NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

NORTHERN VILLAGE OF PINEHOUSE, SASKATCHEWAN

APM-REP-06144-0061

NOVEMBER 2013

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PHASE 1 DESKTOP GEOSCIENTIFIC PRELIMINARY ASSESSMENT

PROCESSING AND INTERPRETATION OF GEOPHYSICAL DATA

Northern Village of Pinehouse, Saskatchewan

Prepared for

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

by

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NWMO Report Number:
APM-REP-06144-0061

Toronto, Canada **November, 2013**

EXECUTIVE SUMMARY

In March, 2012 the Northern Village of Pinehouse, Saskatchewan (Pinehouse) expressed interest in continuing to learn more about the Nuclear Waste Management Organization's (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Pinehouse 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 Pinehouse area contains general areas that have the potential to meet NWMO's geoscientific site evaluation factors.

This report presents the findings of geophysical data interpretation assessment completed as part of the desktop geoscientific preliminary assessment of the Pinehouse area (Golder, 2013). The purpose of this study was to perform a detailed interpretation of all available geophysical data for the Pinehouse 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 units with mapped lithology and structural features in the Pinehouse area.

The geophysical data covering the Pinehouse area are of low dataset resolution. Magnetic, gravity and radiometric data were obtained from the Geological Survey of Canada (GSC) for the entire Pinehouse area. No electromagnetic data were available for the Pinehouse 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 March, 2012 the Northern Village of Pinehouse, Saskatchewan expressed interest in continuing to learn more about the Nuclear Waste Management Organization's (NWMO) nine-step site selection process (NWMO, 2010), and requested that a preliminary assessment be conducted to assess potential suitability of the Pinehouse 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 study completed by Paterson, Grant & Watson Limited (PGW) as part of the desktop geoscientific preliminary assessment of the Pinehouse area (Golder, 2013). The objective of the desktop geoscientific preliminary assessment is to determine whether the Pinehouse area contains general areas that have the potential to satisfy the geoscientific evaluation factors outlined in the NWMO site selection process. The interpretation focused on Pinehouse and its periphery, referred to throughout the report as the "Pinehouse area".

1.1 Study 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 study was to perform a review of available geophysical data for the Pinehouse 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 units with mapped lithology and structural features in the Pinehouse area.

The role of the geophysical interpretation is to extrapolate our current understanding of the mapped lithology and extent of overburden cover to assess how the distribution of rock units may change at depth. 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 Pinehouse 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 waterbodies and/or overburden cover, such as in the Pinehouse 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 Pinehouse Area

The Pinehouse area (2,914 km^2) incorporates the Northern Village of Pinehouse and surrounding areas, situated in north-central Saskatchewan, on the western shore of Pinehouse Lake (Figure 1). The Northern Village of Pinehouse is located 80 km northeast of Beauval, 93 km northwest of La Ronge, and 250 km north of Prince Albert, Saskatchewan. The Pinehouse area is a rectangular area measuring 58 km by 50 km.

1.3 Qualifications of the Geophysical Interpretation Team

The team responsible for the geophysical review, processing and interpretation investigation component of the Phase 1 – Geoscientific Preliminary Assessment of Potential Suitability of the Pinehouse 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, EM interpretation, 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 Pinehouse area is provided in a separate report (Golder, 2013). The following sections on physical geography, bedrock geology, structural history and Quaternary geology present summaries of the information presented in Golder (2013), and JDMA (2013a, b) where applicable, in order to provide the necessary context for discussion of the results of this geophysical interpretation (Section 5).

The Pinehouse area lies on rocks of the Canadian Shield. The Canadian Shield is a collage of Archean cratons and accreted juvenile 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 Orogeny, which resulted from the closure of the Manikewan ocean and terminal collision of the Rae-Hearne, Sask and Superior cratons during the approximate period of 1.9 to 1.8 billion years (Ansdell, 2005; Corrigan et al., 2005; Hajnal et al., 2005; Corrigan et al., 2007; Whitmeyer and Karlstrom, 2007; Corrigan et al., 2009). The Canadian Shield now forms the stable core of North America. Unlike the exposures of the Canadian Shield recognized and mapped in Ontario, the shield exposures in Saskatchewan do not appear to host pervasive mafic dyke swarms.

The Pinehouse area is mostly located within the Hearne craton (historically called Cree Lake zone) that comprises the eastern portion of the Western Churchill Province of the Canadian Shield. A small portion of the Pinehouse area extends into the adjacent Reindeer zone to the east. The Hearne craton (south of the Athabasca basin) is generally composed high grade Archean to Paleoproterozoic metamorphic rocks older than 1.8 billion years (Orrell et al., 1999; Card et al., 2008) that are overlain by sedimentary rocks of the Athabasca Group within the Athabasca Basin and Phanerozoic sedimentary rocks within the Western Canada Sedimentary Basin, north and south of the Pinehouse area, respectively. In the Canadian Shield, these rocks continue southward, with increasing depth beneath the sedimentary rocks of the Western Canada Sedimentary Basin, and northward outcropping again along the northern margin of the Athabasca Basin. The Hearne craton is bounded to the west by the Rae craton along the Snowbird tectonic zone and to the east side by the Reindeer zone along the Needle Falls shear zone (Figure 2). These shear zones are oriented in a north-northeast direction (azimuth of approximately 20°), and reflect the predominant alignment of major Precambrian structural features and lithologies in northern Saskatchewan (Munday, 1978a). The Hearne craton is further divided into three lithostructural domains (Lewry and Sibbald, 1980), from west to east, the Virgin River, Mudjatik, and Wollaston domains. A new proposed domainal reclassification has been advanced where the Virgin River and Mudjatik domains are to be merged and renamed as Mudjatik domain (Card, 2012). For the purpose of simplicity, the old domainal classification has been retained given that it is the one used by all sources utilized and because it does not have any impact in the objective of this assessment. The Pinehouse area is primarily located within the Wollaston domain, with two small portions lying on the Mudjatik domain and the Wathaman batholith, in the northwest corner and southeast corners of the Pinehouse area, respectively (Figure 2).

The eastern Mudjatik domain consists of 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 over 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 in many parts of the Mudjatik domain which are absent in 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 Archean metasedimentary rocks are part of the basement to the Proterozoic metasedimentary rocks and subordinated metavolcanic rocks of the Wollaston domain that form the Wollaston Supergroup (as defined by Yeo and Delaney, 2007), and which was deposited along the eastern edge of the Hearne craton first in a rift/passive margin setting, and later in a foreland basin setting, due to the opening and closure of the Manikewan ocean between the Hearne and Superior cratons. These rocks are mapped as narrow bands of psammitic to pelitic gneisses, defining the north-northeast-trending linear grain in the Wollaston domain. The predominance of metasedimentary gneisses of the Wollaston Supergroup in the north and central parts of the Wollaston domain declines to the south, where they become discontinuous in bands intercalated with Archean felsic (ortho) gneiss and younger granitoid rocks.

The eastern boundary of the Mudjatik domain is generally thought to be transitional with the western boundary of the Wollaston domain (e.g., Munday, 1977, 1978a; Lewry and Sibbald, 1980; Tran, 2001), where a marked change in structural style from arcuate to linear, and a less apparent change in lithology in some areas, has been observed (e.g., Lewry and Sibbald, 1980; Annesley and Madore (1989, 1991, 1994); Delaney, 1993; Card et al., 2006; Yeo and Delaney, 2007). More recently Annesley et al. (2005) have argued that the boundary between both domains corresponds to a major crustal transcurrent fault-shear zone or a 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 has been reported in the literature. Nor did Tran et al. (1999) find evidence of this structural feature in the Mackenzie Falls area. Tran and Smith (1999) pointed out that such a structural feature did not exist in the area of the Cup-Keller-Schmitz Lakes and that if a domain boundary existed then it must have existed prior to the Hudsonian Orogeny.

The Wollaston domain is separated to the east from the Reindeer zone by the Needle Falls shear zone (Delaney, 1993; Yeo and Delaney, 2007) (Figure 2). 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 (Lucas et al., 1996). The Reindeer zone is generally composed of approximately 1.92 to 1.83 billion year old volcano-plutonic assemblages and marginal sedimentary basins, derived from various tectonic settings (Lucas et al., 1996).

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). It is well defined by a strong magnetic anomaly, and geophysical surveys suggest the shear zone extends an additional 300 km to the south, beneath the Paleozoic cover (Stauffer and Lewry, 1993). Seismic imaging suggests this feature dips steeply to the west (Lewry et al., 1994). Field evidence suggests that the shear zone developed late, during the Trans-Hudson Orogeny approximately 1.83 billion years ago with (most recent) dextral movement of 40 to 60 km (Stauffer and Lewry, 1993; Orrell et al., 1999; Hajnal et al., 2005).

The Wathaman batholith is a very large megacrystic monzogranite-granodiorite intrusive body that extends for about 900 km along the eastern boundary of the Hearne craton and the Needle Falls shear zone, separating the craton from the Reindeer zone. The batholith was emplaced during the Trans-Hudson Orogeny in a compressional tectonic regime (Fumerton et al., 1984).

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 Pinehouse 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 included 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). Coupled geophysical modelling of Lithoprobe data for a west-east geophysical transect, located approximately 50 km south of the boundary between the Canadian Shield and the Western Canada Sedimentary Basin, estimates the Archean basement rocks of the Mudjatik domain to extend to depths from 5 to 10 km (White et al., 2005). The Archean basement rocks extend to similar depths in the Wollaston domain. Where present, the metasedimentary rocks of the Wollaston domain are expected to extend to depths ranging from approximately 5 to 8 km (White et al., 2005). Although the data was collected approximately 50 km to the south of the Pinehouse area, these estimates provide some insight with respect to the approximate thickness and continuity of major rock units proximal to the Pinehouse area.

2.1 Physical Geography

A detailed discussion of the physical geography of the Pinehouse area is provided in a separate terrain analysis report by JDMA (2013a). The physical geography of the Pinehouse area exhibits topography and drainage that are characteristic of the Canadian Shield, a low-relief, dome-like, gently undulating land surface. Topography here is generally rugged with up to 100 m of relief. Elevations range from about 521 m in the north, near Snake Rapids, to about 385 m on the shores of Pinehouse Lake.

Two major topographic highs are present within the Pinehouse area that are defined by the relative topographic lows of the Churchill River and Pinehouse Lake. North of the Churchill River the topography is rugged with the highest elevations, greatest relief, and steepest slopes in the Pinehouse area. Incised valleys and depressions in this area appear to be dominantly oriented northeast-southwest and provide surficial expression to the underlying bedrock structures. South of the Churchill River, and to the east of Pinehouse Lake, the topography is similar to the area north of the Churchill River, with steep slopes and high relief, but the topography exhibits progressively lower relief and gentler slopes toward the south. Around Besnard Lake, in the very southeast of the Pinehouse area, the relief and slopes are very low. South of the Churchill River, and west of Pinehouse Lake, the topography is notably subdued, with lower elevations and relief, and gentler slopes. Noteworthy is that in the very southwest of the Pinehouse area, the topography shows slightly higher relief and steeper slopes that impart a topographic fabric trending northwest-southeast. The low relief in the southwest part of the Pinehouse area reflects the cover of Phanerozoic rocks over the Canadian Shield and more extensive Quaternary surficial materials.

Surface water covers a total area of 707 km^2, which represents a coverage of approximately 24% of the 2,914 km^2 Pinehouse area. The surficial hydrology is dominated by Pinehouse Lake, the largest in the Pinehouse area, and the Churchill River system, through which all of the surface flow within the Pinehouse area ultimately drains, eastward to Hudson Bay. The Haultain and Bélanger rivers flow southward into the Churchill River from sub-basins to the north. The Massinahigan River drains the southwest corner of the Pinehouse area into Pinehouse Lake.

2.2 Local Bedrock Geology

The reader is directed to Golder (2013) for a detailed description and discussion of the bedrock and structural geology of the Pinehouse area. The main lithological units in the Pinehouse area include felsic gneiss in the Wollaston and Mudjatik domains, supracrustal rocks in the Wollaston domain, and megacrystic granitoid rocks of the Wathaman batholith in the Reindeer zone (Figure 2). Golder (2011) identifies the felsic gneiss in the Wollaston and Mudjatik domains, as well as the Wathaman batholith as being potentially suitable for hosting a deep geological repository in the Pinehouse area.

2.2.1 Felsic Gneiss

Felsic gneiss covers a substantial portion of the Wollaston domain and is the predominant rock type found in the Mudjatik 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 the appearance of terminology by Streckeisen (1976)), 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 on 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. In the Wollaston domain, metasedimentary rocks of the Wollaston Supergroup either overlay or occur infolded within the felsic gneiss. The exact thickness of the felsic gneiss in the Pinehouse area is unknown, but 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 and 5 to 8 km in the Wollaston Domain. The Archean felsic gneiss has an approximate crystallization age of 2.7 billion years (Orrell et al., 1999).

Despite the overall presence of tonalitic gneiss mentioned above, Tran (2001) reported the predominance of variably-migmatized quartz monzonite to granodiorite and lesser syenogranite, in several areas of the Wollaston domain. This lithology is homogenous, weakly to unfoliated, with mineral composition comprising 5-30 % quartz, 30-60 % K-feldspar, 5-40 % plagioclase, 5-10 % biotite, and traces of hornblende and magnetite. Near Keller Lake some 10 km northwestward of the Pinehouse area, Tran (2001) reported the existence of smaller, usually unmappable bodies such as discrete units of magnetite-rich or pyroxene-bearing granite to granodiorite; charnockite to quartz monzocharnockite; granodiorite to tonalite sheets, and orthogneisses sheets, intruding the predominant quartz monzonite to granodiorite unit.

2.2.2 Metasedimentary and Metavolcanic Rocks

Metasedimentary and metavolcanic rocks unconformably overlie the felsic gneiss in both the Wollaston and Mudjatik domains (Card and Bosman, 2007). The transition from the Mudjatik domain to the Wollaston domain has been defined by the decrease in predominance of north-northeast-trending linear grain of metasedimentary and minor metavolcanic rocks in the northwest corner of the Pinehouse area. The boundary between the Mudjatik and Wollaston domains is a complexly deformed and highly metamorphosed area (Munday, 1978a). Near the mapped boundary, the metasedimentary and minor metavolcanic rocks are interspersed with migmatites and felsic gneiss of similar description as mentioned above. The metasedimentary rocks consist primarily of psammitic and pelitic metasedimentary rocks with minor marble and calc-silicate rocks. The minor metavolcanic rocks consist primarily of thin slivers of amphibolite gneiss.

The psammitic and pelitic gneisses are fine to coarse grained, generally well foliated, and 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. These rocks can include the following minerals in any outcrop-scale assemblage: quartz, feldspar, biotite, muscovite, sillimanite, cordierite, garnet, diopside, epidote and andalusite (Thomas and Slimmon, 1985).

The metasedimentary and metavolcanic rocks also occur in relatively thin linear bands with a north-northeast strike through the center and towards the southeast corner of the Pinehouse area. These bands of rock are generally parallel to the Needle Falls shear zone and range in width from less than 1 km to over 5 km (Figure 2).

2.2.3 Wathaman Batholith

A small portion of the Pinehouse area extends onto the Wathaman batholith to the east of the Needle Falls shear zone (Figure 2). The geological characteristics of the Wathaman batholith are potentially favourable as a repository host rock type. However, the limited volume of this rock in the Pinehouse area and the proximity of the Needle Falls shear zone preclude any further consideration. The Wathaman batholith underlies a triangular shaped parcel of land at the southeast corner of the Pinehouse area measuring some 7 km along its base by 20 km toward the north. The Needle Falls shear zone forms the northwest side of this triangle of land.

The Wathaman batholith is homogeneous, with no evidence of multiple intrusions, although it retains a penetrative internal foliation that can reach augen gneissosity and mylonitic banding in areas of intense deformation (Fumerton et al., 1984). This batholith is variable compositionally. Most of the batholith is composed of a relatively uniform core of megacrystic monzogranite-granodiorite, which is surrounded by marginal zones of non-megacrystic granite, pegmatite, and alaskite (Fumerton et al., 1984; Money, 1965). Although the exact thickness of these rocks in the Pinehouse area is unknown, the Wathaman batholith is expected to be less than 10 km thick, as interpreted from regional geophysical studies (White et al., 2005).

2.2.4 Faults and Shear Zones

Structural features mapped in the Pinehouse area include major northeast- to north-northeast-trending ductile shear zones, and a predominant set of north- to north-northwest-trending brittle faults (Figure 2).

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 northeast to north-northeast direction, which is the predominant alignment of major structural features and lithologies within the Precambrian basement in northern Saskatchewan.

The Cable Bay shear zone is a sub-vertical to steeply northwest-dipping crustal scale feature that defines the boundary of the Mudjatik domain with the Virgin River domain to the west (pers. comm. Card, 2012). 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 Pinehouse area, 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 Trans-Hudson Orogen between approximately 1.83 and 1.80 billion years with a (most recent) dextral movement of 40 to 60 km (Stauffer and Lewry, 1993; Orrell et al., 1999; Hajnal et al., 2005). This is bracketed by the emplacement of the Wathaman batholith at approximately 1.865 billion years and post orogenic uplift and cooling which was likely complete by 1.79 billion years ago (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 low dipping 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 supracrustal rocks of the Wollaston domain may also be associated with some faulting. It should be noted that the above faults were identified along a transect located 50 to 100 km south of the Pinehouse area and should therefore be only considered an indicator of possible conditions within the Pinehouse area.

A series of steeply dipping north-northwest-trending brittle faults are noted at the east end of the Wollaston domain, close to the Needle Falls shear zone (Figure 2; 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 part of the Tabbernor fault system (discussed below). 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.

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 system 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 system was active as recently as the Phanerozoic (Elliot, 1996; Davies, 1998; 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 (e.g., Byers, 1962).

2.2.5 Metamorphism

The Mudjatik and Wollaston domains belong to the Western Churchill Province (Corrigan et al., 2009). As such, all Archean and Paleoproterozoic rocks of the Mudjatik and Wollaston domains record a part of the regional metamorphism characteristic of which the Churchill structural province was subjected to. The metamorphic overprint of the Trans-Hudson Orogeny on the Superior Province was primarily focused within a restricted zone along the western border of this craton. Conversely, the metamorphic effects of the Trans-Hudson Orogeny on the western Churchill Structural 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 and Wollaston domains) were exposed to high grade metamorphism, reaching upper amphibolite to granulite facies (e.g., Pearson, 1977a, b; 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 Trans-Hudson Orogeny. This view has been disputed by other authors (e.g., Bickford et al., 1994; Tran, 2001; Card et al., 2008) who have interpreted the high-grade metamorphism undergone by rocks of the Hearne craton as having occurred during two distinct periods of high temperature, low pressure metamorphism. It is quite possible though that M_2 may have occurred as a continuum of substages rather than occurring as a single event. For example, Annesley et al. (2005) reported three metamorphic events associated to the peak of the Trans-Hudson Orogeny.

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

The second metamorphic period occurred concomitantly with the peak of the Trans-Hudson Orogeny, during the approximate period 1.84 to 1.80 billion years, 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 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 >4-5 kbar, increased to 6-9 kbar at >775°C and later followed by decompression at 3 kbar and increased temperatures of 750-825°C.

2.3 Geological History

Direct information on the geological and structural history of the Pinehouse 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, drawing particularly on information from the Creighton, Saskatchewan area. It is understood that there are potential problems in applying a regional D_x numbering system into a local geological history. Nonetheless, the summary below represents an initial preliminary interpretation for the Pinehouse 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 tectonic events that occurred ca. 2.1 to 1.9 billion years ago during the Trans-Hudson Orogeny imparted the predominant bedrock structure in the Pinehouse area. Based on studies undertaken throughout Northern Saskatchewan, five discernible stages of deformation (D_1 to D_5) have been distinguished which can provide a framework for understanding the structural history of the Pinehouse area. These important phases of the Trans-Hudson Orogeny, as well as events that both pre- and post-date the main orogenic event, are summarized in Table 1 below (Cumming and Scott, 1976; Stauffer and Lewry, 1993; Andsell, 2005; Corrigan et al., 2005; Hajnal et al., 2005; Corrigan et al., 2007; Whitmeyer and Karlstrom, 2007; Corrigan et al., 2009).

The development of the Wollaston domain is intimately related to the Wilson cycle recorded by the Hearne craton and by the Trans-Hudson Orogeny that together took place approximately during the period of 1.90 to 1.5 billion years. Deposition of thick sequences of sediments on the eastern margin of the Hearne craton took place initially under rifting conditions and later under passive margin conditions, forming the Wollaston Supergroup (Yeo and Delaney, 2007). As a continental arc (Rottenstone arc) formed due to reversal of tectonic plate and initiation of subduction under the Hearne craton, change in both environment of deposition and type of lithology followed in rocks of the Wollaston Supergroup (Ansdell, 2005). With time, the Wollaston domain became an extensive back-arc basin and a first episode of metamorphism was imprinted to both rocks of the Wollaston Supergroup and the Archean basement (Tran, 2001). Around 1.88 billion years, collision of the eastern La Ronge island arc with the Hearne craton, initiated build-up of an orogen, deposition of very thick sequences of molasse rocks, and thrusting. Westward shift of forebulge was accompanied of uplift and erosion, and the Wollaston domain became a foreland basin (Tran, 2001; Ansdell, 2005). Progressive infilling of the Wollaston Basin closed it around 1.86 billion years (Yeo and Delaney, 2007). Emplacement of the massive Wathaman batholith and the concurrent final accretion of the La Ronge Arc to the craton developed large overthrusting structures and imbrication of strata. At the same time, the basement and supracrustal rocks of the Wollaston domain underwent regional amphibolite to granulite facies metamorphism associated with the development of tight to isoclinal folds and extensive gneissosity and migmatization (Lewry and Sibbald, 1980; Tran 2001). The subsequent arrival of the Superior Province (ca. 1.83 billion years) developed the Needle Falls shear zone in the eastern margin of the Wollaston domain, either by response to the oblique collision with the Hearne craton or by counter-clockwise oroclinal rotation (Stauffer and Lewry, 1993).

Phanerozoic rocks 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 to the southwest corner of the Pinehouse area. Regional Phanerozoic depocentres of the Hudson Bay and the Western Canada Sedimentary basins, preserved to the northeast and south of the exposed Precambrian basement rocks in northern Saskatchewan, respectively, suggest that the sedimentary cover was formerly much more extensive. Much of the present surface of the Canadian Shield lies close to an exhumed paleoplain interpreted to be of Ordovician age (Brown et al., 1995).

Paleozoic sedimentary rocks nonconformably overlie the Precambrian basement approximately 180 km south of the Pinehouse area. This began with the deposition of the Deadwood formation (upper Cambrian to lower Ordovician at approximately 0.5 billion years) which also outcrops in the west central portion of the Pinehouse area. This Paleozoic outlier represents 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. The proximity of the Western Canada Sedimentary Basin to the south and the apparent continuation of the sequence in the Hudson Bay area of Manitoba to the northeast suggests that the Pinehouse 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. The erosional edge of the Mesozoic succession, located in the southwest corner of the Pinehouse area, is characterized by sedimentary rocks of Cretaceous age. The Cretaceous strata was 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 Cretaceous cover in the Pinehouse area is uncertain. However, given the proximity of the erosional edge of these rocks, it is likely that coverage was extensive in the Pinehouse area.

Table 1. Simplified Geological and Structural History of the Pinehouse Area

Time Period (billion years)	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

Time Period (billion years)	Geological Event
	Wollaston Supergroup.
1.92 to 1.88	Initiation of subduction underneath the eastern margin of Hearne craton leading to the beginning of both closure of the Manikewan Ocean and creation of the Rottenstone magmatic arc. Continued deposition of Wollaston Supergroup in a back-arc basin. This was followed by collisional compression of the rocks of the Wollaston Supergroup, Rottenstone and La Ronge domains. Collision resulted in D_1 ductile deformation that produced isoclinal folds and imparted the S_1 foliation to felsic gneiss.
1.88 to 1.865	Ongoing subduction resulted in the accretion of juvenile island arc terranes (La Ronge-Lynn Lake) to the southeastern margin of the expanded Rae-Hearne craton resulting in the formation of Rottenstone accretionary complex, while Wollaston back-arc basin shifted to foreland basin.
1.865 to 1.83	Closure of Wollaston basin at ca. 1.86 billion years with concomitant emplacement of Wathaman batholith between ca. 1.865-1.855 billion years 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 NE-striking upright folds dominant in the Wollaston domain. Activation (reactivation?) of the Needle Falls and Virgin River shear zones at ca. 1.83 billion years. 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 (ca. 1.8 billion years) and the D_5 steep-brittle faults observed within the Wollaston domain, extending into the Mudjatik domain.
1.72 - 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.

2.4 Regional Structural History

Five main stages of deformation (D_1 to D_5) associated with the Trans-Hudson Orogeny can be distinguished for the Pinehouse area, based on regional studies (e.g., Byers, 1962; Munday, 1978a; Tran and Smith, 1999; Annesley et al., 2005; Hajnal et al., 2005; White et al., 2005; Card and Bosman, 2007; Yeo and Delaney, 2007; Card et al., 2008). The following description is a summary of this previous work, primarily following the numbering system established by Card et al. (2008).

The earliest recognizable deformation event (D_1) resulted in supracrustal and felsic rocks being isoclinally folded (F_1). 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 Pinehouse area. Little information is available regarding this event, and it was not reported in earlier studies (e.g., Munday, 1978a).

The third deformation event, D_3, was characterized by the development of upright, north-northeast-trending folds that also reoriented the S_1 foliation. The north-northeast-trending F_3 fold limbs generally tighten towards the Virgin River and Cable Bay shear zones to the northwest of the Pinehouse area and towards the Needle Falls shear zone in the southeast corner of the Pinehouse 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 during the latter stages of the D_3 event or later 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) noted that the F_4 folds are generally 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 Pinehouse area, and cross-cut the structures associated with the D_1 to D_4 events. These features have likely had a long history of re-activation consistent with the interpretation that they are related to the Tabbernor fault about 200 km to the east of the Northern Village of Pinehouse. The Tabbernor fault initially formed during the Trans-Hudson Orogen approximately 1.83 billion years, likely with more recent periods of reactivation. Features in overlying sedimentary rocks and apatite fission track analyses indicate reactivation of the fault in the late Devonian and early Cretaceous Periods (Elliot, 1996; Davies, 1998; Hajnal et al., 2005).

2.5 Quaternary Geology

Quaternary geology of the Pinehouse area is described in detail in a separate terrain analysis report by JDMA (2013a). During the Quaternary Period, several advances and retreats of continental glaciers occurred in the Pinehouse area. These glaciation periods eroded the bedrock and typically any surficial deposits associated with previous glacial events. The present conditions are a result of the latest Wisconsinan glaciation, during which the Laurentide Ice Sheet covered the entire Pinehouse area (Schreiner, 1984a).

Figure 3 illustrates the Quaternary geology of the Pinehouse area. Regionally, the main Quaternary deposits include morainal plains, and glaciofluvial plains, with sparse occurrences of glaciolacustrine plains. Ground moraines are the dominant glacial landform in northern Saskatchewan and vary from flat to hummocky (Schreiner, 1984a, b). 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. Thickness of the Quaternary strata over the Canadian Shield is variable and is generally thicker down ice (southwest) of the Athabasca Basin.

The most common bedrock surface cover in the Pinehouse area is morainal plain till, which extends along a northeast-trending band centred over Pinehouse. The composition is generally sandy to the northwest, and silty to the southeast. Sand deposits and some silt and clay deposits are noted in the larger lakes in the area, such as Pinehouse Lake, however the overall scarcity of lacustrine sediments indicates that Lake Agassiz may not have extended significantly over the Pinehouse area (Schreiner, 1984a,b). The morainal plain is flanked on both sides by glaciofluvial outwash deposits. A number of eskers have been mapped in the southeast corner of the Pinehouse area and organic bog plains occur to the east and southeast of Pinehouse Lake.

Areas dominated by rock outcrop are present in the east-northeast portion of the Pinehouse area, at about the same latitude as Knee Lake. This includes an area measuring approximately 20 by 20 km (Figure 3). Glacial evidence includes scouring, *roches moutonnées*, drumlinoids, wind flutings and striae (Schreiner, 1984a; Gilboy, 1985). Rugged local relief was enhanced as glaciers eroded low lying areas and polished resistant bedrock knobs. These features indicate that the ice flow direction was generally from northeast to southwest over the Pinehouse area. The direction of ice movement was almost parallel to the structural trend of the bedrock, thus enhancing the erosion of less resistant rock (Schreiner, 1984a).

Glaciofluvial deposits of sand and gravel are found along the Haultain, Bélanger and Massinahigan rivers, which functioned as major meltwater channels (Schreiner et al., 1976). An extensive glaciofluvial outwash plain covers the Pinehouse area to the west and southwest of Sandy Lake. Glaciofluvial deposits also provide thin cover of the area between the Bélanger River in the northeast corner of the Pinehouse area and the eastern side of Bar Lake in the south-central portion of the Pinehouse area. 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.

Estimates of overburden thickness within the Pinehouse area were extracted from descriptions in the available Saskatchewan Geological Survey (SGS) reports. 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.

3 GEOPHYSICAL DATA SOURCES AND QUALITY

For the Pinehouse area, geophysical data were obtained from available public-domain sources, in particular the Geological Survey of Canada (GSC). The flight paths of the aeromagnetic surveys are shown in Figure 4. To supplement these data, the Saskatchewan Geological Survey (SGS) assessment database revealed aeromagnetic surveys flown for the petroleum sector in the Western Canada Sedimentary Basin overlapped the southwestern part of the Pinehouse area. However, these surveys were deemed too old and regional in nature to improve the GSC coverage, and were not pursued further.

The geophysical surveys within the Pinehouse area show consistent data set resolution, whereas surveys from the surrounding areas show some variability. The quality of the data is a function of the flight line spacing, the sensor height and equipment sensitivity. Various geophysical data processing techniques were applied to enhance components of the data most applicable to the current interpretation.

3.1 Data Sources

Low-resolution geophysical data, namely the magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC), cover the entire Pinehouse area. The geophysical data sets are summarized in Table 2 and the characteristics of each of the data sources are discussed in detail below.

3.1.1 Magnetic Data

Magnetic data within the Pinehouse area was acquired as grid and database files from the Geological Survey of Canada (GSC, 2012). The magnetic data were collected during three airborne geophysical surveys using different survey parameters outlined in Table 2. Magnetic data show the distribution of magnetic and nonmagnetic geological bodies within the subsurface, particularly useful for delineating spatial geometry of bodies of rock, and the presence of structural features.

Lower resolution magnetic data from the GSC (Saskatchewan #8 and #9) provides coverage over the entire Pinehouse area. These surveys were all flown at a terrain clearance of 305 m above ground surface, with a flight line spacing of 805 m and 1,609 m, providing these surveys with a relatively low spatial resolution. The Saskatchewan #9 survey covers nearly the entire Pinehouse area, with Saskatchewan #8 covering only a narrow band along the western margin. Flight paths for the three surveys were flown at different orientations, introducing a slight bias towards identifying geological features at different strike orientations. Data from these surveys were recorded on analog charts, and navigation and flight paths were 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. For the purpose of this report, the magnetic data will be discussed in reference to their survey names, and not the regional compilation. The magnetic data sets are summarized in Table 2.

3.1.2 Gravity Data

Gravity data provides complete coverage for the Pinehouse area (GSC, 2012), consisting of an irregular distribution of 20 station measurements, comprising roughly a station every 10 to 15 km.

The retrieved gravity data comprise observed gravity, as well as Bouguer, isostatic, and free-air corrected data. For the purpose of this report the Bouguer gravity data is 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 Pinehouse area 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. The gravity data set is summarized in Table 2.

3.1.3 Radiometric Data

Radiometric data within the Pinehouse area were acquired as grid and database files from the GSC Radiometric coverage database. The radiometric data 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. The GSC radiometric data provided complete coverage of the Pinehouse area from the Île-à-la-Crosse survey. This survey was flown in an E-W orientation at 5000 m line spacing with a terrain clearance of 120 m above the surface. The radiometric data set is summarized in Table 2. 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 Pinehouse area 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 Pinehouse area. The limitation in applying these data types to the Pinehouse 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 Pinehouse Area

Product	Source	Type	Line Spacing/ Sensor Height	Line Direction	Coverage	Date	Additional Comments
Saskatchewan #8	GSC	Fixed wing magnetic	1609m/305m	0°	West margin of Pinehouse 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°	Entire Pinehouse area	1969	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 Pinehouse area	1960-95	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 (Île-à-la-Crosse)	GSC	Fixed wing radiometric data	5000m/120m	90°	Entire Pinehouse area	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.

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 GSC magnetic field grid for the Pinehouse area, published at a 200 m cell size, was projected to the UTM13N/NAD83 coordinate system. The magnetic data were acquired at common flying height of 305 m above ground surface, and therefore did not require the application of upward or downward continuation. 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 Pinehouse area, the residual magnetic intensity grid was reduced to the pole using a magnetic inclination of 79.5° N and magnetic declination of 20.5° 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.

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. The Butterworth filter is a type of signal processing filter designed to have as flat a frequency response as possible in the pass band.

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

The second vertical derivative is commonly applied to the RTP magnetic field data in 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 the GSC surveys, only the average flying height was known. 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

The SPI depth grid in the Pinehouse area (Figure 10) is biased with deeper basement depths due to the lack of high frequency content from the low resolution surveys. 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 Pinehouse area was four cells (equivalent to 800 m), over five scales. The filter sizes were therefore 800 m, 1,600 m, 3,200 m, 6,400 m and 12,800 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 (600 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 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 Pinehouse 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
- Isostatic residual gravity field.

All grids were reprojected to the Pinehouse area's coordinate system, UTM13N/NAD83. The first vertical derivative (1VD) 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 Pinehouse 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 Pinehouse area were collected as far back as 1960, for the older surveys station elevations 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 Pinehouse area, extracted from the GSC's nationwide radiometric compilation (GSC, 2012) at 250 m grid cell size:

- 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)
- Uranium over thorium ratio (eU/eTh).

The grids were already a merge of low resolution surveys prepared by the GSC. 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 Pinehouse 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 units with mapped lithology and structural features were identified and interpreted for the Pinehouse 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 Pinehouse area (JDMA, 2013a). The first and second vertical derivatives were used to trace quasilinear magnetic anomaly peaks to emphasize 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, heterogeneity, texture, foliation (Figure 6 and Figure 7)
- Tilt angle – subtle magnetic responses (Figure 8)
- Analytic signal – anomaly character, texture, boundaries (Figure 9).

Gravity data were of insufficient resolution to be used for interpretation of geological units and boundaries. However, some general characterizations of the regional scale units were possible (Figures 11 and 12). Similar comments apply to the radiometric data (Figure 13).

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 bedrock geologic map 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 bedrock geologic map are presented in Figure 14. The geophysical data were evaluated against the following published geological maps:

- Saskatchewan Energy and Resources, 2010. Geological Atlas of Saskatchewan. NTS Map Sheets 73O/P, 74 A/B (Figure 2).
- Shield Geology of the Ile-A-La Crosse (East) Area, Map 189A, Sheets 1 and 2 (Munday, 1978b). Covers nearly all of the Pinehouse area.

- Geology of the Dipper Lake Area, Map 183A (Scott, 1977). Covers a sliver of the Pinehouse area in the northwest corner.
- Compilation Bedrock Geology, Île-à-la-Crosse, Map 245A, NTS Area 73O (Thomas and Slimmon, 1985). Covers all of the Pinehouse area.

5.2 Results

The following section presents a regional-scale description and interpretation of each geophysical data set in the Pinehouse area, followed by detailed interpretations of geophysical responses within the felsic gneiss units and the Wathaman batholith (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 Pinehouse area presented in Figure 14. In this geophysical interpretation, units A to H have been identified and are described in the subsections that follow.

Much of the southern part of the Pinehouse area is covered by either moderate overburden or, in the southwest, by an appreciable thickness of Phanerozoic sediments, and there are lakes throughout the area (Figure 2). Therefore, actual outcrop mapping is relatively sparse at these locations. Discrepancies in these areas between the published mapping and the geophysical interpretation are to be expected.

5.2.1 Magnetic

The Pinehouse area exhibits significant variability in the magnetic data associated with the complex distribution of felsic gneiss and pelitic and psammopelitic gneiss of the Wollaston and Mudjatik domains, as well as psammitic meta-arkosic gneiss in the Wollaston Domain. In addition, the magnetic data located in the southeastern portion of the Pinehouse area were collected over the augen gneiss and megacrystic granite within the Wathaman batholith (Figure 2). The magnetic field data for the Pinehouse area are presented as the reduced to pole magnetic field (Figure 5). Enhanced grids of the reduced to pole magnetic field are presented as the first (Figure 6) and second (Figure 7) vertical derivatives, tilt angle filter (Figure 8) and analytical signal (Figure 9), which emphasize the subtle magnetic responses predominantly associated with geological rock types and structure.

The major contrast in the structural characteristics between the Wollaston and Mudjatik domains is especially evident on magnetic field maps (Figures 5 to 9), more so when the view is expanded to the west and north. The rocks inside the Wollaston domain are situated inside a major ductile high-strain belt that is several tens of kilometres wide. This belt has a strong, north-northeast-directed, ductile structural anisotropy which could be of major significance for later reactivation in the brittle regime. Over the majority of the Pinehouse area, the magnetic responses clearly reflect a strong north-northeast trending magnetic fabric oriented parallel to the dominant tectonic fabric in the area (i.e., the orientation of the Needle Falls shear zone). The enhanced magnetic grids in the Wollaston domain show both the magnetic and non-magnetic phases of the gneisses to be more continuous along strike (beneath lakes in places) than indicated by the bedrock geological mapping. Their orientations follow the characteristic fold patterns in the region, mainly north-northeast tight folds typical of the Wollaston domain (Card et al., 2008). Magnetic responses from these structures tend to alternate from high and low intensity and generally correlate with the distribution of mapped felsic gneisses and pelitic to psammitic gneisses in the area. The alternating magnetic character likely represents the intense variability in the magnetite content associated with a complex distribution of lithological units. Towards the Mudjatik domain, these units tend to show more concentric anomalies compared to the units elsewhere in the Wollaston domain. These concentric anomalies are more typical of the Mudjatik domain reflecting extensive fold development and the formation of dome and basin structures (Card and Bosman, 2007), and are not completely overprinted by the penetrative north-northeast structural fabric.

The rocks of the Mudjatik domain are located in the northwest corner of the Pinehouse area, and their magnetic response predominantly correspond to units that are weakly magnetized (Figure 14; unit A), primarily mapped as felsic gneiss with only minor amounts of pelitic and psammitic gneiss. Local increases in the magnetic response in the Mudjatik domain may correspond to an increase in the presence of pelitic and psammitic gneiss units which have not previously been mapped or are present at depth (just beyond the northwest corner of the Pinehouse area). There is a distinct drop in the background magnetic intensity from the Wollaston domain to the Mudjatik domain, and the mapped domain boundary correlates quite well with the west edge of the strongly magnetic unit at the east side of the domain boundary.

The rocks of the Wollaston domain are located throughout the central Pinehouse area. Their magnetic response is dominated by the north-northeast-trending structural fabric and consists of moderate to high magnetic anomalies of approximately parallel bands 1-2 km wide. Most of these anomalies can be traced continuously to the south beneath the Manville group and the Deadwood and Meadow Lake formations of the Phanerozoic Western Canada Sedimentary Basin. Based on variation in the magnetic response the Wollaston domain has been divided into three main units. An area located along the boundary with the Mudjatik domain, approximately 8-10 km wide, is characterized by relatively intense magnetic responses (Figure 14; unit B). Within unit B, the mapped felsic gneiss generally correlates well with magnetic lows whereas the pelitic to psammitic gneiss are associated with higher magnetic responses. The magnetic intensity of the pelitic and psammitic gneisses tends to be inconsistent with the character shown elsewhere in the Wollaston domain where they typically exhibit a weaker magnetic response, particularly closer to the Needle Falls shear zone. This change in the magnetic intensity of the mapped pelitic and psammitic gneisses perhaps may be explained, in part, by a strong strain gradient within the Wollaston domain resulting in a change in metamorphic grade along the domain boundary. In addition, the inconsistency may also result from a potential compositional change in the source rocks, where the varying lithologies may reflect the addition of magnetite-rich rocks in unit B. Both, the intensity and distribution of magnetic responses tend to be more complex within unit B, compared to the distribution of the pelitic to psammitic gneisses shown on the bedrock geology map

(Munday 1978b), suggesting that the rocks may possess a higher degree of lithological heterogeneity. Largely, the source of the high magnetic response in unit B is unknown, and would require further investigation. This magnetic response also extends further to the south under the Phanerozoic Western Canada Sedimentary Basin.

The central part of the Wollaston domain shows an approximately 40 km wide zone with a diminished magnetic intensity (Figure 14; unit C) and comprises fewer curvilinear magnetic highs of moderate amplitude compared to unit B. In contrast to other areas of the Wollaston domain, the mapped pelitic to psammitic gneiss in unit C tend to correlate with the lower magnetic responses, whereas the felsic gneiss tends to be more characterized by numerous magnetic highs. This characteristic becomes more obvious towards the Needle Falls shear zone. The increased magnetic response for the felsic gneiss may be the result of tight interfingering of the felsic gneiss, with more magnetic 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 14). Furthermore, the eastern part of unit C shows increased magnetic intensity that correlates well with the mapped felsic gneiss which may be explained by recrystallization of the bedrock minerals and an abrupt change in metamorphic grade from upper greenschist at the Needle Falls shear zone to upper amphibolite approximately 6 km to the west (Munday, 1978a; Thomas and Slimmon, 1985). Locally, minor amounts of psammitic meta-arkosic gneiss mapped within unit C generally correlate with magnetic lows, although some highs traverse this lithology. Minor amounts of amphibolite have been mapped in the northern part of the area and correspond to the strongest magnetic responses within interpreted units B and C in the Wollaston domain. Similar strong magnetic responses occur elsewhere in the area shown to moderately disrupt the linear magnetic structural trend. Although this interpretation has not been identified based on bedrock mapping, it may reflect the presence of amphibolite, or another strongly magnetic source rock at depth.

Located immediately west of the boundary between the Wollaston domain and the Wathaman batholith (demarcated by the Needle Falls shear zone), a 10-14 km wide zone narrowing to the north shows a generally low magnetic response (Figure 14; unit D). Some linear anomalies in the eastern half of unit D are located where felsic gneiss is mapped. The psammitic meta-arkosic gneiss mapped in the southwest part of unit D shows a relatively flat magnetic response, and may be more prevalent than mapped to the north, along the same weakly magnetic corridor. Within unit D, Munday (1978a,b) describes several minor intrusions within the Wollaston Domain. Small leucogranite and elongated gabbroic intrusives are locally mapped along the shores of the northeast part of Sandfly Lake, and on the east shore of Duddridge Lake (Thomas and Slimmon, 1985). These intrusions are located in areas with low magnetic response and do not show a distinct signature from the surrounding gneisses. An additional gabbro is mapped on an island in the west arm of Besnard Lake, located on the west margin of a strong magnetic anomaly that reflects the augen gneiss at the domain boundary with the Wathaman batholith.

The rocks of the Wathaman batholith are located in the southeast corner of the Pinehouse area. A 2 km wide north-northeast-striking magnetic anomaly along the western domain boundary correlates well with the mapped augen gneiss phase of the Wathaman batholith, which can be traced beneath the sedimentary bedrock of the Phanerozoic Western Canada Sedimentary Basin (Figure 14; unit E). The easternmost band of low magnetic response reflects the western edge of the mapped late granitoid (Figure 14; unit F) of the Wathaman batholith. This unit has been characterized as a megacrystic granitoid (Fumerton et al., 1984; Thomas and Slimmon, 1985). The western boundary of the Wathaman batholith is marked by the Needle Falls shear zone. This boundary with the Wollaston domain is clearly demarcated magnetically by the western edge of the augen gneiss (Figure 14; unit E) contrasting with the less magnetic felsic gneiss (unit D). We note that just beyond the edge of the Pinehouse area, roughly 4 km east of the domain boundary, the strike of the rocks change to northeast and then ENE further away. This may reflect a change in the orientation of the shearing.

With respect to smaller intrusions, Munday (1978a,b) provided evidence of an intrusion located just north of the Northern Village of Pinehouse, within the felsic gneiss in the Wollaston Domain (unit C). The magnetic data in this location highlights a high magnetic anomaly surrounded by an oval concentric low, which measures roughly 7.5 km by 3.5 km with a general northeast trend (Figure 14; unit G). The magnetic anomaly tends to disrupt the north-northeast-trending linear pattern of felsic and (psammo) pelitic gneisses and is characterized by somewhat less intense magnetic amplitudes. This anomaly is generally larger than the observation based on bedrock mapping by Munday (1978a,b), and may correspond to magnetic response of this intrusion at depth. Most of the interpreted intrusion lies beneath the northern arm of Pinehouse Lake. An anomaly with similar characteristics is interpreted southwest of Pinehouse is more speculative (Figure 14; unit H). The magnetic source is located beneath the Phanerozoic sediments so there is no ground truth to confirm the existence of an intrusion. The magnetic data show a similar signature to the intrusion described above, but its differentiation with the adjacent gneisses is not as clear in terms of strike direction, concentricity or amplitude.

5.2.2 Gravity

The Bouguer gravity data and gravity station locations across the Pinehouse area are presented in Figure 11, together with the first vertical derivative of the Bouguer gravity in Figure 12. The sparse station density precludes any definitive detailed interpretation of bedrock units within the Pinehouse area. However, a few regional trends are observed that tend to be consistent with the structural fabric observed on bedrock geology maps and magnetic data. Despite the low number of gravity stations, the north-northeast trending boundary between the Wollaston domain and the Wathaman batholith is marked by a strong gravity gradient corresponding to high gravity response east of the Needle Falls shear zone. This gravity high response is probably a result of the 15 km thick slab of the gneissic bedrock units of the Rottenstone domain dipping under the Wathaman batholith, where the former is denser than the latter by approximately 0.12 g/cm^3 (White et al., 2005). Regional gravity modeling along the Trans-Hudson Orogen transect (approximately 100 km south of the Pinehouse area) indicates that the Wathaman batholith may be approximately 9 km thick. An additional broad gravity high anomaly is located in the northwest portion of the Pinehouse area, which at the scale of the gravity data, does not appear to correspond to the mapped distribution of geological units. This anomaly may indicate some degree of regional-scale heterogeneity reflecting changes that appear to occur at depth.

In general, a wide range of gravity values are observed within the Wollaston domain and likely reflect areas of more or less geological complexity and intermixing of felsic gneiss with the pelitic and psammitic gneiss throughout. Areas of higher gravity response roughly correlate with the presence of the pelitic and psammitic gneiss (Figure 14; unit B) and the areas of lower gravity response roughly correlate with the psammitic-meta arkosic gneiss horizons within units C and D (Figure 14). A gravity high within unit C is located west of Pinehouse, reflecting a source beneath the Phanerozoic sediments. It may indicate an extension of unit D at depth, where the pelitic to psammitic gneiss is more widespread within the felsic gneiss.

5.2.3 Radiometric

The low resolution of the radiometric data in the Pinehouse area was not particularly useful for interpretation of geological units and boundaries (Figure 13). In addition, much of the Pinehouse area is covered with overburden material and lakes, which disrupts the radiometric response from the bedrock geology units. Despite these limitations, a subtle north-northeastern regional trend is observed that tends to be consistent with the structural fabric observed on bedrock geology maps. In the case where the overburden material is locally derived from the underlying bedrock, the observed radiometric response may serve as a proxy for interpreting the underlying bedrock geology.

The Wollaston domain shows roughly four radiometric subdivisions of elevated but variable radioelement responses, which roughly correlate with the trend of the magnetic anomaly responses. A uranium-elevated response tends to dominate the southeastern portion of the Pinehouse area associated with bedrock units adjacent the Needle Falls shear zone (Figure 14; unit D). Based on the bedrock geology map, this area may correspond to the increased presence of pelitic, psammitic-meta arkosic gneiss interfingered with the felsic gneiss. A potassium-elevated zone is located in the central portion of the Pinehouse area that parallels the general north-northeastern trend of the bedrock geology units, and may correspond to an area dominated by felsic gneiss (unit C). A thorium-elevated anomaly occurs parallel to the western boundary of the Wollaston domain, and tends to extend into the Mudjatik domain (Figure 14; unit B). The Mudjatik domain, however, tends to show slightly higher concentrations of all three radioelements. A similar anomaly is also exposed in the northeastern portion of the Pinehouse area, which is slightly higher in thorium. To the east of the Needle Falls shear zone, the Wathaman batholith displays a subtle response that is somewhat elevated in potassium, which corresponds to potassium rich bedrock (Figure 14; unit F). Very low radioelement responses tend to correspond to larger lakes in the Pinehouse area, in particular the response associated with the Pinehouse and Sandfly Lakes.

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

Table 3. Radioelement Responses of the Pinehouse area

Radioelement	Minimum	Maximum	Mean
Potassium (%)	0.09	2.69	1.36
Uranium (ppm)	0.05	2.33	0.86
Thorium (ppm)	0.53	15.57	6.29
Natural air absorbed dose rate (nGy/h)	3.32	82.14	39.24

These levels are typical of metamorphic rocks (IAEA, 2003).

The low uranium levels suggest low radon risk. However, radon risk is also quite dependent on soil permeability and should be verified by soil gas measurements (IAEA, 2003). The one location with elevated uranium (~2.3 ppm) and dose rate levels (~82 nGy/h) within the screening area, that might be of more concern for radon, is the anomaly centred near the west boundary south of Knee Lake (369000 E, 6178500 N), just beyond the western boundary of the Pinehouse area. It is located within the felsic gneisses of the Mudjatik domain. Similar elevated levels are noted outside the Pinehouse area to the north of Knee Lake in similar rocks.

5.3 Geophysical Interpretation of the Prospective Geology in the Pinehouse Area

The following section provides more detailed interpretations with a focus on identifying internal heterogeneity associated with lithology contrasts within the three geological units of greatest interest (felsic gneiss, metavolcanic and metasedimentary rocks, and the Wathaman batholith) in the Pinehouse area.

5.3.1 Felsic Gneiss

Within the Wollaston domain, the felsic gneiss is characterized as a moderate to high magnetic response (Figures 5 to 9) which predominantly forms a strong northeast-trending linear fabric that parallels the dominant tectonic foliation in the area. Much of the magnetic anomalies in the Wollaston domain result from the tight interfingering of the felsic gneiss with the pelitic and psammitic gneiss, and minor amphibolite, making their individual geological units difficult to differentiate. In general, the higher aeromagnetic response tends to correlate well with the distribution of mapped felsic gneiss units, and the lower magnetic intensity generally correlates with thinner pelitic and psammitic horizons. Although the distribution of geological units on the surface is fairly well-understood (Munday, 1978b), the results of the magnetic data indicate that the distribution of geological units, at the scale observed in the magnetic data, may lead to a fairly complex lithological heterogeneity within the felsic gneiss compared to the mapped bedrock units, particularly in areas covered by overburden or units located at depth. For example, many of the north-northeast-striking magnetic bands of felsic gneiss of 1-2 km width, reaching 3 km in places, are interspersed with weakly magnetic bands of pelitic, psammitic meta-arkosic gneiss throughout the Wollaston and Mudjatik domains, with a few bands of amphibolite present as well.

The coarseness of the gravity and the radiometric data in the Wollaston domain result in images (Figures 11 to 13) that do not correspond well to the distribution of geological units. In general, a wide range of gravity values are observed within the Wollaston domain and likely reflect areas of more or less geological complexity and intermixing of felsic gneiss with the pelitic and psammitic gneiss throughout. Gravity modeling by White et al. (2005) indicates that the gneisses may have a maximum thickness of approximately 8 km at the boundary between the Wollaston and Mudjatik domains. This is reflected in the 10 mGal gravity anomaly along this domain boundary, which is mainly confined within the Pinehouse area (defined by very few sample points).

The radiometric data displays a broadly distributed anomaly with elevated uranium levels trending in a northeast direction through the Wollaston domain, which gradually becomes more potassium-elevated towards the east (into the Wathaman batholith) and west. However, the resolution of these data sets is too coarse to distinguish between the different lithologies that have been mapped in the area. Further field investigations would be required to resolve ambiguities between the available mapping and geophysical data.

5.3.2 Metavolcanic and Metasedimentary Rocks

The mapped distribution of the psammitic and pelitic metasedimentary rocks within the Wollaston domain tend to correlate generally well with the lower magnetic responses in the area (Figure 6). In much of the area, the magnetic response observed may represent the tight interfingering between the psammitic and pelitic metasedimentary rocks and the felsic gneiss units, resulting in an alternating sequence of high and low magnetic character oriented in a strong northeast structural fabric. This strong fabric is also illustrated on the bedrock geology map as a northeast oriented trend to the distribution of lithological units. Unit C displays these anomalies as locally tightly interfingered with the higher magnetic responses, resulting in differentiation between the boundaries of adjacent units to be difficult (Figure 14). However, in several areas the magnetic data tend to delineate evidence of more pelitic and psammitic gneiss horizons, characterized as interspersed bands of low magnetic response that can be continuously traced through units predominantly mapped as felsic gneiss (Figure 14; unit B). This is observed in the area a few kilometres northwest of Pinehouse Lake. Although only minor evidence of metavolcanic and metasedimentary units has been mapped on the surface (Munday, 1978a; Thomas and Slimmon, 1985), the magnetic data may reflect the tight interfingering of bedrock units in the subsurface, and in bedrock that is covered by overburden deposits. Such results indicate that the distribution of geological units, at the scale observed in the magnetic data, lead to a more complex lithological heterogeneity within the felsic gneiss than is evident on the current bedrock geology map. The distributions of felsic gneiss and psammitic and pelitic metasedimentary rocks can be traced under the Western Canada Sedimentary Basin to the southwest (i.e., White et al., 2005).

Although the low resolution of the gravity data limits the ability to highlight different lithological units, the range of gravity values observed within the Wollaston domain may reflect areas of more or less geological complexity of the felsic gneiss with interspersed bands of pelitic and psammitic gneiss throughout.

5.3.3 Wathaman Batholith

Within the Pinehouse area, the extent of the Wathaman batholith is fairly limited. A 2 km wide north-northeast-striking curvilinear magnetic anomaly along the western boundary of the Wollaston domain correlates generally well with the Wathaman batholith (Figure 14; unit E). It is observed however, that the trend of the Needle Falls shear zone, adjacent to the Wathaman batholith in the southern portion of the Pinehouse area, may be located approximately 4 km further to the west compared to the location shown on the bedrock geology map. Evidence is provided in the magnetic data where the prominent northeast-trending linear fabric crosses the mapped Needle Falls shear zone near Duddridge Lake. A separate stronger magnetic anomaly is interpreted to reflect the boundary crossing into the weakly magnetic megacrystic granitoid (Figure 14; unit F) of the Wathaman batholith.

The Needle Falls shear zone boundary is similarly reflected in the gravity and radiometric data. Gravity data show a sharp increase in the gravity response towards the Wathaman batholith. This high gravity anomaly over the Wathaman batholith generally contradicts the typical negative anomalies associated with granitic batholiths observed across the Precambrian Shield, and is ascribed to a thick wedge of westward-dipping Rottenstone domain metasediments underlying the less dense batholith (White et al., 2005). This batholith response has been modelled with regional gravity data to have a 9 km thickness. Radiometric data shows a fairly uniform potassium-elevated response within the Wathaman batholith.

6 SUMMARY OF RESULTS

The purpose of this assessment was to identify and obtain the available geophysical data for the Pinehouse 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 units with mapped lithology and structural features in the Pinehouse area.

The geophysical data covering the Pinehouse area are all low-resolution, comprised of the regional magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC).

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.

Over the majority of the Pinehouse area, the magnetic responses clearly reflect a strong north-northeast trending magnetic fabric oriented parallel to the dominant tectonic fabric in the area. The magnetic data show both the magnetic and non-magnetic phases of the gneisses to be more continuous along strike than indicated by the bedrock geological mapping. Magnetic responses from these structures tend to alternate from high and low intensity and generally correlate with the distribution of mapped felsic gneisses and pelitic to psammitic gneisses in the area. The alternating magnetic character likely represents the intense variability in the magnetite content associated with a complex distribution of lithological units.

Resolution of the gravity data were 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 series of regional-scale gravity highs that may reflect a thickening of the gneisses to 8 km in the Wollaston and Mudjatik domains, and of a denser wedge of the Rottenstone Domain dipping westwards beneath the lighter, 9 km thick Wathaman batholith (White et al., 2005).

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

Respectfully Submitted,

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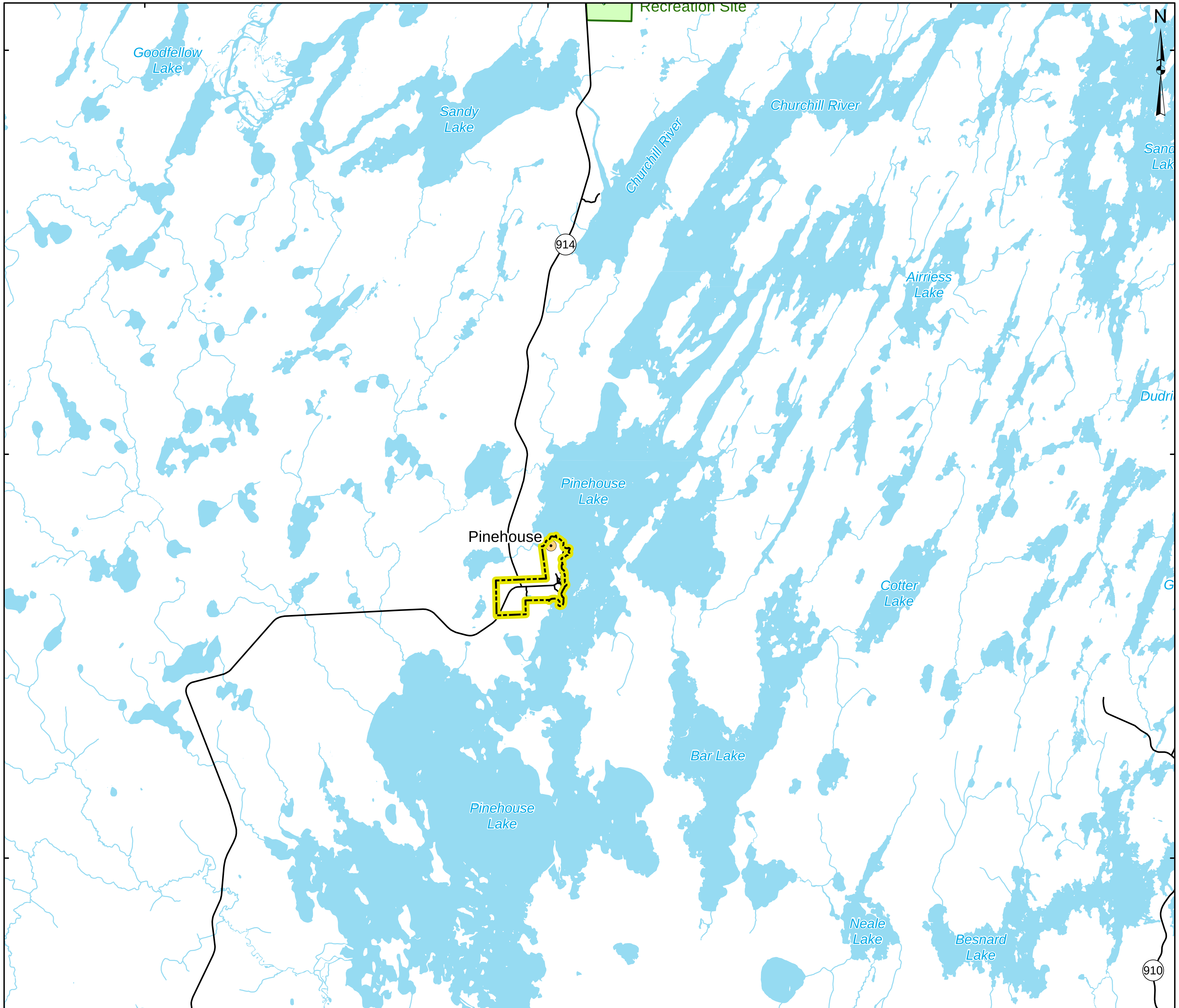
FIGURES



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Municipal Boundary
- Pinehouse
- Federal Land - Indian Reserve
- Park and Recreation Area
- Highway
- Watercourse
- Waterbody

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

5 2.5 0 5 10
SCALE 1:200,000 KILOMETRES

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, PINEHOUSE AREA, SASKATCHEWAN

TITLE
Northern Village of Pinehouse and surrounding area

Golder Associates
Mississauga, Ontario

PROJECT No. 12-1152-0026			SCALE AS SHOWN	REV. 1.0
DESIGN	PM	3 MAY 2012	**FIGURE 1**	
GIS	PMJB	16 AUG 2013		
CHECK	AM	19 AUG 2013		
REVIEW	GWS	19 AUG 2013		

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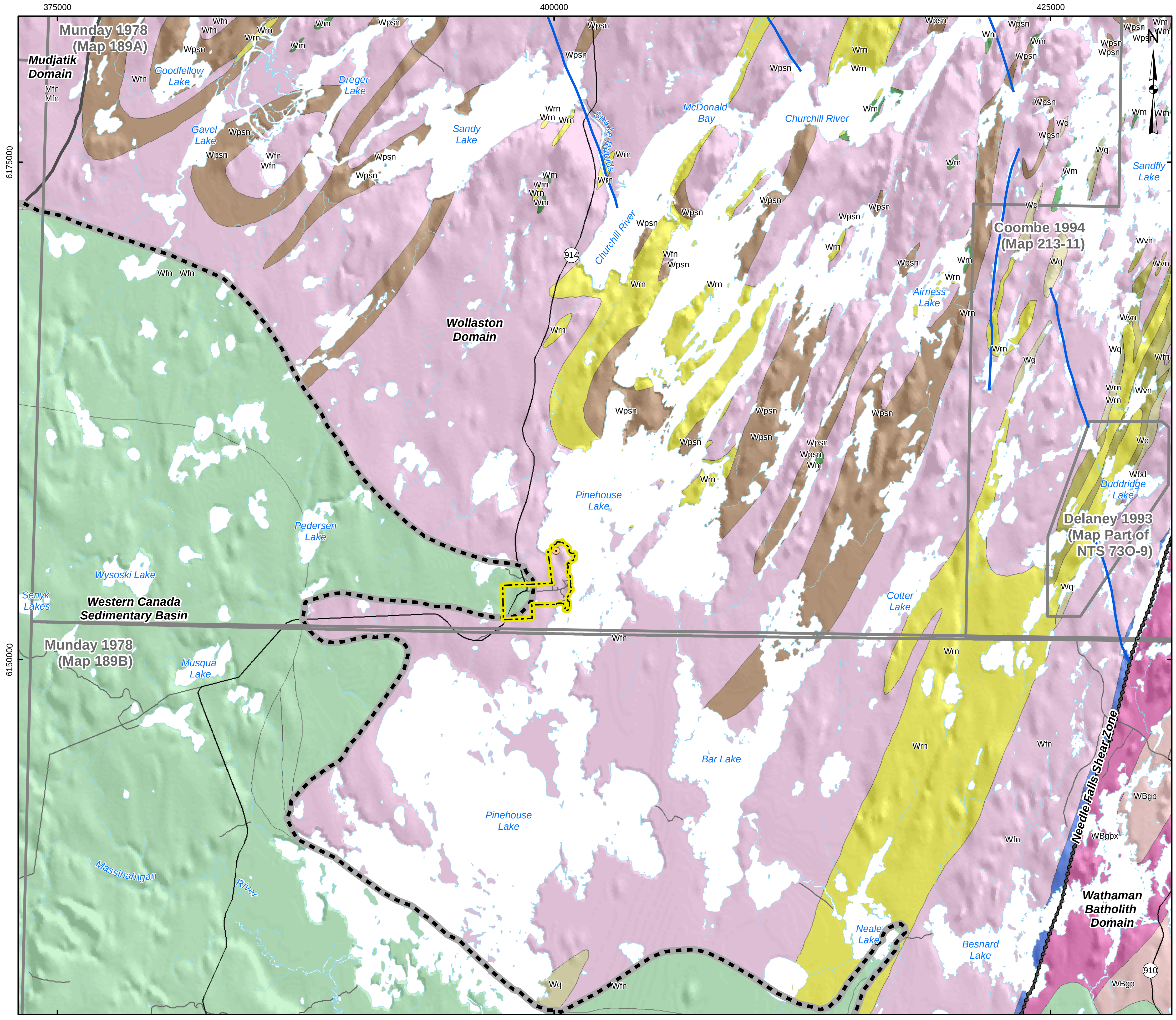

LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Detailed Geology Extents
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mfn - Felsic gneiss

Wollaston Domain

- Wbd - Diorite
- Wfn - Felsic gneiss
- Wm - Amphibolite
- Wpsn - Pelitic, psammopelitic gneiss
- Wq - Metaquartzite
- Wrn - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss
- x - Mylonite/cataclastic rocks

Wathaman Batholith

- WBgpx - Augen gneiss
- WBgp - Megacrystic granitoid

Scott and Thomas 1977 (Map 183A)
Munday 1978 (Map 189A)
Munday 1978 (Map 189B)
Thomas and Slimmon 1985 (Map 245A)
Delaney 1993 (Map Part of NTS 73O-9)
Coombe 1994 (Map 213-11)

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REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Admin. Boundaries - Info. Services Corporation of Sask., Administrative Boundary Overlays (2012)
Bedrock Geology - SGS 1:250,000 map 189A (Munday 1978), Geological Atlas of Saskatchewan (Saskatchewan Industry and Resources, 2010)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

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SCALE 1:200,000 KILOMETERS

PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, PINEHOUSE AREA, SASKATCHEWAN

TITLE
Bedrock geology of the Pinehouse area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012		
GIS	PMJB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		

FIGURE 2

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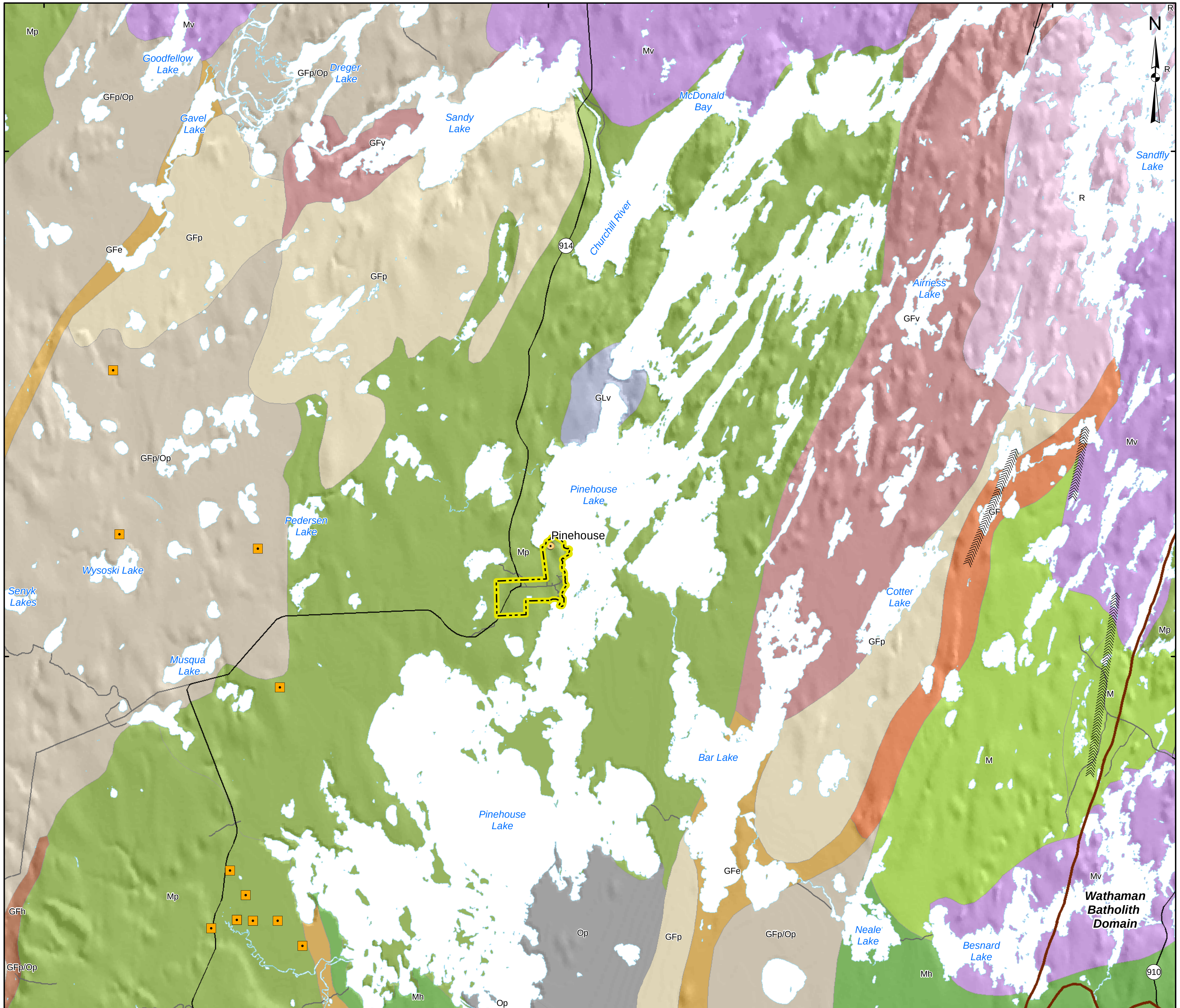

LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Waterbody
- Drill hole (Regina databse)
- Esker
- Striation
- Wathaman Batholith

Surficial Geology

- Op - Organic plain
- GF - Glaciofluvial
- GFe - Glaciofluvial eroded
- GFh - Glaciofluvial hummocky
- GFp - Glaciofluvial plain
- GFp/Op - Glaciofluvial/organic plain
- GFv - Glaciofluvial veneer
- GLv - Glaiolacustrine veneer
- M - Morainal
- Mh - Morainal hummocky
- Mp - Morainal plain
- Mv - Morainal veneer
- R - Rock

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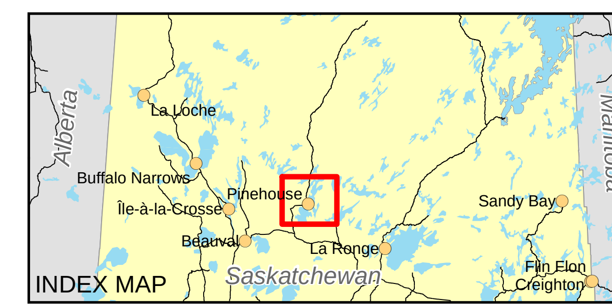


REFERENCE

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)
Quaternary Geology - Saskatchewan Geological Atlas (1:250,000)
Drill holes - Sask Geological Atlas
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10
SCALE 1:200,000 KILOMETRES

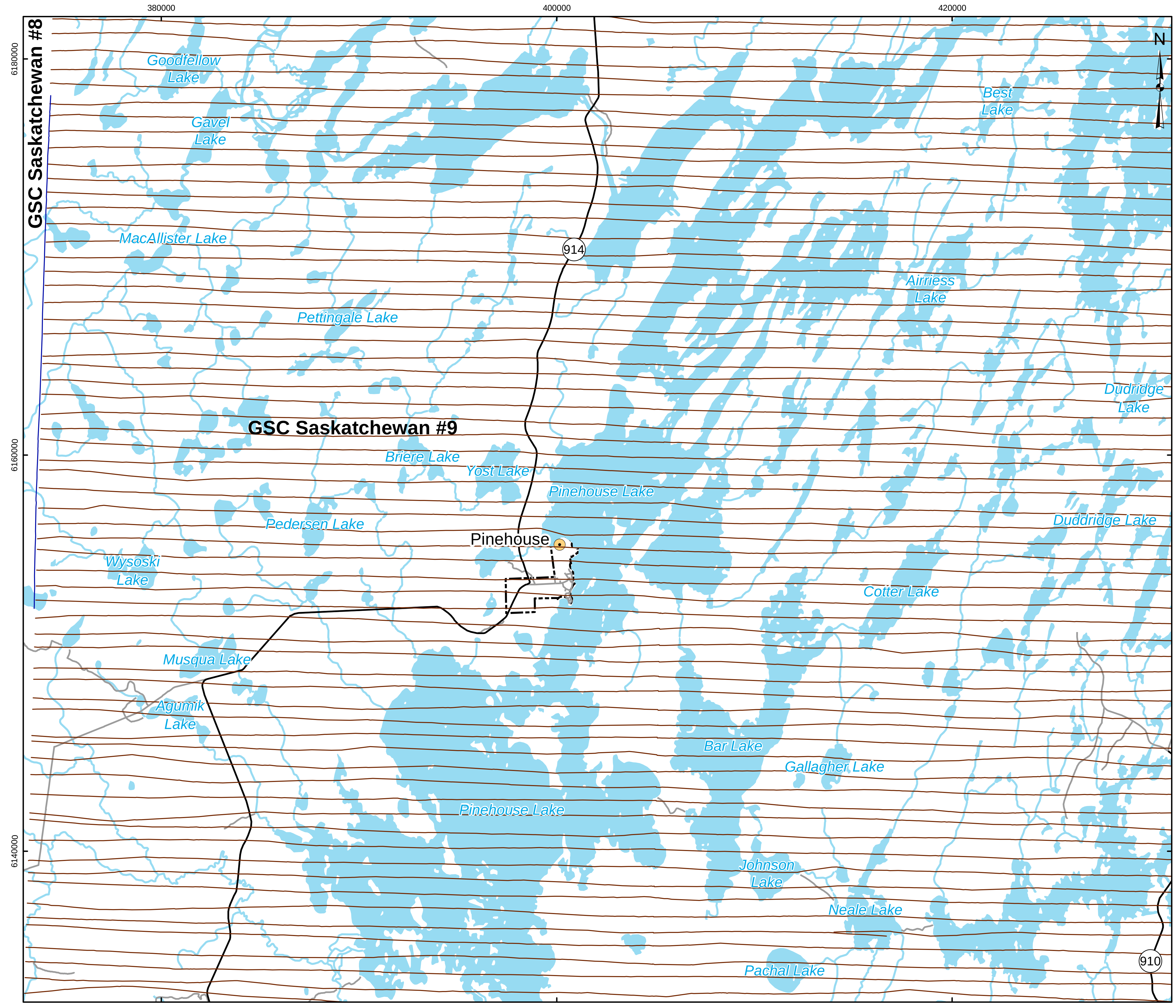
PROJECT
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, PINEHOUSE AREA, SASKATCHEWAN

TITLE
Quaternary geology of the Pinehouse area

Golder Associates
Mississauga, Ontario

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

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



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Watercourse
- Waterbody
- Flightpath GSC Saskatchewan #8
- Flightpath GSC Saskatchewan #9

REFERENCE

Flightpath: Geological Survey of Canada

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10
SCALE 1:200,000 KILOMETERS

PROJECT

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

TITLE

Airborne geophysical coverage of the Pinehouse area

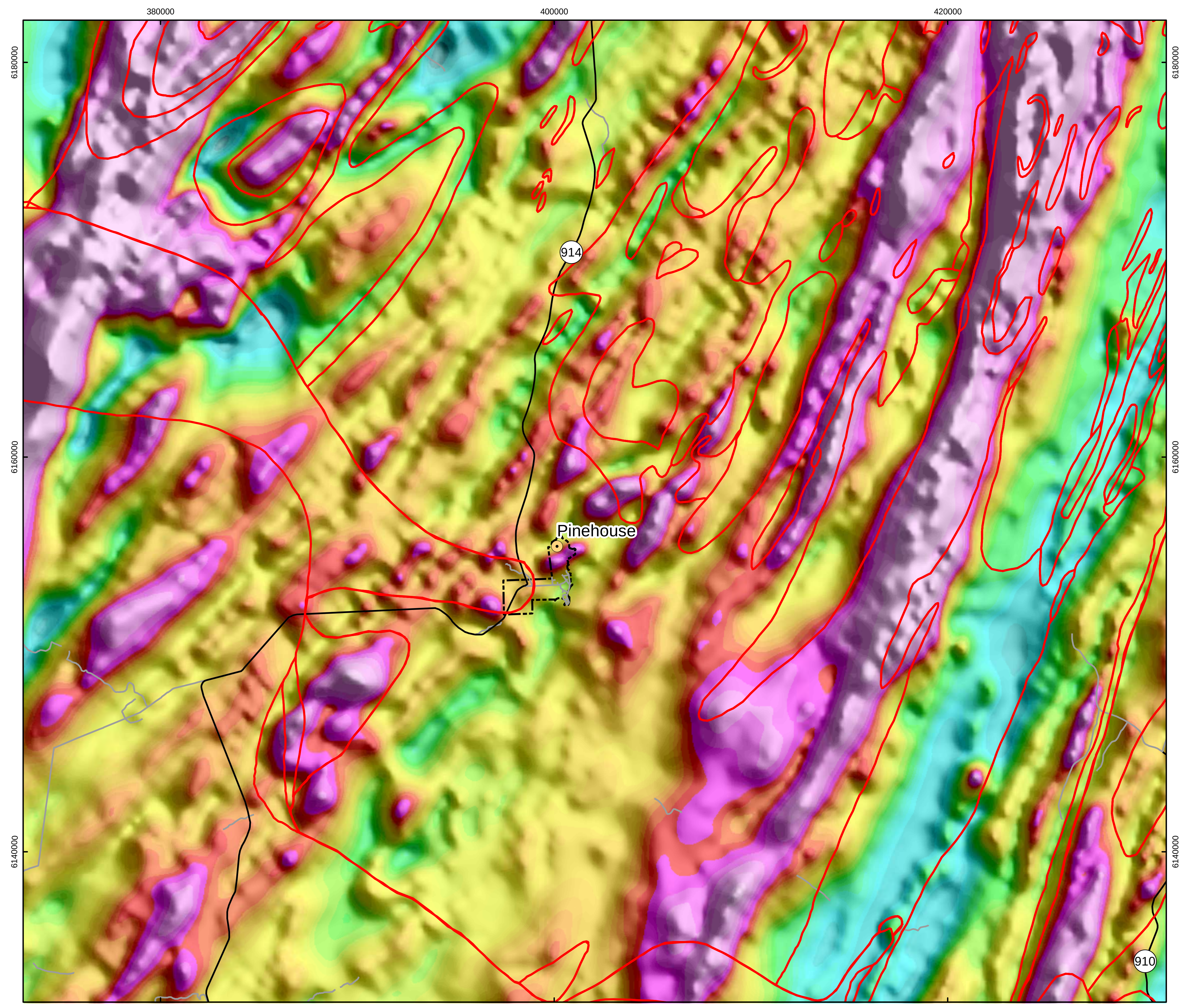
Paterson, Grant & Watson Limited
Consulting Geophysicists
www.pgw.on.ca

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013		
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	19 Aug 2013		

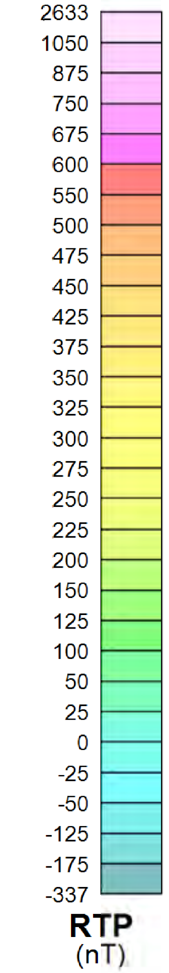
FIGURE 4

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



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts



REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10

SCALE 1:200,000 KILOMETERS

PROJECT

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

TITLE

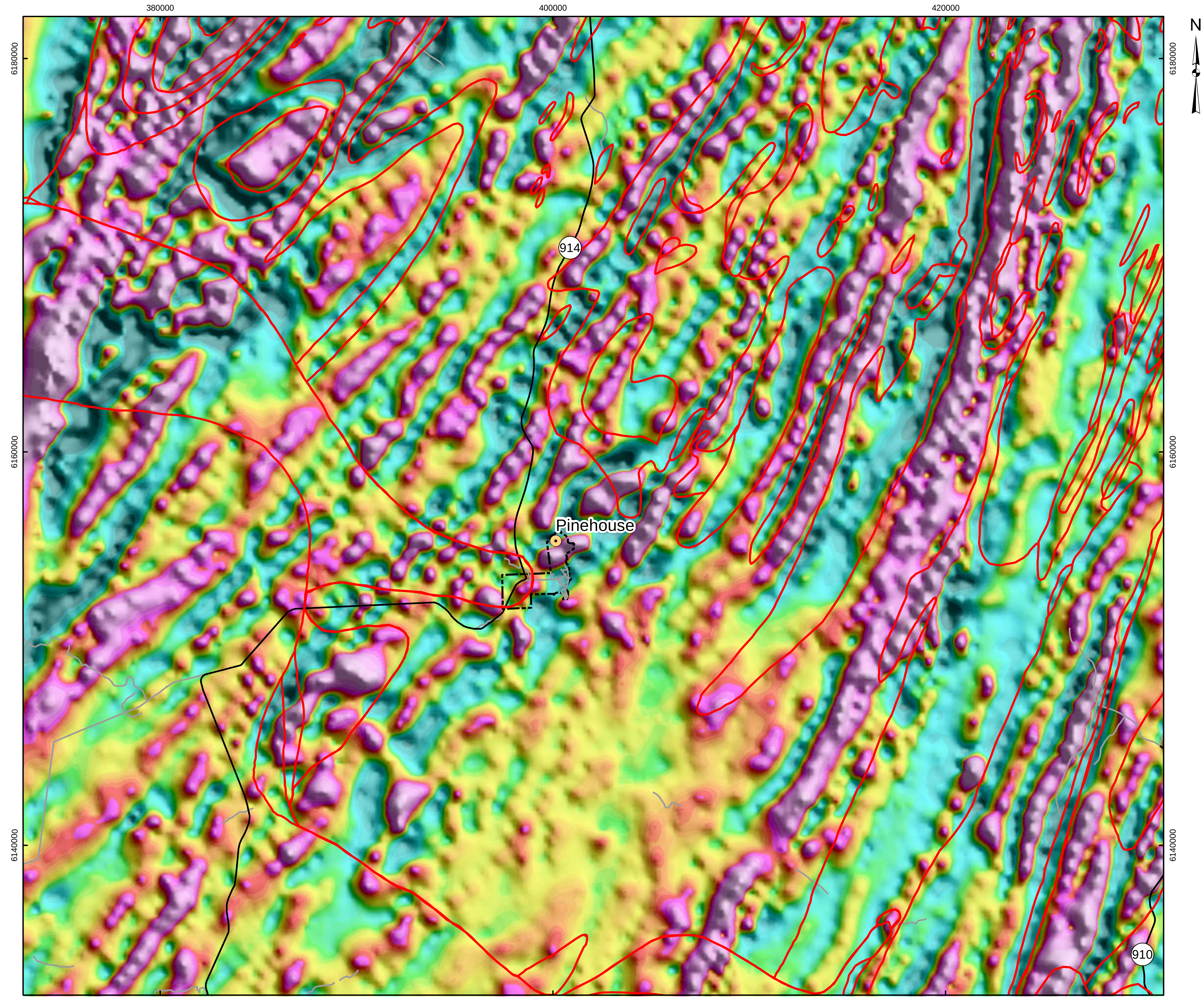
Residual magnetic field reduced to pole (with mapped geological contacts)

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

Golder Associates

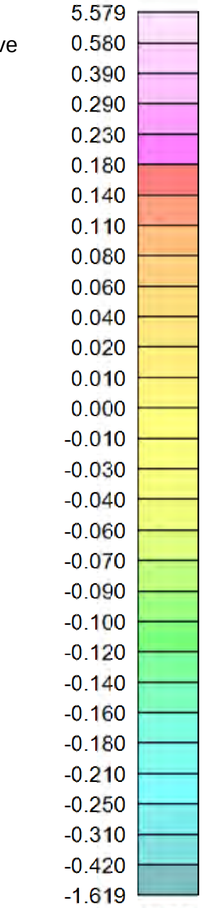
PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	FIGURE 5	
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	19 Aug 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Env_Safety_Report\Pinehouse\PinehouseBedrockGeology.mxd



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts



1VD of RTP
(nT/m)

REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10

SCALE 1:200,000 KILOMETERS

PROJECT

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

TITLE

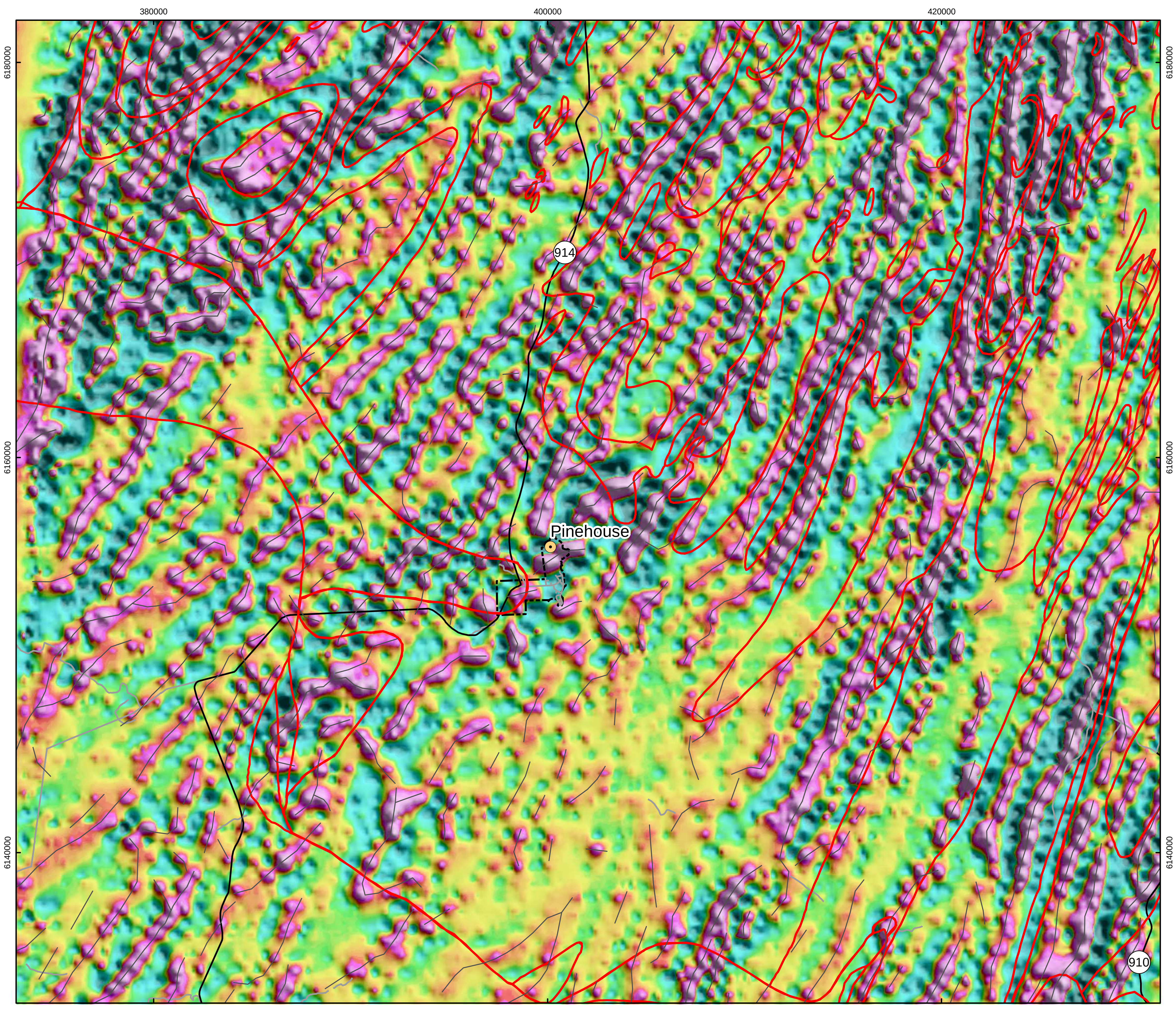
First vertical derivative of the pole reduced magnetic field (with mapped geological contacts)

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

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	**FIGURE 6**	
GIS	SWR	16 Aug 2013		
CHECK	ELM	16 Aug 2013		
REVIEW	AM	16 Aug 2013		

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



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts
- Foliation

0.03062
0.00144
0.00090
0.00064
0.00048
0.00036
0.00028
0.00022
0.00016
0.00012
0.00008
0.00004
0.00002
0.00000
-0.00004
-0.00006
-0.00008
-0.00010
-0.00014
-0.00018
-0.00022
-0.00028
-0.00034
-0.00042
-0.00052
-0.00066
-0.00086
-0.00126
-0.01007

2VD of RTP
(nT/m2)

REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10

SCALE 1:200,000 KILOMETERS

PROJECT

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

TITLE

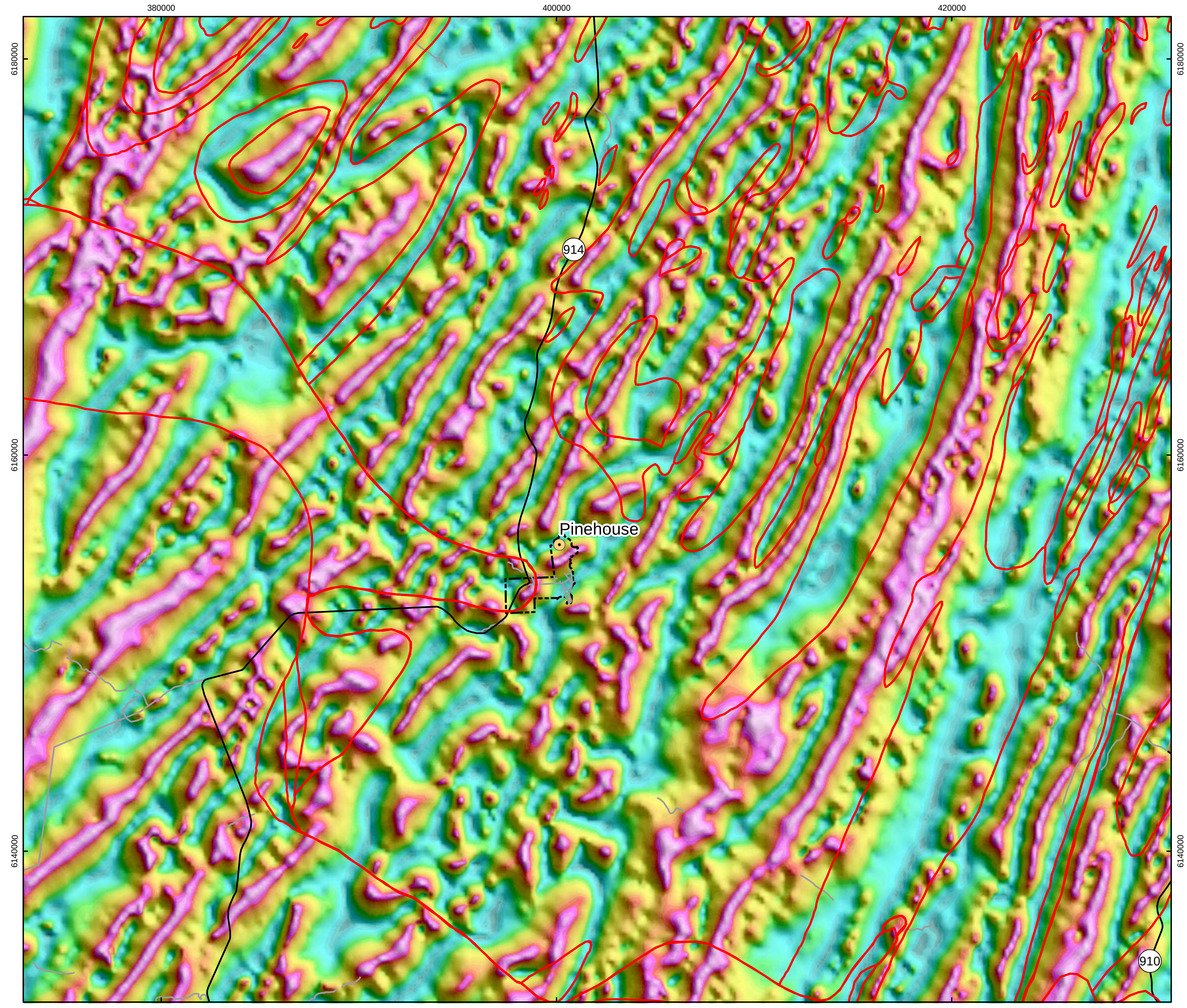
Second vertical derivative of the pole reduced magnetic field with magnetic foliation (with mapped geological contacts)

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

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	**FIGURE 7**	
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	16 Aug 2013		

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



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts

1.570
1.320
1.190
1.080
0.970
0.860
0.750
0.640
0.530
0.420
0.300
0.190
0.080
-0.030
-0.130
-0.240
-0.350
-0.450
-0.550
-0.650
-0.740
-0.830
-0.910
-1.000
-1.080
-1.150
-1.230
-1.310
-1.390
-1.570

Tilt Angle
(radians)

REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10
SCALE 1:200,000 KILOMETERS

PROJECT

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

TITLE

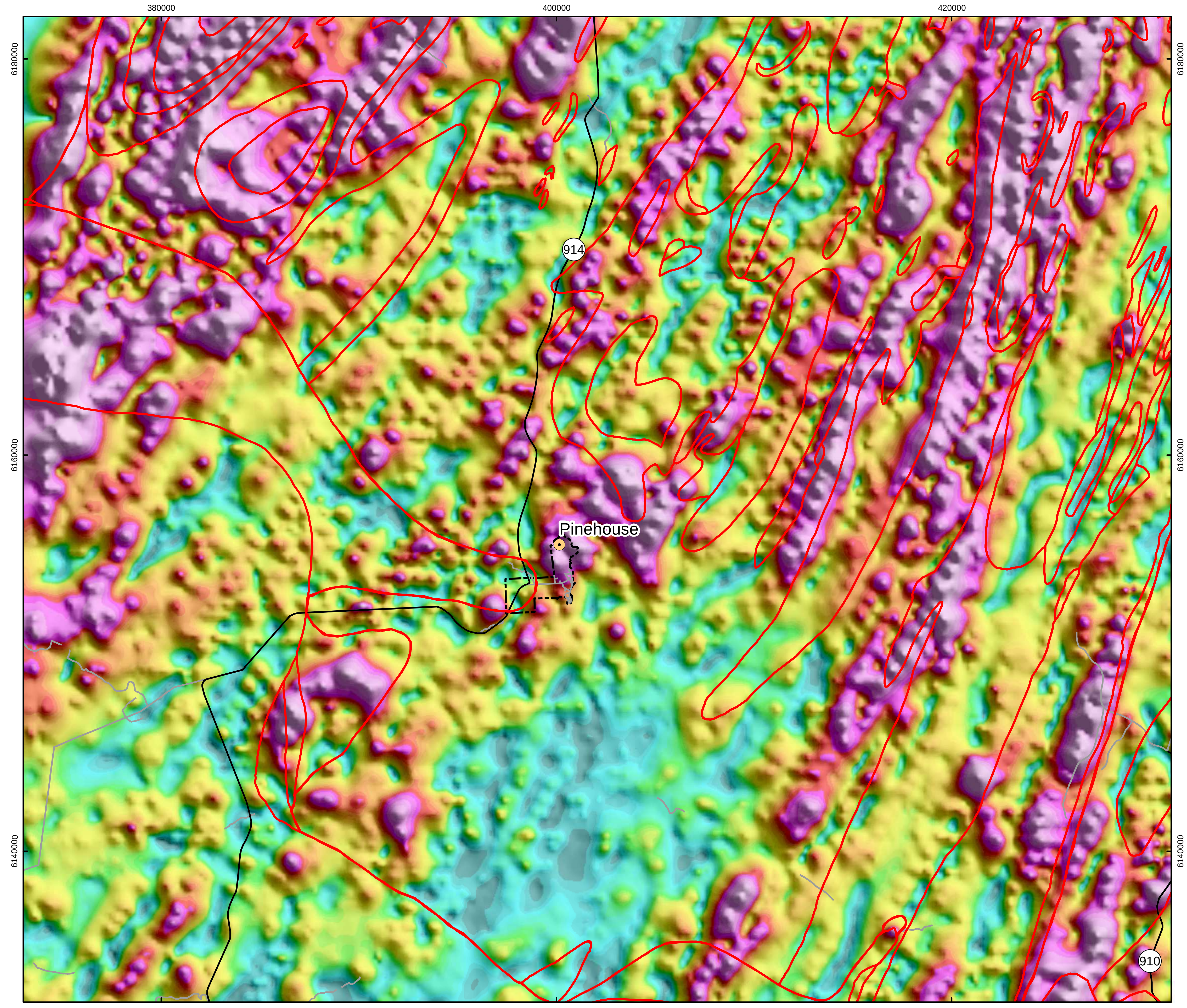
Tilt angle of the pole reduced magnetic field (with mapped geological contacts)

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

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	**FIGURE 8**	
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	19 Aug 2013		

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



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts

5.40
0.70
0.62
0.56
0.52
0.48
0.46
0.42
0.40
0.36
0.34
0.32
0.30
0.28
0.24
0.22
0.20
0.18
0.14
0.12
0.10
0.06
0.02
0.00

Analytic Signal
(nT/m)

REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10
SCALE 1:200,000 KILOMETERS

PROJECT

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

TITLE

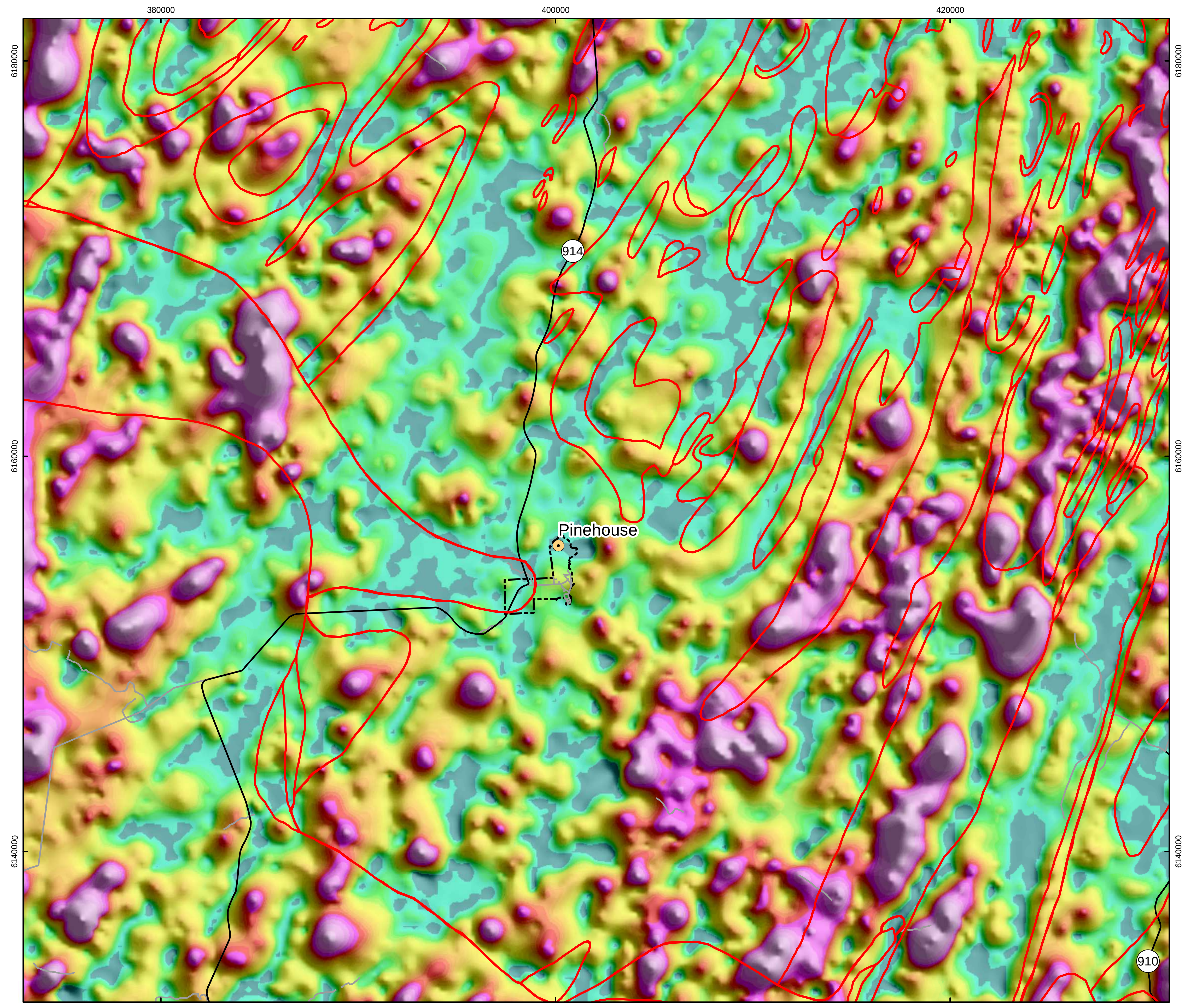
Analytic signal amplitude of the total magnetic field (with mapped geological contacts)

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

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	**FIGURE 9**	
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	19 Aug 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Env_Safety_Report\Pinehouse\PinehouseBedrockGeology.mxd



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts

8989
1100
800
640
540
470
410
360
320
280
250
220
200
170
150
130
110
90
80
60
50
40
20
10
0
-164

Depth to Sources
(m below surface)

REFERENCE

Magnetics: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10
SCALE 1:200,000 KILOMETERS

PROJECT

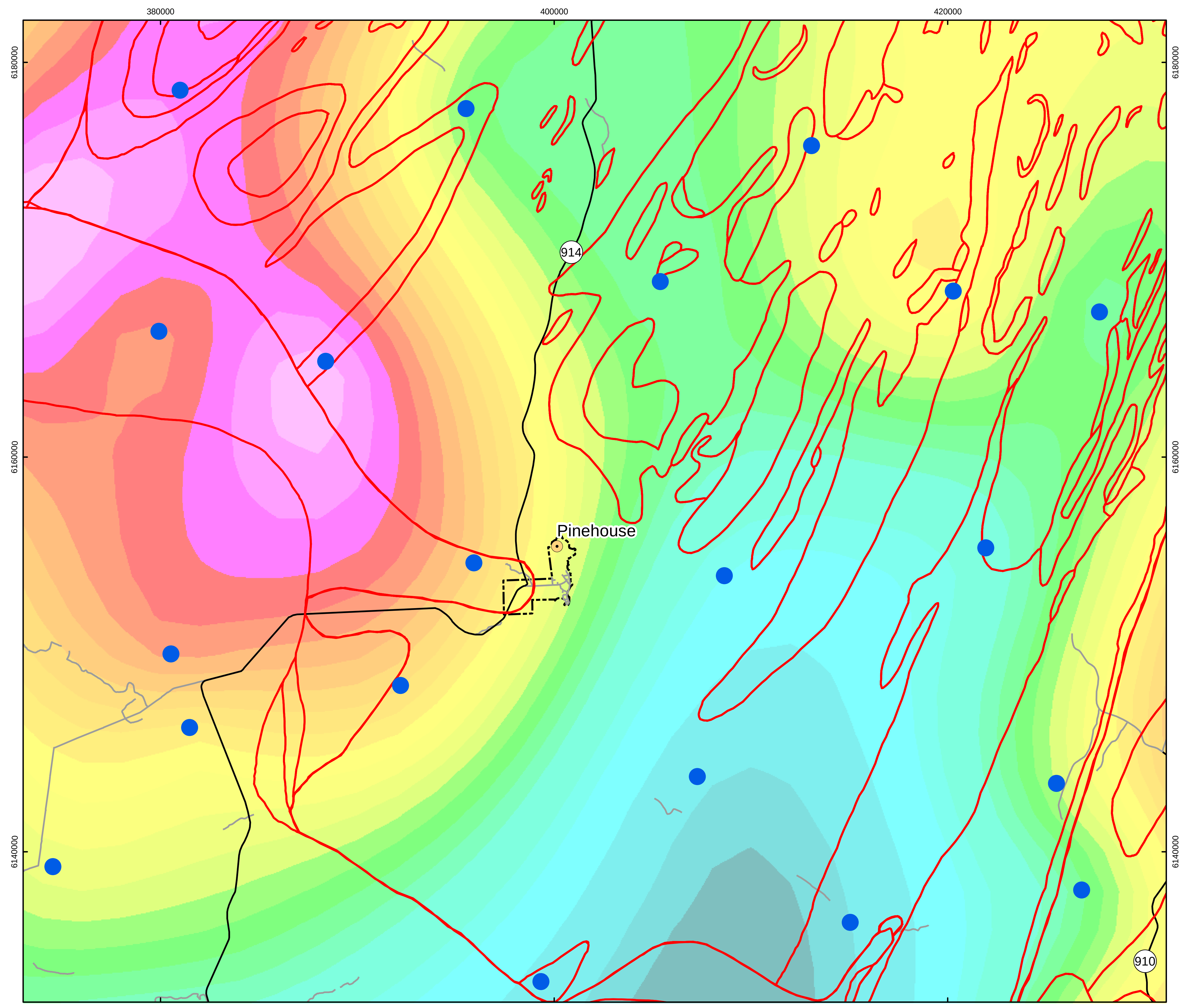
PHASE 1 GEOSCIENTIFIC DESKTOP PRELIMINARY ASSESSMENT, GEOPHYSICAL STUDY, PINEHOUSE AREA, SASKATCHEWAN

TITLE

Depth to magnetic sources from source parameter imaging (with mapped geological contacts)

Paterson, Grant & Watson Limited
Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	**FIGURE 10**	
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	19 Aug 2013		



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts
- Gravity station

-48.5
-52.0
-54.0
-55.5
-56.0
-56.5
-57.0
-57.5
-58.0
-58.5
-59.0
-59.5
-60.0
-60.5
-61.0
-61.5
-62.0
-62.5
-63.0
-63.5
-64.0
-65.0
-65.5
-66.5
-67.5
-68.0
-69.8

Bouguer Gravity
(mGal)

REFERENCE

Gravity: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10
SCALE 1:200,000 KILOMETERS

PROJECT

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

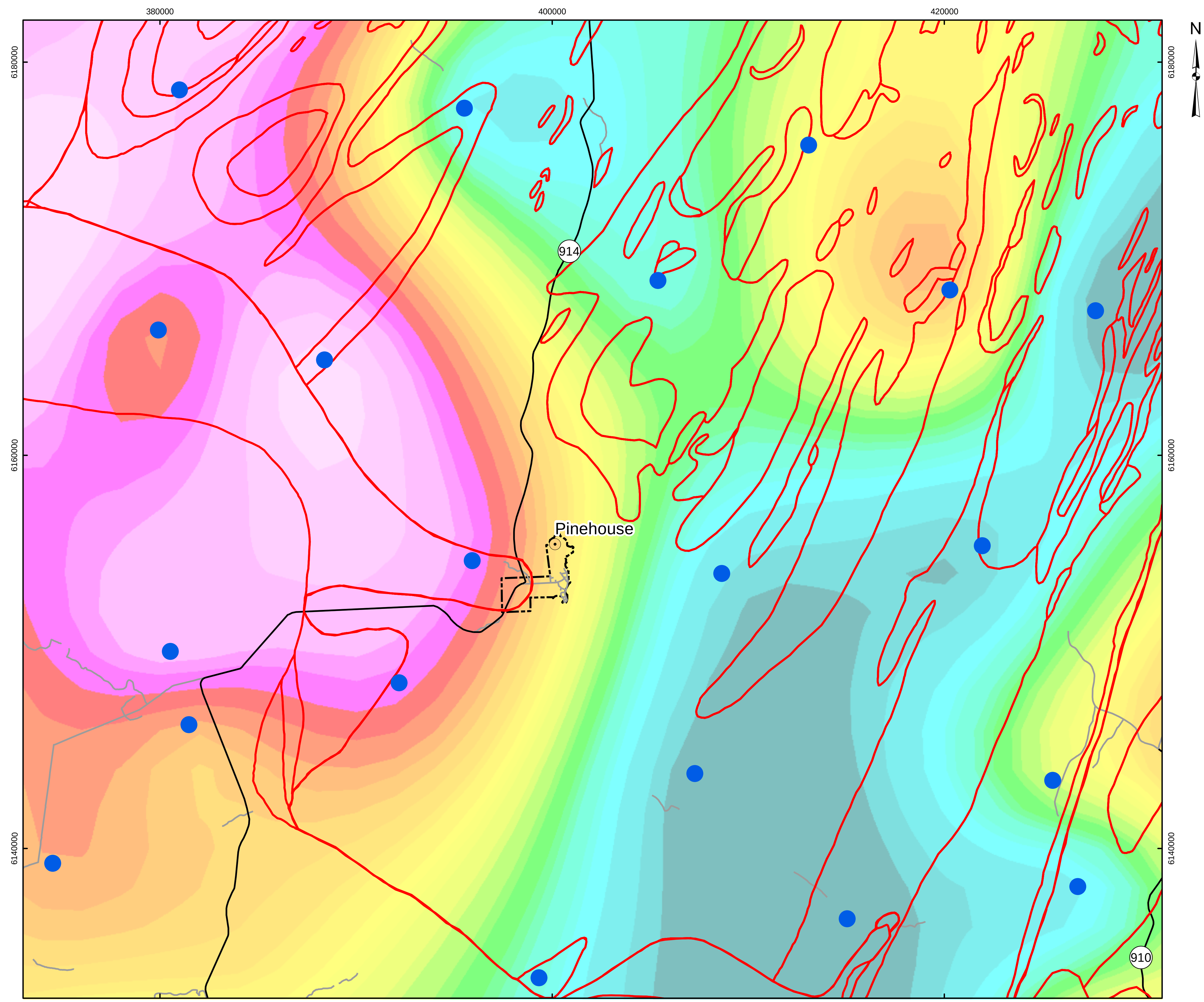
TITLE

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

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

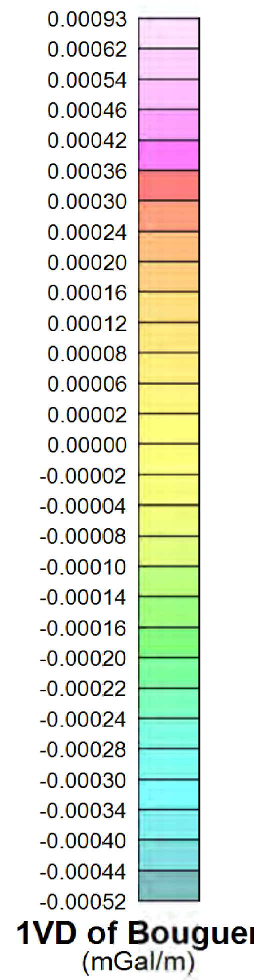
Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	**FIGURE 11**	
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	19 Aug 2013		



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts
- Gravity station



REFERENCE

Gravity: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10
SCALE 1:200,000 KILOMETERS

PROJECT

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

TITLE

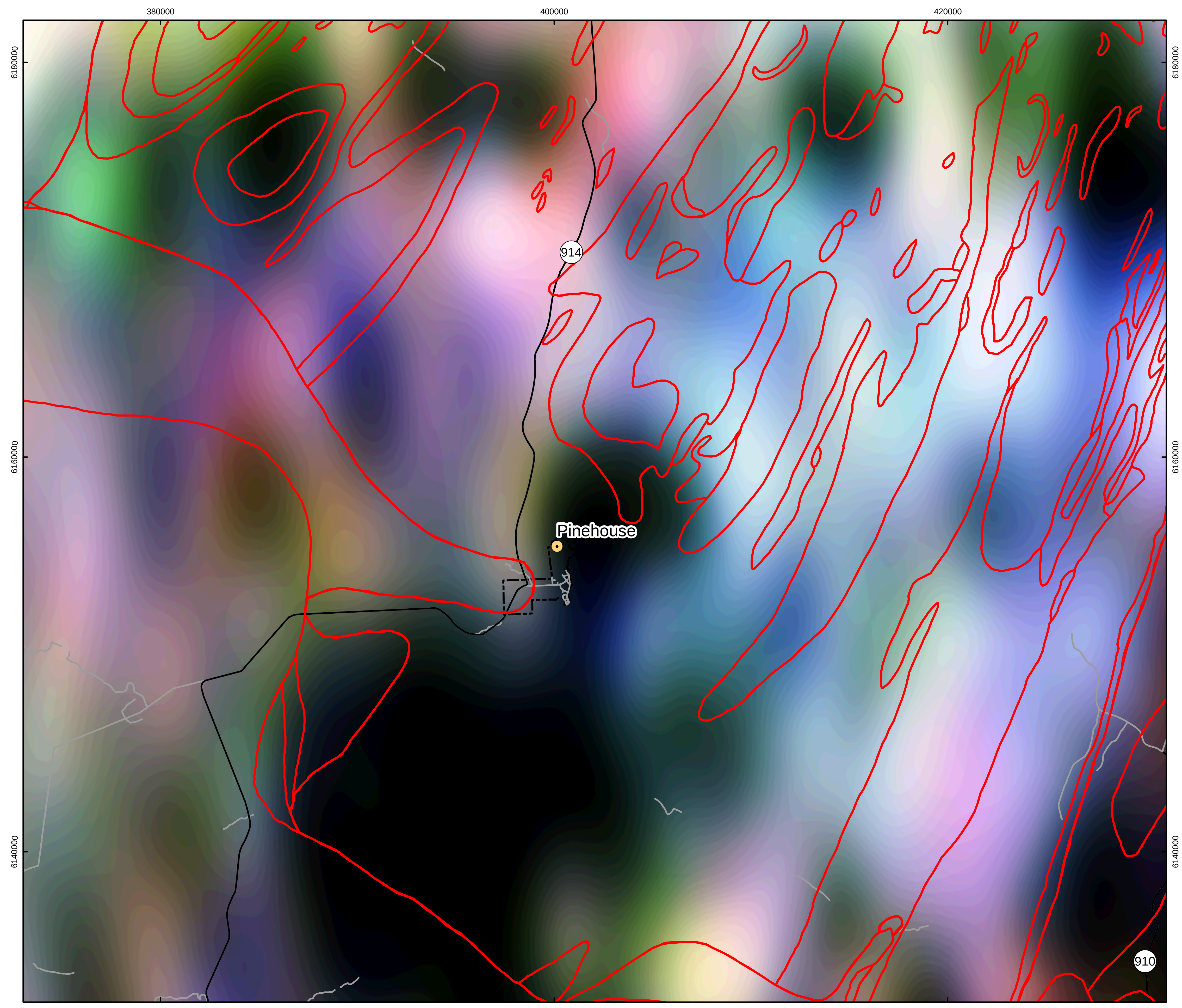
First vertical derivative of the Bouguer gravity field with station locations (with mapped geological contacts)

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

Golder Associates

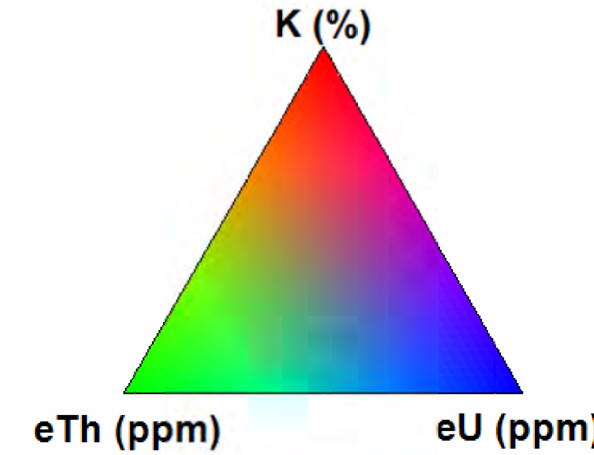
PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	**FIGURE 12**	
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	19 Aug 2013		

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



LEGEND

- Community
- Municipal Boundary
- Federal Land - Indian Reserve
- Main Road
- Local Road
- Bedrock Geology Contacts



REFERENCE

Radiometrics: Geological Survey of Canada nationwide compilation
Geology: Saskatchewan Geological Atlas (1:250,000)

NTS Mapsheet 73P
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10

SCALE 1:200,000 KILOMETERS

PROJECT

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

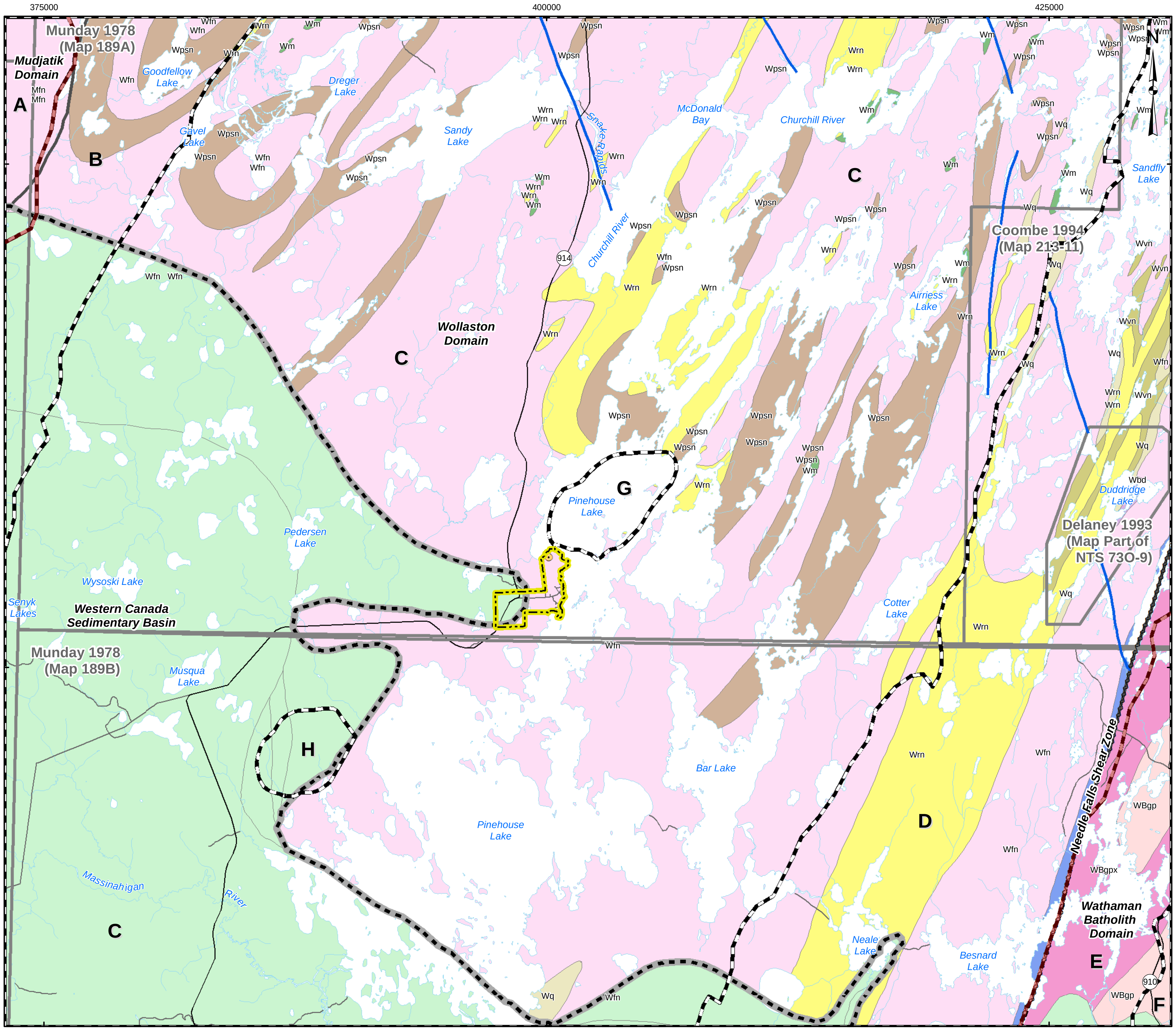
TITLE

Radiometric ternary image (RGB = K-eTh-eU) (with mapped geological contacts)

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

Golder Associates

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV 2
DESIGN	SWR	20 Mar 2013	**FIGURE 13**	
GIS	SWR	16 Aug 2013		
CHECK	ELM	19 Aug 2013		
REVIEW	AM	19 Aug 2013		



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Detailed Geology Extents
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mfn - Felsic gneiss

Wollaston Domain

- Wbd - Diorite
- Wfn - Felsic gneiss
- Wm - Amphibolite
- Wpsn - Pelitic, psammopelitic gneiss
- Wq - Metaquartzite
- Wrn - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss
- x - Mylonite/cataclastic rocks

Wathaman Batholith

- WBgpx - Augen gneiss
- WBgp - Megacrystic granitoid
- Interpreted domain boundary
- Geological units interpreted from geophysics

Scott and Thomas 1977 (Map 183A)
Munday 1978 (Map 189A)
Munday 1978 (Map 189B)
Thomas and Slimmon 1985 (Map 245A)
Delaney 1993 (Map Part of NTS 73O-9)
Coombe 1994 (Map 213-11)

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

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Admin. Boundaries - Info. Services Corporation of Sask., Administrative Boundary Overlays (2012)
Bedrock Geology - SGS 1:250,000 map 189A (Munday 1978), Geological Atlas of Saskatchewan (Saskatchewan Industry and Resources, 2010)
Hillshade - CDED slope raster: Geobase.ca (1:50,000)
Projection: Universal Transverse Mercator Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10
SCALE 1:200,000 KILOMETERS

PROJECT

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

TITLE

Geophysical interpretation showing distribution of bedrock units for the Pinehouse area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	SWR	1 Apr 2013	**FIGURE 14**	
GIS	SWR	16 Aug 2013		
CHECK	DJM	25 Sep 2013		
REVIEW	AM	26 Sep 2013		

G:\Projects\2012\12-1152-0026_NWMO_Phase1_Feasibility\GIS\MXDs\Reporting\Pinehouse\Draft_Integrated_Report\LocalBedrockGeologyPinehouseArea.mxd