	-0.48	3.18	0.84
Thorium (ppm)	-0.38	41.74	6.03
Natural air absorbed dose rate (nGy/h)	-2.26	142.8	34.27

*Negative values are not unusual due to the statistical nature of gamma-ray spectrometer data and grid interpolation effects.

These levels are typical of metamorphic rocks (IAEA, 2003). The low uranium levels suggest a lower potential for radon risk. However, radon risk is also quite dependent on soil permeability and should be verified by soil gas measurements (IAEA, 2003). Within the ERFN area, the uranium levels rarely exceed 2.5 ppm.

5.3 Geophysical Interpretation of the Sub-Regions in the ERFN Area

The following section provides more detailed interpretations, with a focus on identifying internal heterogeneities associated with lithology contrasts within the three sub-regions in the ERFN area. Interpretations include a description of the geophysical characteristics, as well as the identification of units associated with lithological heterogeneities in the sub-regions, where present. These units are presented alongside the current bedrock geology mapping in Figures 14 to 16 for sub-regions 2.1 to 2.3 respectively, and are discussed further in the sections below.

5.3.1 Sub-Region 2.1

Haultain Lake IR Area

The variation in lithology across the area is reflected in the aeromagnetic data (Figures 5 to 9). Within sub-region 2.1, the magnetic data response is predominantly associated with the 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. A large area displaying these magnetic characteristics is located to the south and southwest of the Haultain Lake IR (Figure 14; unit A). The response in this area is consistent with the felsic gneiss mapped. Although minor amounts of pelitic, psammitic and psammopelitic gneiss are mapped locally within unit A, they do not tend to dominate or influence the magnitude and variability of the magnetic data. Towards the south within

the higher resolution coverage, folding and ductile deformation is evident near the domain boundary.

The division between the higher 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 west and northwest, the magnetic response shows a visible change in the magnitude expressed as a slightly higher magnetic signal (Figure 14; unit B). The magnetic response suggests a larger degree of lithological heterogeneity, as the magnetic peaks can be traced as curvilinear ductile features. As a result, underlying rock units in the area appear to be more heterogeneous than indicated in the current geological mapping, potentially comprising a higher amount of psammitic and pelitic gneiss and amphibolite. Curvilinear magnetic features such as these in the Mudjatik domain have been found to correspond to domal structures (Card and Bosman, 2007). In this sub-region, the orientation varies but is dominates by a northeast strike.

Further east into the Wollaston domain, the magnetic response increases, showing a more linear, north-northeast trending fabric along the eastern boundary of sub-region 2.1 (Figure 14; units C and D). The two units are differentiated mainly by their structural fabric, although unit D has a slightly diminished magnetic response relative to unit C. Unit C shows the north-northeast-directed, ductile structural anisotropy typical of the Wollaston domain, with some axial fold patterns, especially to the south. Unit D forms more concentric ductile features, possibly dome and basin structures. The dominant bedrock geology mapped in the eastern third of the Haultain area comprise two felsic gneiss units: the psammitic meta-arkosic gneiss and the pelitic and psammopelitic gneiss. The geological mapping of these units and associated fold patterns clearly contrast with the magnetic data, suggesting a greater degree of heterogeneity than mapped.

A local gravity low (shown in Figure 12) correlates well with the felsic gneiss interpreted from the magnetic data (Figure 14; unit A) whereas the local gravity highs to the east and west correspond to an increase in lithological heterogeneity (Figure 14; units B, C and D) associated with an interpreted higher amount of intermixed rock units (i.e. psammopelitic gneiss and amphibolites).

5.3.2 Sub-Region 2.2

Porter Lake Island IR Area and Flatstone Lake IR Area

Magnetic data (Figures 5 to 9) for the sub-region 2.2, which rests entirely within the Mudjatik domain, shows a large area to the west of Porter Lake, as well as two smaller areas along the southern sub-region boundary characterized by a weak response with little variability in the magnetic data. The magnetic response in these areas suggests that the bedrock may be characterized by a lower degree of lithological heterogeneity (Figure 15; unit A). This observation is consistent with the bedrock geology map in these areas dominated by felsic gneiss. Weak curvilinear anomalies within unit A suggest some intermixing with the psammitic, pelitic and/or amphibolite gneisses. In other areas of sub-

region 2.2, particularly the southern and eastern portions, the magnetic response displays more variability with a higher magnetic signal (Figure 15; unit B). Magnetic data in these areas suggest increased lithological heterogeneity, corresponding to an increase in the presence of curvilinear ductile structures. Few of these ductile structures tend to correlate with mapped psammitic and pelitic gneiss units. However, some correlate well with amphibolite gneiss. The magnetic data indicates that the bedrock in these areas may be more heterogeneous and geologically more complex than suggested by current geological mapping. Dome and basin structures evident within unit B in the geological mapping are supported by the magnetic data.

The Bouguer gravity field for this sub-region is the lowest in the ERFN area, which is attributed to regional-scale isostatic compensation (Figure 12). Local gravity lows to the north and west correlate mainly with the felsic gneiss, whereas a weak high coincides with the sliver of amphibolite that cuts through the center of the area on an east-west axis.

5.3.3 Sub-Region 2.3

Dipper Rapids IR, Primeau Lake IR, Knee Lake IR and Elak Dase IR Areas

Within sub-region 2.3, the magnetic responses are typical of the mixture of rock units mapped in the Mudjatik and Wollaston domains. Magnetic results in the western half of sub-region 2.3 are dominated by a weak to moderate magnetic response with subtle variability of the magnetic field (Figure 16; unit A). Bedrock units correspond predominantly to the mapped felsic gneiss, and minor amounts of pelitic, psammitic and psammopelitic gneiss and amphibolites.

In some cases, the bedrock geology map shows several small slivers of pelitic to psammitic gneiss that are not clearly evident in the magnetic data. This may result from a low magnetic contrast between the pelitic and psammitic gneiss and the felsic gneiss, or more likely from a sampling bias associated with the wide magnetic survey flight-line spacing (1609 m) in this area. Similarly, a significant portion of the area is also mapped as an alaskite (leucogranite) intrusion within this area. However, identification of its geological contact with the host felsic gneiss is likely hindered by the presence of poor quality magnetic data.
Locally along the northern boundary of the sub-region 2.3, and extending south-southwest in a narrow band to the southern boundary, the intensity and variability of the magnetic data show a subtle increase (Figure 16; unit B). These responses suggest an increase in lithological heterogeneity, where the magnetic peaks can be traced as curvilinear ductile features. As a result, underlying rock units in these areas may be more heterogeneous than suggested in the current geological mapping, potentially comprising a higher amount of psammitic and pelitic gneiss and amphibolite. In this area, the curvilinear magnetic features correspond to domal structures in the Mudjatik domain (Card and Bosman, 2007).

The magnetic results for the eastern half of the sub-region 2.3 show a significant increase in the magnetic intensity associated with the linear, north-northeast trending fabric along

the boundary of the Wollaston domain (Figure 16; units C and D). The magnetic response adjacent to the domain boundary tends to show a much stronger magnitude associated with a roughly 5 km wide zone mapped as a mixture of pelitic gneiss, with lesser amounts of felsic and psammitic meta-arkosic gneiss (Figure 16; unit C). A similar response is present along the eastern boundary of the sub-region although the magnitude of the magnetic data is slightly diminished (Figure 16; unit D). The overall magnetic response associated with units C and D are likely the result of the north-northeast fabric development, and from tight interfingering of the felsic gneiss, pelitic and psammitic gneiss, and amphibolite rocks in the strongly deformed zone. These results suggest that rock units within the Wollaston domain may be more lithologically heterogeneous than current geological mapping indicates.

The Bouguer gravity field for this sub-region is generally low to the west in the Mudjatik domain, particular where the alaskite (leucogranite) intrusion has been mapped, and moderate to high in the east within the Wollaston Domain, noting a small local gravity high just southwest of Elak Dase IR.

6 SUMMARY OF RESULTS

The purpose of this assessment was to identify and obtain the available geophysical data (e.g., magnetic, gravity and radiometric) for the ERFN area, followed by a detailed interpretation to identify additional information that could be extracted from the data, in particular regarding the coincidence of geophysical features with mapped lithology and structural features in the ERFN area.

The geophysical data covering the ERFN area are mainly low-resolution, comprised of the regional magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC). Two magnetic/radiometric surveys extending into the northeast and northwest parts of the ERFN area improve the characterization of the geology.

The coincidence between the geophysical data and the mapped lithology and structural faults were interpreted using all available geophysical data sets (e.g., magnetic, gravity and radiometric). In particular, the pole reduced magnetic field (RTP) and its first vertical derivative (1VD) were the most reliable for mapping variations in geological contacts, and identifying heterogeneity. In general, the coincidence between the geophysical interpretations and the published geological maps is in good agreement, but in some locations the geophysical data provided new interpretations.

Within the Mudjatik domain in all three sub-regions (Figures 14, 15 and 16), areas were identified that showed a subdued magnetic response consistent with that of felsic gneiss. These areas have been designated as geophysical unit A on all three sub-region maps. Additionally within the Mudjatik domain, areas were identified that showed a slightly higher magnetic response, suggesting a larger degree of lithological heterogeneity, as the magnetic peaks can be traced as curvilinear ductile features indicative of domal structures. These areas are potentially comprised of a higher amount of psammitic and

pelitic gneiss and amphibolite, and have been designated as geophysical unit B on all three sub-region maps.

Within the Wollaston domain in sub-regions 2.1 and 2.3 (Figures 14 and 16), areas were identified where the magnetic response increases, showing a more linear, north-northeast trending fabric. This response is coincident with a mixture of psammitic meta-arkosic gneiss and pelitic and psammopelitic gneiss, and is designated as geophysical unit C in both sub-regions, adjacent to the domain boundary. Where the pelitic and psammopelitic gneiss units are predominantly mapped, the magnetic response tends to be slightly diminished. These areas correspond to geophysical unit D, as interpreted in both sub-regions. There is good correlation between the mapped bedrock geology and associated fold patterns in sub-region 2.3, but less so in sub-region 2.1. In the latter area, the differentiation of the geophysical units mainly results from the typical Wollaston domain linear fabric in unit C contrasting with concentric patterns in unit D.

Resolution of the gravity data was insufficient to be used for interpretation of geological units and boundaries. However, some general characterizations of the regional scale geological units were possible. The Bouguer gravity field shows a regional-scale gravity high to the northeast that reflects a thickening of the gneisses in the Wollaston domain, estimated by White et al. (2005) as 8 km thick beneath the gravity peak.

Radiometric responses, due to the presence of potassium, uranium and thorium related minerals, vary across the ERFN area. The low resolution of these data over most of the ERFN area prevents the interpretation of distinct signatures for the exposed rocks. However, several generalized correlations have been noted, limited somewhat by the lakes and wetlands.

Respectfully Submitted,

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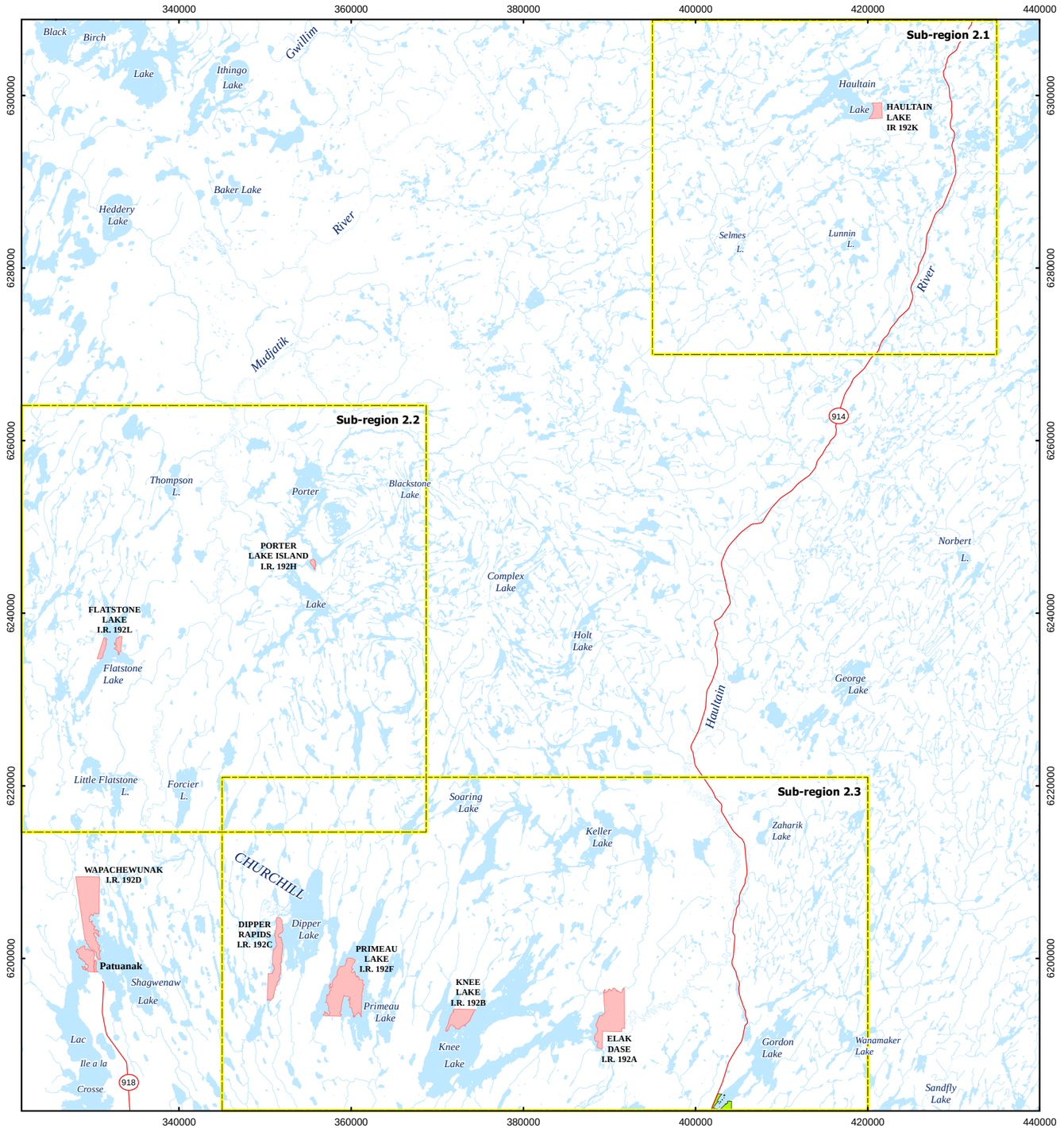
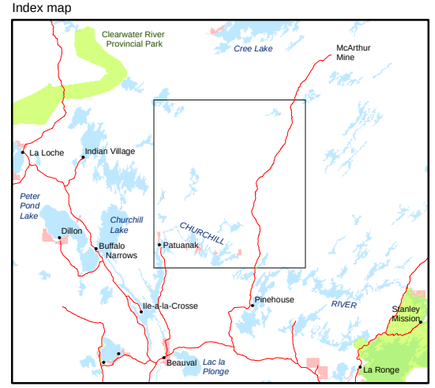
FIGURES



LEGEND

- English River First Nation Detailed Area
- First Nation reserve
- Recreation site
- Main road
- Waterbody
- Watercourse

Index map



- Main road
- Park
- First Nation reserve
- ERFN area
- Large lake

Data sources:
First Nation reserve: Sask Admin
Recreation site: Sask Admin
Main road: ISC SURN11
Waterbody: CanVec 1:50,000
Watercourse: CanVec 1:50,000

NORTH

5 km

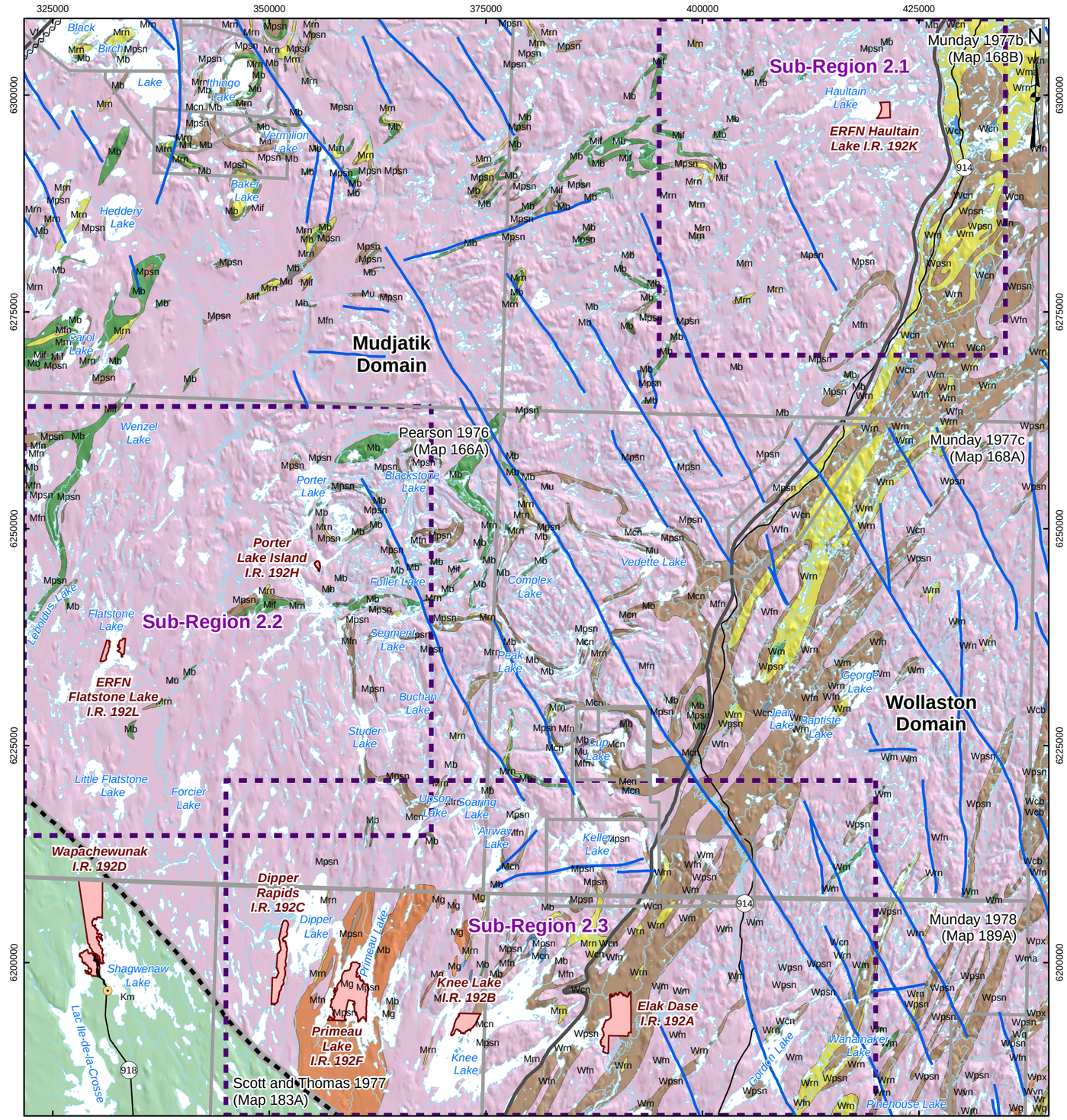
Paterson, Grant & Watson Limited
Consulting Geoscientists
www.pgw.on.ca

J.D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE
English River First Nation and surrounding area

DESIGN	DVZ	25 JUN 2012	FIGURE 1	REVISION 2
GIS	DVZ	27 AUG 2013		UTM ZONE 13
CHECK	JIC	28 AUG 2013		NAD 1983
REVIEW	AM	28 AUG 2013		1:550,000



LEGEND

- English River First Nation Detailed Area
- Community
- Highway
- Watercourse
- Waterbody
- 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)

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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
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ERFN AREA, SASKATCHEWAN

TITLE
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 2		
GIS	PMJB	18 Sep. 2013			
CHECK	AM	18 Sep. 2013			
REVIEW	GWS	18 Sep. 2013			

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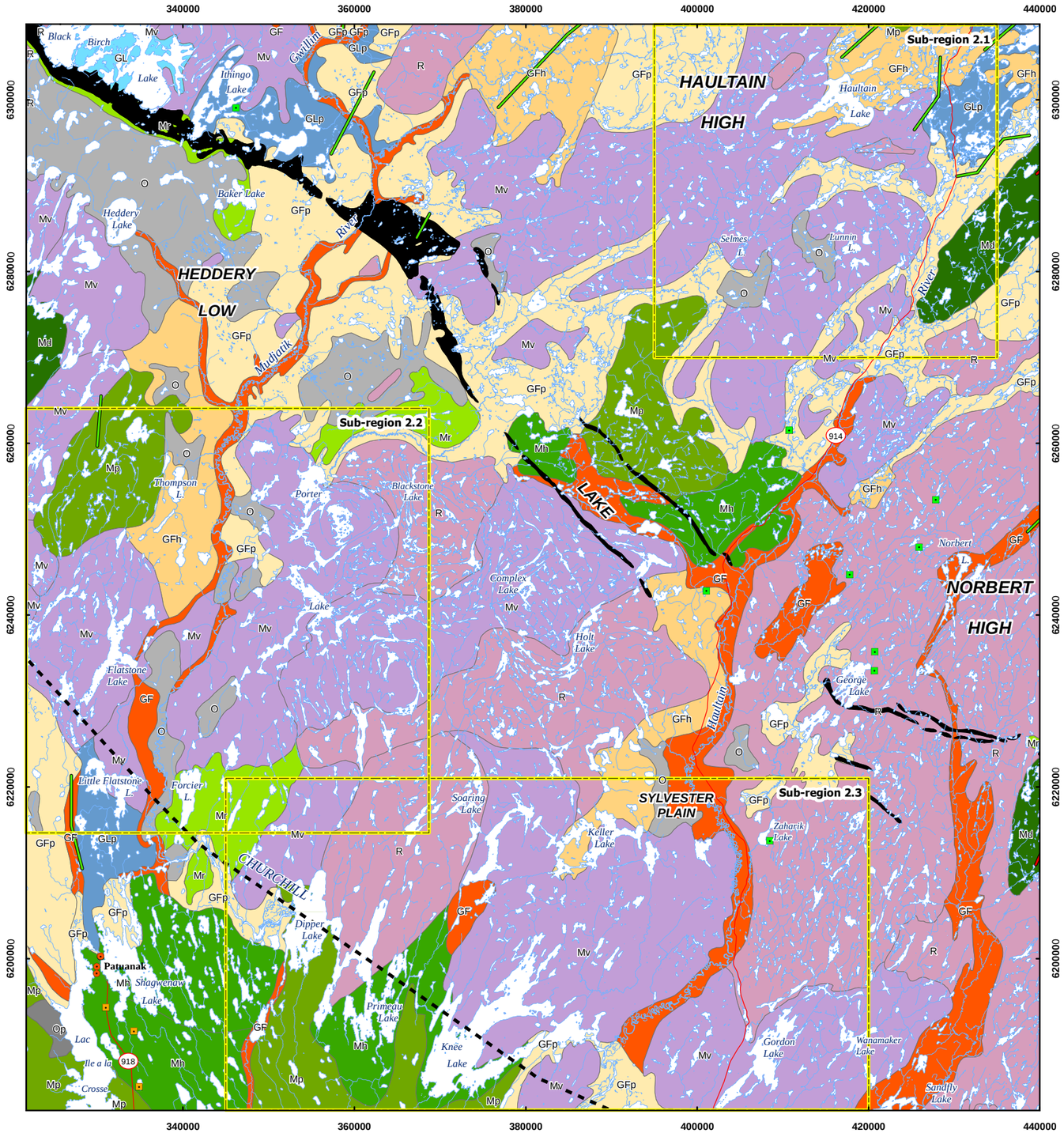


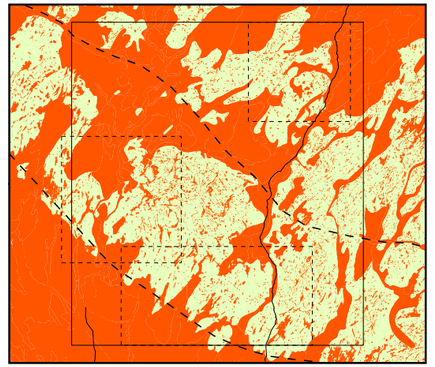
LEGEND

- English River First Nation Detailed Area
- Main road
- Waterbody
- Watercourse
- Water well
- Drill hole (Regina databse)
- Drill hole (La Ronge database)
- Churchill low
- Drumlin
- Esker
- Cree Lake 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

Areas covered by water and thicker drift (shown in orange)



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

Data sources:
Geology: Sask Geological Atlas 1:250,000
Drill holes: Sask Geological Atlas
Water well: Water Well Information Database
Road: ISC SURN11
Waterbody: CanVec 1:50,000
Watercourse: CanVec 1:50,000

NORTH

5 km

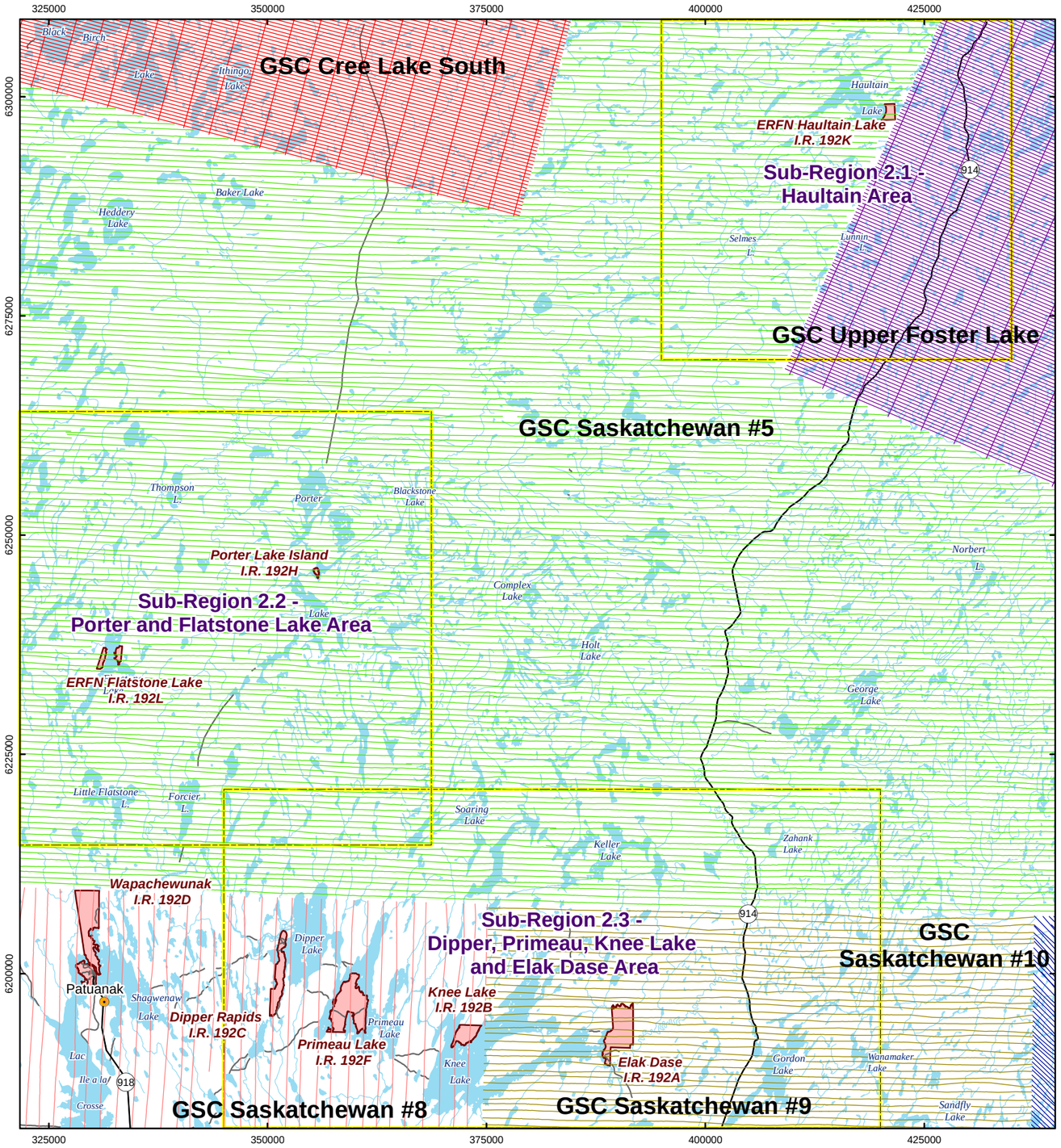
Paterson, Grant & Watson Limited
Consulting Geophysicists
www.pgw.on.ca

J.D. MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE
Quaternary geology of the English River First Nation area

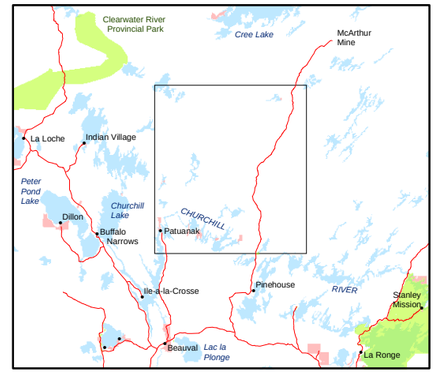
DESIGN	DVZ	25 JUN 2012	FIGURE 3	REVISION 2
GIS	DVZ	27 AUG 2013		UTM ZONE 13
CHECK	JIC	28 AUG 2013		NAD 1983
REVIEW	GS	28 AUG 2013		1:550,000



N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Watercourse
- Waterbody
- Flightpath GSC Cree Lake South
- Flightpath GSC Upper Foster Lake
- Flightpath GSC Saskatchewan #5
- Flightpath GSC Saskatchewan #8
- Flightpath GSC Saskatchewan #9
- Flightpath GSC Saskatchewan #10



REFERENCE

Flightpath: Geological Survey of Canada
Saskatchewan Government, Ministry of Environment
Government of Canada, Natural Resources Canada, Earth Sciences Sector, Geomatics Canada, Surveyor General
First Nations Map Of Saskatchewan http://www.aadnc-aandc.gc.ca/eng/1100100020616 (Aboriginal Affairs and Northern Development Canada (AANDC)). Accessed June 2012.
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Datum: NAD 83 Coordinate System: UTM Zone 13

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SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

Airborne geophysical coverage of the English River First Nation area

Paterson, Grant & Watson Limited
Consulting Geophysicists
www.pgw.on.ca

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013	FIGURE 4	
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

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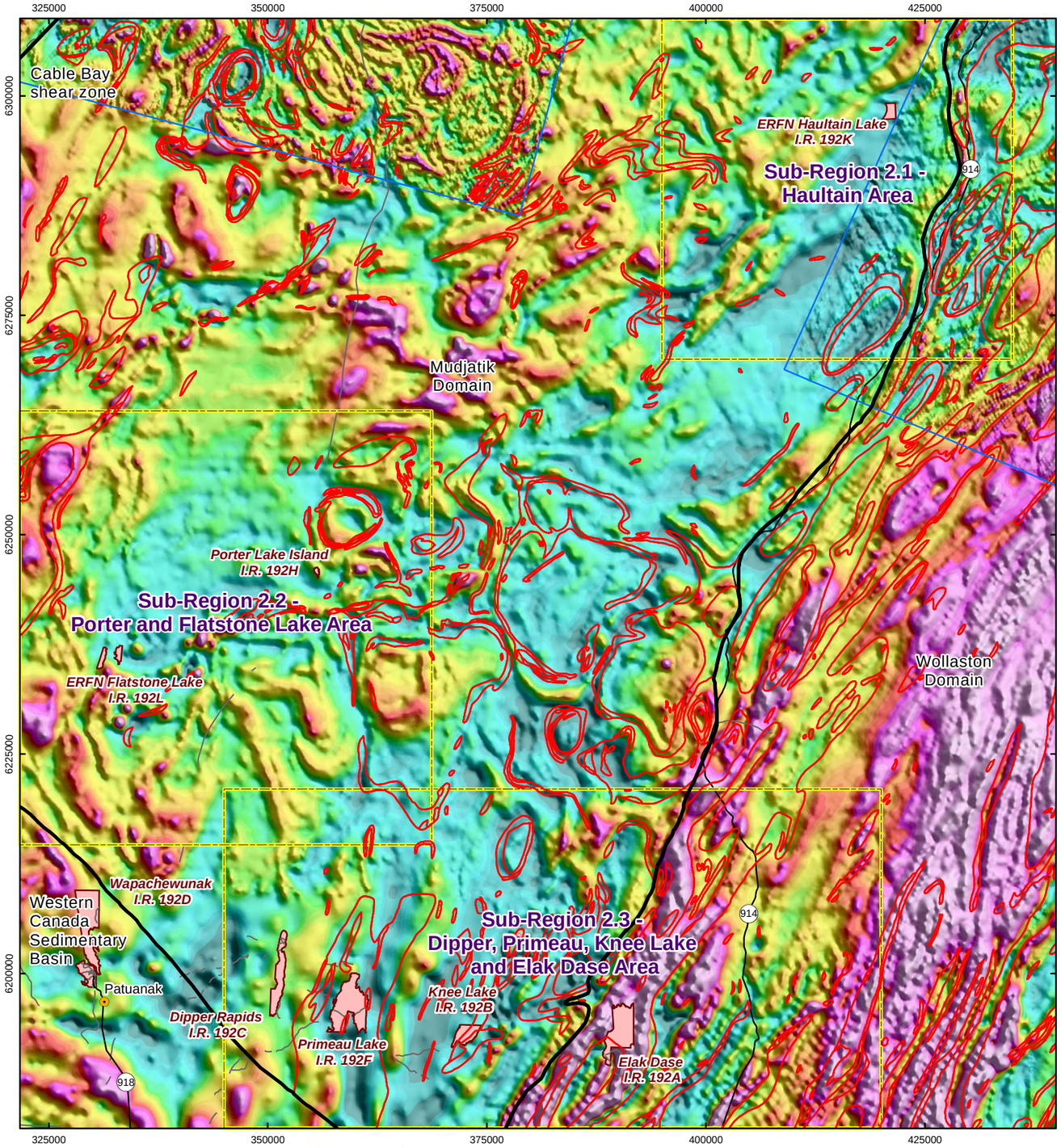
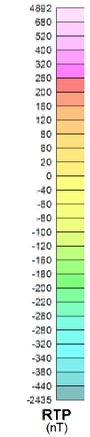
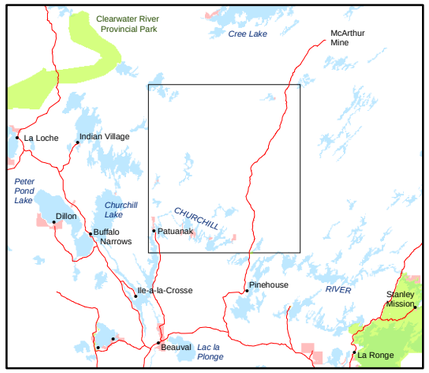


N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- High resolution geophysical survey outlines
- Domain boundary
- Bedrock geology contacts





REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT,
GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

Residual magnetic field reduced to pole.
(with mapped geological contacts and geophysical survey outlines)

Paterson, Grant & Watson Limited
Geophysical Geophysicists
www.pgw.on.ca

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013	FIGURE 5	
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

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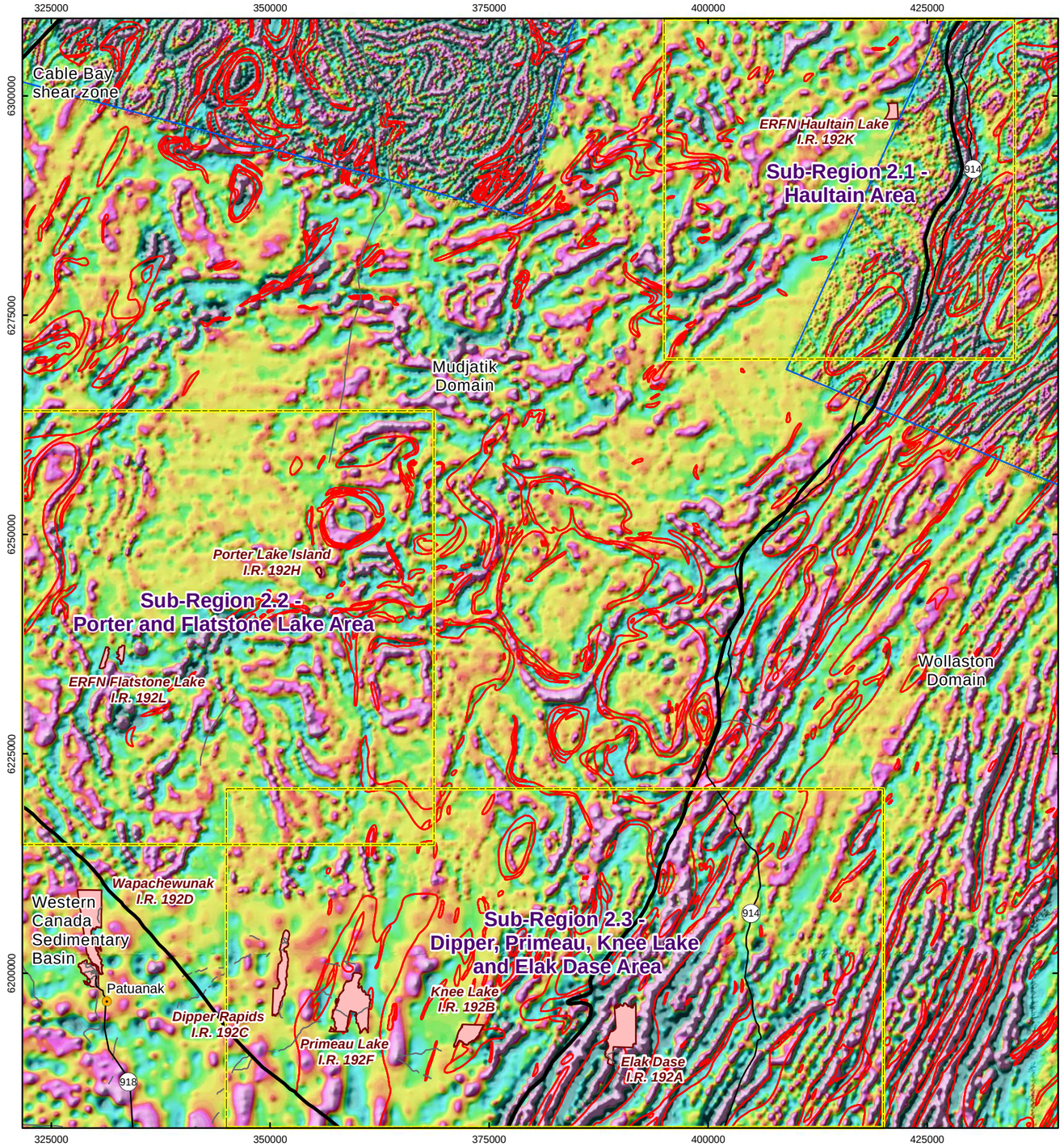
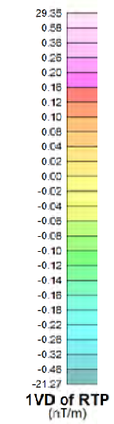
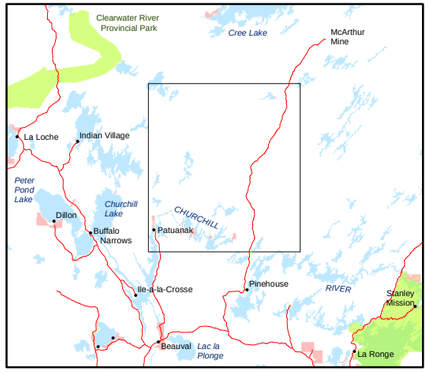


N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- High resolution geophysical survey outlines
- Domain boundary
- Bedrock geology contacts





REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

First vertical derivative of the pole reduced magnetic field. (with mapped geological contacts and geophysical survey outlines)

Paterson, Grant & Watson Limited
Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013		
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

FIGURE 6

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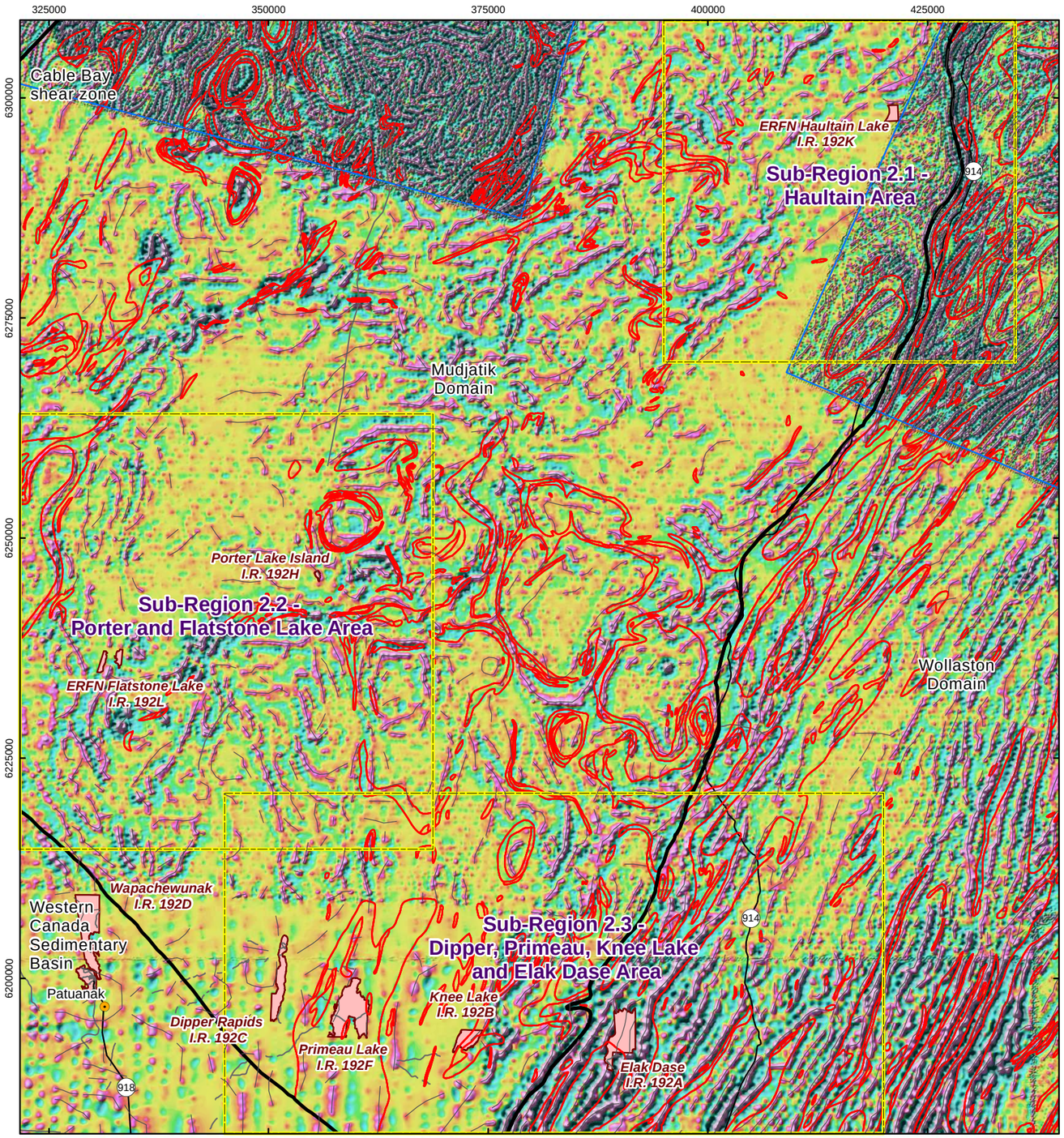
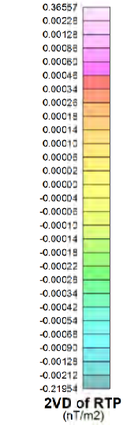
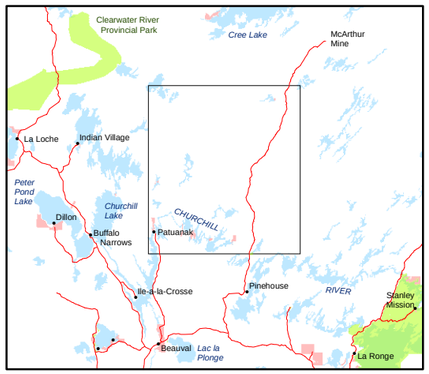


N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- High resolution geophysical survey outlines
- Magnetic Foliation
- Domain boundary
- Bedrock geology contacts





REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30
SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

Second vertical derivative of the pole reduced magnetic field with magnetic foliation (with mapped geological contacts and geophysical survey outlines)

Paterson, Grant & Watson Limited
Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013		
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

FIGURE 7

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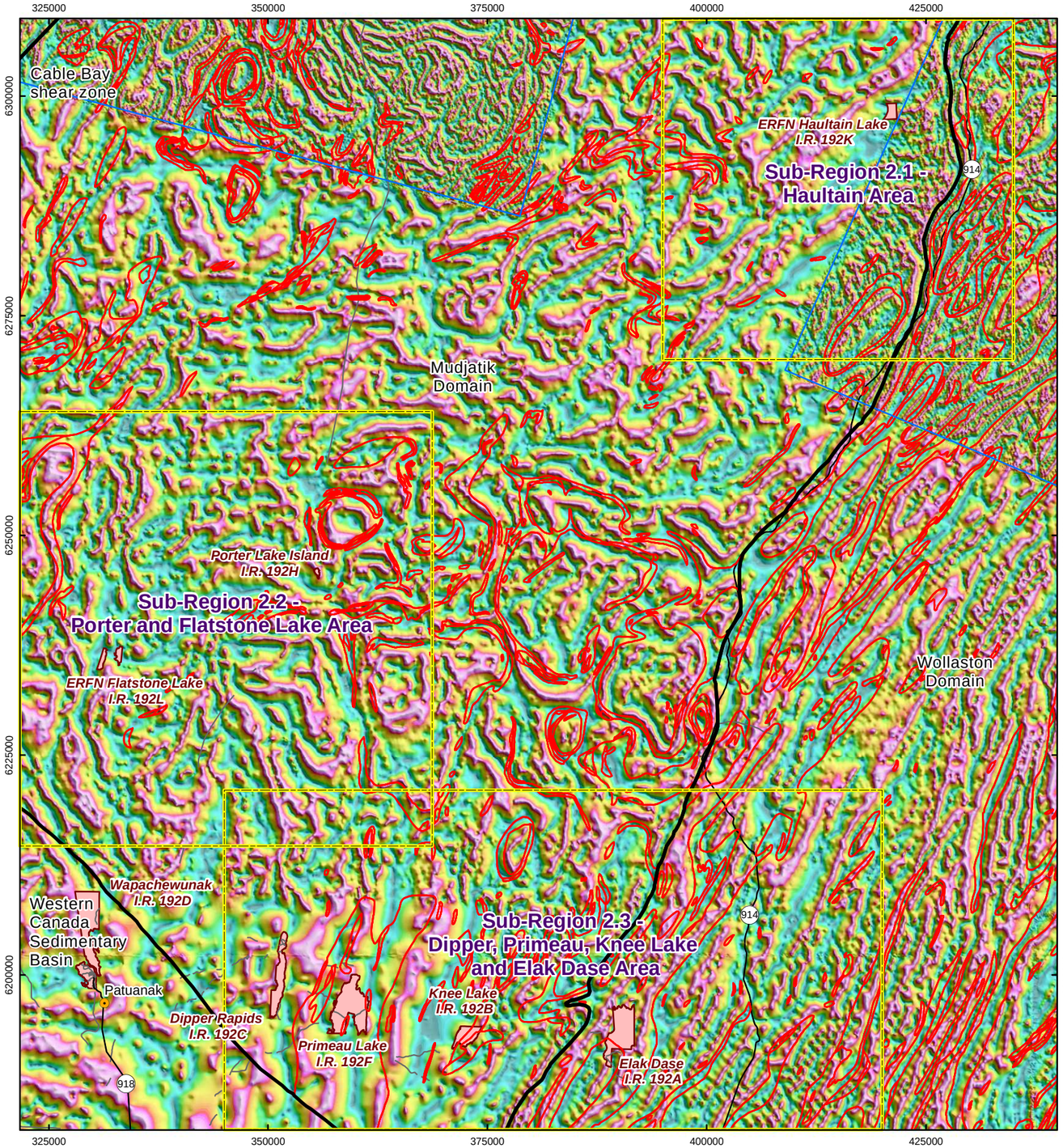
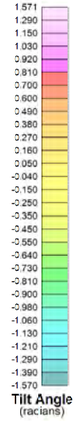
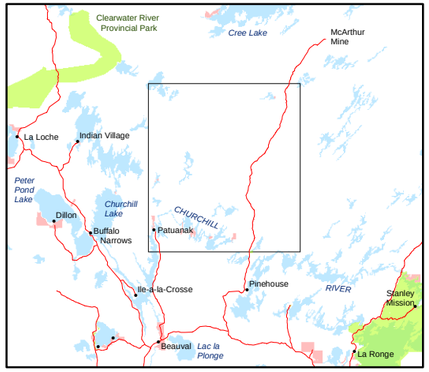


N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- High resolution geophysical survey outlines
- Domain boundary
- Bedrock geology contacts





REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30
SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT,
GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

Tilt angle of the pole reduced magnetic field
(with mapped geological contacts and geophysical survey outlines)

Paterson, Grant & Watson Limited
Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013	FIGURE 8	
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

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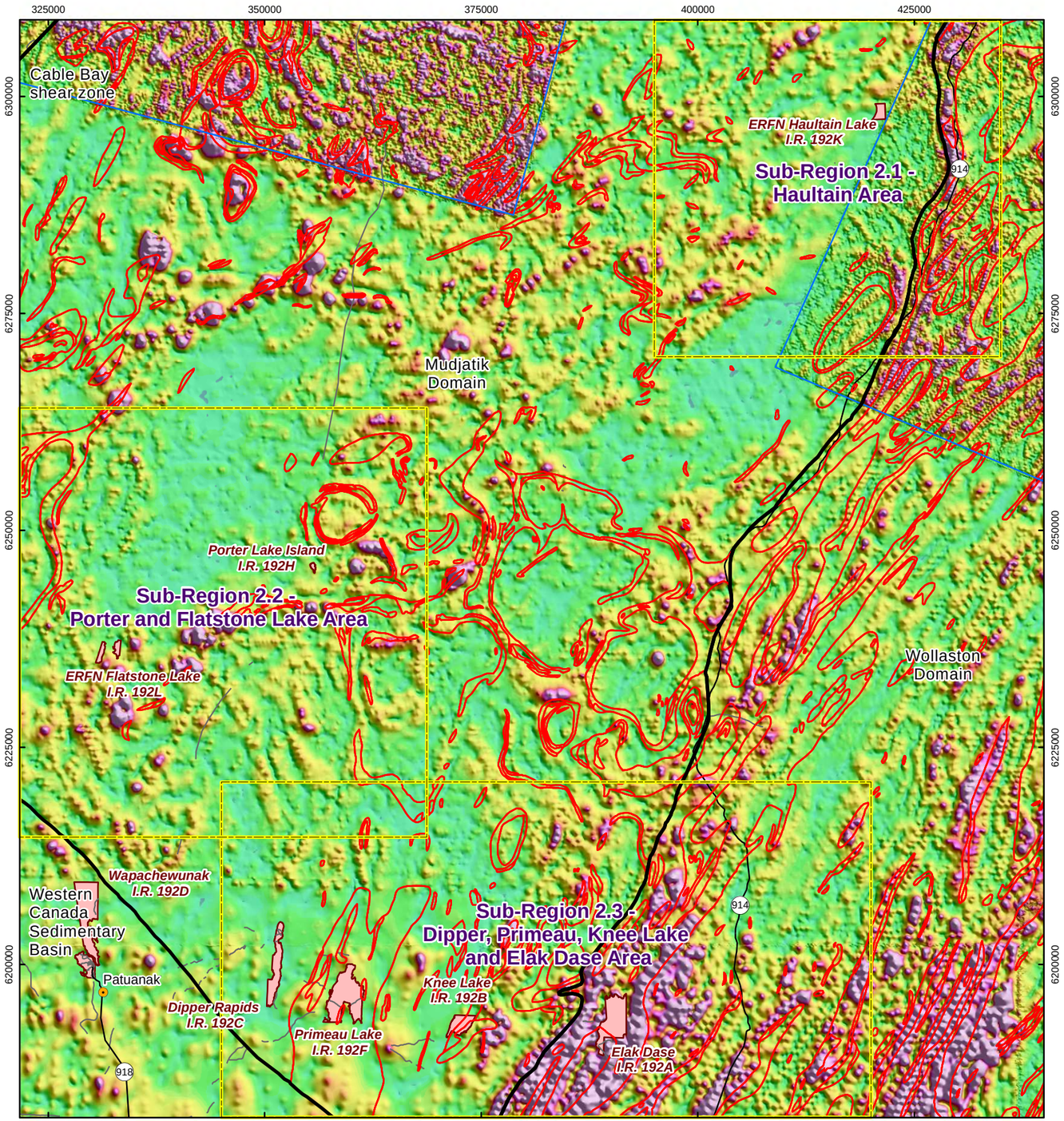
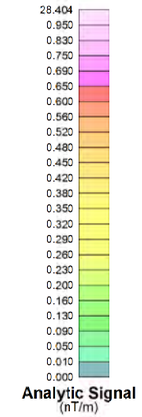
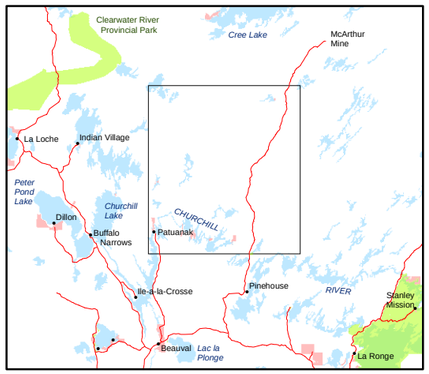


N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- High resolution geophysical survey outlines
- Domain boundary
- Bedrock geology contacts





REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30
SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT,
GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

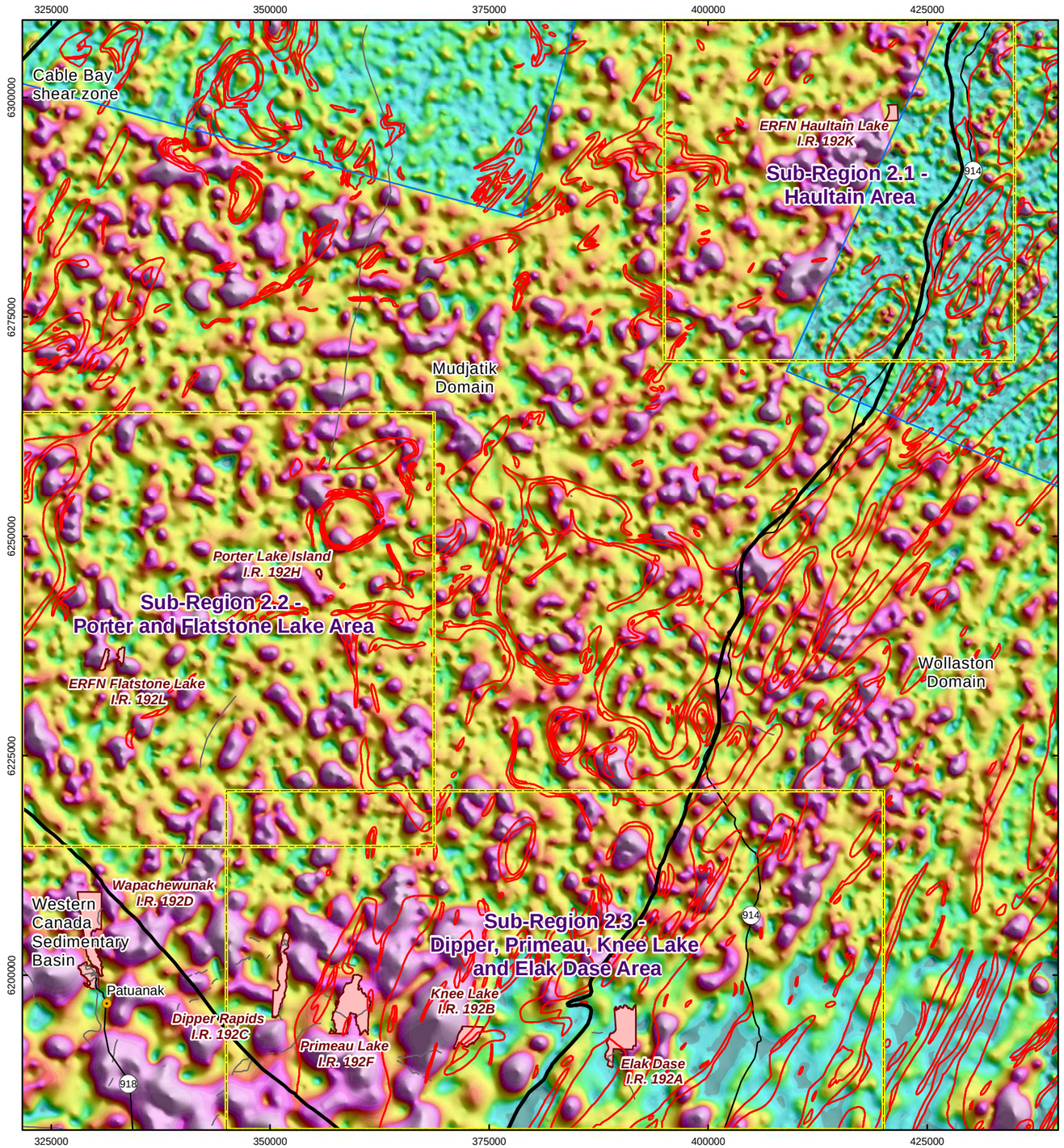
Analytic signal amplitude of the total magnetic field (with mapped geological contacts and geophysical survey outlines)

Paterson, Grant & Watson Limited
Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013		
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

FIGURE 9

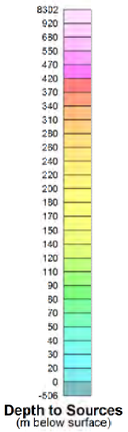
G:\Projects\2012\12-1152-0026_NWMO_Phase1_FeasibilityGISMXDs\Reporting\Env_Safety_Report\ERFN\ERFNBedrockGeology.mxd

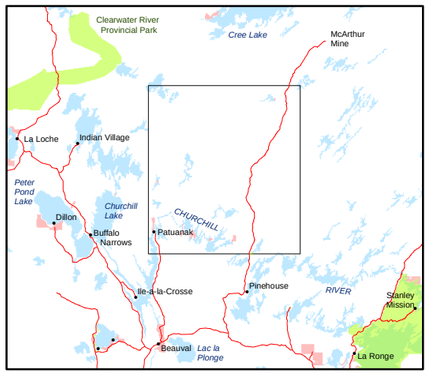


N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- High resolution geophysical survey outlines
- Domain boundary
- Bedrock geology contacts





REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30
SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT,
GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

Depth to magnetic sources from source parameter imaging (with mapped geological contacts and geophysical survey outlines)

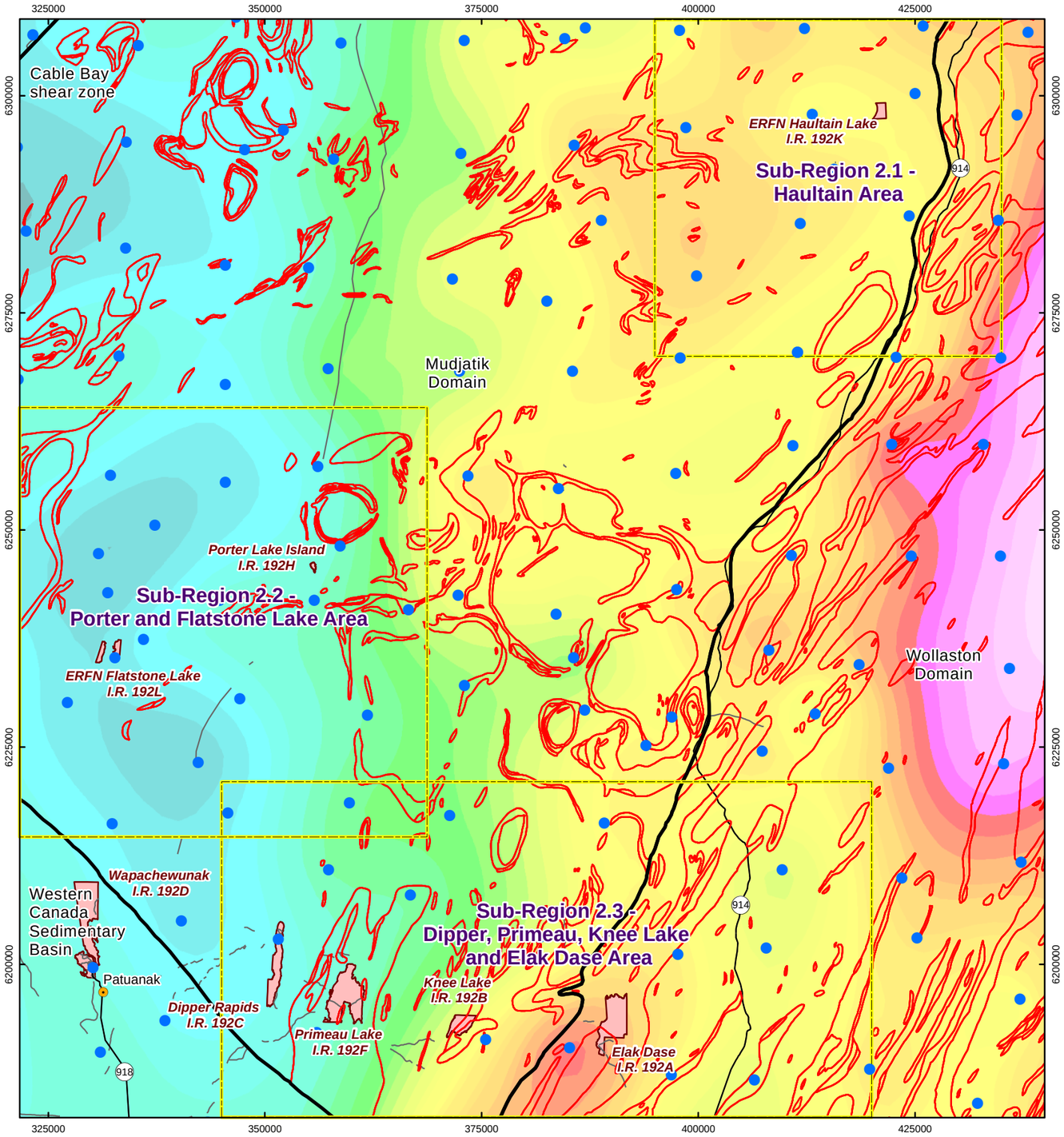
Paterson, Grant & Watson Limited
Consulting Geophysicists
www.pgw.on.ca

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013		
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

FIGURE 10

G:\Projects\2012\12-1152-0026_NWMO_Phase1_Feasibility\GIS\MXDs\Reporting\Env_Safety_Report\ERFN\ERFNBedrockGeology.mxd



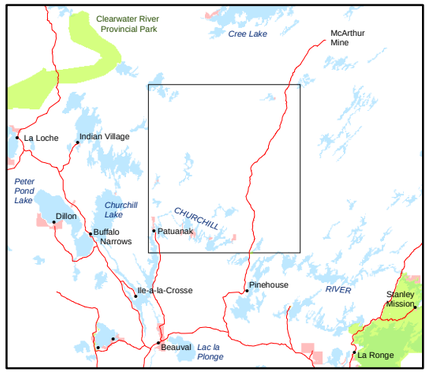
N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Domain boundary
- Bedrock geology contacts
- Gravity station

-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
-83.7

Bouguer Gravity
(mGal)



REFERENCE

Gravity: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30
SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT,
GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

Bouguer gravity field with station locations (with mapped geological contacts)

Paterson, Grant & Watson Limited
Geophysics
www.pgw.on.ca

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013	FIGURE 11	
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

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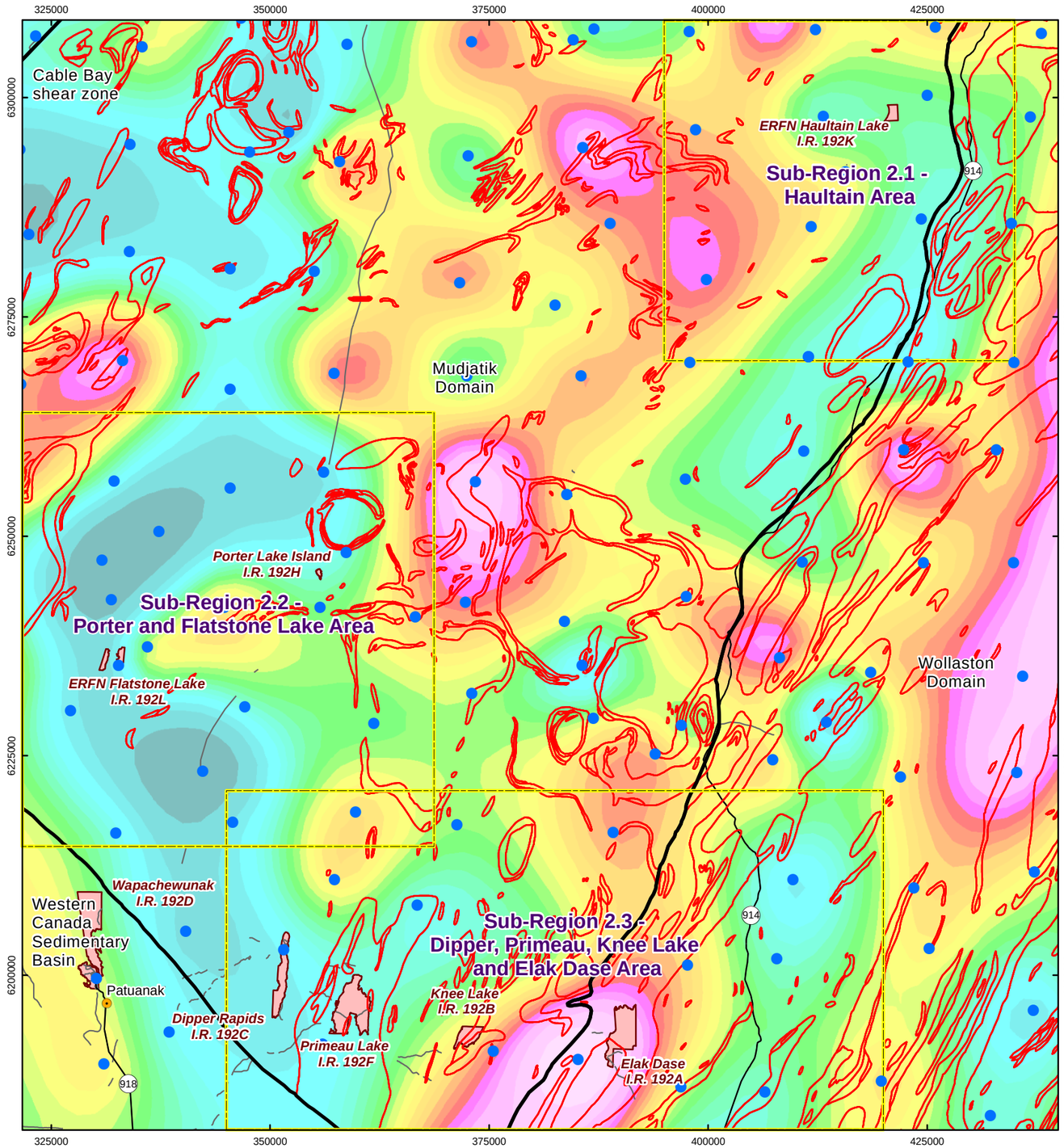
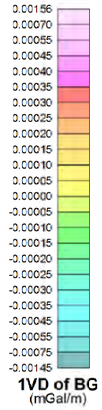
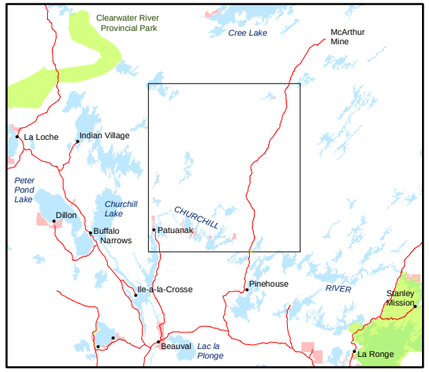


N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock geology contacts
- Domain boundary
- Gravity station





REFERENCE

Gravity: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30
SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT,
GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

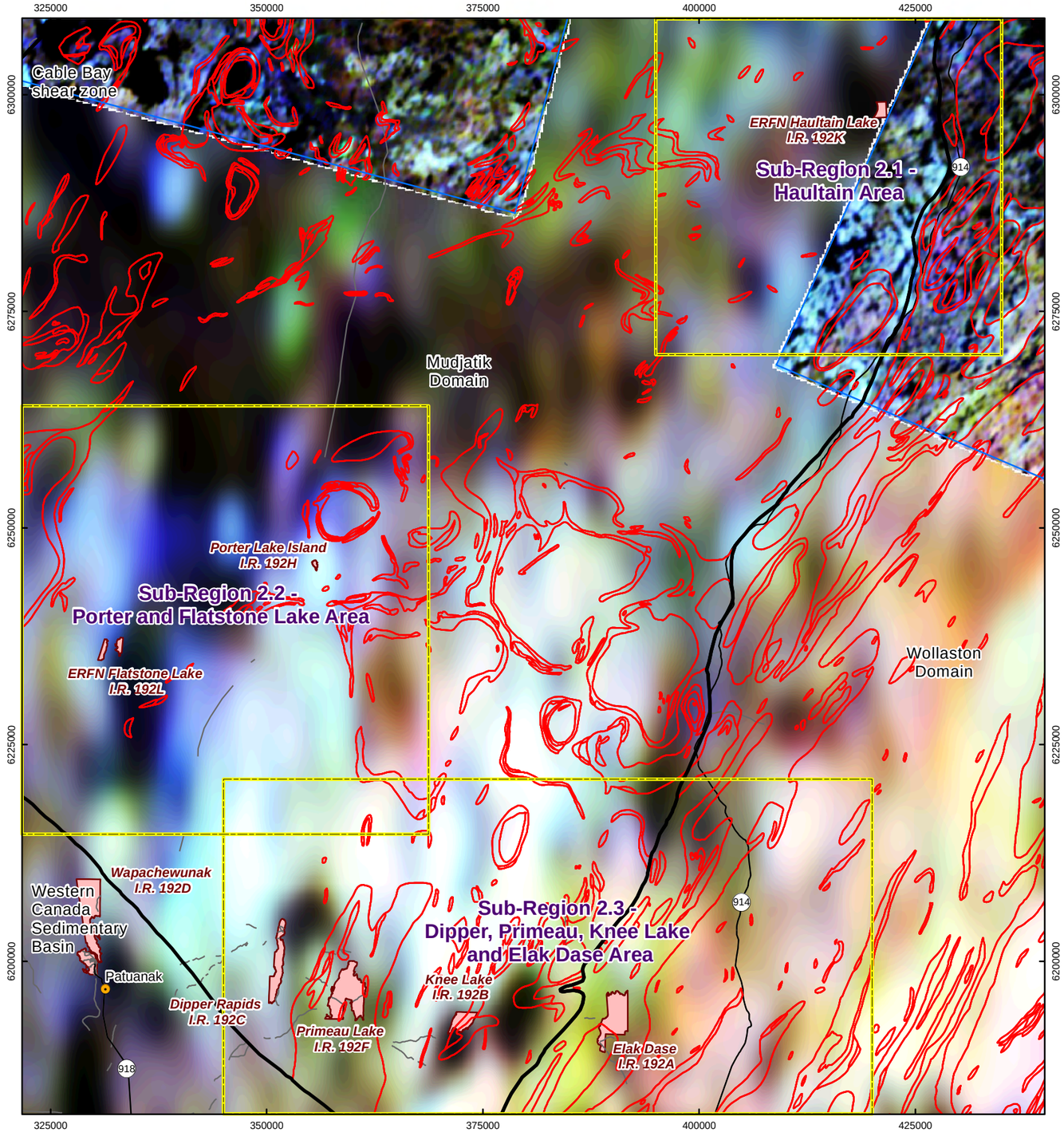
First vertical derivative of the Bouguer gravity field with station locations (with mapped geological contacts)

Paterson, Grant & Watson Limited
Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013		
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

FIGURE 12

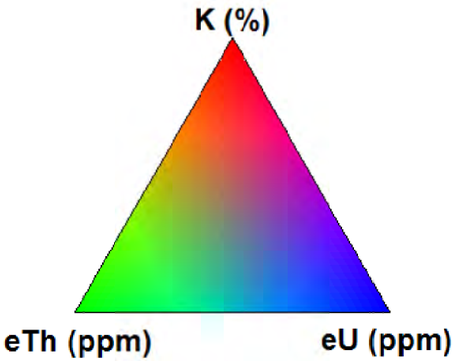
G:\Projects\201212-1152-0026_NWMO_Phase1_FeasibilityGIS\MXDs\Reporting\Env_Safety_Report\ERFN\ERFNBedrockGeology.mxd

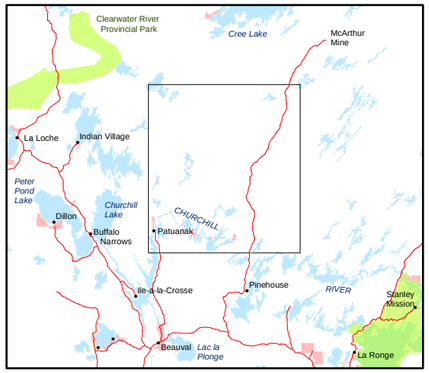


N

LEGEND

- English River First Nation Detailed Area
- Federal Land - Indian Reserve
- Main Road
- Local Road
- High resolution geophysical survey outlines
- Domain boundary
- Bedrock geology contacts





REFERENCE

Gravity: Geological Survey of Canada nationwide compilation
Geology: Geological Atlas of Saskatchewan, Saskatchewan Energy and Resources

Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

10 5 0 10 20 30

SCALE 1:550,000 KILOMETRES

PROJECT

PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE

Radiometric ternary image (RGB = K-eTh-eU) (with mapped geological contacts and geophysical survey outlines)

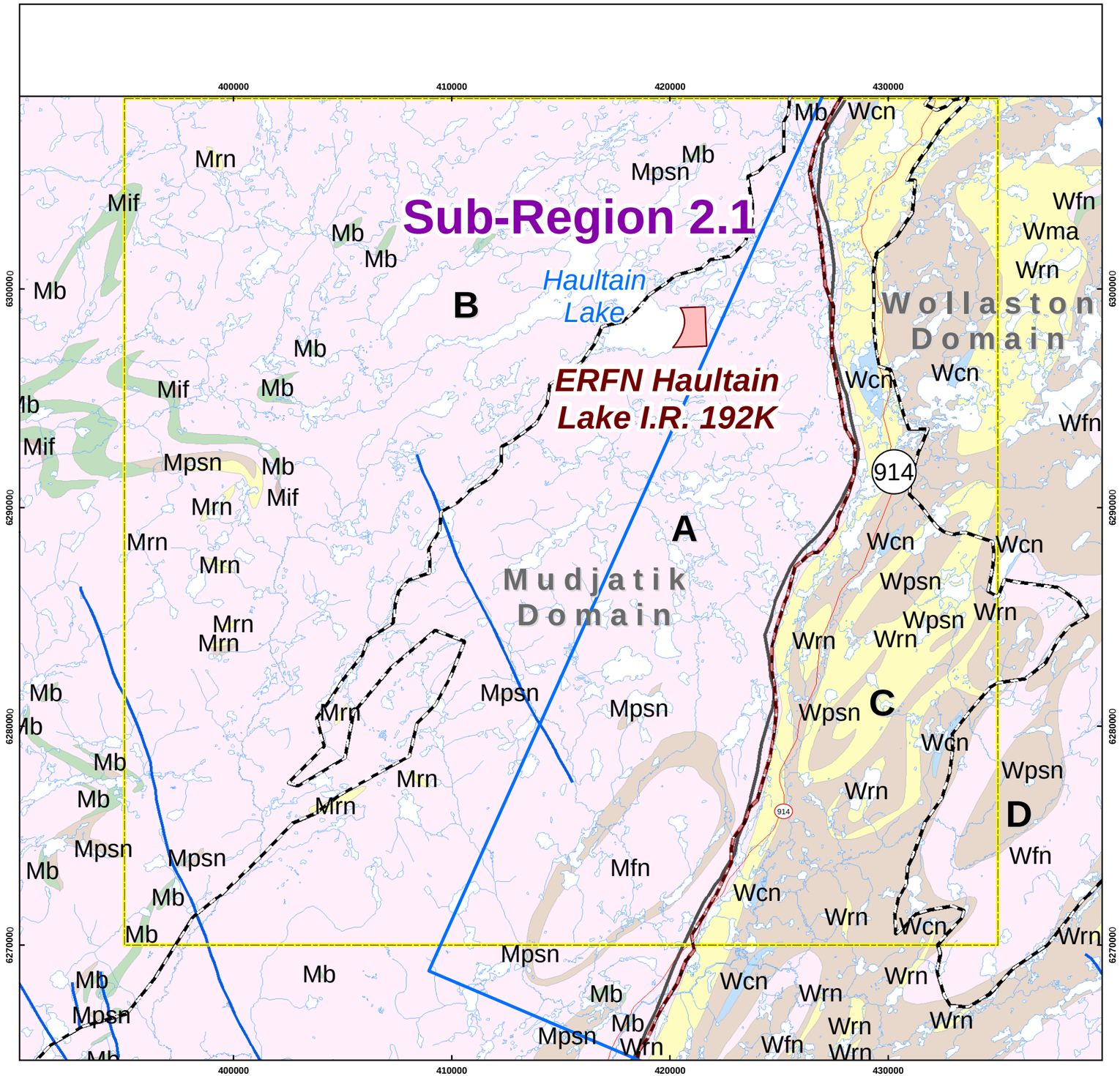
Paterson, Grant & Watson Limited
Geosoftware Geophysicists
www.pgw.on.ca

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 2.0
DESIGN	SWR	15 MAR 2013		
GIS	SWR	27 AUG 2013		
CHECK	ELM	28 AUG 2013		
REVIEW	AM	28 AUG 2013		

FIGURE 13

G:\Projects\2012\12-1152-0026_NWMO_Phase1_Feasibility\GIS\MXD\Reporting\Env_Safety_Report\ERFN\ERFNBedrockGeology.mxd



LEGEND

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

Western Canada Sedimentary Basin

- 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
- High resolution geophysical survey outlines
- Interpreted domain boundary
- Geological units interpreted from geophysics

Data sources:
Geology: Sask Geological Atlas 1:250,000
Road: ISC SURN11
Waterbody: CanVec 1:50,000
Watercourse: CanVec 1:50,000

NORTH

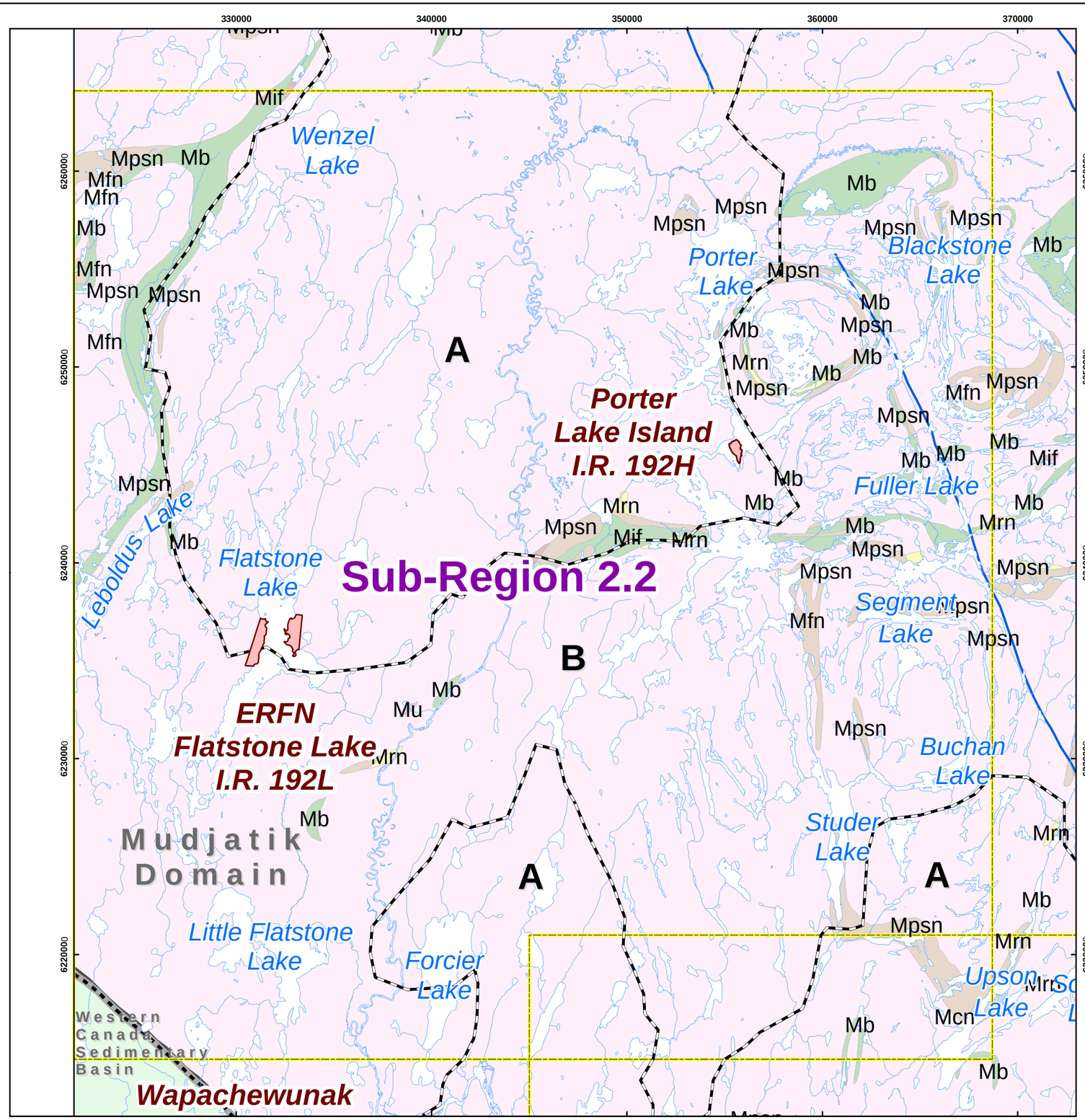
5 km

Paterson, Grant & Watson Limited Consulting Geophysicists www.pgw.on.ca
Golder Associates
I.D. MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE
Geophysical interpretation showing distribution of bedrock units for the English River First Nation area (with geophysical survey outlines) Sub-region 2.1 - Haultain Area

DESIGN	DVZ	25 JUN 2012	FIGURE 14	REVISION 2.1
GIS	SR/NP	19 SEP 2013		UTM ZONE 13
CHECK	DJM	20 SEP 2013		NAD 1983
REVIEW	GS/AM	20 SEP 2013		1:200,000



LEGEND

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

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

- Geological units interpreted from geophysics

Data sources:
Geology: Sask Geological Atlas 1:250,000
Road: ISC SURN11
Waterbody: CanVec 1:50,000
Watercourse: CanVec 1:50,000

NORTH

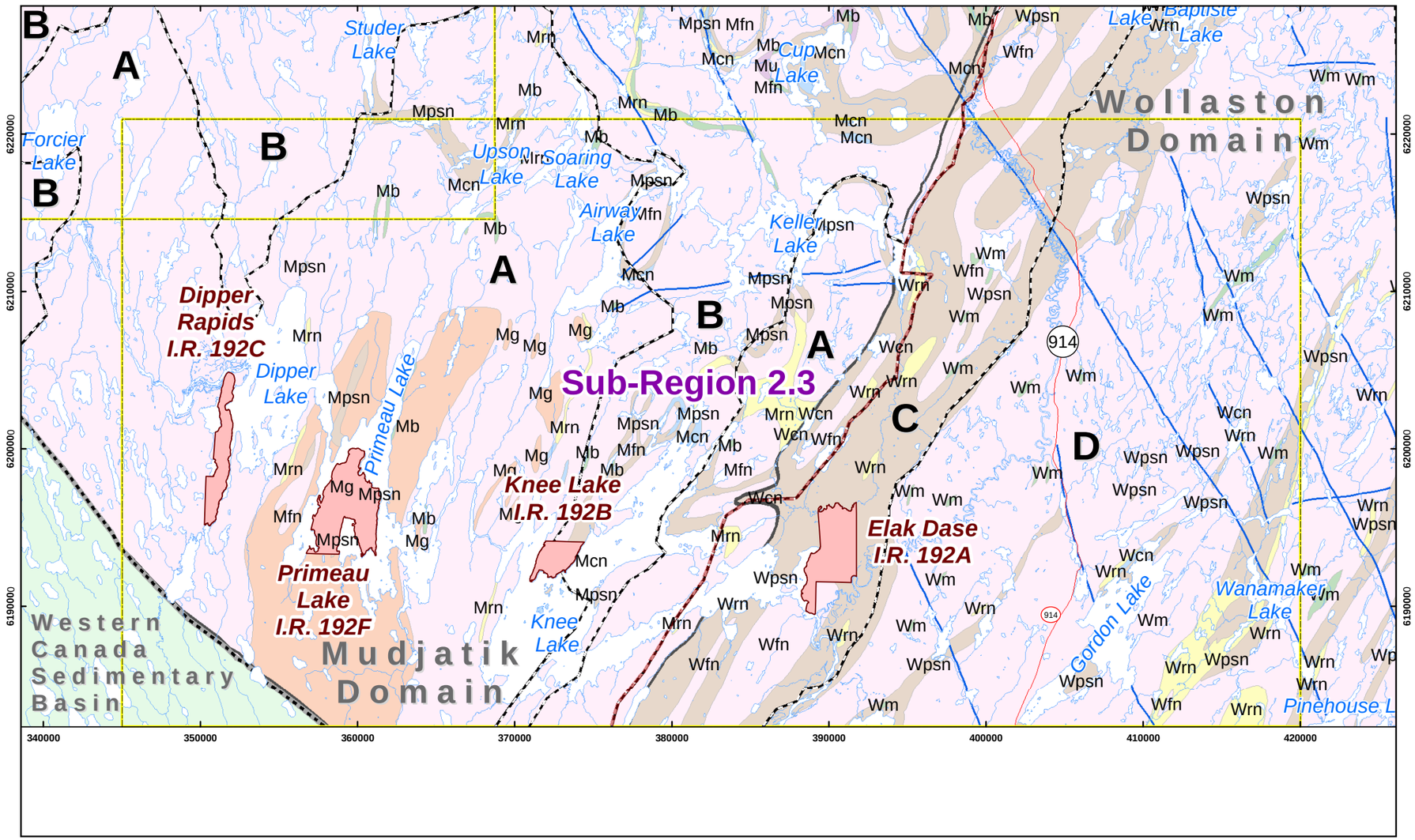
5 km

Paterson, Grant & Watson Limited Consulting Geophysicists www.pgw.on.ca | Golder Associates | I.D. MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE
Geophysical interpretation showing distribution of bedrock units for the English River First Nation area (with geophysical survey outlines) Sub-region 2.2 - Porter and Flatstone Lake Area

DESIGN	DVZ	25 JUN 2012	FIGURE 15	REVISION 2.1
GIS	SR/NP	19 SEP 2013		UTM ZONE 13
CHECK	DJM	20 SEP 2013		NAD 1983
REVIEW	GS/AM	20 SEP 2013		1:220,000



LEGEND

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

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

- Interpreted domain boundary
- Geological units interpreted from geophysics

Data sources:
Geology: Sask Geological Atlas 1:250,000
Road: ISC SURN11
Waterbody: CanVec 1:50,000
Watercourse: CanVec 1:50,000

NORTH

5 km

Paterson, Grant & Watson Limited — Consulting Geophysicists — www.pgw.on.ca
Golder Associates
I D MOLLARD

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, ENGLISH RIVER FIRST NATION AREA, SASKATCHEWAN

TITLE
Geophysical interpretation showing distribution of bedrock units for the English River First Nation area (with geophysical survey outlines) Sub-region 2.3 - Dipper, Primeau, Knee Lake and Elak Dase Area

DESIGN	DVZ	25 JUN 2012	FIGURE 16	REVISION 2.1
GIS	SR/NP	19 SEP 2013		UTM ZONE 13
CHECK	DJM	20 SEP 2013		NAD 1983
REVIEW	GS/AM	20 SEP 2013		1:300,000