NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

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

NORTHERN VILLAGE OF PINEHOUSE, SASKATCHEWAN

APM-REP-06144-0059

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

Northern Village of Pinehouse, Saskatchewan

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Executive Summary

In March 2012, the Northern Village of Pinehouse (Pinehouse), Saskatchewan, expressed interest in continuing to learn more about the Nuclear Waste Management Organization's (NWMO) nine-step site selection process, and requested that a preliminary assessment be conducted to assess potential suitability of the Pinehouse area for safely hosting a deep geological repository (Step 3). This request followed a successful completion of an initial screening conducted during Step 2 of the site selection process. The preliminary assessment is a multidisciplinary study integrating both technical and community well-being studies, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations. The findings of the overall preliminary assessment are reported in an integrated report (NWMO, 2013).

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

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

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

The desktop geoscientific preliminary assessment showed that the Pinehouse area contains at least two general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. Both areas are located in the northeastern part of the Pinehouse area.

The bedrock within the two potentially suitable areas identified (felsic gneiss) appears to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. The felsic gneiss has sufficient depth and extends over a large area at surface. It also appears to have low potential for natural

resources and limited surface constraints. The two potentially suitable areas have complex orientations of interpreted lineament, but are generally amenable to site characterization.

While the Pinehouse areass appears to have favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties include the low resolution of available geophysical data, the lithological homogeneity of the felsic gneiss and the influence of the Needle Falls shear zone.

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

Table of Contents

TABLES

FIGURES (in order following text)

APPENDICES

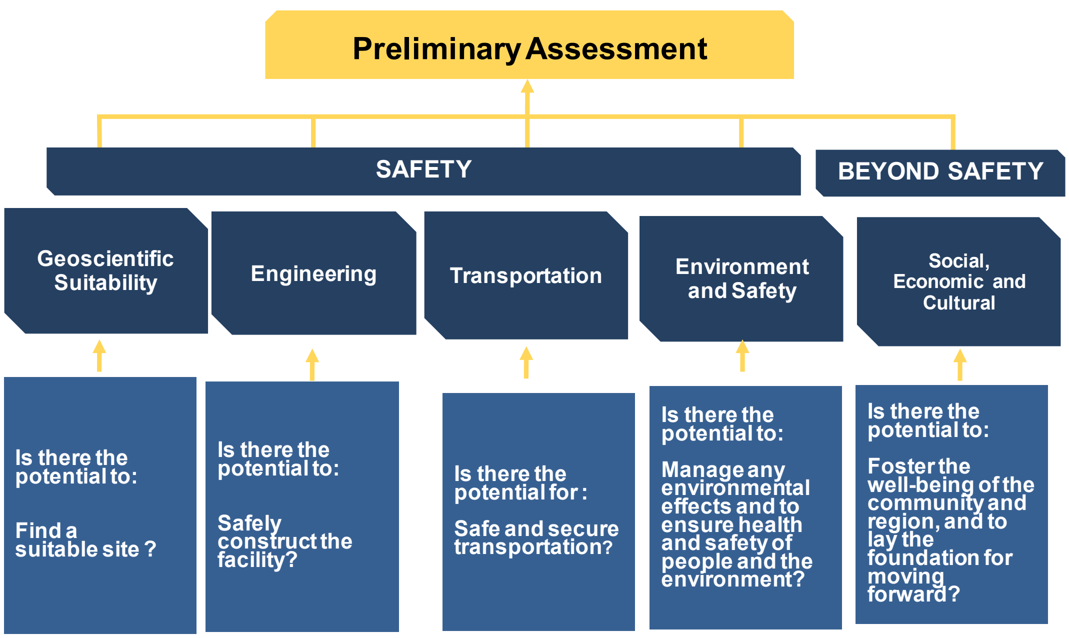
SUPPORTING DOCUMENTS

1.0 INTRODUCTION

1.1 Background

In March 2012, the Northern Village of Pinehouse (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, Saskatchewan 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 (Golder, 2011).

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



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

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

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

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

This report documents the results of a geoscientific preliminary assessment of potential suitability (Phase 1), conducted by Golder Associates Ltd.

1.2 Desktop Geoscientific Preliminary Assessment Approach

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

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

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

The details of these various studies are documented in three supporting documents: Terrain Analysis (JDMA, 2013a); Geophysical Interpretation (PGW, 2013); and Lineament Analysis (JDMA, 2013b). Key findings from these studies are summarized in this report.

1.3 Geoscientific Site Evaluation Factors

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

- ***Safe containment and isolation of used nuclear fuel:*** Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances caused by human activities and natural events?
- ***Long-term resilience to future geological processes and climate change:*** Is the rock formation at the siting area geologically stable and likely to remain stable over the very long term in a manner that will ensure the repository will not be substantially affected by geological and climate change process such as earthquakes and glacial cycles?
- ***Safe construction, operation and closure of the repository:*** Are conditions at the site suitable for the safe construction, operation and closure of the repository?
- ***Isolation of used fuel from future human activities:*** Is human intrusion at the site unlikely, for instance, through future exploration or mining?
- ***Amenable to site characterization and data interpretation activities:*** Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

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

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

1.4 Available Geoscientific Information

Geoscientific information for the Pinehouse area was obtained from several data sources, including maps, reports, databases and technical papers. In summary, the review of existing information identified that there was sufficient geoscientific information available to conduct the Phase 1 preliminary geoscientific assessment and to identify potentially suitable general siting areas in the Pinehouse area. Key geoscientific information sources are summarized in this section, with a complete listing provided in Appendix B.

1.4.1 Satellite Imagery and Geophysics

Low-resolution geophysical data, particularly the magnetic, gravity and radiometric data obtained from the Geological Survey of Canada (GSC), covers the entire Pinehouse area (Table 1.1) (GSC, 2012). Low-resolution magnetic data (805 m flight line spacing) obtained as Saskatchewan #9 survey from the GSC provides complete coverage of the entire Pinehouse area (Figure 1.2 and Table 1.1). Saskatchewan #8 survey provides lower resolution magnetic data (1,609 m flight line spacing) located along the western margin of the Pinehouse area and further west of the Pinehouse area. Gravity data for the Pinehouse area was acquired from the GSC and consists of an irregular distribution of 20 gravity stations, comprising roughly a station every 10 to 15 km. Radiometric data was acquired from the GSC providing low-resolution (5 km flight line spacing) coverage over the entire Pinehouse area. Additionally, deep seismic surveys have been conducted approximately 40 km south of the Pinehouse area as part of the Lithoprobe initiative (Lithoprobe Line 9 of the Trans-Hudson Orogeny Transect) (Lucas et al., 1993; Lewry et al., 1994; White et al., 2005).

The digital elevation model (DEM) data for the Pinehouse area is the Canadian Digital Elevation Data (CDED). The CDED is a 1:50,000 scale, 20 m resolution elevation model constructed by the Mapping Information Branch of Natural Resources Canada (NRCan). It was constructed using 1:50,000 scale source data from the National Topographic Data Base (NTDB) which was created from black and white aerial photographs (1:60,000 and 1:70,000 scale) acquired in the late 1950s and 1970s (Table 1.1; GeoBase, 2011a).

SPOT multispectral (20 m resolution) and panchromatic (10 m resolution) orthoimagery were available for the Pinehouse area (Table 1.1; GeoBase, 2011b). Five SPOT images (scenes) provided complete coverage for the Pinehouse area (Table 1.1). The scenes are from the SPOT 4 and 5 satellites with images acquired between May 2006 and September 2008.

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

Dataset	Product	Source	Resolution	Coverage	Acquired	Additional Comments
DEM	Canadian Digital Elevation Data (CDED); 1:50,000 scale	Geobase	20 m	Entire area	1950s – 1970s	Hillshaded and slope rasters used for mapping
Satellite Imagery	Spot 4/5; Orthoimage, multispectral/ panchromatic	Geobase	10 m (panchromatic) 20 m (multispectral)	Entire area	2006 - 2008	Panchromatic mosaic used for mapping
Geophysics	Saskatchewan #8 Fixed wing magnetic	Geological Survey of Canada	1,609 m line spacing, sensor height 305 m	West margin of area	1952	Magnetic data. Low resolution
	Saskatchewan #9 Fixed wing magnetic	Geological Survey of Canada	805 m line spacing, sensor height 305 m	Entire area	1969	Magnetic data. Mudjatik-Wollaston contact. Low resolution
Geophysics (Cont)	GSC - National Gravity Compilation	Geological Survey of Canada	10 to 15 km	Entire area	1960-1995	Ground gravity measurements
	GSC - National Radiometric Compilation	Geological Survey of Canada	5,000 m line spacing, Sensor height 120 m	Entire area	1976	Radiometric data, Ile-a-La-Crosse Survey

1.4.2 Geology

The most recent mapping in the Pinehouse area is available from the Geological Atlas of Saskatchewan (Saskatchewan Industry and Resources, 2010). This compilation map was derived from bedrock geology mapping at a scale of 1:100,000 (Scott, 1977a, b; Munday, 1978b), map compilation by Thomas and Slimmon

(1985), and more recent mapping by Delaney (1993b) and Coombe (1994). These maps and their associated reports provide information on geologic history, structural geology and lithology. They also show areas where the overburden was sufficiently thick to obscure bedrock mapping. Research on the major structural boundaries in or near the Pinehouse area has provided further insight to the geological history of the area and large scale structure (Gilboy, 1985; Thomas and Slimmon, 1985; Delaney, 1993b; SGS, 2003; Card and Bosman, 2007; Yeo and Delaney, 2007). A number of peer reviewed articles also address the possible origin of brittle deformation features in the area (Byers, 1962; Elliot, 1996; Davies, 1998).

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

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

1.4.3 Hydrogeology and Hydrogeochemistry

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

No information is available regarding deep groundwater flow systems or deep hydrogeochemistry for the Pinehouse area, so inferences have been made based on studies at sites with similar types of rock elsewhere in the Canadian Shield. Specific reports and studies include Frape et al., 1984; Frape and Fritz, 1987; Gascoyne et al., 1987; Farvolden et al., 1988; Gascoyne, 1994, 2000 and 2004; Everitt et al., 1996; and Rivard et al., 2009.

1.4.4 Natural Resources – Economic Geology

The primary source of information on past and present mining activities is the Saskatchewan Energy and Resources (2012) Mineral Deposit Index. Active exploration and mining dispositions in the Pinehouse region, as well as the known mineral occurrences were extracted from this source of information. A search of the Mineral Deposit Index also provided associated geological reports and borehole logs available for the area. Some historical exploration has occurred in the area, as reported by Scott (1977a), Munday (1978a), Gilboy (1985) and Harper (1988b).

1.4.5 Geomechanical Properties

There was no available site-specific information on rock geomechanical properties of potentially suitable rocks within the Pinehouse area. As such, inferences on rock geomechanical properties have been made from data collected from elsewhere in the Canadian Shield. Much of this information is a result of the work done by Atomic Energy of Canada Limited (AECL) in the 1980s and 1990s as part of the Canadian Nuclear Fuel Waste Management Program.

Rock strength and rock quality data for granitic rocks of the Canadian Shield are available from AECL's Underground Research Laboratory (URL) near Pinawa Manitoba (Brown and Rey, 1989; Brown et al., 1989; Baumgartner et al., 1996; Martino et al., 1997; Martino and Chandler, 2004) and AECL's Atikokan research area in Ontario (Stone et al., 1989; Sikorsky, 1996). Rock strength and rock quality data for gneissic rocks are available from AECL's Chalk River research area (Annor et al., 1979; Raven, 1980; Larocque and Annor, 1985; Sikorsky et al., 2011). Rock properties for the Mudjatik gneiss in Saskatchewan, including thermal conductivity, magnetic susceptibility, electrical resistivity and seismic velocities have been compiled by Fowler et al. (2005) to support interpretations of geophysical surveys (Lithoprobe) of the Trans-Hudson Orogen.

Information on *in situ* stresses in crystalline rocks is available for the Underground Research Laboratory (Martin, 1990; Thompson and Chandler, 2004), Chalk River Laboratories (Thompson et al., 2011), mines in the Canadian Shield (Herget, 1973; Arjang and Herget, 1997), as well as from reviews and assessments of *in situ* stress databases for the Canadian Shield (Kaiser and Maloney, 2005; Maloney et al., 2006; Heidbach et al., 2009).

2.0 PHYSICAL GEOGRAPHY

2.1 Location

The Northern Village of Pinehouse (Pinehouse) is located in north-central Saskatchewan along the west shore of Pinehouse Lake (Figure 1.1). The nearest large centre is the City of Prince Albert, about 250 km to the south via Highway 914, Highway 165 and Highway 2. Pinehouse and its periphery, referred to in this report as the "Pinehouse area", is approximately 2,914 km^2 in size, as shown on Figure 1.1. It is a rectangular area measuring about 58 km by 50 km. The approximate western, northern, eastern and southern limits of the Pinehouse area are defined by UTM (Zone 13, NAD83) coordinates: 373000, 6182340, 431100 and 6132200 m, respectively. Satellite imagery for the Pinehouse area (SPOT panchromatic, taken in 2006, 2007 and 2008) is presented on Figure 2.1.

2.2 Topography and Landforms

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

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

The topography of the Pinehouse area is presented on Figure 2.2. Ground surface elevation generally ranges from about 521 masl in the north, near Snake Rapids, to about 385 masl on the shores of Pinehouse Lake. The Pinehouse area is bounded by two major topographic highs informally referred to as the Norbert and Belton highs in this report (Figure 2.2). The Norbert upland is a rugged bedrock-controlled area located in the furthest northeast part of the Pinehouse area and beyond. The Belton upland is located in the southwest part of the Pinehouse area and beyond toward the Western Canada Sedimentary Basin. The vast majority of the Pinehouse area is a low-lying area associated with the Churchill River and Pinehouse Lake (JDMA, 2013a).

North of the Churchill River, in the Norbert upland area, the topography is rugged and includes high elevations, high relief and steep slopes. Incised valleys and depressions in this area appear dominantly oriented to the northeast and provide surficial expression to the underlying bedrock structures. South of the Churchill River, 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. In the southwest of the Pinehouse area, the topography shows slightly higher relief and steeper slopes trending to the northwest-southeast. The low relief in the southern section of the Pinehouse area reflects the cover of Phanerozoic rocks over the Canadian Shield and more extensive Quaternary surficial materials.

In the Pinehouse area, bedrock topography appears to be only minimally obscured in areas characterized by morainal veneer (Figure 2.3). Due to the general lack of high relief surficial deposits (end moraines, eskers, drumlins) in the region, the majority of knobs and ridges with 20 to 50 m (up to 100 m) of relief appear to reflect the underlying bedrock topography and structure. As such, the areas with the thinnest overburden are likely correlated to the areas with highest relief. This suggests that the Norbert high area and its extensions to the southwest are the main areas with thin overburden. Conversely, thicker deposits are expected in the Belton upland, and in the Churchill River low. Relatively thicker overburden in the southwest half of the Pinehouse area largely masks the underlying bedrock relief. Many of the broad, flat plains in this area are locations where organic landforms such as muskegs, fens and peat bogs are situated over relatively thick overburden deposits.

2.3 Watersheds and Surface Water Features

As part of the terrain study, JDMA (2013a) carried out a drainage basin analysis in order to confirm and, where possible, further partition the most detailed available mapping of watersheds by the Agriculture and Agri-Food Canada (AAFC) (formerly known as the Prairie Farm Rehabilitation Administration (PFRA)). The resulting mapping is shown on Figure 2.4 and was used to infer regional and local surface water and shallow groundwater flow directions.

The entire Pinehouse area is within the Churchill River basin, which drains towards Hudson Bay. The Churchill River begins at the outlet of Churchill Lake and flows from west to east through Saskatchewan and Manitoba. The Pinehouse area is part of the Upper and Central Churchill River tertiary watersheds. The vast majority of the Pinehouse area is contained within the Central Churchill tertiary watershed (Figure 2.4). The Churchill River generally flows from west to east through the northern half of the Pinehouse area. Within the Pinehouse area a number of lakes make up the Churchill River system, including Dreger Lake, Sandy Lake, McDonald Bay, Pinehouse Lake and Sandfly Lake. All watercourses within the Pinehouse area drain into this river system.

The topographic high near Snake Rapids (an extension of the Norbert upland toward the southwest) (Figure 2.2) is one of the most prominent highlands dividing flow within the Central Churchill tertiary watershed (Figure 2.4). North of this feature, flow is directed into the Churchill River through Gavel Lake, Sandy Lake and Dreger Lake. South of this feature, flow is directed into Pinehouse Lake. Other prominent drainage divides within the Central Churchill tertiary watershed include the northeast trending ridges east of Pinehouse Lake.

The southern limit of the Upper Churchill tertiary watershed in the northwest corner of the Pinehouse area represents a highland south of Bentley Bay. The Haultain River, which drains an area to the north empties into the Churchill River in this area.

The Pinehouse area contains a large number of lakes of various sizes, five of which are larger than 20 km^2, with approximately 24% (707 km^2) of the area occupied by waterbodies. The larger lakes are sufficiently large to conceal the surface expression of geological structures up to about 10 km in length, and clusters of small lakes have additional potential to conceal structures, especially when the lakes are located in areas where the surface expression of geological structures are already largely concealed by overburden. In general, the interconnected lakes that are a part of the Churchill River in the south tend to be larger (>20 km^2). These larger lakes include Sandy Lake, Pinehouse Lake and Sandfly Lake. Smaller waterbodies are generally associated with the two major uplands to the northeast and southwest of the Pinehouse area.

Table 2.1 summarizes the available bathymetric data for some of the lakes in the Pinehouse area. Depth values vary widely and range from approximately 4 to 26 m. The only bathymetric data available for the lakes composing the Churchill River is for Shagwenaw Lake located upstream of the area, with a maximum water depth of 16.5 m. Besnard Lake is located in the southeast corner of the Pinehouse area and extends further east. It is the only large lake in the Pinehouse area with available bathymetric data and has a maximum recorded depth of 25.6 m.

Table 2.1: Dimensional Characteristics of Selected Lakes in the Pinehouse Area

Lake	Area (km^2)	Maximum Recorded Depth (m) [a]
Churchill River [b]	44	16.5
Sandy Lake	34	N/A
Pinehouse Lake	240	N/A
Sandfly Lake	86	N/A
Besnard Lake	159	25.6
Musqua Lake	3.4	5.0
Domino Lake	0.23	6.0

N/A = Information not available

(a) Data from Saskatchewan Bathymetric map

(b) Data from Shagwenaw Lake which is located upstream of the area and is the only lake on the Churchill River with readily available bathymetric data

Wetlands cover 10% of the Pinehouse area (302 km^2). The most extensive wetlands in the Pinehouse area are located in topographic lows, particularly concentrated in the low-relief areas of the southwest half of the Pinehouse area. Higher concentrations are also seen around Pinehouse Lake and along the Churchill River (Figure 2.4). Wetlands appear elongated and oriented parallel to the axis of glacial advance over the Phanerozoic rocks in the southwest corner of the area. In addition to these extensive wetlands, small and discontinuous wetlands are dispersed throughout the Pinehouse area, particularly in areas of relatively high relief such as in the northeast, where wetlands occupy the lows between bedrock knobs and ridges. The wetlands in each of these areas can be expected to be associated with relatively thick, poorly drained overburden deposits.

2.4 Land Use and Protected Areas

Figure 2.5 shows a summary of land disposition and ownership within the Pinehouse area including known protected areas. The following summarizes the status of current land use and protected areas within the Pinehouse area.

2.4.1 Land Use

The Pinehouse area is located in a remote portion of northern Saskatchewan that is almost completely undeveloped. Pinehouse is the largest community in the area with a population of 978 (Statistics Canada, 2012). This community is accessed by Provincial Road 914 which runs generally north-south through the center of the Pinehouse area (Figure 2.5). The Churchill River represents a major traditional transportation corridor through the Provinces of Alberta, Saskatchewan and Manitoba. It was used extensively during the fur trade with the Hudson’s Bay Company in the early 1800s. Several outfitters are located along the Churchill River.

The Pinehouse area is largely situated in an Observation Zone designated by the Saskatchewan Wildfire Management Plan. This Observation Zone extends north from the Churchill River to the northern Provincial boundary. In such areas, wildfires are observed and generally not suppressed unless the cost of suppression is less than the value of the potential losses.

2.4.2 Parks and Reserves

There are no parks, wildlife areas, or conservation reserves in the Pinehouse area (Environment Canada, 2013). However, the Gordon Lake Recreation Site is partially located in the north-central portion of the Pinehouse area, approximately 27 km north of the Northern Village of Pinehouse along Provincial Road 914 (Figure 2.5). This recreation site is small, with a total area of 3.7 km^2.

2.4.3 Heritage Sites

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

The results of the database search indicate that 17 archaeological sites have been recorded within the Pinehouse area. There are 11 precontact artifact find and scatter sites, one pictograph or rock art site, and three artifact/feature combination sites. Two heritage resources have insufficient information to be given a site type designation. According to the site database, known heritage resources were recorded between 1960 and 1980 as part of various research and assessment projects. The majority of the sites are located on the Churchill River and associated tributaries and lakes. Twenty-three sites were recorded during the Key Lake Road assessment with sites associated with the Churchill and Haultain Rivers (Meyer, 1979). The remainder of the sites are found on Besnard and Pinehouse Lakes.

The Churchill River was a significant waterway during both precontact and historic times. Archaeological evidence indicates that people were occupying the Churchill River area as early as 10,000 years ago (Meyer, 1995). During the early fur trade period, explorers and traders began travelling the Churchill River in the 1770s. This was soon followed by the establishment of fur trade posts beginning in 1775 and continuing through to the 1930s (Russell and Meyer, 1999). Posts were established not only on the Churchill River proper, but also in Lac La Ronge, Lac Île-à-la-Crosse, Lac La Plonge, and Pinehouse Lake. The presence of heritage sites in the area would need to be further discussed with the local Aboriginal people.

3.0 GEOLOGY

This section provides a description of the geology and seismicity of the Pinehouse area based on a review of available geoscientific information. Based on the initial screening of the Pinehouse area (Golder, 2011), the land located to the south within the Western Canada Sedimentary Basin has been excluded from further consideration for potential repository locations. As such, only land situated on the Canadian Shield is considered in this report. The discussion of regional geology provides a general overview of the region of the Canadian Shield being considered, while the local geology discussion focuses on geological conditions within the Pinehouse area.

3.1 Regional Bedrock Geology

3.1.1 Geological Setting

The Pinehouse area lies on rocks of the Canadian Shield. The Canadian Shield is a collage of Archean cratons, accreted juvenile terranes and sedimentary basins that were progressively amalgamated over a period of more than 2 billion years during the Proterozoic Eon (see Figure 3.1, and further discussed in Section 3.1.2 below). Among the major orogenies that contributed to the assembly of the Canadian Shield is the Trans-Hudson 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 Ga (Ansdell, 2005; Corrigan et al., 2005; Hajnal et al., 2005; Corrigan et al., 2007; Whitmeyer and Karlstrom, 2007; Corrigan et al., 2009). The Canadian Shield now forms the stable core of North America. 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.

Regional geophysical surveys have been used to assist in mapping geologic structures within the Precambrian provinces and zones of northern Saskatchewan (Hajnal et al., 2005; White et al., 2005). Figure 3.2 shows a cross section through the Trans-Hudson Orogen in the Pinehouse area that was constructed by White et al. (2005) based on geophysical surveys conducted as part of the Lithoprobe project (a multi-year continent-scale geophysical subsurface mapping initiative). Geophysical surveys conducted as part of this initiative 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 were 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.

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 (Figure 3.1). 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 of high grade Archean to Paleoproterozoic metamorphic rocks older than 1.8 Ga (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 3.1). These shear zones are oriented in a north-northeast to northeast direction, 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) including, 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 (of the Reindeer zone), in the northwest corner and southeast corners of the Pinehouse area, respectively (Figure 3.1).

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, 1993a). 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 marking the opening of the Manikewan ocean, 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, 1993a; 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, 1993a; Yeo and Delaney, 2007) (Figure 3.1). 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 Ga 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 (Figures 3.1 and 3.2). 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 Ga 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).

3.1.2 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 regional area shown on Figure 3.3, 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.

The tectonic events that occurred during the ca. 2.1 to 1.9 Ga 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 3.1 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 1.9 to 1.5 Ga. 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 movement 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 Ga, 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 by 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 Ga (Yeo and Delaney, 2007). Concurrently, the emplacement of the massive Wathaman batholith with the final accretion of the La Ronge Arc to the craton developed large overthrusting and imbrication of strata, and the basement and supracrustal rocks of the Wollaston domain underwent regional metamorphism from upper amphibolite to granulite facies, with development of tight and isoclinal folding of rocks, and creation of extensive gneissification and migmatization of rocks (Lewry and Sibbald, 1980; Tran, 2001). The subsequent arrival of the Superior Province (ca. 1.83 Ga) 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).

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

Phanerozoic rocks (i.e., rocks younger than approximately 541 million years old) of the Western Canada Sedimentary Basin nonconformably overlie Precambrian basement rocks over the entire southern half of Saskatchewan (Figures 3.1 and 3.3). The present day zero thickness erosional edge of the basin trends northwesterly across the province 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 Ga) 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. Given 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 (i.e., 145 to 66 million years old). The Cretaceous strata were deposited during a series of regressions and transgressions of the Cretaceous sea over the western interior of North America (Mossop and Shetsen, 1994). The prior extent of 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 3.1: Summary of the Geological and Structural History of the Pinehouse Area

Time Period (Ga)	Geological Event
2.7	Approximate crystallization age of the felsic gneiss in the region that comprises the Hearne craton.
2.1 to 1.92	Initiation of rifting on the eastern margin of the Hearne craton and opening of the Manikewan ocean. Passive margin in the eastern margin of Hearne craton during rifting, with sedimentation of the Wollaston Supergroup.
1.92 to 1.88	Initiation of subduction underneath the eastern margin of Hearne craton leading to the beginning of both closure of the Manikewan Ocean and creation of the Rottenstone magmatic arc. Continued deposition of Wollaston Supergroup in a back-arc basin. This was followed by collisional compression of the rocks of the Wollaston Supergroup, Rottenstone and La Ronge domains. Collision resulted in D_1 ductile deformation that produced isoclinal folds and imparted the S_1 foliation to felsic gneiss.
1.88 to 1.865	Ongoing subduction resulted in the accretion of juvenile island arc terranes (La Ronge-Lynn Lake) to the southeastern margin of the expanded Rae-Hearne craton resulting in the formation of Rottenstone accretionary complex, while the Wollaston back-arc basin shifted to a foreland basin.
1.865 to 1.83	Closure of Wollaston basin at ca. 1.86 Ga with concomitant emplacement of the Wathaman batholith between ca. 1.865 to 1.855 Ga along eastern margin of Rae-Hearne craton. Regional D_2 ductile deformation produced upright folds that overprinted the S_1 foliation. Ongoing subduction resulted in the accretion of the Glennie-Flin Flon complex to the Rae-Hearne craton. Collision of the Sask craton with the Rae-Hearne craton, which thrusted the accreted juvenile terranes over the Sask craton.
1.83 to 1.80	Terminal collision of Superior craton with the Rae-Hearne craton leading to final closure of the Manikewan ocean. Crustal shortening that occurred during this period resulted in movement along the Needle Falls shear zone. D_3 ductile deformation creates NNE-striking upright folds dominant in the Wollaston domain. Activation (reactivation?) of the Needle Falls and Virgin River shear zones at ca. 1.83 Ga. Development of thick-skin imbrication in Mudjatik domain and thin-skin imbrication in Wollaston domain. D_4 ductile deformation creates NW-striking upright folds orthogonal to F_3 after movement on the Virgin River and Cable Bay shear zones.
1.80 to 1.72	Activation of the Tabbernor fault zone (ca. 1.8 Ga) and the D_5 steep-brittle faults observed within the Wollaston domain, extending into the Mudjatik domain.

Time Period (Ga)	Geological Event
1.72 to 1.5	Development of successor basins across parts of the Hearne craton, including formation of Athabasca basin.
< ca. 0.5	Deposition of Deadwood Formation in Phanerozoic Williston basin. Progressive infilling of Phanerozoic Western Canadian Sedimentary Basin in southern Saskatchewan and other regional areas.

3.1.3 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.

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

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

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 reactivation consistent with the interpretation that they are related to the Tabbernor fault located 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 Ga, likely with more recent periods of reactivation.

Features in overlying sedimentary rocks and apatite fission tracking indicate reactivation of the fault in the late Devonian and early Cretaceous (Elliot, 1996; Davies, 1998; Hajnal et al., 2005).

3.1.4 Mapped Regional Structure

Structural features previously 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 (Figures 3.1 and 3.3).

The Hearne craton is bounded to the west by the Rae craton along the Snowbird tectonic zone, and is bounded to the east by the Reindeer zone along the Needle Falls shear zone. 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 (Figure 3.1).

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 (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 being considered in this assessment, but it is interpreted to continue under the Athabasca Basin in the Cree Lake area. The Cable Bay shear zone does not appear to be a major lithologic boundary (Card and Bosman, 2007).

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

The results of geophysical surveys conducted as part of the Lithoprobe Trans-Hudson Orogen transect (White et al., 2005) suggest the presence of two sub-horizontal to low dipping (to the east) faults at depths of about 5 km and 13 km beneath the Mudjatik domain (Figure 3.2). The mapped contact between the Archean basement rocks and the 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 (Figures 3.2 and 3.3) (White et al., 2005). The longest of these brittle structures are over 120 km in length and appear as prominent topographical lineaments. They have been associated with brecciation, shearing, mylonitization and hydrothermal alteration (Byers, 1962). Sinistral strike-slip displacement of up to 800 m is observed along the faults, and geophysical interpretations suggest near vertical dips for the fault planes (Pearson, 1977b). Some evidence suggests that reactivation and displacement has occurred along these faults as recent as the Cretaceous period (Byers, 1962). These steep faults were interpreted by Hajnal et al. (2005) to be the north-northwest-trending faults that are part of the Tabbernor fault (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 domain.

The Tabbernor fault is a north-south-trending topographical, geophysical and geological lineament (Figure 3.1) that extends a lateral distance greater than 1,500 km from the Northwest Territories to the states of North and South Dakota (Giroux, 1995). Based on geophysical evidence, the fault zone extends to a depth of approximately 30 km (White et al., 2005). In Saskatchewan, the fault has a north-south strike and displays sinistral movement. Several researchers have discussed evidence that the Tabbernor fault 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). 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).

3.1.5 Metamorphism

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

Rocks of the Hearne craton (Mudjatik domain and Wollaston domain) were exposed to high-grade metamorphism, reaching upper amphibolite to granulite facies (e.g., Pearson, 1977a; Tran, 2001). Orrell et al. (1999) proposed that all metamorphic fabrics observed in the Hearne craton were the result of a single thermotectonic cycle caused by the Trans-Hudson Orogeny. This view has been disputed by other authors (e.g., Bickford et al., 1994; Tran, 2001; Card et al., 2007) 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 M_1 and M_2. 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 2.075 Ga for M_1 (Ansdell et al., 2000). Bickford et al. (1994) in turn suggested that thermotectonic reworking could have occurred as early as approximately 2.3 Ga, possibly associated with the Thelon Orogeny, whereas Annesley et al. (2005) suggested two granulite-facies metamorphic events around

2.689 and 2.566 Ga, respectively. Although the timing may remain elusive, M_1 seems to have begun before peak D_1 conditions and to have outlasted them (e.g., Tran, 2001; Card et al., 2006; Card and Bosman, 2007).

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

3.1.6 Erosion

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

Flint (1947) made one of the first efforts to map and determine the volume of all the terrestrial glacial sediment in North America, and concluded that all of the Plio-Pleistocene advances of the Laurentide ice-sheet had accomplished only a few tens of feet of erosion of the Canadian Shield. White (1972) pointed out that this ignored the much larger quantity of sediment deposited in the oceans, and revised the estimate upward by about an order of magnitude. Subsequently, Laine (1980; 1982) used North Atlantic deposits, and Bell and Laine (1985) used all the marine sediment repositories of the Laurentide ice-sheet (excluding the Cordilleran ice-sheet) to arrive at an average erosion of 120 m over 3 million years. Bell and Laine (1985) considered this to be a minimum value, although they make no allowance for non-glacial erosion or the role of rock weathering on erosion rates during the initial glacial advances in the late Pliocene. Hay et al. (1989), contending that in the Gulf of Mexico the depth of sediment of Laurentide provenance is greatly overestimated by Bell and Laine (1985), reduced this estimate of regional erosion to 80 m over the same time period.

3.2 Local Bedrock and Quaternary Geology

Information on local geology for the Pinehouse area was obtained from the various published reports for the area, geological maps (Section 1.5.1), and the geophysical interpretation of the area conducted as part of this preliminary assessment (PGW, 2013). Findings from the geophysical, lineament and terrain analysis studies carried out as part of the preliminary assessment of the Pinehouse area (JDMA, 2013a; JDMA, 2013b; and PGW, 2013) are integrated in this assessment to provide insight on the lithological variability, structures and extent of the overburden cover for areas considered in the Pinehouse area.

3.2.1 Bedrock Geology

The bedrock geology of the Pinehouse area is shown on Figure 3.4. In accordance with the known characteristics of the regional geological setting, no mafic dykes are interpreted to be present in the Pinehouse area. Geophysical data is of regional quality throughout most of the Pinehouse area, with 805 m line spacings

(PGW, 2013). The total magnetic field and the first vertical derivative of the residual magnetic field over the Pinehouse area are shown on Figures 3.5 and 3.6, respectively. The regional Bouguer gravity data is shown on Figure 3.7. In general, the coincidence between the geophysical interpretations (PGW, 2013) and the published geological maps is good, with some possible new interpretations.

The initial screening study (Golder, 2011) identified the felsic gneiss of the Mudjatik and Wollaston domains as geological environments that could contain potentially suitable areas to host a deep geological repository site. A brief description of the felsic gneiss and other predominant lithologies in the Pinehouse area is included below.

3.2.1.1 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 (Hajnal et al., 2005; White et al., 2005) have interpreted its thickness to be in the range of 5 to 10 km in the Mudjatik domain and 5 to 8 km in the Wollaston Domain. The Archean felsic gneiss has an approximate crystallization age of 2.7 Ga (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 homogeneous, weakly to unfoliated, with mineral composition comprising 5 to 30% quartz, 30 to 60% K-feldspar, 5 to 40% plagioclase, 5 to 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 magnenite-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.

Within the Wollaston Domain, the felsic gneiss units have a moderate to high magnetic response (Figures 3.5 and 3.6) which predominantly forms a strong northeast-trending linear fabric that parallels the dominant tectonic foliation in the area. Much of the magnetic aeromagnetic response in the Wollaston domain results from the tight interfingering of the felsic gneiss with the pelitic and psammitic gneiss, and minor amphibolite rocks 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 indicate a fairly complex lithological heterogeneity within the felsic gneiss compared to the distribution of mapped bedrock units, particularly in areas covered by overburden or units located at depth.

The coarseness of the gravity (Figure 3.7) and the radiometric data in the Wollaston domain results in poor correspondence 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. A 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. 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-rich 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.

3.2.1.2 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. This transitional boundary passes through 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 centre 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 3.4).

The mapped distribution of the psammitic and pelitic metasedimentary rocks within the Wollaston domain generally possess a low magnetic response in the area (Figure 3.5). However, in much of the area, the magnetic response observed represents tight interfingering between the psammitic and pelitic metasedimentary rocks and the felsic gneiss units, resulting in a strong north-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. In particular, this structural trend is observed to extend under the sedimentary cover of the Western Canada Sedimentary Basin to the southwest, consisting of alternating magnetic highs and lows characteristic of both the felsic gneiss and psammitic and pelitic metasedimentary rocks (i.e., White et al., 2005). The Bouguer gravity also shows a north-northeast trend, which is consistent with the trend of the mapped geology and magnetic data (Figure 3.7).

3.2.1.3 Wathaman Batholith

A small portion of the Pinehouse area extends onto the Wathaman batholith to the east of the Needle Falls shear zone (Figure 3.4). The geological characteristics of the Wathaman batholith are potentially favourable as a repository host rock type. However, the limited volume of this rock available 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 (Money, 1965; Fumerton et al., 1984). 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 (Figure 3.2), as interpreted from regional geophysical studies (White et al., 2005).

A 2 km wide north-northeast-striking curvilinear magnetic anomaly along the boundary of the Wollaston domain correlates generally well with the boundary of the Wathaman batholith (PGW, 2013). It is observed, however, that the trend of the mapped Needle Falls shear zone, adjacent to the Wathaman batholith in the southern portion of the Pinehouse area, is slightly discordant to the dominant trend of the linear magnetic fabric. 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 higher magnetic anomaly is interpreted to reflect the boundary crossing into the megacrystic granitoid of the Wathaman batholith. This broad boundary is similarly reflected in the gravity and radiometric 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 a 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). Similarly, radiometric data display a broadly distributed anomaly with elevated uranium levels trending parallel to the Wollaston domain boundary, which gradually become more potassium-rich into the Wathaman batholith.

3.2.1.4 Local Structure

Evidence of brittle deformation is displayed by a series of long faults with a north- to north-northwest strike, mapped in the northeastern half of the Pinehouse area. The faults are roughly parallel with spacings of approximately 5 to 10 km. These faults are inferred to be associated with regional faulting pattern discussed in Section 3.1.3 and extend for lengths of over 100 km further north-northwest of the Pinehouse area (Figure 3.3). Geophysical evidence suggests that these faults are sub-vertical (White et al., 2005). Further south in the

Pinehouse area, another series of mapped faults is noted with a north to northeast strike. One of these faults cuts through the eastern side of Pinehouse Lake.

As mentioned above, the Needle Falls shear zone passes through the southeast corner of the Pinehouse area. This feature represents a major structural boundary and may influence shallow and deep hydrogeological flow systems in the area. The Needle Falls shear zone has a steep dip and strikes with an azimuth of 20º, approximately parallel to the mapped boundary of the Mudjatik and Wollaston domains (Munday, 1978a). It is marked by long linear features (for example Burrell Lake) and coincident bands of mylonite. The general trend of the shear zone is demarcated magnetically by the western edge of the augen gneiss unit (Figure 3.4). However, the dominant trend of the linear magnetic fabric tends to be slightly discordant to the mapped outline of the Needle Falls shear zone, and may reflect a more regional-scale structural pattern.

Folding in the Wollaston domain is more linear than the dome-and-basin pattern of the Mudjatik domain to the west. The Wollaston fold belt contains doubly plunging, north-northeasterly trending antiforms and synforms that follow the trend of the Needle Falls shear zone (Munday, 1978a). Numerous north-northeast-striking magnetic anomalies of approximately 1 to 2 km width traverse the entire Pinehouse area (Figure 3.5). These anomalies 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. This alternating magnetic character likely represents the intense variability in the magnetite content, associated with a complex distribution of lithological units (PGW, 2013).

3.2.1.5 Local Subsurface Investigations

Two investigations involving drilling in the Pinehouse area are included in the Saskatchewan Energy and Resources (2012) Mineral Deposit Index. The Pinehouse Project investigation was conducted to the west of Pinehouse and involved drilling through Phanerozoic sedimentary rocks into the underlying gneissic rocks of the Wollaston domain. The second investigation was conducted near Duddridge Lake along the eastern boundary of the Pinehouse area. A summary of the geological information extracted from the database is provided below.

The Pinehouse Project was conducted by AGIP Canada Ltd. in association with Saskatchewan Mining and Development Corporation and Home Oil Company Ltd. in 1980, in an area about 15 km west of Pinehouse. The investigation included vertical drilling of 12 boreholes targeting five zones of interest with a collective total of 1,354 m of core obtained from the investigation. The boreholes were collared in overburden and reached depths of over 90 m into the basement gneiss. The Precambrian rock encountered generally consisted of granitic to granodioritic gneiss with minor intercalated amphibolites.

Five boreholes were drilled in an area located between 12 to 15 km west to west-southwest of Pinehouse where gneissic rock was encountered between 34 to 63 m below surface. Its main compositions found were fine- to coarse-grained biotite-quartz-feldspar gneiss and fine- to medium-grained, biotite-hornblende-plagioclase gneiss, with steeply-dipping gneissosity and local foliation defined by biotite. Chlorite occurred as alteration of biotite and hornblende, while hematite staining was observed along fracture surfaces. Shear zones noted in the felsic gneiss averaged 30 cm in thickness and contained up to 40% chlorite. Breccia zones of less than 1 m in width were noted in the felsic gneiss. The breccia was slightly hematized, with angular fragments of host gneiss up to 5 cm in size in a calcite-rock fluor-chlorite matrix.

Four boreholes were drilled in an area located approximately 22 to 25 km west to northwest of Pinehouse. Gneissic rock was encountered between 90 to 112 m below surface. Two main gneissic types with steeply dipping gneissosity were found. A fine to medium grained mafic gneiss with a mineral composition of 30 to 50% clay minerals, 10 to 30% biotite, 15 to 30% chlorite, 0 to 10% quartz and 0 to 10% feldspar biotite foliation defined from relic gneissosity, and with calcite veinlets and graphite dissemination; and a fine to medium grained, well foliated, biotite-quartz-feldspar gneiss. All units show extensive alteration to chlorite and kaolinite and hematite staining. Lastly, one borehole drilled approximately 35 km west-northwest of Pinehouse encountered gneissic rock approximately 100 m below surface. The gneiss was medium- to coarse-grained with a steeply dipping gneissosity, and with localized to pervasive kaolinization and hematization.

The second drilling investigation conducted in the Pinehouse area was undertaken by the Fission Energy Corporation in 2008 near Duddridge Lake. Duddridge Lake is located near the eastern boundary of the Pinehouse area and is surrounded by bands of pelitic and psammitic gneiss (Figure 3.3). A generalized stratigraphic column from a total of five borehole logs available for the Duddridge Lake area consists of a 3 m thin blanket of overburden underlain by a bedding of micaceous quartzite to quartz-feldspar metasandstone with thickness varying between 10 to 40 m. This unit is underlain by a transitional metasandstone unit that usually includes pegmatite granite veins with variable thickness between 5 and 25 m. Underneath, there is a hematitic, quartz-felspatic metasandstone, which seems to include a marker layer of pegmatitic granite. This unit varies in thickness from 20 to 80 m. At its base this unit changes to a carbonaceous quartz-feldspatic metasandstone 10 to 80 m thick that rests nonconformably on biotite schist and gneiss.

3.2.2 Quaternary Geology

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

During the Quaternary Period, several advances and retreats of continental glaciers occurred in the Pinehouse area. These glaciations 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).

The Laurentide ice sheet scoured and transported sediments beneath (subglacial), within (englacial) and on (superglacial) the glacier. End moraines were formed at the glacial limits, the most notable of which was the Cree Lake moraine to the north of the Pinehouse area, trending in a northwest-southeast direction. Its location represents the frontal ice position approximately 10,000 years before present (B.P.) (Prest, 1970). Schreiner (1984a) suggested that south of the Cree Lake moraine within the Pinehouse area, sandy till is so thin that the underlying bedrock structure is detectable. Ablation tills and ground moraines were subsequently deposited north of the Cree Lake moraine as the glacier retreated. Meltwater that was impounded against the retreating glacier drained south through the Mudjatik and Haultain River channels and into the Churchill River system.

These channels directed a significant amount of flow towards the Pinehouse area between approximately 10,000 years B.P. and 9,000 years B.P. As such, relatively coarse-grained glaciofluvial deposits of sand and gravel can be seen associated with these channels. Finer grained sediments were transported further and deposited in deltas as these rivers flowed into the Churchill River. The Churchill River's southward drainage of meltwater flowed into Glacial Lake Agassiz, before switching north to Lake Athabasca as the ice receded sufficiently north of the Pinehouse area. It is estimated that Glacial Lake Agassiz drained from the area between 9,000 and 8,500 years B.P. (Schreiner, 1984a).

Figure 2.3 shows the Quaternary geology of the Pinehouse area. The main Quaternary deposits include morainal plains, and glaciofluvial plains, with sparse occurrences of glaciolacustrine plains. Ground moraines are the dominant glacial landform in northern Saskatchewan and vary from flat to hummocky (Schreiner, 1984a). Glaciofluvial plains mainly consist of outwash plains that were incised through the morainal deposits as the glacier receded and melt waters drained. Glaciofluvial deposits are found mainly along the Haultain and Bélanger Rivers, which functioned as meltwater channels in the Pinehouse area. The glacialfluvial deposits are primarily sandy, with varying amounts of silt and clay fractions (Schreiner, 1984a).

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 the glaciofluvial outwash deposits mentioned above. 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.

Towards the northeast, the Quaternary deposits are characterized by a morainal veneer that is generally sufficiently thin to allow observation of the underlying bedrock structure. Areas dominated by rock outcrop are present in the northeast portion of the Pinehouse area. 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).

The descriptions of the Quaternary deposits are based on surface mapping, and little to no information is available on the variation of the thickness, and deposit types and compositions at depth. However, note that most of the ridges and other positively expressed bedrock-controlled landforms in the Pinehouse area were not delineated as areas of morainal veneer or bedrock on Figure 2.3 due to the coarse scale of the surficial mapping. Many of the areas of thin drift and abundant bedrock exposure within the Pinehouse area have been imprecisely mapped as being enclosed within large areas mapped as overburden deposits such as glaciofluvial outwash or ground moraine. The positively expressed bedrock-controlled landforms in the Pinehouse area where thin drift (i.e., 1 to 2 m thick) is expected were delineated and described in Section 2.2. This is supported by the bedrock mapping conducted by Munday (1978a,b) that shows areas with thick overburden, and conversely areas with sufficient bedrock exposure to allow bedrock mapping including detailed structural measurements. Comparing the available mapping, it appeared prudent to consider areas characterized by morainal veneer as sufficiently thin to allow for detailed bedrock mapping. This use of the available information is reflected in the selection of potential siting areas discussed in Section 7. More detailed mapping is required to confirm this interpretation.

3.2.3 Lineament Investigation

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

The lineament investigation identified interpreted brittle and ductile lineaments in the Pinehouse area, and evaluated their relative timing relationships within the context of the local and regional geological setting. A detailed analysis of interpreted lineaments is provided by JDMA (2013b) and key aspects of the lineament investigation are summarized in this section.

At this desktop stage of lineament investigation, the remotely-sensed character of interpreted features allows only for their preliminary categorization, based on expert judgement, into two general lineament classes, including ductile and brittle lineaments. Consistent with the known bedrock geology of the Pinehouse area, no dyke lineaments were interpreted during this assessment. The two lineament categories employed in the analysis are described in more detail below in the context of their usage in this preliminary desktop assessment.

- **Ductile lineaments**: Features which were interpreted as being associated with the internal fabric of the rock units (including sedimentary or volcanic layering, tectonic foliation or gneissosity, and magmatic foliation) were classified as ductile lineaments. This category also includes recognizable penetrative shear zone fabric. These features are included to provide context to our understanding of the tectonic history of the Pinehouse area, but were not included in the merged lineament sets or statistical analyses.
- **Brittle lineaments**: Features interpreted as fractures (joints or joint sets, faults or fault zones, and veins or vein sets), including those that offset the continuity of the ductile fabric described above, were classified as brittle lineaments. This category also includes brittle-ductile shear zones and brittle partings interpreted to represent discontinuous reactivation parallel to the ductile fabric, including shear zones. At the desktop stage of the investigation, this category also includes features of unknown affinity. This category does not include interpreted dykes.

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

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

In addition, ductile geophysical lineaments, including all interpreted features which conform to the penetrative rock fabric in the Pinehouse area, such as foliation traces and lithostructural contacts, were picked using the aeromagnetic geophysical survey data by an automated picking routine with confirmation by a single documented specialist observer. These lineaments are presented to provide context to the tectonic history of the Pinehouse area, but were not included in the merged lineament sets or statistical analyses.

The SPOT and CDED datasets (Figures 2.1 and 2.2, respectively) were used to identify surficial lineaments expressed in the topography, drainage and vegetation. The SPOT dataset has a uniform resolution of 10 m (panchromatic) and 20 m (multispectral) over the entire Pinehouse area (JDMA, 2013b). The CDED dataset is at a 1:50,000 scale, with a uniform 20 m resolution over the entire Pinehouse area (JDMA, 2013b). The resolution of the SPOT and CDED datasets allowed for the identification of surficial lineaments as short as a few hundred metres in length and provided sufficient detail to reveal surficial structural patterns. Aeromagnetic datasets (Figures 3.5 and 3.6) were used to identify linear geophysical anomalies indicative of bedrock structures. Regional low resolution data (at 805 m line spacing) are available for the entire Pinehouse area. The available geophysical coverage allowed for the identification of geophysical lineaments on the order of 200 m or longer in length.

Figure 3.8 shows the combined surficial lineament interpretation of the SPOT and CDED datasets binned into four length categories (<1 km, 1 to 5 km, 5 to 10 km, >10 km) and using the results from RA_1, without any filtering of overlapping features. The SPOT dataset yielded a total of 472 surficial lineaments, ranging from 220 m to 44.4 km in length, with a geometric mean length of 2.1 km, while the CDED dataset yielded a total of 338 lineaments, ranging from 446 m to 45.4 km long, with a geometric mean length of 3.3 km. The density and distribution of surficial lineaments (especially shorter <1 km lineaments) was seen to be influenced by the approximately 59% overburden coverage in the area. However, drift cover over the northeast portion of the Pinehouse area is characterized by a thin (less than 2 m) morainal veneer that only minimally obscures the underlying bedrock structure. Thicker overburden is noted towards the south near the Churchill River and to the southwest near Pinehouse Lake. Both the SPOT and CDED datasets offered advantages to characterize the surficial lineaments. The higher resolution of the SPOT imagery allowed for finer structures to be identified that were not resolved by the CDED data, but the CDED data often revealed subtle trends masked by the surficial cover present in the SPOT imagery.

The aeromagnetic dataset yielded a total of 661 lineaments, 338 interpreted as brittle lineaments and 323 interpreted as ductile features (Figures 3.9 and 3.10, respectively). The brittle lineaments on Figure 3.9 were binned into four length categories (<1 km, 1 to 5 km, 5 to 10 km, >10 km). The length of the brittle geophysical lineaments ranged from 229 m to 51.2 km, with a geometric mean length of 10.1 km. The density and distribution of geophysical lineaments reflect the uniform, low resolution data available for the entire Pinehouse area. Shorter lineaments could be present but remain undetectable due to the low resolution aeromagnetic coverage.

Aeromagnetic features interpreted as ductile lineaments were mapped separately and are shown on Figure 3.10. Such features are particularly useful in identifying the degree of deformation within the felsic gneisses and the supracrustal rocks. For example, the north-northeast-striking linear fabric orientation that dominates the Wollaston domain is visible in the ductile lineament interpretation of the Pinehouse area. The geophysical lineament data have advantages over surficial lineament data in that they are minimally affected by overburden cover, which may partially or completely mask surficial lineaments. This is illustrated by the relatively uniform distribution of geophysical lineaments (Figure 3.9) across the Pinehouse area compared to the surficial lineaments (Figure 3.8). Importantly, aeromagnetic lineaments may be indicative of features present at depth. In addition, there does not appear to be any bias in the geophysical lineament interpretation due to the east-west flight line orientation. There is no evidence of a flight line parallel lineament trend in either the SPOT or CDED lineament interpretations, while a weak westerly lineament trend is evident in the aeromagnetic interpretation.

It should be noted that the disparity between the number of identified ductile features (n = 323) versus brittle features (n = 338) in the aeromagnetic dataset is a result of the interpretation of the strongly linear magnetic character in the Wollaston domain as representing the ductile shear zone fabric. It is likely, although hard to quantify at the remote desktop stage of the investigation, that brittle reactivation of the ductile fabric also occurred in the Wollaston domain. This understanding would suggest that the density of brittle structures interpreted in areas with a strongly developed magnetic (ductile) character should be considered as minimum estimates of the *in situ* brittle lineament density.

Figure 3.11 shows the distribution of brittle lineaments from the merged surficial and geophysical datasets, classified by length. The merged lineament dataset yielded a total of 900 lineaments, ranging from 220 m to 51.2 km in length, with a geometric mean length of 4.5 km. A rose plot of length-weighted orientations of brittle lineaments, also provided on Figure 3.11, highlights the several dominant lineament trends that are evident in the merged dataset. Lineament orientation trends for these individual domains are presented on Figure 3.12. The most prominent lineament trend is toward the north-northeast to northeast and corresponds to the direction of the regional foliation, and the Needle Falls shear zone, within the Wollaston domain. The north-northeast- to northeast-trending lineaments, which tend to be tightly spaced at between several hundreds of metres to 1 km across the Pinehouse area, were recognized in the interpretation of the surficial datasets, but were not identified as brittle lineaments in the interpretation of the aeromagnetic dataset. In the case of the latter dataset, these features were instead interpreted to represent ductile lineaments. This suggests that the north-northeast- to northeast-trending ductile fabric is a penetrative bedrock feature with a recognizable fabric-parallel surface expression.

The next most prominent trend in the merged lineament dataset is northwest to north-northwest. The northwest- to north-northwest-trending lineaments show agreement among all datasets, but are most pronounced in the geophysical dataset. This trend corresponds with the previously mapped set of brittle faults (Figures 3.3 and 3.4). The spacing of these lineaments ranges from one to several kilometres.

Another trend ranges from east-northeast to east. This trend primarily comprises aeromagnetic lineaments with less agreement with the surficial lineaments. These lineaments are relatively sparse across the Pinehouse area with spacings in the range of 1 to 11 km. They may correspond with a set of regionally mapped faults of the same general orientation (Figures 3.3 and 3.4).

There is also a notable trend to the north. This trend is most pronounced in the geophysical dataset. It is also weakly evident in the CDED dataset, but was not recognized in the SPOT dataset (discussed below).

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

- Longer lineaments generally have a higher certainty and reproducibility.
- Areas defined by higher lineament density tend to correspond to areas having better bedrock exposure.
- There is a much greater coincidence between surficial lineaments (33% coincidence between CDED and SPOT) than between geophysical lineaments and surficial lineaments (less than 5% of geophysical lineaments are observed in surficial datasets), presumably since surficial lineaments interpreted from CDED and SPOT are expressions of the same bedrock feature. A total of 180 lineaments (19%) were coincident with a lineament from one other dataset (RA_2 = 2) and 17 lineaments (1.8%) were identified and coincident between all three datasets (RA_2 = 3). Several factors may contribute to the low degree of coincidence observed among the different datasets in this area. The lack of coincidence between surficial lineaments appears to be the result of low coincidence among the shorter lineaments. Another notable observation is that the geophysics identified strong north and east trends that were not mapped from the surficial datasets.
- The low coincidence between surficial and geophysical lineaments is presumably due to a variety of factors. For example, the structures identified in the aeromagnetic data may not have a surface expression; surficial features may not extend to great depth; structural features may not possess a magnetic susceptibility contrast with the host rock; surface expressions of lineaments may be masked by the presence of infilling or overburden; and the geometry of the feature (e.g., dipping versus vertical). These factors are also constrained by the resolution of the differing datasets. At 805 m flight line spacing, small features or features in the aeromagnetic dataset oriented at a low angle to the flight lines may not be recognizable.

Figures 3.13 to 3.16 were produced in order to provide some insight into the influence of lineament length on the distribution of lineament density across the Pinehouse area. This set of figures illustrates how lineament density varies across the Pinehouse area when lineaments are progressively “filtered” by length. The progressive filtering (removing) of lineaments was done in correspondence to the same length bins used above (<1 km, 1 to 5 km, 5 to 10 km, >10 km), and with the remaining lineaments plotted on top of the density gradient. In other words, Figure 3.13 includes all lineaments shown on Figure 3.11 and with a background showing the same information as a density gradient map (in km/km^2). Figure 3.14 filters out the <1 km long lineaments and so the underlying density gradient map represents only those lineaments 1 km in length or greater. The same is done, in a step-wise manner, for Figure 3.15 (filtering all lineaments <5 km) and for Figure 3.16 (filtering all lineaments <10 km).

Figure 3.13 shows that lineament density is relatively low across the Pinehouse area, with a maximum value of about 4 km/km^2. As noted above, higher densities correspond with areas of increased bedrock exposure such as in the northeast corner of the Pinehouse area. The figures show that filtering out the shorter lineaments greatly increases the spacing between remaining lineaments, including within areas having more exposed bedrock. For example, Figure 3.16 shows that there are locations within the Pinehouse area that contain relatively few lineaments that are longer than 10 km, leaving large volumes of rock between interpreted long lineaments. Also, filtering out the shorter lineaments appears to reduce the effects of variable overburden cover (in the case of surficial lineaments). The product of the filtering process provided on Figure 3.16 (>10 km lineaments) is a map that is useful for assisting with the identification of potential general siting areas. The effects of variable overburden cover tend to be leveled out, and the longest and prominent structures are still identified. For example, the filtered and combined surficial and geophysical lineaments consistently identified the long mapped regional faults in the Pinehouse area.

The following subsections describe the characteristics of the interpreted lineaments for each of the main geological units in the area, as well as the relative age of the lineaments identified in the Pinehouse area.

3.2.3.1 Felsic Gneiss

Felsic gneiss of the Wollaston domain covers the largest portion of the Pinehouse area at about 1,500 km^2 and exhibits a total of 638 lineaments. This unit is relatively high in elevation and exhibits the highest relief and steepest slopes, particularly to the northeast of the Pinehouse area. Unlike the other geological units, surficial cover is minimal, resulting in exposed bedrock from which lineaments are readily mapped. This results in higher lineament densities towards the northeast where bedrock exposure increases (Figure 3.13). These felsic gneisses exhibit a strong north-northeast-oriented foliation. Many of the lineaments mapped in this unit reflect a surficial expression of this foliation and also show a strong orientation to the north-northeast (Figure 3.12). This prominent foliation trend to the north-northeast is cut by long, north-northwest-oriented brittle faults that are well-defined in the aeromagnetic dataset and occur across the northeast portion of the Pinehouse area.

Felsic gneiss of the Mudjatik domain covers a relatively small portion of the Pinehouse area (26 km^2) to the northwest and contains a total of 16 lineaments. The area to the northwest offers exposed bedrock, but to the west and south, this unit is covered extensively with surficial materials that limit the identification of bedrock features. Lineaments mapped in this geological unit mostly trend to the north-northeast or northwest and were interpreted to represent a combination of both brittle and ductile features.

3.2.3.2 Metasedimentary and Metavolcanic Rocks

The supracrustal rocks of the Wollaston domain feature a total of 418 lineaments over an area of 589 km^2. Relative to the felsic gneiss discussed above, the metasedimentary and metavolcanic rocks contribute a greater proportion of lineaments used to calculate overall lineament density (Figure 3.13). The most extensive areas of these rocks include a reach along the Churchill River between Goodfellow Lake and Sandfly Lake, the northern portion of Pinehouse Lake and McDonald Bay, and a section trending to the southwest from Sandfly Lake. Compared to the felsic gneiss, this unit is relatively low in elevation and exhibits lower relief and gentler slopes. As is common in the Canadian Shield, these relatively low areas are more extensively covered by surficial deposits and lakes and rivers. For example, long reaches of the Churchill River, along with Sandy Lake, Gordon Lake, McDonald Bay and Pinehouse Lake are underlain by the pelitic to psammopelitc gneiss. Nevertheless, the lineaments identified within this geological unit display strong trends to the north-northeast that appear to reflect the strata and the strong foliation in these metasedimentary rocks. This foliation trend is cross-cut by the long, north-northwesterly trending lineaments that appear to be related to the mapped brittle faults with the same orientation.

3.2.3.3 Wathaman Batholith

The Wathaman batholith covers an area of 86 km^2 in the southeast corner of the Pinehouse area from which a total of 52 lineaments were mapped. The close proximity of this portion of the Wathaman batholith to the Needle

Falls shear zone explains the relatively high contribution to the overall lineament density in this part of the Pinehouse area. In this area, all of the datasets captured an expression of the Needle Falls shear zone that bounds the west side of the Wathaman batholith. Azimuths of the lineaments mapped from this unit display the same trends as the felsic gneiss from the Mudjatik and Wollaston domains in the Pinehouse area. The dominant orientation is to the north-northeast, consistent with the regional foliation and deformation, with a secondary trend to the north-northwest that reflects the regional pattern of brittle faulting.

3.2.3.4 Relative Age Relationships of Lineaments

Figure 3.17 shows the combined datasets (i.e., mapped regional faults, brittle lineaments, major shear zones and ductile features) which helps provide a structural understanding of the Pinehouse area. The most important tectonic features within the Pinehouse area are the long mapped regional faults and the Needle Falls shear zone. As mentioned above, most of these faults are oriented to the north-northwest, but to the north of the Pinehouse area there is a sub-set of faults oriented approximately northeast to east. The most reliable parameter in identifying these structures through the lineament analysis appears to be coincidence amongst datasets. A significant number of these faults and the Needle Falls shear zone were observed in all three datasets (RA_2 = 3). This is a fairly unique identifier in the available dataset for these important structures. Lineament length also assists in the identification of these features. Many of the mapped regional faults are represented by lineaments greater than 10 km long over most of their mapped length. However, length is somewhat less unique in its ability to highlight the mapped faults as many of the longer geophysical lineaments did not correspond to these features.

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

Based on the available literature regarding the structural history of the Pinehouse area, and observations of the orientation of lineament sets and cross-cutting relationships, the relative ages of the mapped lineaments can be tentatively related to reactivation of fabrics developed during the first four distinct regional deformation episodes (D_1 to D_4), or to new structures formed during the D_5 event. The earliest fabric recognized by structural geologists in the field (Card and Bosman, 2007; Card et al., 2008), is the composite S_1 fabric formed during D_1. The D_2 folding event was not assigned to any of the lineaments identified in this assessment. Interference between the D_3-D_4 re-folding events produced the distinctive dome-and-basin pattern identified as the curviplanar S_1 foliation. D_4 produced a dominant north-northeast lineament trend close to the Needle Falls shear zone that is also captured in the ductile lineament interpretation (Figure 3.10) and in the surficial datasets (Figure 3.8). These deformation events are constrained to have occurred prior to ca. 1.80 Ga (Table 3.1; e.g., Stauffer and Lewry, 1993).

All of the brittle lineaments identified in the Pinehouse area reflect the reactivation of structures and fabrics formed during Proterozoic deformational events, or the development of new structures during the latest, brittle, stages of the regional deformation history. The brittle north-northwest-striking D_5 lineaments represent the youngest deformation event interpreted to overprint the Pinehouse area. The D_5 brittle structures appear as prominent lineaments in the SPOT imagery, CDED and aeromagnetic data and display the best reproducibility and coincidence within the Pinehouse area. Each of the datasets used in this assessment expressed these features over various portions of their length and both interpreters identified those with the longest lengths. Most of these mapped faults are represented by lineaments with coincidence among two datasets (RA_2 = 2) with a significant proportion being mapped in all three datasets (RA_2 = 3) (Figure 3.17). The longer lineaments (>10 km), with agreement between two or more datasets, are interpreted to be more representative of features that may be associated with fracture zones at depth. Spacing of these longer structures with higher ranking reproducibility generally ranges from 1 to 10 km.

The timing of the D_5 episode of brittle overprint is poorly constrained. The association between these structures and the Tabbernor fault suggests a long-lived, post-1.80 Ga, history that may include a Paleozoic and Mesozoic history (e.g., Byers, 1962; Elliot, 1996). A long history of movement on the Tabbernor fault is consistent with the interpretation that surficial D_5 lineaments show similar orientations regardless of whether they are drawn over the area covered by Paleozoic sedimentary rocks or the area covered by the older Precambrian lithologies.

In summary, the most important mapped faults, with established age relationships, have been identified through the lineament analysis. They are defined by longer (>10 km) lineaments generally with greater coincidence amongst datasets. This allows the known age relationships to be extended to the other identified lineaments with similar orientations, placing more importance on the longer coincident lineaments. Based on the analysis, the most important lineaments are the long north-northwest-trending D_5 lineaments which are interpreted to have formed after ca. 1.80 Ga. All three datasets used to map lineaments identified these features (RA_2 = 3). This information supports the use of longer lineaments with these orientations to assist in the identification of potential general siting areas.

3.3 Seismicity and Neotectonics

3.3.1 Seismicity

Saskatchewan is one of the most seismically stable regions in North America (NRCan, 2012). Historically, very few earthquakes of magnitude m_N greater than 3 (Nuttli magnitude) have been recorded within Saskatchewan and none in the Pinehouse area, as shown on Figure 3.18. The largest earthquake ever recorded in Saskatchewan occurred in 1909 in the southern portion of the province near the USA border, and measured a magnitude of 5.5 (NRCan, 2010). This event occurred at a location approximately 750 km south of the Northern Village of Pinehouse.

A significant portion of the seismicity measured in Saskatchewan is due to mining activities near Wollaston Lake, Esterhazy and Saskatoon (Gendzwill and Unrau, 1996). Of the 43 seismic events with a magnitude greater than 1.8 in the period between 1985 and 2008 in Saskatchewan, 30 of those are identified as anthropogenic (man-made). The remaining 13 have been documented by Natural Resources Canada as natural earthquakes (NRCan, 2012). A query of the Geological Survey of Canada's National Earthquake Database found no earthquakes of magnitude greater than 3 in the Pinehouse area for their period of active monitoring, 1985 through present. No information was available regarding the focal depth of these events.

In summary, the available literature and recorded seismic events indicate that Saskatchewan is located within an area of very low seismicity. Specifically, there were no earthquakes recorded of magnitude greater than 3 near the Pinehouse area from 1985 through 2012 and no evidence of historical earthquakes prior 1985 from available sources. However, this could be the result of scarcity of seismography stations in the region. Atkinson and

Martens (2007) calculated the annual earthquake probability for stable Canadian craton to be in the order of 10^{-4} to 10^{-3}.

3.3.2 Neotectonic Activity

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

The movement and interaction of tectonic plates creates horizontal stresses that result in the compression of crustal rocks. The mean of the current major principal stress orientation in central North America, based on the World Stress Map (Heidbach et al., 2009) is northeast (63° ± 28°). This orientation coincides roughly with both the absolute and relative plate motions of North America (Baird and McKinnon, 2007; Heidbach et al., 2009), and is controlled by the present tectonic configuration of the North Atlantic spreading ridge (Sbar and Sykes, 1973) which has likely persisted since the most recent Paleocene-Eocene plate reorganization (Rona and Richardson, 1978; Gordon and Jurdy, 1986).

Possible evidence of neotectonics preserved in Paleozoic rocks above the Tabbernor fault has been noted by a number of researchers (Elliot, 1996; Davies, 1998; Kreis et al., 2004). The Tabbernor fault is located about 200 km east of the Northern Village of Pinehouse (Figure 3.1), but may be related to north-northwest-trending faults located in the region. Any neotectonic activity might be expected to occur as reactivation of such faults, since these features are existing planes of weakness. However, no cases of neotectonic evidence have been documented for the immediate Pinehouse area. The current average major principal stress orientation is at a high angle to the Tabbernor fault and the regional north-northwest-trending faults. The resulting stress state across the faults would tend to reduce the likelihood of movement along these and related features. Given that 90° rotations have been observed in similar Canadian Shield locations (Martino et al., 1997), site-specific testing is required to characterize the current stress state in the Pinehouse area.

The geology of the Pinehouse area is typical of many areas of the Canadian Shield, which has been subjected to numerous glacial cycles during the last million years. The continental scale motions are therefore overprinted by post-glacial isostasy in the northern portion of the North America plate. During the last glaciations (Wisconsinan), most of Saskatchewan was covered by the Laurentide ice sheet that flowed from Hudson Bay, located to the northeast. The thickness of the Laurentide ice sheet across Saskatchewan is unknown, although it likely thinned to the southwest at the edges of the flow. As such, the thickness of ice that covered the Pinehouse area is unknown. At the maximum extent of the Wisconsinan glaciation, approximately 21,000 years ago (Barnett, 1992), the Earth's crust was depressed by more than 340 m in the Minnesota/North Dakota area (Brevic and Reid, 1999), due to the weight of glacial ice. The amount of crustal depression in the Pinehouse area would have been somewhat greater, due to its closer proximity to the main center of glaciation located over Hudson Bay.

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

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

Under the appropriate conditions, glaciolacustrine deposits may preserve neotectonic features indicative of paleo-seismic activity (JDMA, 2013a). Existence of such features can be used to extend the seismic record for a region well into the past. As shown on Figure 2.3, glaciolacustrine terrain in the Pinehouse area is limited. An area of glaciolacustrine deposits is located north of Pinehouse along the shores of Pinehouse Lake. This area may be appropriate for the investigation of neotectonic features in subsequent stages of the evaluation process.

4.0 HYDROGEOLOGY AND HYDROGEOCHEMISTRY

4.1 Groundwater Use

Pinehouse Lake is used as the source of potable water for the Northern Village of Pinehouse. There is no groundwater use information available for the area. A search of the Saskatchewan Watershed Authority (SWA) Water Well Record (WWR) database indicated that there are no water wells in the Pinehouse area (SWA, 2009).

The nearest well to the Pinehouse area is within the Western Canada Sedimentary Basin approximately 30 km south-southwest of Pinehouse. The well is located on the east side of Provincial Road 914 and is registered to the English River IR as a domestic water source (Figure 4.1). The well was installed on January 10, 1996, to a depth of 22 m.

4.2 Overburden Aquifers

There is no available information on the presence, extent or other characteristics of overburden aquifers in the Pinehouse area. In general, the main Quaternary deposits of this region include morainal, glaciofluvial and glaciolacustrine plains, although the thickness of these deposits is unknown. It is expected that any overburden aquifers in these areas will be quite localized in extent. The water table is expected to be near surface in low-lying areas and deeper in areas of higher elevation. Shallow unconfined groundwater flow is expected to generally parallel surface water drainage patterns.

4.3 Bedrock Aquifers

No information was found on deep bedrock groundwater conditions in the Pinehouse area at typical repository depth of approximately 500 m. The SWA WWR database (SWA, 2009) indicates that no potable water supply wells are known to exploit aquifers at typical repository depths in the Pinehouse area or anywhere else in this part of Saskatchewan.

4.4 Regional Groundwater Flow

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

With the general concept in mind and with reference to the drainage features in the Pinehouse area shown on Figure 2.4, it is inferred that shallow groundwater flow in the overburden and shallow bedrock (e.g., upper 50 to 100 m of bedrock) will mimic the surface water flow systems.

The Pinehouse area is located in the Churchill River Basin, with the vast majority within the Central Churchill Basin. Only the northwest corner of the Pinehouse area is contained within the Upper Churchill Basin. The Central Churchill Basin is approximately centred on Pinehouse Lake which is connected to the Churchill River at its north end. To the north of the Churchill River, regional groundwater flow is expected to be generally south towards the river. Local variations may occur, for example, in the northwest corner of the Pinehouse area where groundwater flow likely discharges to the Haultain River before it flows into the Churchill River.

To the south of the Churchill River, regional groundwater flow is expected to be generally north towards the river. Around Pinehouse Lake to the south, the flow direction is expected to be radially towards the lake before it drains into the Churchill River. Local variations are expected with discharge occurring radially towards the nearest lake before entering the Churchill River. The Churchill River enters the Pinehouse area at Dreger Lake in the northwest corner and flows east-southeast, exiting the Pinehouse area at Sandfly Lake.

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

Deeper into the bedrock, fracture frequency in a mass of rock will tend to decline, and eventually, the movement of ions will be diffusion-dominated. However, fracture networks associated with deep faults and shear zones will control advective groundwater flow around bodies of rock characterized by diffusion-limited conditions. As such, in the Pinehouse area, it can be expected that features such as the Needle Falls shear zone and the north-northwest-trending subvertical faults within the Wollaston domain, may be important in the deeper groundwater flow system.

There is little known about the hydrogeologic properties of the deep bedrock in the Pinehouse area, as no deep boreholes have been advanced for this purpose. Experience from other areas in the Canadian Shield has shown that active groundwater flow in bedrock is generally confined to localized shallow fracture systems, and is dependent on the secondary permeability associated with the fracture networks. For example, in Manitoba's Lac du Bonnet batholith, groundwater movement is largely controlled by a fractured zone down to about 200 m depth (Everitt et al., 1996). The low topographic relief of the Canadian Shield tends to result in low hydraulic gradients for groundwater movement in the shallow active region (McMurry et al., 2003). In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell and Atikokan research areas range from approximately 10^{-15} to 10^{-10} ms^{-1} (Ophori and Chan, 1996; Stevenson et al., 1996). Data reported by Raven et al. (1985) show that the hydraulic conductivity of the East Bull Lake pluton decreases from an average near surface value of 10^{-8} ms^{-1} to less than 10^{-12} ms^{-1} below a depth of 400 to 500 m.

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

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

4.5 Hydrogeochemistry

No information on hydrogeochemistry was found for the Pinehouse area. Existing literature, however, has shown that groundwater within the Canadian Shield can be subdivided into two main hydrogeochemical regimes: a shallow, generally fresh water flow system, and a deep, saline water flow system (Gascoyne et al., 1987; Gascoyne, 2000; 2004). Gascoyne et al. (1987) investigated the saline brines within Precambrian plutons and identified a chemical transition at around 300 m depth marked by a uniform and rapid rise in total dissolved solids (TDS) and chloride. This was attributed to advective mixing occurring above 300 m with a shift to diffusion-controlled flow below that depth. It was noted that major fracture zones within the bedrock can, where present, extend the influence of advective processes to greater depths and hence lower the transition to the more saline conditions characteristic of deeper, diffusion-controlled conditions.

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

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

5.0 NATURAL RESOURCES – ECONOMIC GEOLOGY

The primary source of information on past and present mining activities is the Saskatchewan Energy and Resources (2012) Mineral Deposit Index. In the Pinehouse area, there is no record of mineral production in the past. Current mining dispositions on the Canadian Shield portion of the area, of which there are six, are shown on Figure 5.1. These are primarily concentrated along the Needle Falls shear zone, and focussed on parallel bands of pelitic and psammopelitic metasedimentary rocks. The potential economic interest of these occurrences is discussed below.

5.1 Metallic Mineral Resources

There is no record of economic metallic mineral production within or near the Pinehouse area. Past exploration has occurred in the area, but on a reconnaissance level. Figure 5.1 shows areas of active exploration and mining dispositions in the Pinehouse area, based on information extracted from the Saskatchewan Energy and Resources (2012) Mineral Deposit Index. The basement rocks composed of felsic gneiss are generally considered devoid of economically exploitable metallic mineral resources (Munday, 1978a; Card, 2012).

Gold, Precious Metals, Iron and Base Metals

Only one gold showing has been identified in the Pinehouse area. The showing is located approximately 12 km to the southwest of the Northern Village of Pinehouse at the boundary of the sedimentary rocks in the area. Additionally, one silver showing has been identified in the Pinehouse area. This silver showing is located approximately 25 km southeast of the Northern Village of Pinehouse, within the psammitic meta-arkosic gneiss of the Wollaston Supergroup. However, there are no occurrences within the Pinehouse area that are economically proven.

All identified iron and base metal occurrences within the Pinehouse area occur within the thin bands of metasedimentary rocks of the Wollaston Supergroup. These metasedimentary rocks are located next to the Needle Falls shear zone. Psammites in the Duddridge Lake area, located approximately 30 km east-northeast of the Northern Village of Pinehouse, contain potentially economic copper (and uranium) mineralization (Munday, 1978a). Tourmaline, pyrite and iron showings have also been identified in this area. East of the Needle Falls shear zone, migmatites and gneisses are considered to have low economic potential (Munday, 1978a); however, some pyrite and copper showings have been identified.

Rare Metals and Rare Earths

Rare metals include Li, Rb, Cs, Be, Nb, Ta and Ga and the lanthanide elements (rare earth elements or REE) which are often associated with minerals such as spodumene, lepidolite, beryl and columbite-tantalite in highly fractionated phases of the peraluminous granite suite. There are no known rare earth metal occurrences within the Pinehouse area.

Uranium

Within the rocks of the Canadian Shield in the Mudjatik and Wollaston domains, uranium occurrences have been found within granitoids, leucogranitoids and granitic pegmatites (Harper, 1988b). These are generally associated with metasedimentary rocks and mapped regional faults throughout the Mudjatik and Wollaston domains. Conglomerates associated with the supracrustal basement and pegmatites close to the supracrustal unconformity of the Wollaston domain are anomalously radioactive, but are not considered economic (Munday, 1978a).

The main focus of exploration for uranium within the Pinehouse area is associated with a band of pelitic and psammitic metasedimentary rocks located near the Needle Falls shear zone. These metasedimentary rocks appear to have economic potential for uranium mineralization (and potentially copper) (Munday, 1978a). This area contains the only active mining claims in the Pinehouse area (Figure 5.1).

To date, no active uranium mining has occurred in the Pinehouse area. However, an area approximately 170 km north of the Pinehouse area at Key Lake has been mined for uranium. Active uranium exploration is currently focused on the Mudjatik-Wollaston transitional boundary approximately 70 km north of the Pinehouse area. Based on the geological conditions and alteration features, it is possible that the Mudjatik-Wollaston transitional boundary in that area is similar to the non-conformable uranium deposits in the Athabasca Basin, and may have the potential to be an economic uranium deposit.

5.2 Non-Metallic Mineral Resources

Known non-metallic mineral resources within the Pinehouse area include building stone, sand and gravel, and peat. Fault breccias, trending northeast from Pinehouse Lake, can be permeated by fluorite (Munday, 1978a); however, no assays are available and the deposits are not currently economic.

Sand, Stone and Gravel

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

Building stone is not currently significantly exploited as a resource in the Pinehouse area or surrounding regions. However, a potential resource of limestone has been identified to the southwest of the Pinehouse area located within the Western Canada Sedimentary Basin (Golder, 2011).

Peat

The major peat lands of Saskatchewan occur on the northern margin of the Western Canada Sedimentary Basin. Peatlands west of La Ronge contain a large quantity of well-humidified sedge fuel peat, generally with a sphagnum cover (SGS, 2003). Only one peat producer operates within Saskatchewan, near Carrot River, which is approximately 250 km to the southeast of the Pinehouse area (SGS, 2003). There may be potential for expanding this industry in the future but all peat resources occur at shallow depths and would not affect a geological repository.

Diamonds

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

5.3 Petroleum Resources

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

6.0 ROCK GEOMECHANICAL PROPERTIES

Geomechanical information including intact rock properties, rock mass properties and *in situ* stresses are needed to design stable underground openings, predict the subsequent behaviour of the rock mass around these openings and predict the response of the groundwater flow system. As such, geomechanical information associated with a potential host rock can be used when addressing several geoscientific, safety-related factors defined in the site selection process document (NWMO, 2010). There is limited geomechanical information on the felsic gneiss in the Pinehouse area. Table 6.1 summarizes all available geomechanical information available for the area and from sites elsewhere in the Canadian Shield with rock types similar to those of interest. These sites are the Lac du Bonnet granite at AECL's Underground Research Laboratory (URL) in Manitoba, the Eye-Dashwa granite near Atikokan, Ontario and the felsic gneiss beneath AECL's Chalk River Laboratories. The majority of the geomechanical characterization work for the URL in Pinawa, Manitoba, was conducted on these rocks as part of AECL's Nuclear Fuel Waste Management Program in the 1990s.

6.1 Intact Rock Properties

Intact rock properties tabulated in Table 6.1 are based on laboratory testing of rock core specimens from boreholes. The table also includes basic rock properties such as density, porosity, uniaxial compressive strength and tensile strength for use in engineering design and structural analyses. These parameters feed into the rock mass classification schemes, and *in situ* stress determination.

No specific information is available regarding the intact rock properties of the felsic gneiss in the Pinehouse area. Fowler et al. (2005) present a database of rock properties from the Trans-Hudson Orogen. Samples of Mudjatik gneiss were collected from an area south of Baker Lake approximately 150 km northwest of Pinehouse. Between 20 and 23 samples were tested for saturated density, porosity, magnetic susceptibility, P-wave velocity and S-wave velocity. For other important properties, the felsic rocks of the Pinehouse area share a similar mineralogical composition to the comparatively well-studied Lac du Bonnet batholith, Eye-Dashwa pluton and Chalk River gneiss. As such, at this early stage of the site evaluation process, it is reasonable to assume that the geomechanical properties of intact rock in the Pinehouse area may resemble those of the Lac du Bonnet batholith, Eye-Dashwa pluton and Chalk River gneiss.

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

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

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

NA = Not Available

[a] Fowler et al., 2005

[b] Stone et al., 1989

[c] Annor et al., 1979

[d] Thomas and Hayles 1988

[e] Gorski et al., 2009

[f] Gorski and Conlon, 2010

6.2 Rock Mass Properties

Fracture spacing, orientation and condition (width or aperture, mineral fill, evidence of relative displacement, etc.) of the fractures tend to dominate the overall mechanical response of the rock mass. There is no information available on rock mass properties of the felsic gneiss in the Pinehouse area.

In general, there will be a downward decreasing fracture density from highly fractured rocks in shallow horizons (ca. <300 mbgs) to sparsely fractured intact rock at greater depths as experienced at other sites in the Canadian Shield (e.g., Everitt, 2002). Fractures observed on surface bedrock exposures may occur as well-defined sets of geological discontinuities, or as randomly oriented and variably-dipping features. Based on observations from other sites in the anadian Shield (e.g., Everitt, 2002) and stress measurement data (e.g., Maloney et al., 2006), one could infer that a shallowly-dipping to sub-horizontal fracture set may exist as a result of either strain releasing during the isostatic rebound from the last glacial cycle or the presence of pre-existing fabric anisotropy (e.g., bedding, tectonic foliation) in the rock structure. Rock mass properties for the Pinehouse area would need to be determined at later stages of the assessment.

6.3 *In situ* Stresses

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

No site-specific information is available regarding the *in situ* stress conditions within the Pinehouse area. The nearest *in situ* stress measurements were taken at the Ruttan Mine (Churchill Province/Lynn Lake Sub-province) located approximately 450 km to the northeast of Pinehouse. At a depth of 661 m in the Ruttan Mine, the minimum principal stress ranges from 14 MPa to 27.5 MPa (with an average value of 22 MPa) and dips at an angle of 59° (Kaiser and Maloney, 2005). As a check, vertical *in situ* stresses may also be estimated using the unit weight of the rock measured on intact core specimens. Assuming a rock density of 2.8 Mg/m^3, and a corresponding unit weight of 27.5 kN/m^3, the approximate magnitude of the *in situ* vertical stress at a depth of 500 m at the Ruttan Mine is 14 MPa.

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

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

Local stress relief features such as faults and shear zones can be expected to locally affect the stress regime. For example, thrust faults at AECL's URL were shown to be boundaries between significant changes in the magnitude and orientation of the principal stresses. Above a major thrust fault, located at a depth of 270 m (referred to as Fracture Zone 2, or FZ2 at the site), the magnitude was close to the average value for the Canadian Shield and the orientation of the maximum horizontal stress was consistent with the average predicted by the World Stress Map (i.e., southwest). Below the same thrust fault, the stress magnitudes are much higher than the average data for the Canadian Shield, and the maximum principal stress rotates approximately 90° to a southeast orientation (Martino et al., 1997). The principal maximum horizontal stress magnitude below the Fracture Zone 2 thrust fault remains relatively constant around 55 to 60 MPa, which is more typical of the values found at greater depths. The southeast orientation of the maximum principal horizontal stress is consistent with the data presented by Herget (1980) for the area which indicates maximum compression clustered in the southwest and southeast for the Canadian Shield.

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

6.4 Thermal Conductivity

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

There are no site-specific thermal conductivity values or detailed quantitative mineral compositions available for the Pinehouse area. However, Fowler et al. (2005) provide an average thermal conductivity value of 2.3 W/(m˚K) for Mudjatik gneiss, based on measurements taken on three samples (Table 6.1). For the purposes of comparison, typical values of thermal conductivity for similar rock types are presented in Table 6.2. The mineralogy of the felsic gneiss is described in Section 3.2.1. Available information indicates that the composition of the felsic gneiss ranges from granite to granodiorite and tonalite. The quartz mineral content of these rock types can range from approximately 20 to 60% by volume (Streckeisen, 1976).

Table 6.2: Thermal Conductivity Values for Granite, Granodiorite and Tonalite

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

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

Although no thermal conductivity values are available for the Pinehouse area, some useful comparisons are provided by Stone et al. (1989) in their summary of thermal conductivity values for two late Archean granitic intrusions of the Superior Province of the Canadian Shield, including the Lac du Bonnet batholith and the Eye-Dashwa pluton (Table 6.1). Both intrusions were described as having similar mineralogical compositions, with quartz content generally varying between 23% and 27%. The average thermal conductivity for the Eye-Dashwa pluton was 3.3 W/(m˚K) based on 35 samples. The average thermal conductivity for the Lac du Bonnet batholith was 3.4 W/(m˚K) based on 227 samples. For comparison, a value of 3 W/(m˚K) was selected for numerical modelling studies conducted to evaluate the thermo-mechanical performance of hypothetical repository designs in a similar crystalline rock environment (Golder, 2012a, b).

The above literature values for thermal conductivity are considered useful for comparison purposes as part of this preliminary assessment. However, actual values would need to be determined at later stages of the assessment.

7.0 POTENTIAL GEOSCIENTIFIC SUITABILITY OF THE PINEHOUSE AREA

7.1 Approach

The objective of the Phase 1 desktop geoscientific preliminary assessment is to assess whether the Pinehouse area contains general areas that have the potential to satisfy the NWMO's geoscientific site evaluation factors (NWMO, 2010). The location and extent of potentially suitable siting areas would be refined during the second phase of the preliminary assessment through more detailed assessments and field evaluations.

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

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

The potential for finding general potentially suitable areas was assessed using the following key geoscientific characteristics:

- ***Geological Setting:*** Areas of unfavourable geology identified during the initial screening (Golder, 2011) were avoided. The pelitic and psammitic gneiss and amphibole mafic gneiss were considered unfavourable rock units for siting a deep geological repository. These rocks typically occur in thin, complexly folded bands with uncertain geometry at depth. They would therefore be difficult to characterize and may not provide a sufficient volume of rock for hosting a repository. Further, it is likely that their physical properties (e.g., permeability) are highly variable and may not meet the safety functions of a repository (i.e., containment and isolation). The felsic gneiss is potentially suitable rock that has a predominantly granitic to tonalitic composition and has the potential for favourable rock properties (e.g., permeability, fracture conditions, homogeneity) that will meet the safety functions of a repository. There is some uncertainty in homogeneity of the felsic gneiss as discussed in Section 3.2.1.1. There are large lateral extents of felsic gneiss in the Pinehouse area and it has the potential to extend to considerable depth (5 to 8 km).
- ***Structural Geology:*** The spatial distribution, character and history of local and regional scale mapped faults and domain boundaries in the Pinehouse area were considered. The most prominent structural features in the Pinehouse area are the Needle Falls shear zone and brittle faults that overprint this shear zone (Figure 3.4). The Pinehouse area contains a series of mapped long, north-northwest trending brittle faults (Figures 3.3 and 3.4). The location of these faults was readily identified by the available bedrock geology maps for the Pinehouse area. While there is no available evidence to suggest these faults have been tectonically active within the past approximately 1.8 Ga, they were avoided in selecting general

potential areas. It is expected that these long regional faults will act as geomechanical and hydrogeological boundaries that surround blocks of potentially suitable rock. The general potentially suitable areas presented below reflect the preferred north-northwest orientation of these structures. The Mudjatik-Wollaston domain contact in the northwest of the Pinehouse area was avoided due to the abundance of pelitic and psammitic gneiss to the east of the contact (Figures 3.3 and 3.4). This area is also associated with shearing and possible low angle faults. Potential host rock thickness was also considered, noting that the felsic gneiss in the Pinehouse area is estimated to range from 5 to 8 km in thickness, which is sufficient for the purpose of the repository. The potential for groundwater movement at repository depth within a general area is, in part, controlled by the fracture frequency, their degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of infilling. With respect to selecting general potentially suitable areas in Pinehouse, current stress conditions, and fracture aperture orientation and frequency that could affect groundwater movement at depth are difficult to assess at this stage, due to an absence of site-specific information. Factors potentially influencing groundwater movement at repository depth are addressed at a generic level in Section 7.3.

- ***Lineament Analysis:*** In the search for potentially suitable general siting areas, there is a preference to select areas that have a relatively low density of lineaments, particularly a low density of longer lineaments, as these features could be indicative of structural discontinuities at depth. Geophysical lineaments were particularly considered as relevant as they are not significantly affected by overburden. The presence of a higher number of short surface lineaments in a particular area was not necessarily considered as an indication of poor suitability, as surface features may not all extend to repository depth and may not be structural discontinuities. There may be under-identification of brittle lineaments in the Pinehouse area due to high ductile strain associated with the Needle Falls shear zone (Section 3.2.3). The lineament filtering process, as described in Section 3.2.3 and presented on Figures 3.13 to 3.16, helped the identification of potentially suitable areas. The removal of shorter lineaments through the filtering process also helped compensate for bias in lineament density due to overburden cover (in the case of surficial lineaments) and low resolution aeromagnetic surveys (in the case of geophysical lineaments).

- ***Overburden:*** The distribution and thickness of overburden cover is an important factor to consider when assessing amenability to site characterization of a general potentially suitable area. For practical reasons, it is considered that areas covered by more than 2 m of overburden deposits would not be amenable to trenching for the purpose of structural mapping. This consideration is consistent with international practices related to site characterization in areas covered by overburden deposits (e.g., Finland; Andersson et al., 2007).

  For the purpose of identifying general potentially suitable areas, preference was given to areas with greater bedrock exposures (Figure 7.1). The thickness and distribution of overburden within the Pinehouse area is defined only at a regional (1:250,000 scale) level. Based on the terrain analysis conducted for the Pinehouse area (JDMA, 2013a), areas characterized by morainal veneer appear to have sufficiently thin cover to allow for generally unobscured mapping of the underlying bedrock structure. This is further supported by a Saskatchewan Geological Survey bedrock geology map (Munday, 1978b), which provide detailed definition of areas with thick overburden (shown on Figures 7.1

and 7.2). Much of the southwestern half of the area is largely covered by relatively thick overburden and bog plains. Bedrock exposure improves toward the northeast in the Pinehouse area. The location and extent of general potentially suitable areas will be refined during Phase 2 of the preliminary assessment, when site-specific data on overburden thickness and distribution is collected.

- ***Protected Areas:*** All provincial and federal parks and other protected areas as identified in Section 2.4 were excluded from consideration in the selection of potentially suitable siting areas. There are no Provincial or federal parks, wildlife areas or conservation reserves within Pinehouse area. As such, this was not a major factor in evaluating the Pinehouse area for potentially suitable siting areas. There is a recreation area, the Gordon Lake Recreation Site, located in the north-eastern part of the Pinehouse area. This recreation site is small, covering less that 4 km^2, and was therefore readily avoided (Figure 7.1). The absence of locally protected areas would need to be confirmed in discussion with the community and Aboriginal peoples in the area during subsequent site evaluation stages.

- ***Natural Resources:*** Areas associated with known and exploitable natural resources were excluded from further consideration. Readily available information on the past and potential future occurrence of natural resources such as oil and gas, metallic and non-metallic mineral resources indicates that there is no evidence of past or present exploration or development activities associated with oil and gas or coal resources at or near the Pinehouse area within the Canadian Shield. There are no currently operating or past producing mines within the Pinehouse area. There are several metallic mineral occurrences within the area such as gold, silver, copper and iron. These occurrences and the current mining claims are shown on Figure 7.1. However, none of these are known to be economically exploitable. Mineral occurrences in the area appear to be primarily associated with inferred fault traces, and metasedimentary rocks, both of which are excluded based on geoscientific evaluation factors discussed above. Uranium within the Pinehouse area is associated with a band of pelitic and psammitic gneissic rocks located near the Needle Falls shear zone (Figure 5.1). These gneisses appear to have potential for uranium mineralization and contain the only active mining claims in the Pinehouse area. The felsic gneiss of the Pinehouse area has a generally low economic mineral potential. As such, this was not a major factor in the identification of general potentially suitable areas within the felsic gneiss.

- ***Surface Conditions:*** Areas of obvious topographic constraint (high density of steep slopes), and large water bodies (wetlands, lakes) were considered during the identification of potential siting areas. While areas with such constraints were not explicitly excluded at this stage of the assessment, they are considered less preferable, all other factors being equal. There are no significant topographic features in the Pinehouse area that would make site investigation or construction exceptionally difficult. As discussed in Section 2, topography is moderately variable with the most relief occurring as bedrock ridges covered by a thin veneer of glacial moraine (Figures 2.2 and 2.3), and low lands with marshy areas. The most extensive areas containing wetlands are to the south of the Churchill River. The Churchill River itself consists of a chain of relatively large lakes in the Pinehouse area. These lakes are considered unfavourable in terms of surface conditions; however, the area has largely been excluded on the basis of unsuitable geology and thick overburden. The Pinehouse area is largely undeveloped, with no major infrastructure present. The closest infrastructure is associated with the Northern Village of Pinehouse itself and Provincial Road 914 which runs in a north-south direction through the Village.

7.2 Potential for Finding General Potentially Suitable Areas

The consideration of the above key geoscientific evaluation factors revealed that the Pinehouse area contains two general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. These general areas are located within the felsic gneiss of the Wollaston domain in the northeastern part of the Pinehouse area. Figure 7.1 shows features illustrating some of the key characteristics and constraints used to identify general potentially suitable areas, including: bedrock geology, protected areas, areas of thick overburden cover, surficial and geophysical lineaments, existing road network, the potential for natural resources and mining claims. A zoomed-in view of the northeastern part of the Pinehouse area is shown on Figure 7.2. The legend of both figures includes a 2 by 3 km box to illustrate the approximate extent of potentially suitable rock that would be needed to host a repository.

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

7.2.1 Felsic Gneiss in North-eastern Part of Pinehouse

As discussed in Section 3.2.1, the approximately 2.7 Ga felsic gneisses are 5 to 8 km thick, granitic in composition, have the potential for favourable rock properties and are extensive in the Pinehouse area. Most of the felsic gneiss within the Pinehouse area has low potential for natural resources, and is free of protected areas and surface constraints (i.e., topography and large waterbodies). Therefore, the differentiating factors for selecting potentially suitable areas within the felsic gneiss in Pinehouse area were considered to be mainly geology, overburden thickness, structural geology and, to a certain extent, lineament analysis.

The felsic gneiss in the northeastern part of the Pinehouse area (Figure 7.2) appears to contains several repository-sized areas that are away from the gneisses of sedimentary origin that were considered unfavourable for siting a deep geological repository. The felsic gneiss in the northeastern part of the Pinehouse area (Figure 3.4) has moderate aeromagnetic response, indicating there may be some lithological heterogeneity.

The first general potentially suitable area is located in the felsic gneiss immediately south of Gordon Lake, between Sandy Lake and McDonald Bay. This area appears to have the lowest lineament density within the Pinehouse area that is not covered by the Western Canada Sedimentary Basin. Approximately 30% of this area is exposed bedrock or covered by relatively thin overburden (less than 2 m). The area is free of mapped faults, but is bounded to the east and west by mapped faults that extend outside of the Pinehouse area (Figures 3.4 and 7.2). The potential impact of the Needle Falls shear zone on the suitability of the identified general area is uncertain and would need to be assessed during subsequent site evaluation stages.

The second general potentially suitable area is located in the felsic gneiss immediately north of Airriess Lake. This area was selected for its very high bedrock exposure and low lineament density. Approximately 95% of this area is exposed bedrock or is covered by relatively thin overburden (less than 2 m). This general potentially suitable area is free of mapped faults (Figures 3.4 and 7.2), but, as for the first area, the potential impact of the Needle Falls shear zone remains uncertain.

Both identified potentially suitable areas are mapped as felsic gneiss. However, as indicated in Section 3.2.1.1, the lithological homogeneity of the felsic gneiss in these areas remains uncertain and would need to be further investigated in subsequent site evaluation stages.

Figures 3.9 and 7.1 show that the geophysical lineament density over the two general potentially suitable areas is low, reflecting the low resolution of available magnetic surveys (805 to 1,609 m line spacing). There is also a potential for under-identification of lineaments due to the difficulty of recognizing such features in a region affected by high strain and a strong northeast pattern in the magnetic data (Section 3.2.3).

The distribution of geophysical lineaments within the two areas includes long northwest lineaments spaced between 1 and 6 km and east-west lineaments with spacing between 1 and 3 km. The orientation of geophysical lineaments is complex, showing groupings of lineaments in northwest, north and northeast directions. There is good agreement between interpreted geophysical lineaments and the mapped faults in the two areas (Figures 3.4 and 7.2).

Figures 3.8 and 7.1 show the surficial lineament density to be generally low throughout the Pinehouse area, with higher density of lineaments associated with areas of exposed bedrock. The orientation of surficial lineaments in the northeastern part of the Pinehouse area is simpler, likely due to the strong northeast fabric of the rock in this area. The density of surficial lineament in the first potentially suitable area (immediately south of Gordon Lake, between Sandy Lake and McDonald Bay) is very low, likely due to higher overburden cover. The surficial lineament density in the second potentially suitable area (immediately north of Airriess Lake) is also low, in spite of the very high bedrock exposure. At the desktop stage of the assessment, it is uncertain if surficial lineaments represent real bedrock structure and how far they extend to depth, particularly the shorter lineaments.

The distribution of lineament density as a function of lineament length over the Pinehouse area is shown on Figures 3.14 to 3.16 for all lineaments and lengths greater than 1 km, 5 km and 10 km, respectively. Overall, the northeastern part of the Pinehouse area exhibits low lineament density without applying any lineament filtering. There are areas with equally low lineament density to the west and to the southwest, but these are in areas of thick overburden cover, where amphibole gneiss and pelitic to psammitic gneiss are present, or where the Western Canada Sedimentary Basin covers the shield rocks. As expected, the figures show that, in general, the density of lineaments progressively decreases throughout the Pinehouse area as shorter lineaments are filtered out. Geophysical lineaments in the northeastern part of the Pinehouse area longer than 10 km are typically spaced on the order of 1 to 6 km.

The two identified general potentially suitable areas are on Crown Land and do not contain any protected areas. The Gordon Lake Recreational Site is immediately north of the first general potentially suitable area and about 15 km to the northwest of the second area. Both identified potentially suitable areas have no known exploitable mineral resources and are free of mineral showings and active mining claims (Figures 5.1 and 7.2).

Access to the first general potentially suitable area (south of Gordon Lake) is good via Highway 914, although no additional all-season roads are available off the highway. However, general access to the second area (immediately north of Airriess Lake) is poor. Highway 914 is located approximately 15 km to the west with no additional all-season roads available off the highway. There are no significant topographic features on the surface that would make site investigation or construction exceptionally difficult. The two general potentially suitable areas are within the Central Churchill tertiary watershed. The first area is poorly to well drained with lake/wetland cover of approximately 8% while the second area is well drained with lake/wetland cover of approximately 8%.

7.2.2 Other Areas

No prospective general potentially suitable areas were identified within the amphibole gneiss and the pelitic to psammic gneiss, as these rock types were considered unfavourable rock units for siting a deep geological repository. A prospective general area was identified within the felsic gneiss of the Wollaston domain using geology, overburden cover, structural geology and lineament analysis to further refine the extent of the areas. It may be possible to identify additional general potentially suitable areas. However, the two areas identified are those judged to best meet the key geoscientific characteristics outlined in Table 7.1, based on available information.

7.2.3 Summary of Characteristics of Areas in the Pinehouse Area

Table 7.1 provides a summary of the key geoscientific descriptive characteristics of the two identified potential siting areas in the Pinehouse area.

Table 7.1: Summary of Characteristics for the Northeastern Pinehouse Area

Geoscientific Descriptive Characteristic	Felsic Gneiss in the Northeastern Pinehouse Area
Rock Type	Felsic gneiss of the Wollaston domain
Age	ca. 2.65 Ga
Inferred host rock thickness	5 to 8 km
Extent of rock unit within the Pinehouse area	1,500 km^2
Relative proximity to mapped geological features (fault zones, shear zones, geological sub-province boundaries, etc.)	Needle Falls shear zone – approximately 15 km
Structure: faults, foliation, dykes, joints	>10 km long NNW faults run through the area
Aeromagnetic characteristics and resolution	Moderately noisy to high, NNE trend, low resolution
Terrain: topography, vegetation	Upland area, moderate relief, knobby in center, ridged to the east
Access	Good, Hwy 914 along W side
Resource Potential	Low, moderate at Needle Falls shear zone to the east
Bedrock exposure	Generally high
Drainage	Generally good, draining to Churchill River

7.3 Evaluation of the General Potentially Suitable Areas in the Pinehouse Area

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

- ***Safe containment and isolation of used nuclear fuel:*** Are the characteristics of the rock at the site appropriate to ensuring the long-term containment and isolation of used nuclear fuel from humans, the environment and surface disturbances caused by human activities and natural events?
- ***Long-term resilience to future geological processes and climate change:*** Is the rock formation at the siting area geologically stable and likely to remain stable over the very long term in a manner that will ensure the repository will not be substantially affected by geological and climate change process such as earthquakes and glacial cycles?
- ***Safe construction, operation and closure of the repository:*** Are rock conditions at the site suitable for the safe construction, operation and closure of the repository?
- ***Isolation of used fuel from future human activities:*** Is human intrusion at the site unlikely, for instance, through future exploration or mining?
- ***Amenable to site characterization and data interpretation activities:*** Can the geologic conditions at the site be practically studied and described on dimensions that are important for demonstrating long-term safety?

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

An evaluation of the two general potentially suitable areas in the Pinehouse area is provided in the following subsections.

7.3.1 Safe Containment and Isolation of Used Nuclear Fuel

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

This requires that:

- The depth of the host rock formation should be sufficient for isolating the repository from surface disturbances and changes caused by human activities and natural events;
- The volume of available competent rock at repository depth should be sufficient to host the repository and provide sufficient distance from active geological features such as zones of deformation or faults and unfavourable heterogeneities;
- The hydrogeological regime within the host rock should exhibit low groundwater velocities;

- The mineralogy of the rock, the geochemical composition of the groundwater and rock porewater at repository depth should not adversely impact the expected performance of the repository multiple-barrier system;
- The mineralogy of the host rock, the geochemical composition of the groundwater and rock porewater should be favourable to retarding radionuclide movement; and
- The host rock should be capable of withstanding natural stresses and thermal stresses induced by the repository without significant structural deformations or fracturing that could compromise the containment and isolation functions of the repository.

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

As discussed in Section 3 and summarized in Table 7.1, available geophysical information indicates that the estimated thickness of the felsic gneiss in the Wollaston domain is potentially greater than 5 km (Figure 3.2). Based on this, the thickness of the rock in the area identified (Section 7.2) is likely to extend well below typical repository depths (approximately 500 m), which would contribute to the isolation of the repository from human activities and natural surface events.

Analysis of interpreted lineament spacing (Section 3.2.3) indicate that the two identified general areas in the Pinehouse area have a lower density of lineaments and the potential to contain structurally bounded rock volumes of sufficient size to host a deep geological repository. The distribution of lineament density as a function of lineament length over the potentially suitable host rocks shows that the variable density and spacing of shorter brittle lineaments is influenced by the amount of exposed bedrock. By classifying the lineaments according to length, this local bias is reduced and the general area exhibits lineament spacing between longer lineaments (i.e., those longer than 10 km) on the order of 1 to 6 km, suggesting there is a potential for there to be sufficient volumes of structurally favourable rock at typical repository depth. Repository-sized areas can be located away from mapped faults. The general area to the east has a strong northeast ductile fabric to the rock that may be related to the Needle Falls shear zone, located about 15 km away to the southeast. There is a potential for under-identification of lineaments in this area as discussed in Section 3.2.3.

The hydrogeological regime at repository depth should exhibit low groundwater velocities and retard the movement of any potentially released radioactive material. There is limited information on the hydrogeological properties of the deep bedrock in the Pinehouse area. It is, therefore, not possible at this stage of the evaluation to predict the nature of the groundwater regime at repository depth in the identified area. The potential for groundwater movement at repository depth is, in part, controlled by the fracture frequency, the degree of interconnection and the extent to which the fractures are sealed due to higher stress levels and the presence of mineral infilling. Experience from other areas in the Canadian Shield indicates that ancient faults, similar to those in the Pinehouse area, have been subjected to extensive periods of rock-water interaction resulting in the long-term deposition of infilling materials that contribute to sealing and a much reduced potential for groundwater flow at depth. Site-specific conditions that can influence the nature of deep groundwater flow systems need to be investigated at later stages in the site evaluation process through site characterization activities that include drilling and testing of deep boreholes.

As discussed in Section 4.4, available information for granitic intrusions and gneisses within the Canadian Shield, indicates that active groundwater flow within structurally bounded blocks tends to be generally limited to shallow fracture systems, typically less than 300 m. In deeper regions, hydraulic conductivity tends to decrease as fractures become less common and less interconnected (Stevenson et al., 1996; McMurry et al., 2003). Increased vertical and horizontal stresses at depth tend to close or prevent fractures thereby reducing permeability and resulting in diffusion-dominated groundwater movement (Stevenson et al., 1996; McMurry et al., 2003). Hydraulic conductivity values measured at typical repository depths (500 m or greater) at the Whiteshell Research Area and Atikokan range from approximately 10^{-15} to 10^{-10} m/s (Ophori and Chan, 1996; Stevenson et al., 1996). Data reported by Raven et al. (1985) show that the hydraulic conductivity of the East Bull Lake pluton east of Elliot Lake, Ontario, decreases from an average near-surface value of 10^{-8} ms^{-1} to less than 10^{-12} ms^{-1} below a depth of 400 to 500 m.

Information on other geoscientific characteristics relevant to the containment and isolation functions of a deep geological repository, such as the mineralogy of the rock, the geochemical composition of the groundwater and rock porewater, the thermal and geomechanical properties of the rock are not available, or very limited at this stage of the site selection process. The review of available information from other locations with similar geological settings did not reveal any obvious conditions that would suggest unfavourable mineralogical or hydrogeochemical characteristics for the felsic gneiss rocks characterizing the two general potentially suitable areas identified within the Pinehouse area. Specific mineralogical and hydrogeochemical characteristics, including pH, Eh and salinity, would need to be assessed during subsequent site evaluation stages. Similarly, it is expected that the geomechanical and thermal characteristics of the felsic gneiss within the Pinehouse area may resemble those of the Lac du Bonnet batholith and Eye-Dashwa pluton with no obvious unfavourable conditions known at present. These characteristics would need to be assessed during subsequent site evaluation stages.

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

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

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

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

- Current and future seismic activity at the repository site should not adversely impact the integrity and safety of the repository system during operation and in the very long term;
- The expected rates of land uplift, subsidence and erosion at the repository site should not adversely impact the containment and isolation functions of the repository;
- The evolution of the geomechanical, hydrogeological and geochemical conditions at repository depth during future climate change scenarios such as glacial cycles should not have a detrimental impact on the long-term safety of the repository; and

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

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

The Pinehouse area is located within the Canadian Shield, where large portions of land have remained tectonically stable for more than 1.6 Ga. Historically, very few earthquakes of magnitude greater than 3 on the Richter scale have been recorded within Saskatchewan and none in the Pinehouse area over the last 25 years. As discussed in Section 3.2, fault zones have been identified in the Pinehouse area. These brittle features were probably created in the area approximately 1.8 Ga as part of the last significant deformation event known to have occurred in the area (D_5). There is some evidence suggesting periods of reactivation along a fault system (Tabbernor fault) about 200 km to the east of the Northern Village of Pinehouse. This fault initially formed approximately 1.8 Ga (Davies, 1998), but likely experienced more recent periods of reactivation (Elliot, 1996). However, there is no evidence of recent movement in the Pinehouse area and the majority of the movement along any related faults is inferred to have occurred 1.8 to 1.6 Ga. The identified general areas are away from these fault zones.

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

Land in the Pinehouse area is still experiencing isostatic rebound following the end of the Wisconsinan glaciations (Section 3.3.2). Vertical velocities show present-day uplift of about 10 mm/yr near Hudson Bay, the site of thickest ice at the last glacial maximum (Sella et al., 2007). The uplift rates generally decrease with distance from Hudson Bay and change to subsidence (1 to 2 mm/yr) south of the Great Lakes. Present day isostatic rebound rates in the Prairie Provinces should be on the order of 5 mm/yr (Lambert et al., 1998). There is no site-specific information on erosion rates for the Pinehouse area. However, as discussed in Section 3.1.6, the erosion rates from wind, water and past glaciations on the Canadian Shield are reported to be low.

In summary, available information indicates that the identified areas in the Pinehouse area have the potential to meet the long-term stability factor. The review did not identify any obvious geological or hydrogeological conditions that would cause the performance of a repository to be substantially altered by future geological and climate change processes, or prevent the identified areas from remaining stable over the long term. The long-term stability factor would need to be further assessed through detailed multidisciplinary site specific geoscientific and climate change site investigations.

7.3.3 Safe Construction, Operation and Closure of the Repository

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

This requires that:

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

There are few surface constraints that would limit the construction of surface facilities in the potentially suitable areas identified in the Pinehouse area. The area is characterized by moderate to low relief and contains enough surface land outside protected areas and major waterbodies to accommodate the required repository surface facilities.

From a constructability perspective, limited site-specific information is available on the local rock strength characteristics and *in situ* stresses for the felsic gneiss in the Pinehouse area. However, there is abundant information at other locations of the Canadian Shield with similar types of rock that could provide insight into what should be expected for the Pinehouse area in general. As discussed in Section 6, available information suggests that granitic crystalline rock units within the Canadian Shield generally possess good geomechanical characteristics that are amenable to the type of excavation activities involved in the development of a deep geological repository for used nuclear fuel (Arjang and Herget, 1997; Everitt, 1999; McMurry et al., 2003; Chandler et al., 2004). The conceptual model developed by Kaiser and Maloney (2005), based on available stress measurement data, describes the variable stress state in the upper 1,500 m of the Canadian Shield. Although this model can be used as an early indicator of average stress changes with depth, significant variations such as the principal horizontal stress rotation and the higher than average stress magnitudes found at typical repository depth (500 m) at AECL's URL (Martino et al, 1997) could occur as a result of local variations in geological structure and rock mass complexity.

The general potentially suitable areas have generally low overburden cover. At this stage of the site evaluation process, it is not possible to accurately determine the thickness of the overburden deposits in these areas due to the low resolution of available data. Figure 2.3 shows these areas to be dominated by rock with some ground moraine (till) and outwash deposits, soil types that are generally geotechnically suitable in terms of bearing capacity and stability for the construction of surface infrastructure associated with a repository.

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

7.3.4 Isolation of Used Fuel from Future Human Activities

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

This requires that:

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

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

The review of available information did not identify any groundwater resources at repository depth for the Pinehouse area. As discussed in Section 4.1, the SWA WWR database shows that there are no water wells known in the Canadian Shield portion of the Pinehouse area. Experience from other areas with similar rock types in the Canadian Shield has shown that active groundwater flow in crystalline rocks is generally confined to shallow fractured localized systems (Stevenson et al., 1996; McMurry et al., 2003). SWA WWRs indicate that no potable water supply wells are known to exploit aquifers at typical repository depths in the Pinehouse area or anywhere else in northern Saskatchewan. Groundwater at such depths is generally saline and very low groundwater recharge at such depths limits potential yield, even if suitable water quality were to be found.

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

7.3.5 Amenability to Site Characterization and Data Interpretation Activities

In order to support the case for demonstrating long-term safety, the geologic conditions at a potential site must be amenable to site characterization and data interpretation. That is, physical, geochemical and hydraulic properties of the site must be describable in a fashion that can be used in performance and safety assessment models.

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

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

The identification and mapping of geology and structure is strongly influenced by the extent and thickness of overburden cover and the presence of large lakes. The Pinehouse area is dominated by a thin veneer of morainal sediments or exposed bedrock. Thicker overburden deposits occur over the western and southern lowland portions of the Pinehouse area. Provincial Highway 914 provides direct access to the western general potentially suitable area. Currently there is no all-season road access to the east side of the general potentially suitable area.

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

8.0 GEOSCIENTIFIC PRELIMINARY ASSESSMENT FINDINGS

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

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

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

The desktop geoscientific preliminary assessment showed that the Pinehouse area contains at least two general areas that have the potential to satisfy NWMO's geoscientific site evaluation factors. Both areas are located in the northeastern part of the Pinehouse area.

The bedrock within the two areas identified (felsic gneiss) appears to have a number of geoscientific characteristics that are favourable for hosting a deep geological repository. It has a sufficient depth and extends over a large area at surface. It also appears to have low potential for natural resources and limited surface constraints. The two potentially suitable areas have complex orientations of interpreted lineament, but are generally amenable to site characterization.

While the Pinehouse area appears to have favourable geoscientific characteristics, there are inherent uncertainties that would need to be addressed during subsequent stages of the site evaluation process. The main uncertainties include the low resolution of available geophysical data, the potential for lithological homogeneity of the felsic gneiss and the influence of the Needle Falls shear zone.

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

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

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Report Signature Page

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Senior Geological Engineer, Associate

George Schneider, M.Sc., P.Geo. (Ontario)
Senior Geoscientist, Principal

AM/GWS/wlm

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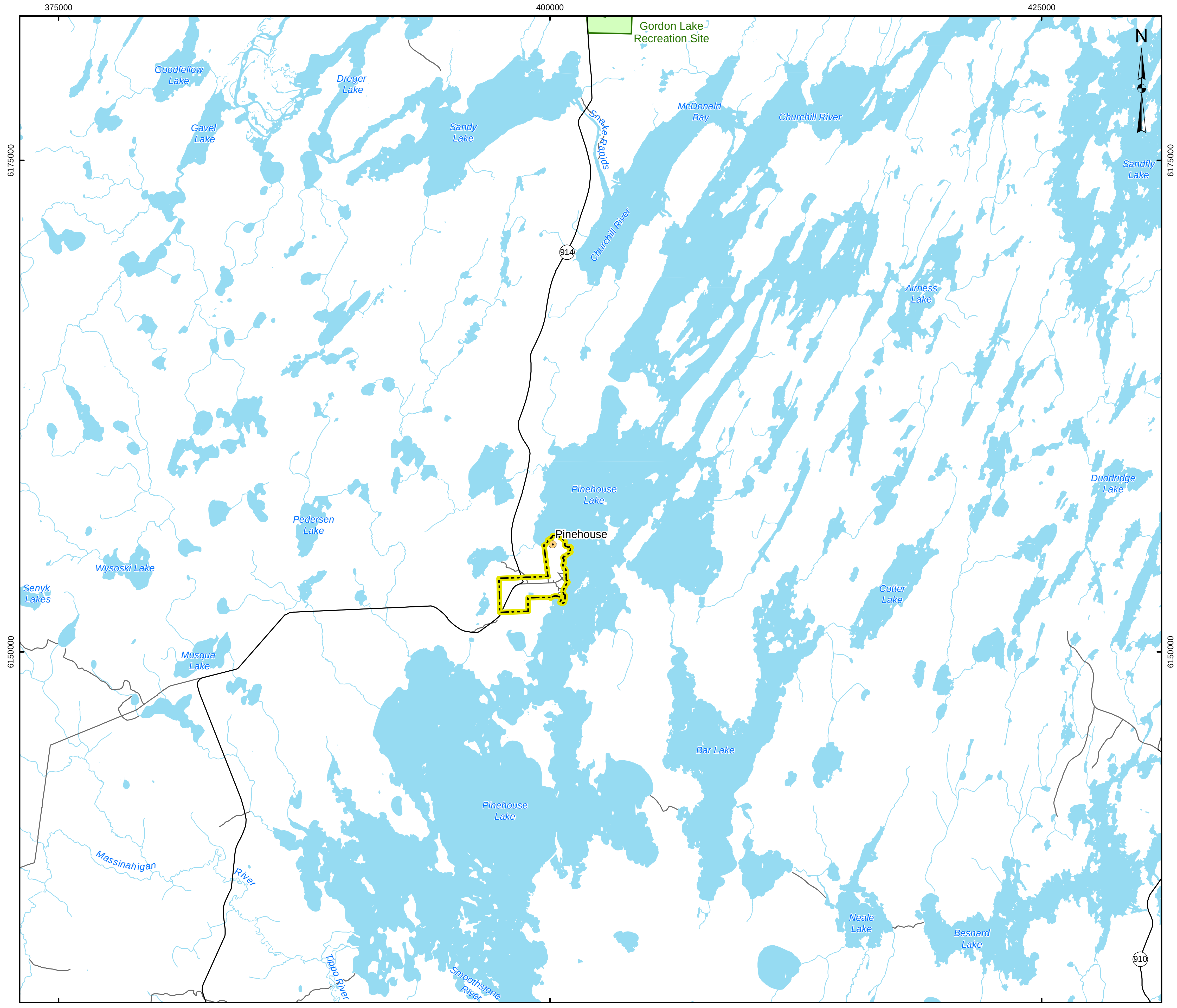
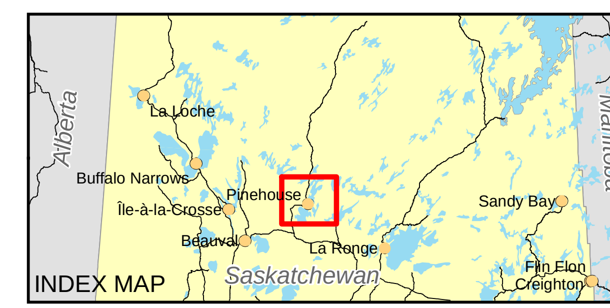
FIGURES



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Park and Recreation Area



REFERENCE

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

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SCALE 1:200,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

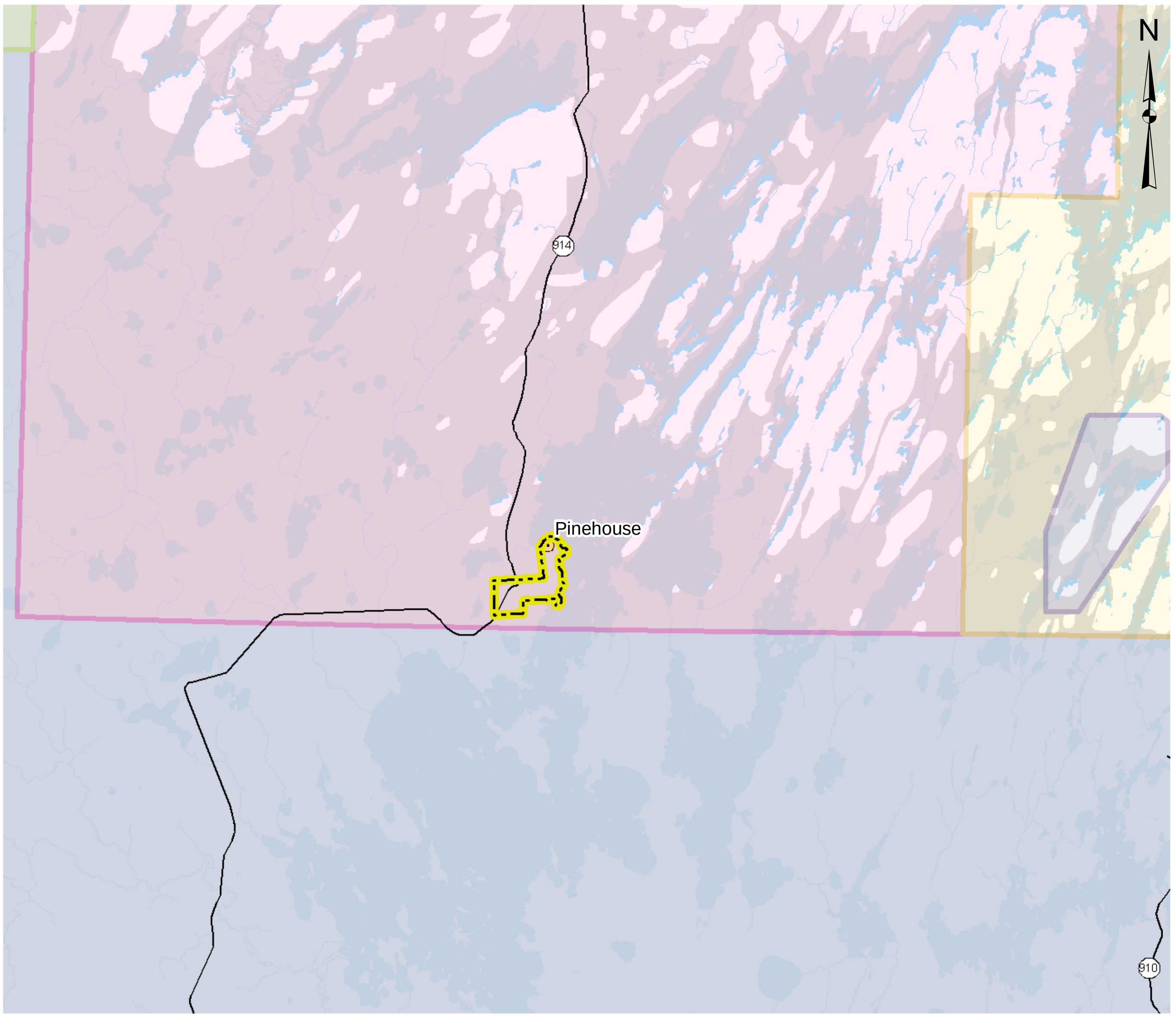
Northern Village of Pinehouse and Surrounding Area

Golder Associates
Mississauga, Ontario

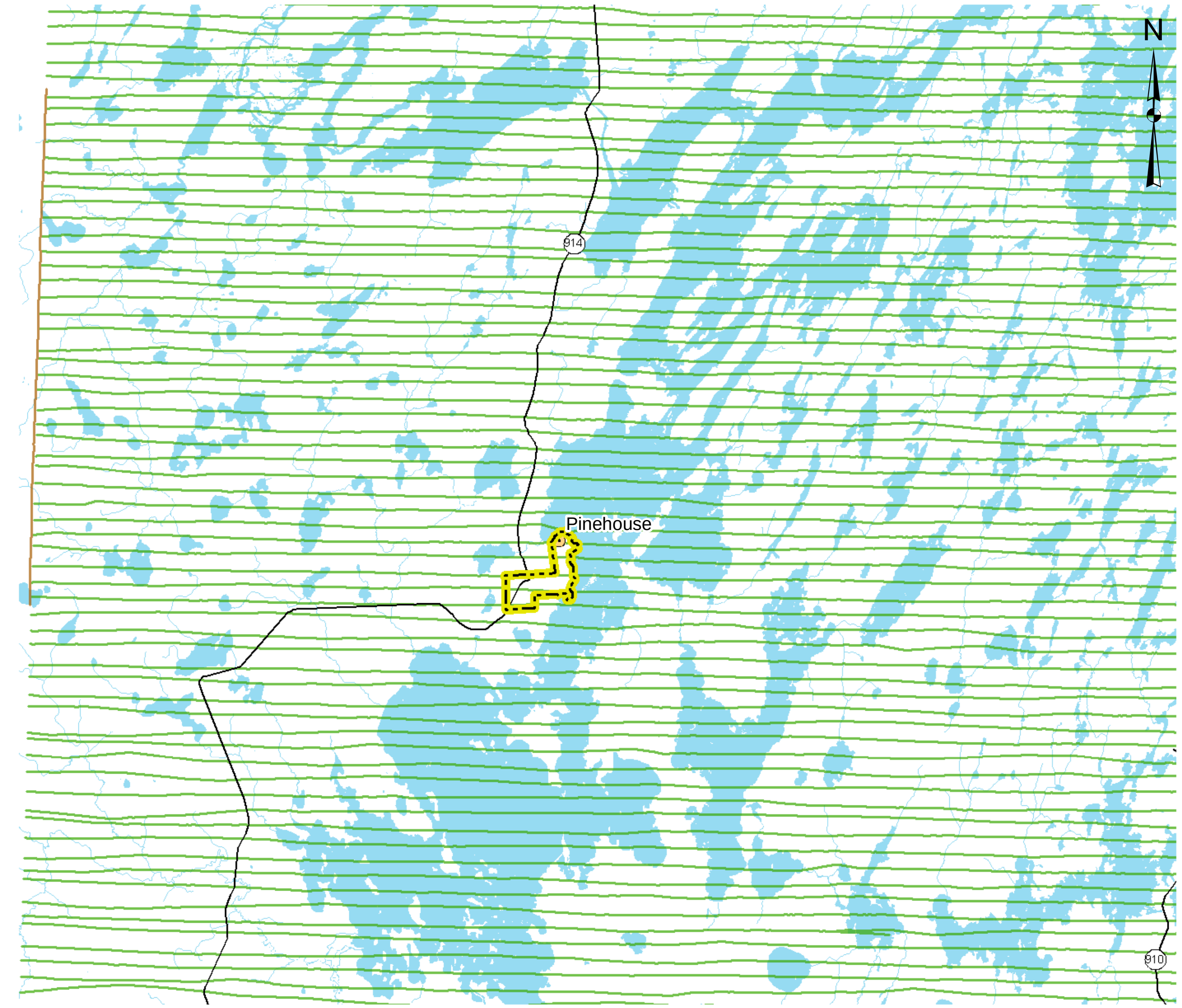
PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012		
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

FIGURE: 1.1

Geology Mapping Coverage



Geophysics Mapping Coverage



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Watercourse
- Waterbody
- Overburden Cover

Detailed Geology Extent

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

Full Geology Coverage
Saskatchewan Industry and Resources, 2010

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

LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Watercourse
- Waterbody

Geophysical Survey Extents

- Geophysics Flight Paths GSC Saskatchewan #8
- Geophysics Flight Paths GSC Saskatchewan #9

6 3 0 6 12 18

SCALE 1:325,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Geoscience Mapping and Geophysical Coverage of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM/JB	19 Nov. 2012	FIGURE: 1.2	
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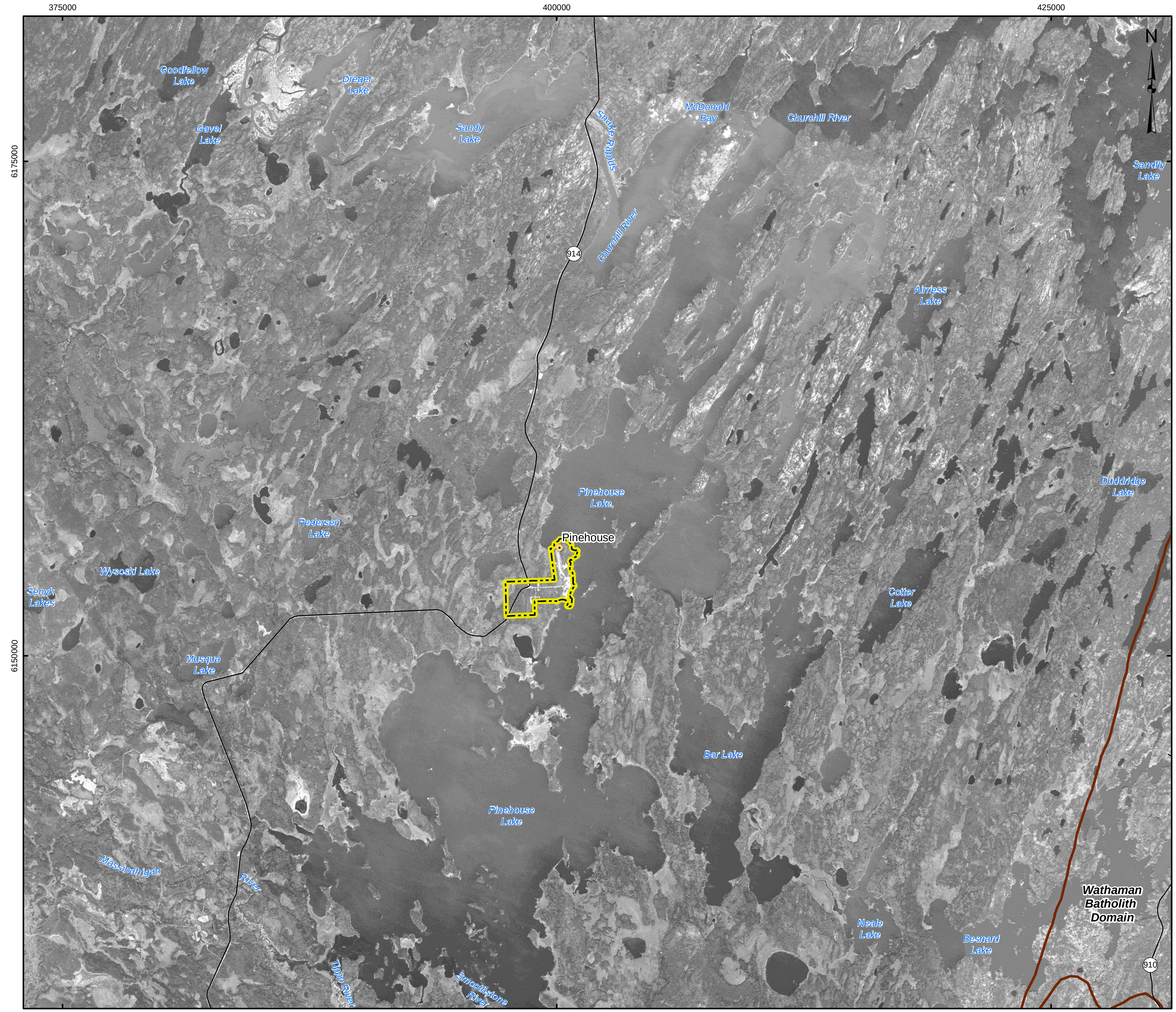
REVIEW	GWS	20 Sep. 2013		



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Wathaman Batholith

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)
Imagery - SPOT obtained from GeoBase (2005, 10m resolution)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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SCALE 1:200,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Satellite Imagery of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 2.1	
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

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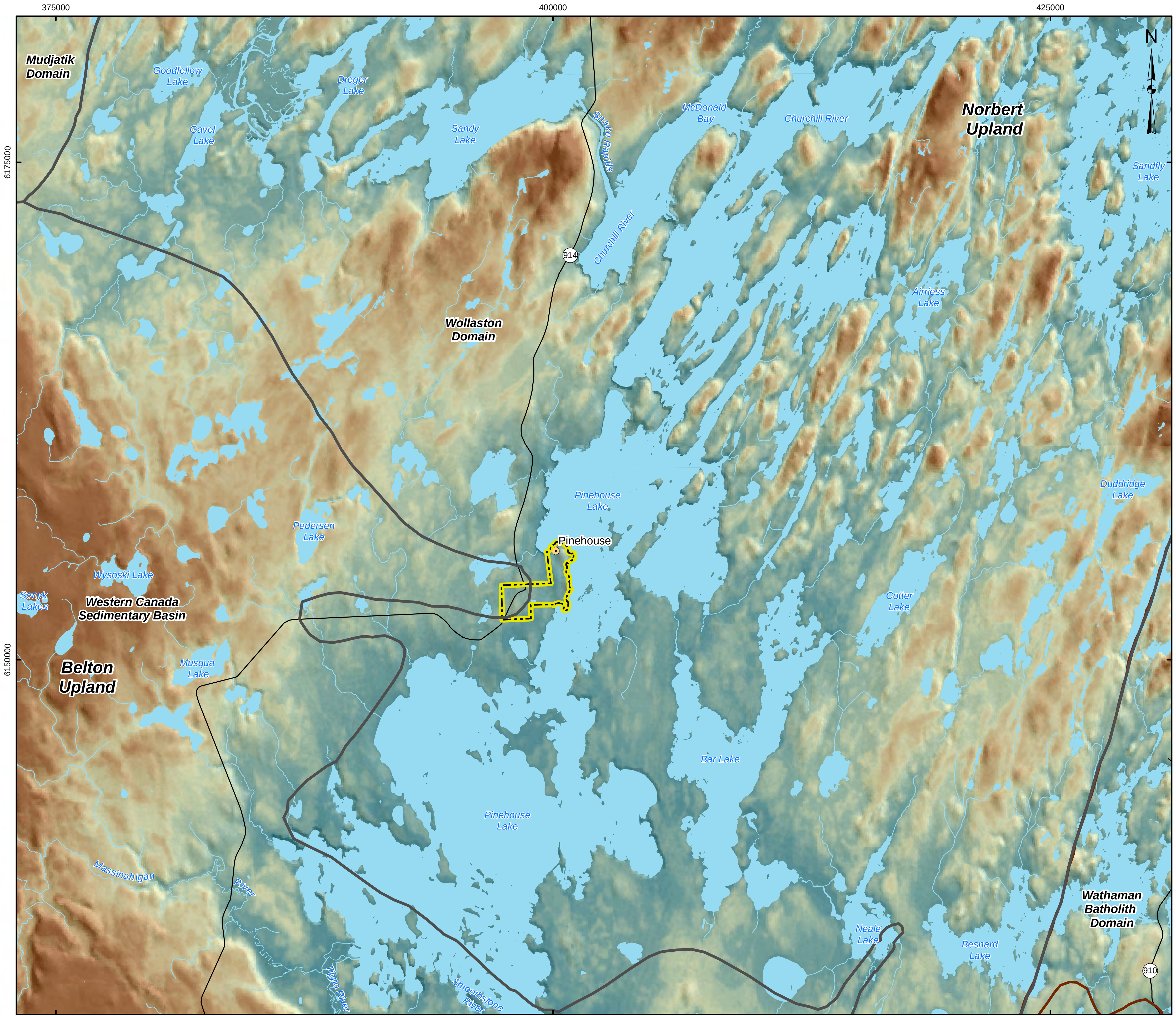


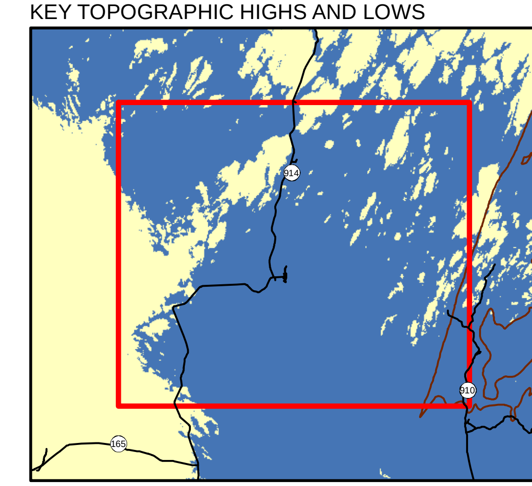
LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Watercourse
- Waterbody
- Wathaman Batholith
- Domain Boundary

Elevation (masl)

515
500
475
450
425
400
375

KEY TOPOGRAPHIC HIGHS AND LOWS



Elevation (m)

370 - 425   426 - 550

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)
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 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Elevation and Major Topographic Features of the Pinehouse Area

Golder Associates
Mississauga, Ontario

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

FIGURE: 2.2

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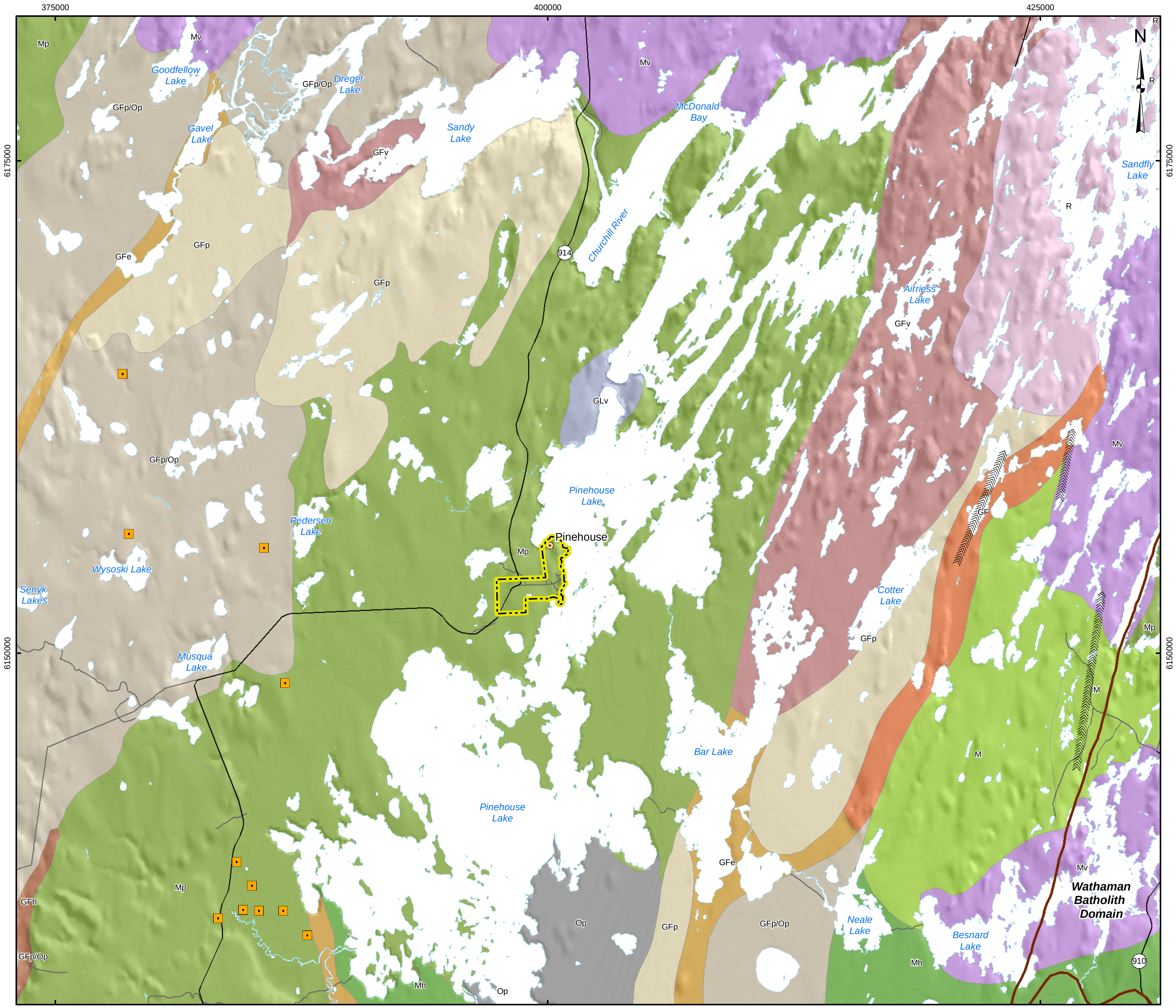
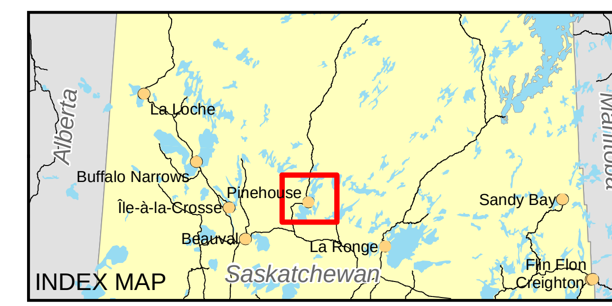


LEGEND

- 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



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

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Terrain Features of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 2.3	
GIS	PM/JB	20 Sep. 2013		
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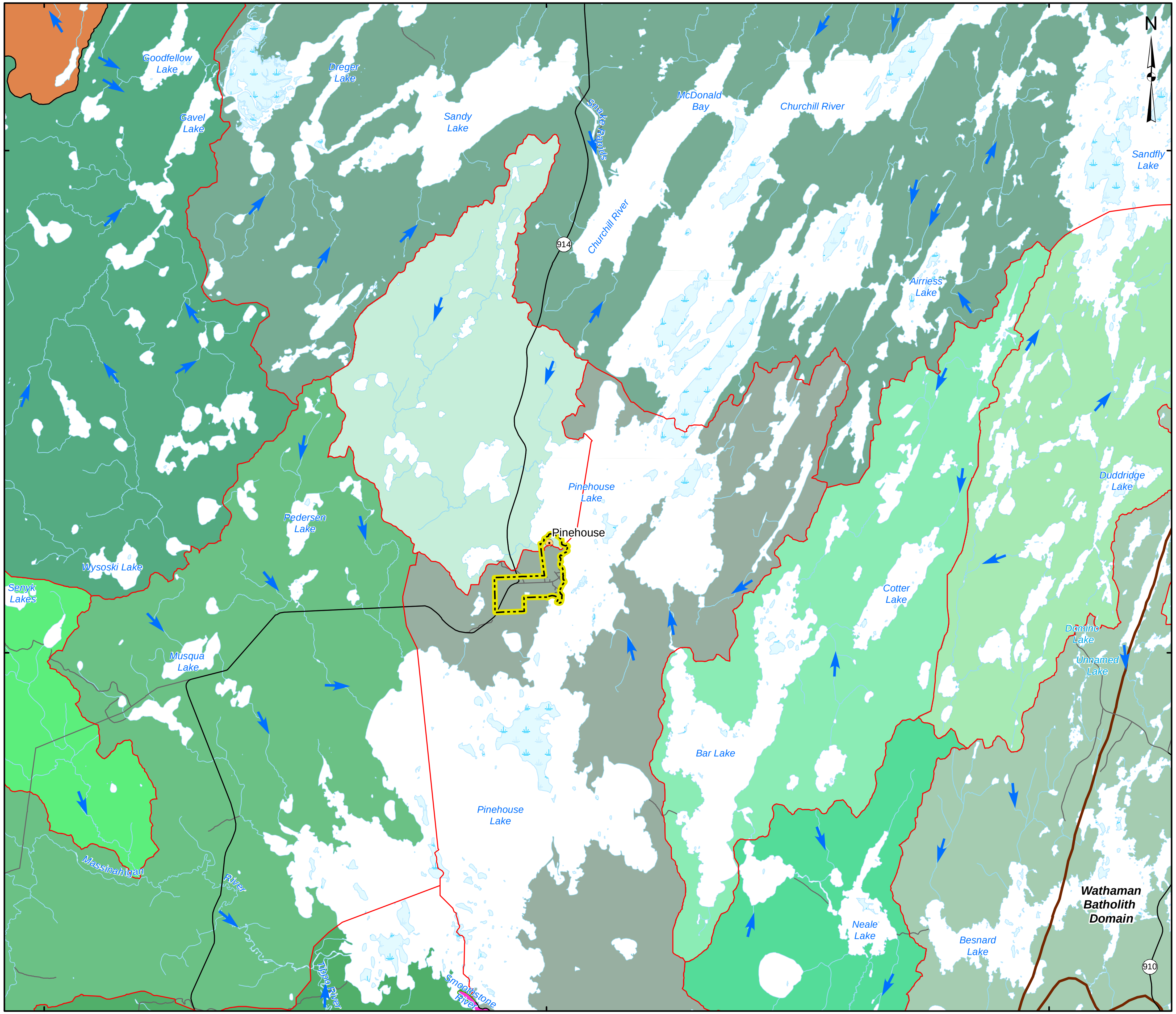


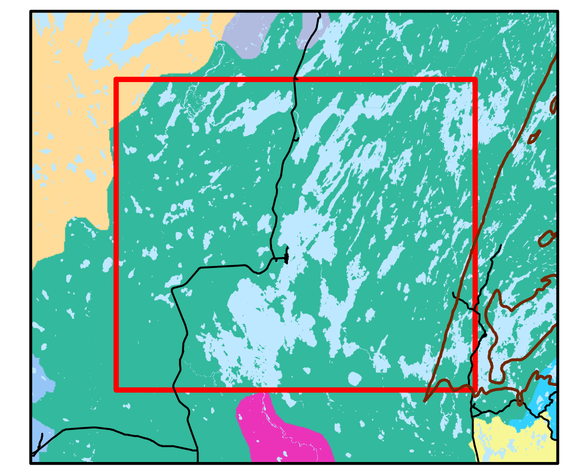
LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Wathaman Batholith
- Flow Direction

Drainage Divide

- Confirmed by PFRA/JDMA
- Modelled by JDMA
- Delineated by PFRA
- Watercourse
- Waterbody
- Wetland

MAP OF TERTIARY WATERSHEDS



Tertiary Watershed

- Upper Churchill
- Haultain
- Central Churchill
- Smoothstone
- Lower Beaver
- Montreal (Sask.)
- Rapid

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)
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PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Drainage Features
of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
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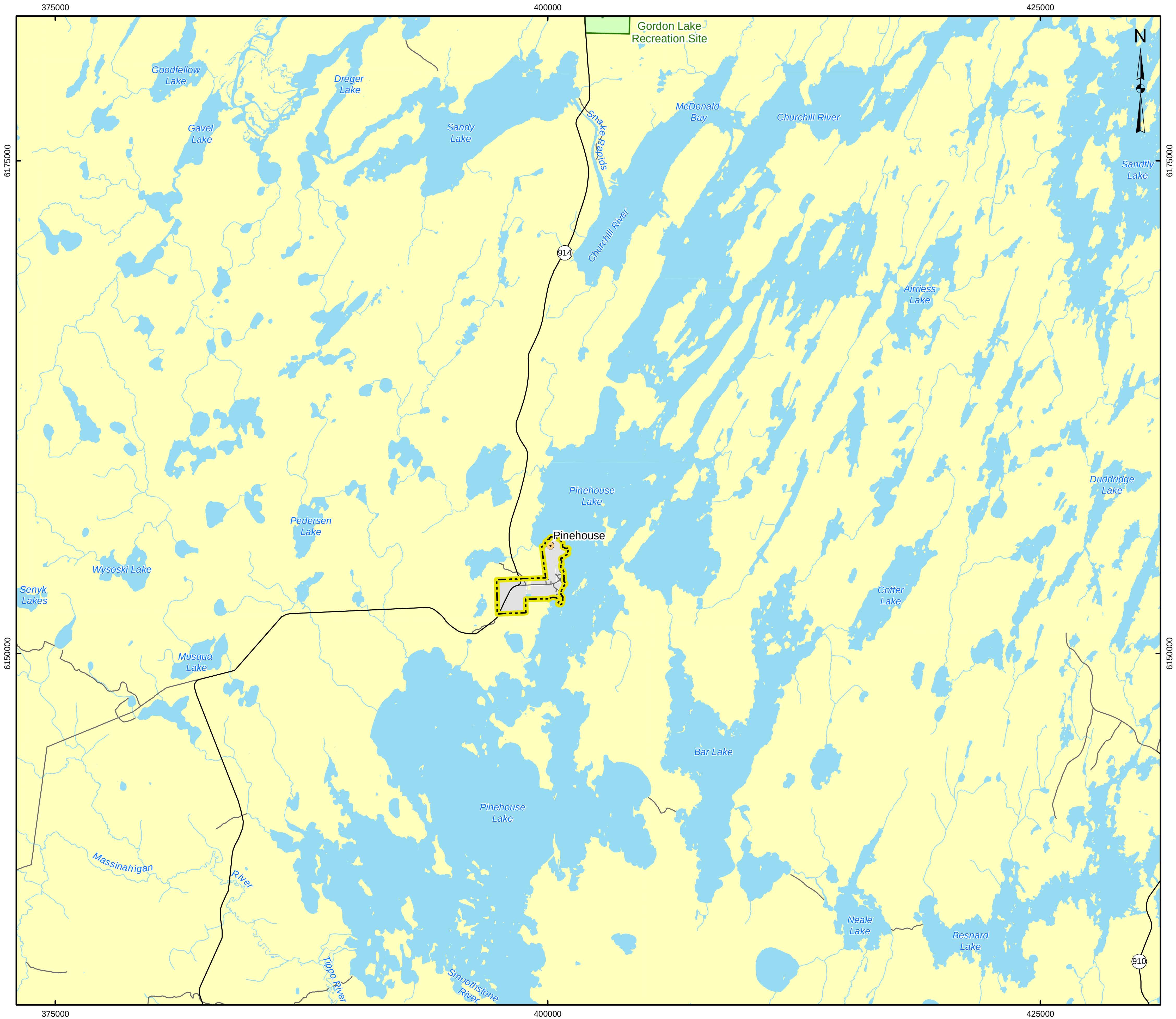
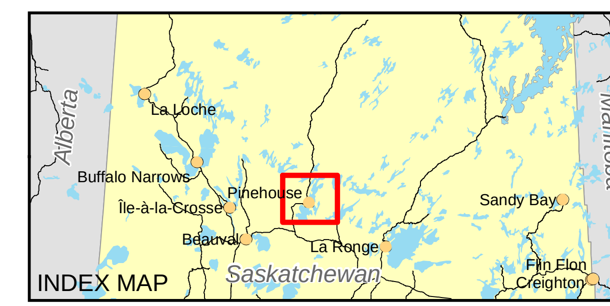


LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Park and Recreation Area
- Crown Land
- Private Land



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Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
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KILOMETERS
SCALE 1:200,000

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Land Disposition and Ownership within the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 2.5	
GIS	PM/JB	20 Sep. 2013		
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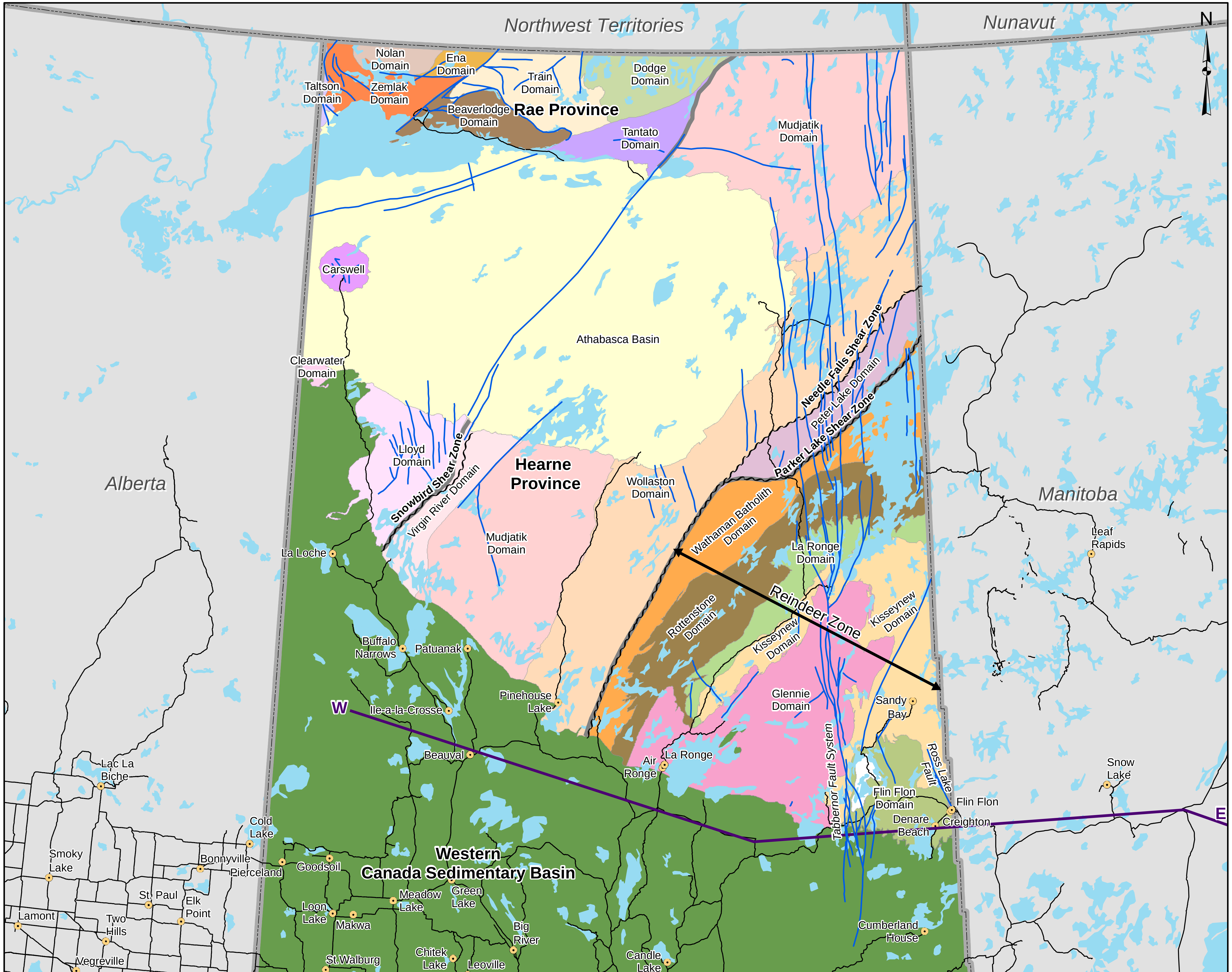


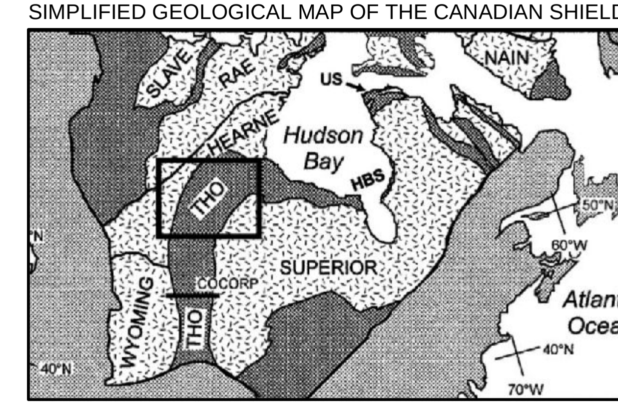
LEGEND

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

Lithotectonic Domain

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

SIMPLIFIED GEOLOGICAL MAP OF THE CANADIAN SHIELD



REFERENCE

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

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PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Lithostructural Domains of Northern Saskatchewan

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	JB	8 Nov. 2012	FIGURE: 3.1	
GIS	PM/JB	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

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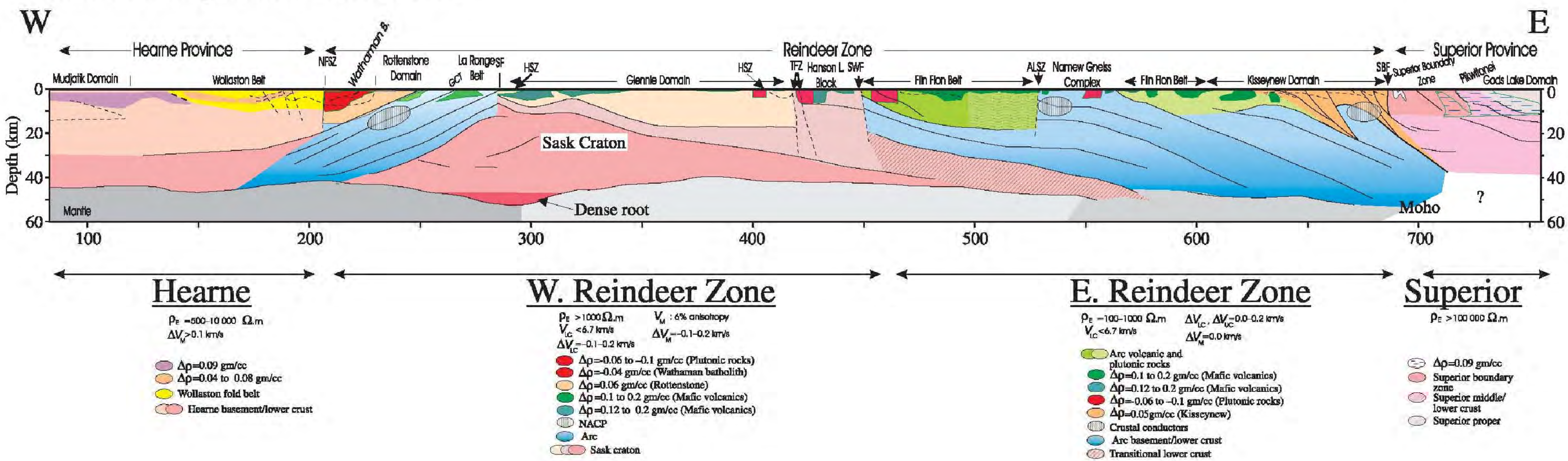

REFERENCE

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

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Geological Cross Section Through Northern Saskatchewan

Golder Associates
Saskatoon, Saskatchewan

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	JB	8 Nov. 2012	FIGURE: 3.2	
GIS	BDS	20 Sep. 2013		
CHECK	AM	20 Sep. 2013		
REVIEW	GWS	20 Sep. 2013		

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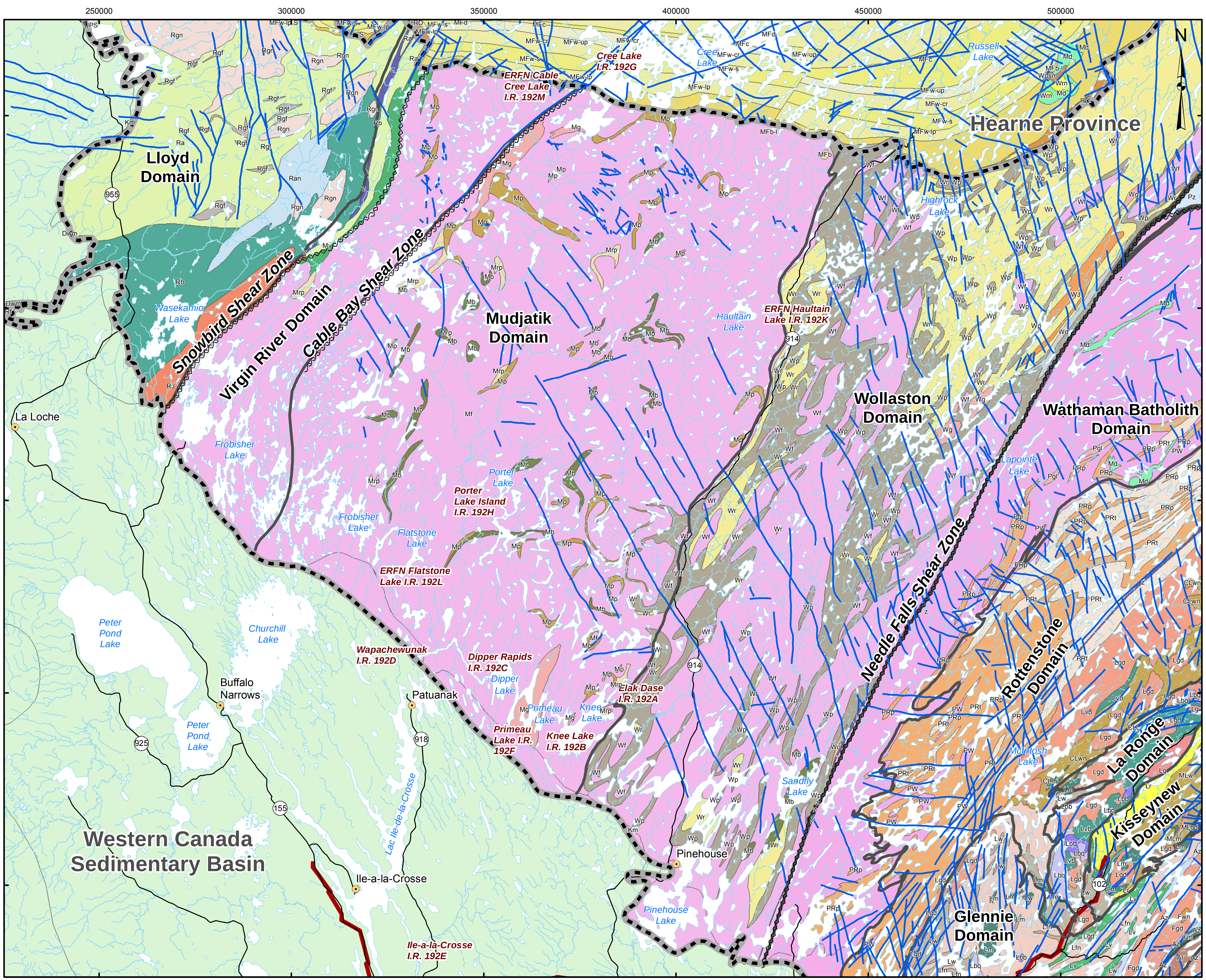

LEGEND

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

Western Canada Sedimentary Basin
- Western Canada Sedimentary Basin

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

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

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

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

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

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

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

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

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

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

REFERENCE

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

20 10 0 20 40 60

SCALE 1:1,000,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Regional Geology of
Northern Saskatchewan

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.3	
GIS	PM/JB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		

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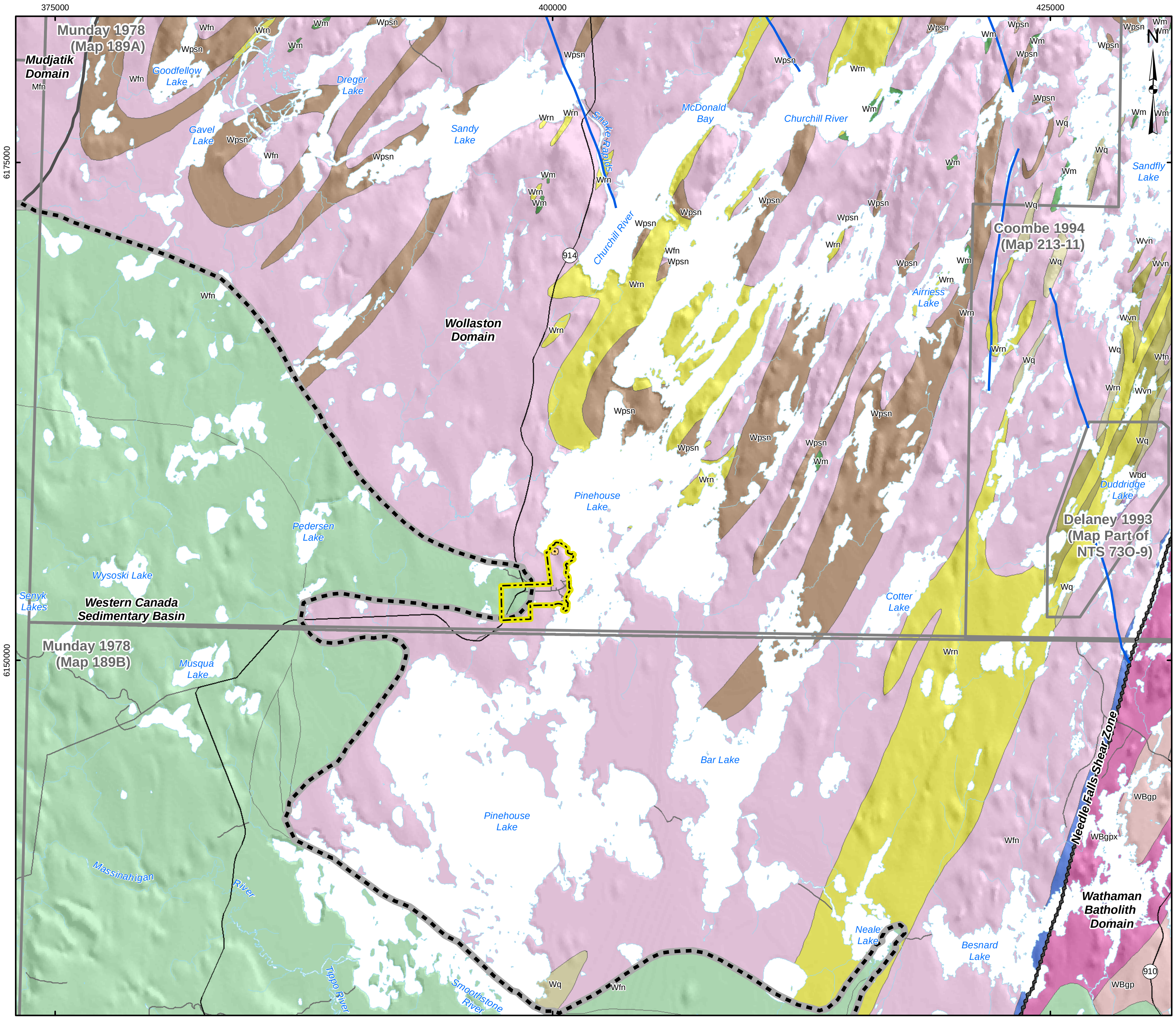

LEGEND

- 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)

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
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Local 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	FIGURE: 3.4	
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

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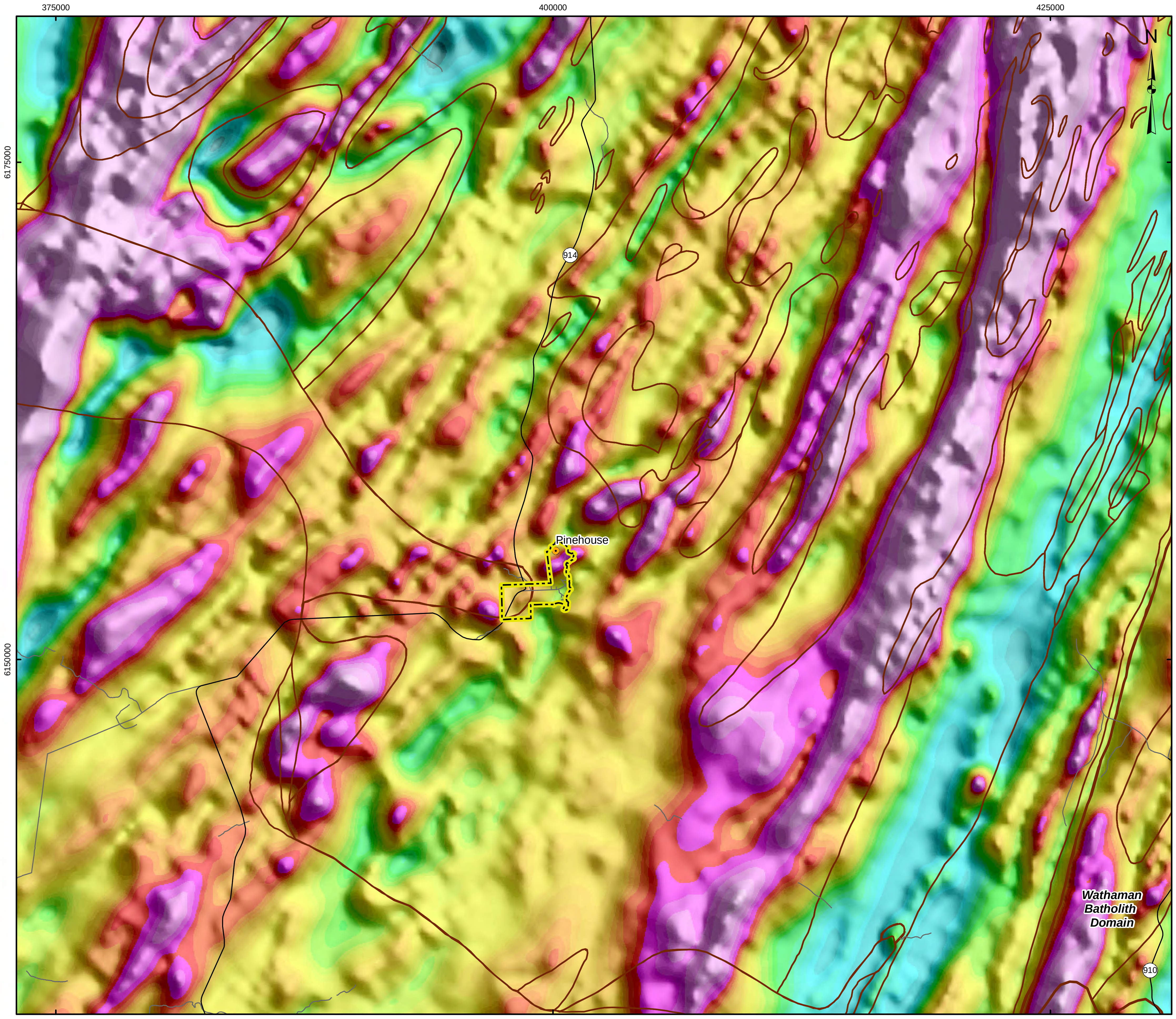


LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Metasedimentary Rock
- Wathaman Batholith

Residual Total Magnetic Field (nT)

2633
1050
875
750
675
600
550
500
475
450
425
375
350
325
300
275
250
225
200
150
125
100
50
25
0
-25
-550
-125
-175
-337

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)
Geophysics - GSC Canada - 200m - Magnetic - Residual Total Field, 2008; Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

5 2.5 0 5 10

SCALE 1:200,000 KILOMETRES

PROJECT

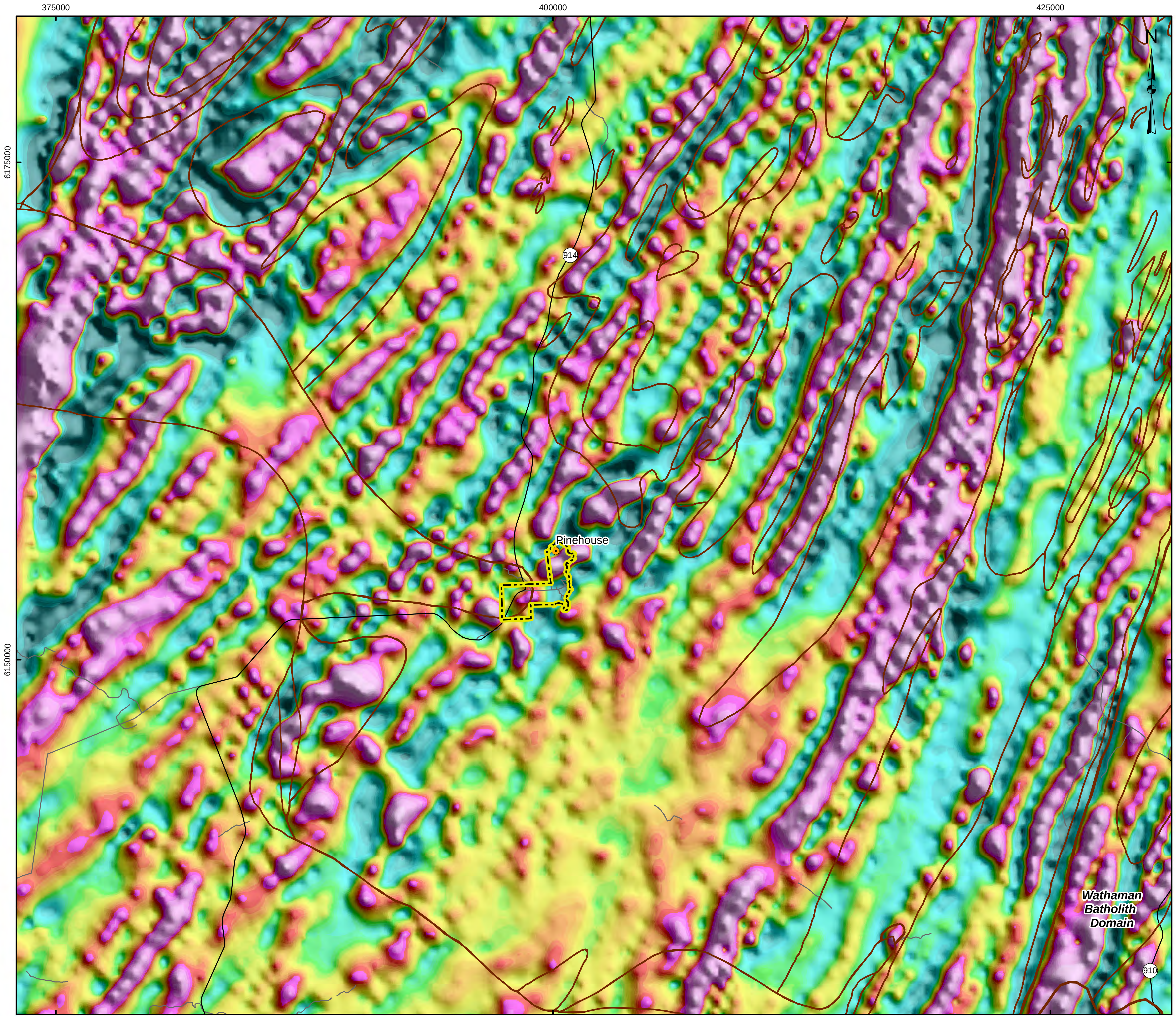
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Total Magnetic Field (Reduced to Pole) of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.5	
GIS	PM/JB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Metasedimentary Rock
- Wathaman Batholith

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

5.579
0.580
0.390
0.290
0.230
0.180
0.140
0.110
0.080
0.060
0.040
0.020
0.010
0.000
-0.010
-0.030
-0.040
-0.060
-0.070
-0.090
-0.100
-0.120
-0.140
-0.160
-0.180
-0.210
-0.250
-0.310
-0.420
-1.619

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)
Geophysics - GSC Canada - 200m - Magnetic - Residual Total Field, 2008;
Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

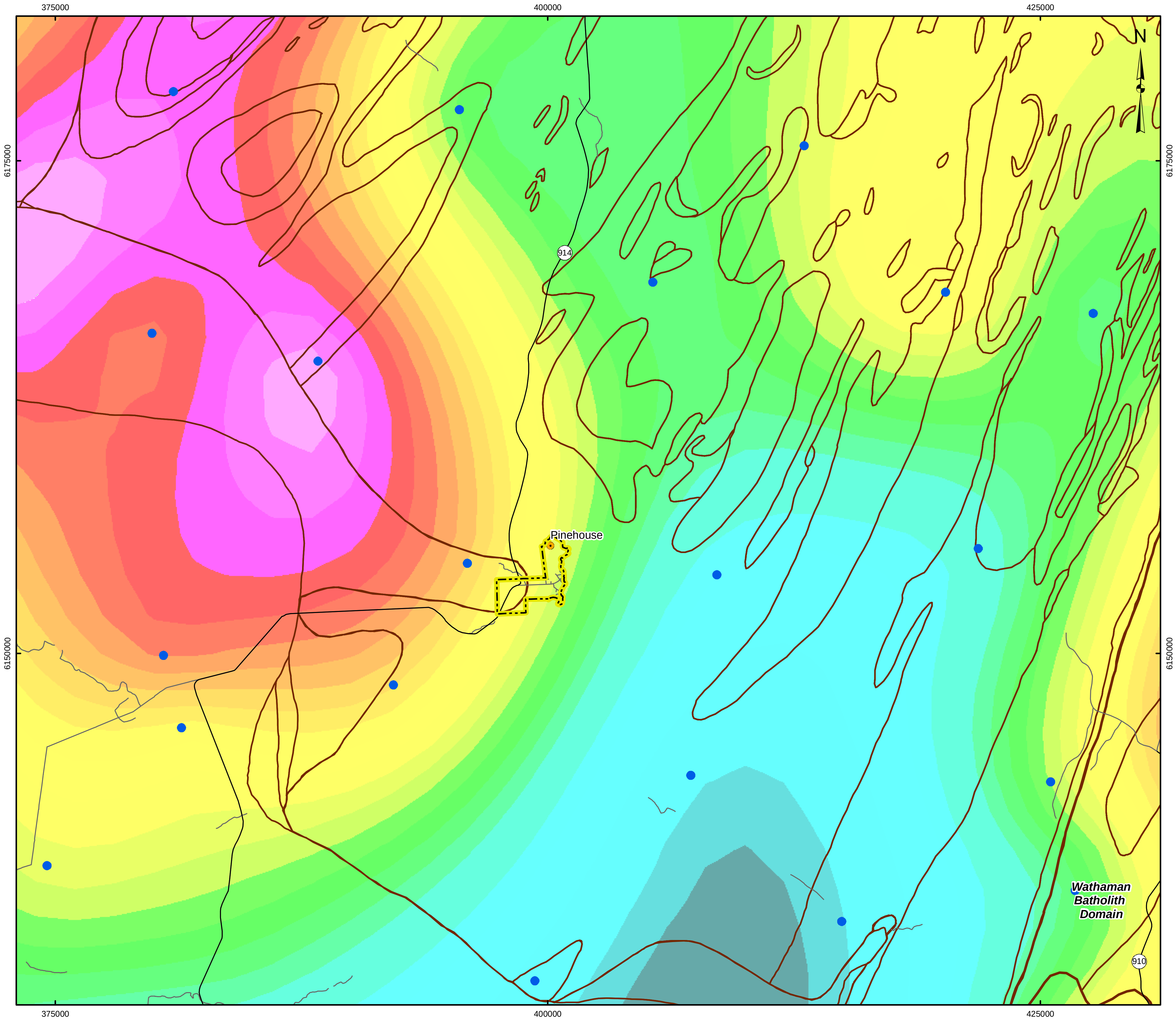
PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

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

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.6	
GIS	PM/JB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		

G:\Projects\2012\12-1152-0026_NWMO_PhaseI_Feasibility\GIS\MXDs\Reporting\Pinehouse\Draft_Integrated_Report\1stVerticalDerivativeResidualMagneticFieldPinehouseArea.mxd



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Gravity Station
- Metasedimentary Rock
- Wathaman Batholith

Gravity Anomaly (mGal)

-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
-64.5
-65.0
-65.5
-66.0
-66.5
-67.0
-67.5
-68.0
-69.8

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)
Geophysics - GSC Canada - 2km - Gravity Anomalies, 2010;
Canadian Aeromagnetic Data Base, Airborne Geophysics Section, GSC - Central Canada
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Bouguer Gravity of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.7	
GIS	PM/JB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		

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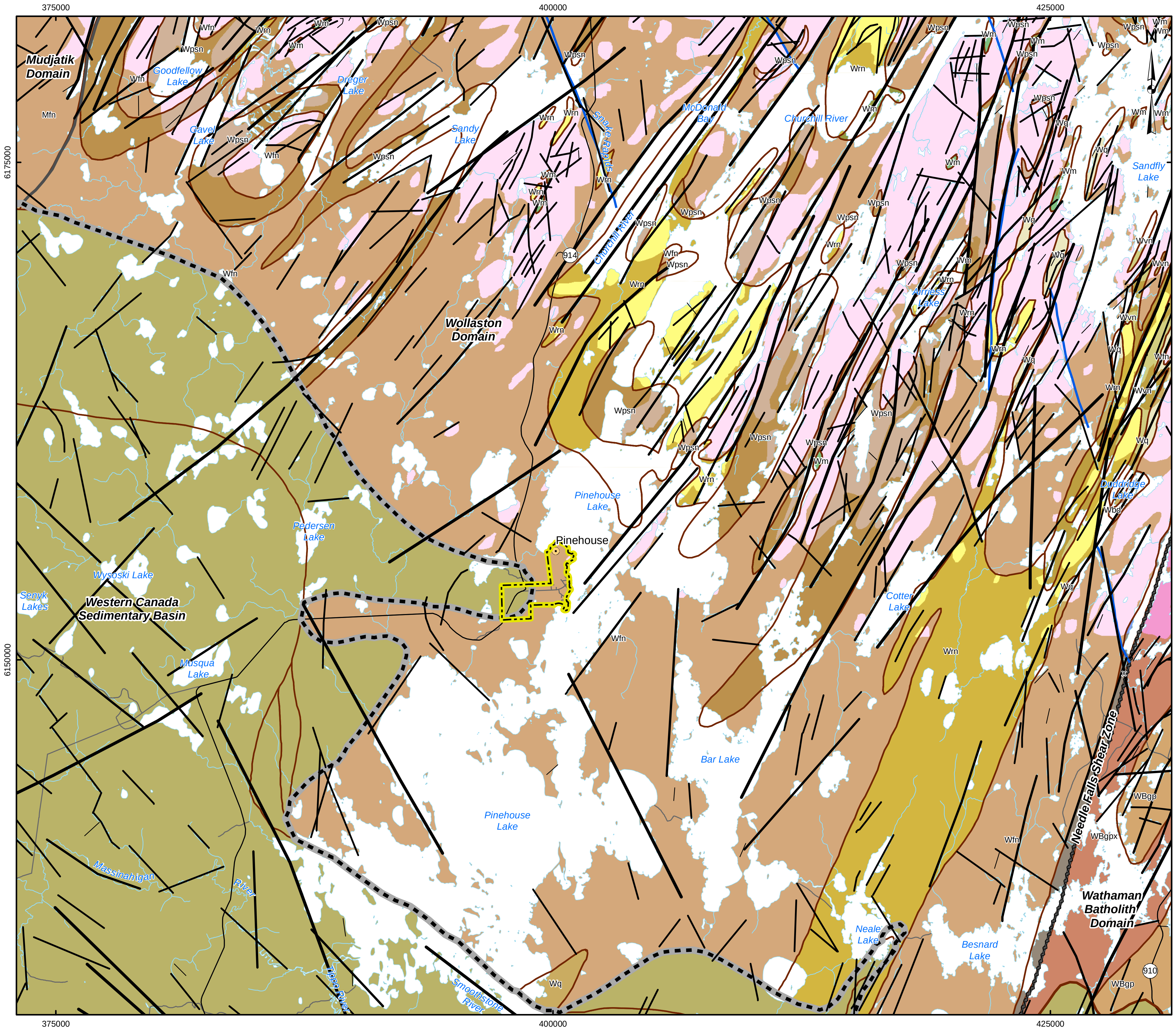


LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Metasedimentary Rock
- Wathaman Batholith
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Overburden Cover

Western Canada Sedimentary Basin
- Western Canada Sedimentary Basin

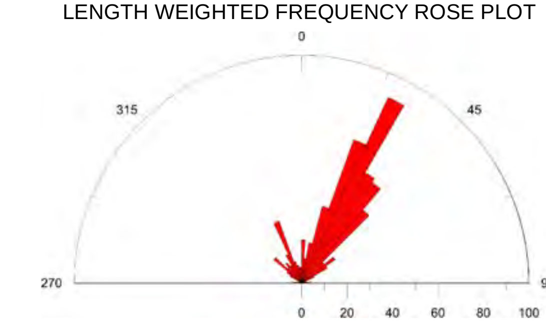
Mudjatik Domain
- Mfn - Felsic gneiss

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

Surficial Lineaments (SPOT and CDED)
- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km

PINEHOUSE SURFICIAL LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Lineaments - Lineament Interpretation, Pinehouse, Saskatchewan (JDMA, 2013)
Overburden - Munday, R.J.C., 1978b. The Shield Geology of the Ile-a-la-Crosse (East) Area Saskatchewan. Part of the NTS Area 73-0. 1:100,000 Sheet 1, Map 189A, SGS
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Surficial Lineaments 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	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

FIGURE: 3.8

LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Metasedimentary Rock
- Wathaman Batholith
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Geophysical Lineaments

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

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mfn - Felsic gneiss

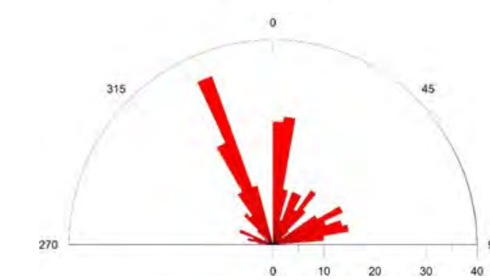
Wollaston Domain

- 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

PINEHOUSE GEOPHYSICAL LINEAMENTS - LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

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

5 2.5 0 5 10

SCALE 1:200,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Geophysical Lineaments of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT No. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.9	
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

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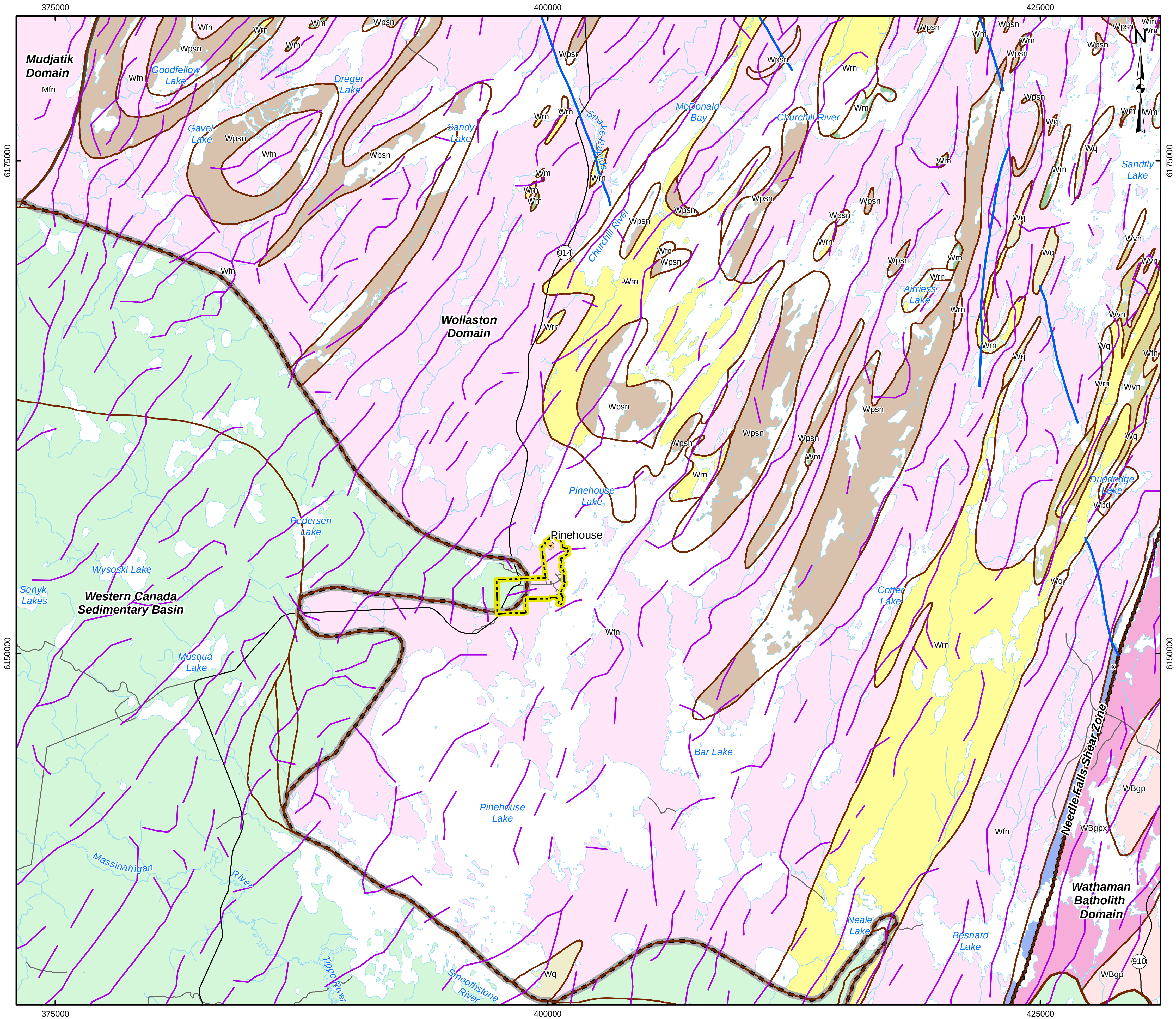

LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Ductile Lineaments
- Metasedimentary Rock
- Wathaman Batholith
- 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

REFERENCE

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

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Ductile Lineaments
of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.10	
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

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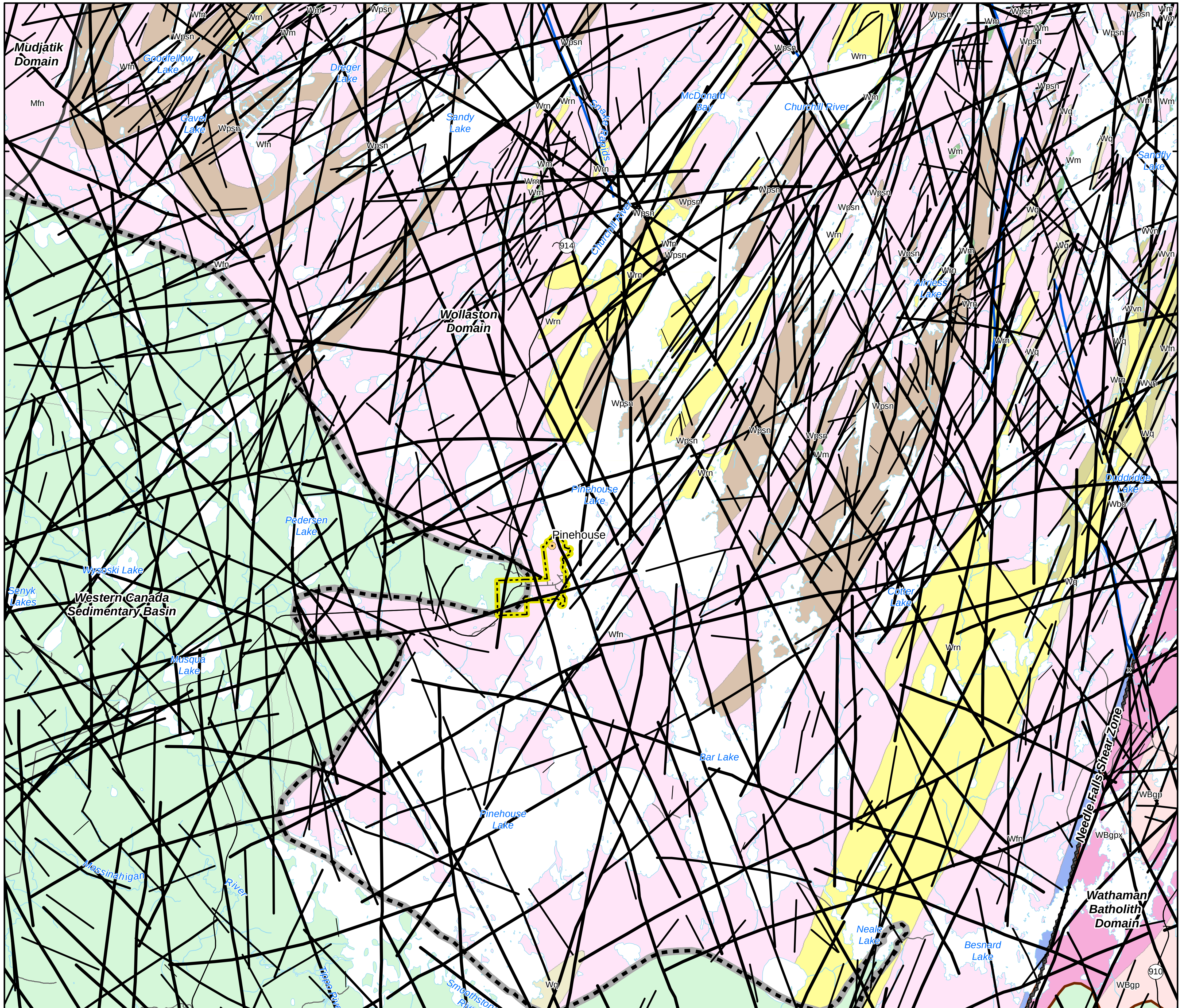


LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Wathaman Batholith

Brittle Lineaments (Surficial and Geophysical)

- < 1 km
- 1 - 5 km
- 5 - 10 km
- > 10 km
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Western Canada Sedimentary Basin

- Western Canada Sedimentary Basin

Mudjatik Domain

- Mfn - Felsic gneiss

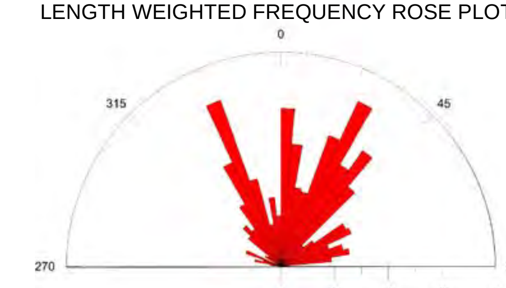
Wollaston Domain

- 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

PINEHOUSE ALL LINEAMENTS -
LENGTH WEIGHTED FREQUENCY ROSE PLOT



REFERENCE

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

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineaments
of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.11	
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

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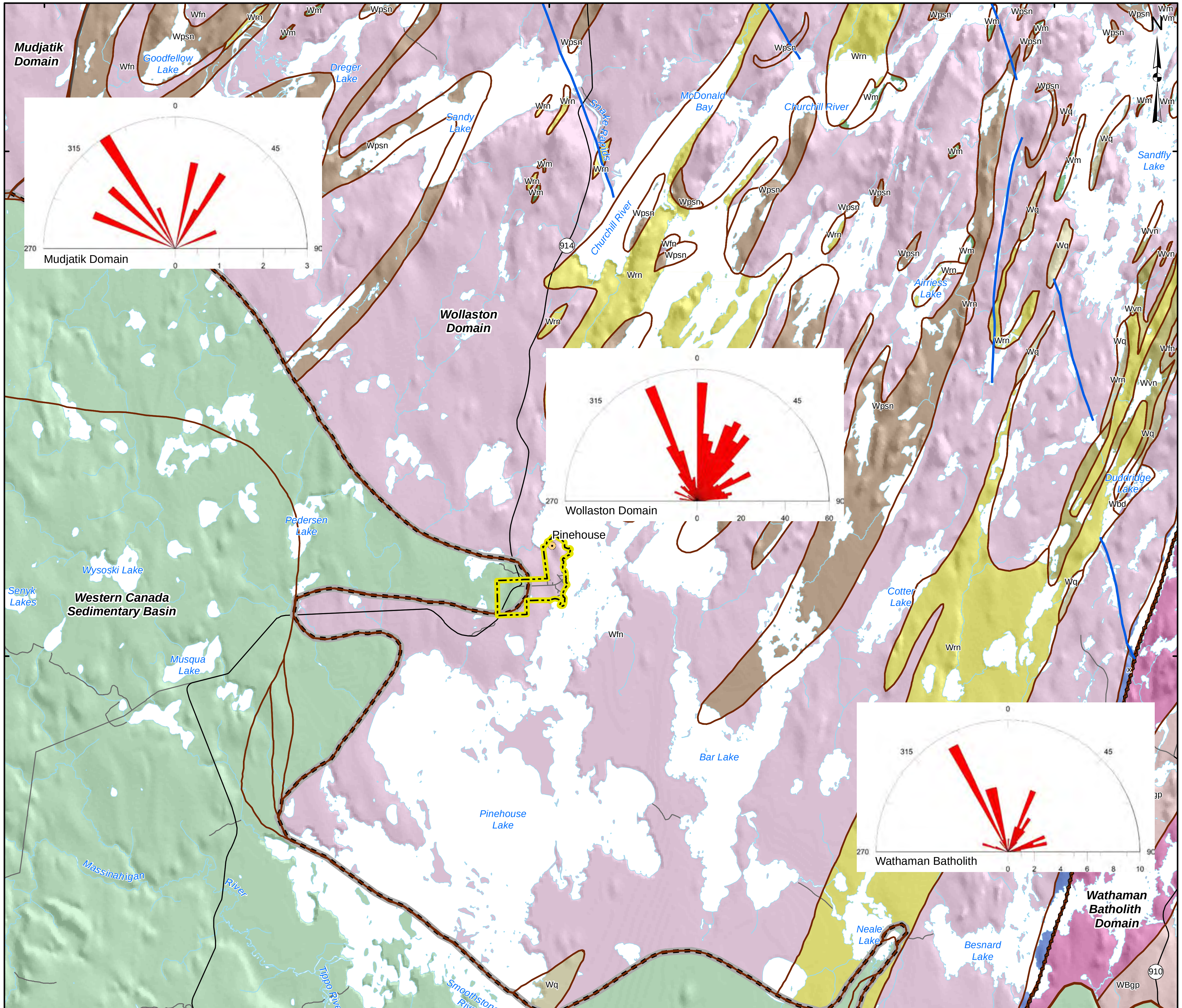

LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Metasedimentary Rock
- Wathaman Batholith
- 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

REFERENCE

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

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Lineament Orientations of Principal Geological Units of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.12	
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

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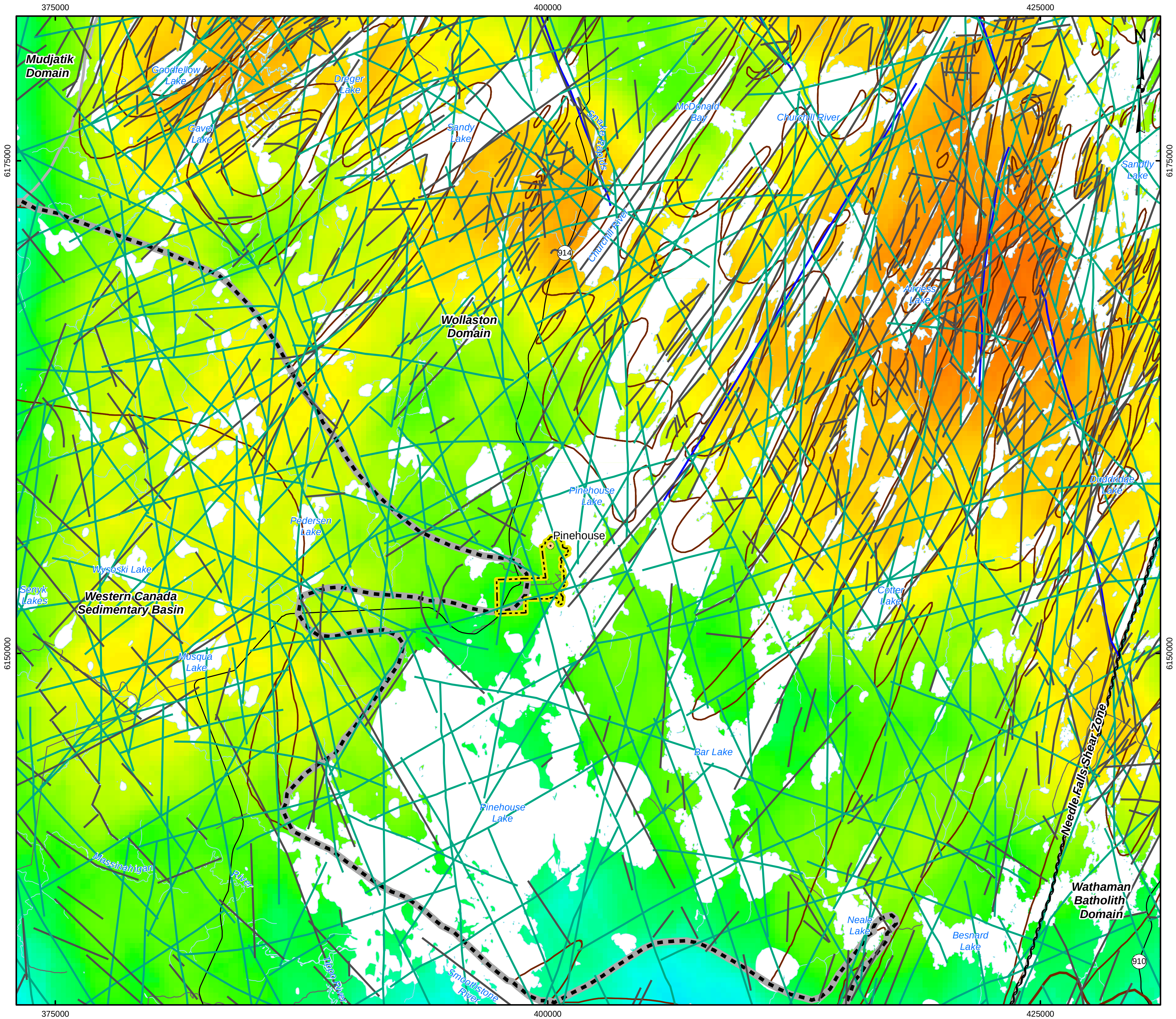

LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Metasedimentary Rock
- Wathaman Batholith
- Geophysical Lineament
- Surficial Lineament
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Lineament Density (km/km²)

High : 4

Low : 0

REFERENCE

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

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Brittle Lineament Density Calculated for Lineaments in the Pinehouse Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT NO. 12-1152-0026		
DESIGN	PRM	8 Jun. 2012
GIS	PM/JB	25 Sep. 2013
CHECK	AM	25 Sep. 2013
REVIEW	GWS	25 Sep. 2013

SCALE AS SHOWN REV. 0.0

FIGURE: 3.13

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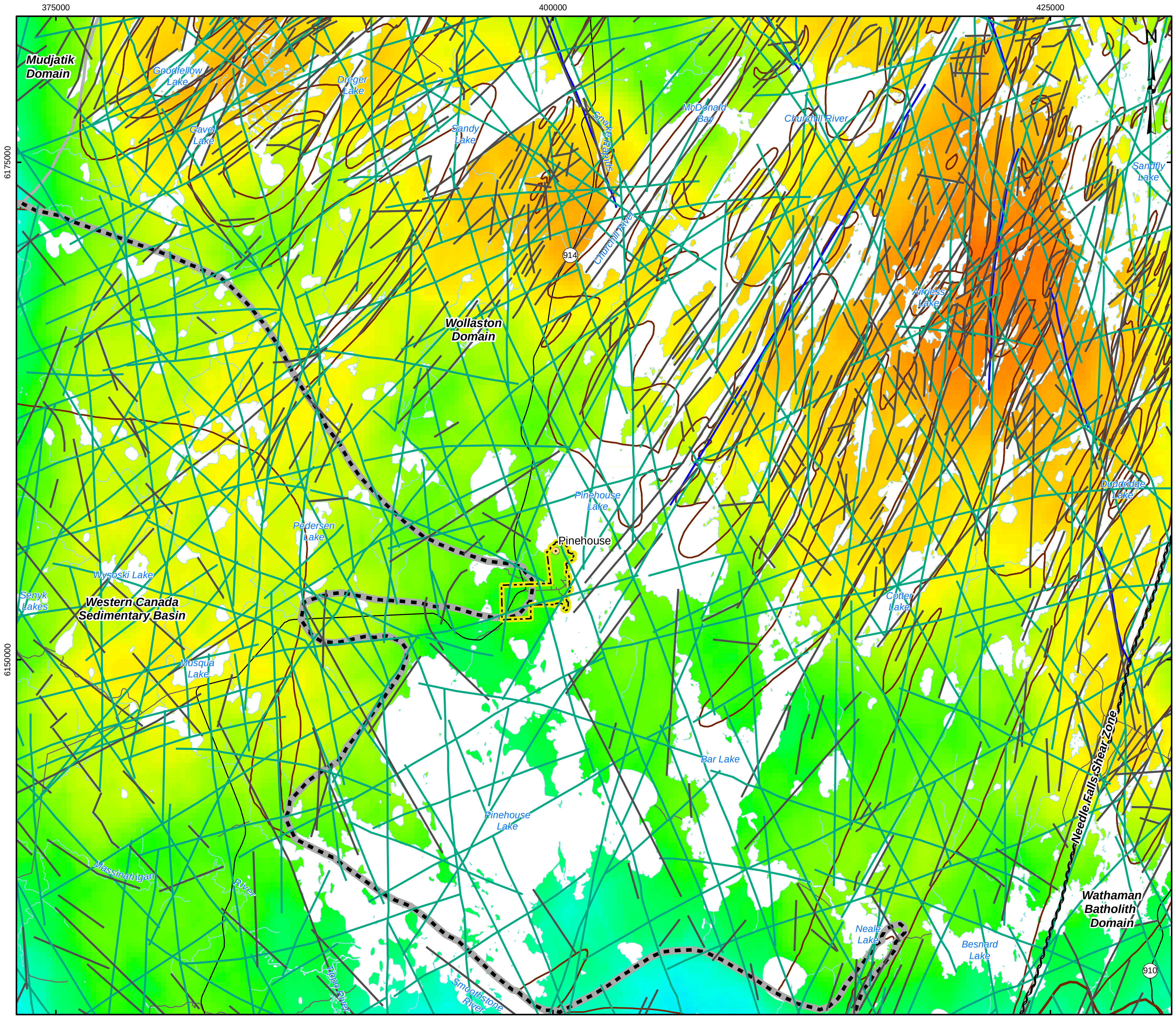


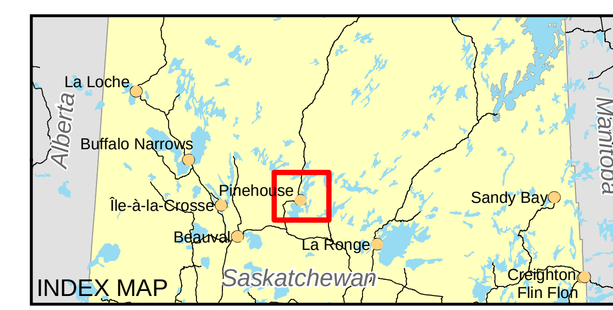
LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Metasedimentary Rock
- Wathaman Batholith
- Geophysical Lineament (>1 km)
- Surficial Lineament (>1 km)
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Lineament Density (km/km²)

High : 4

Low : 0



REFERENCE

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

5 2.5 0 5 10

SCALE 1:200,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Brittle Lineament Density Calculated for Lineaments >1 km in the Pinehouse Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	8 Jun. 2012	FIGURE: 3.14	
GIS	PM/JB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		

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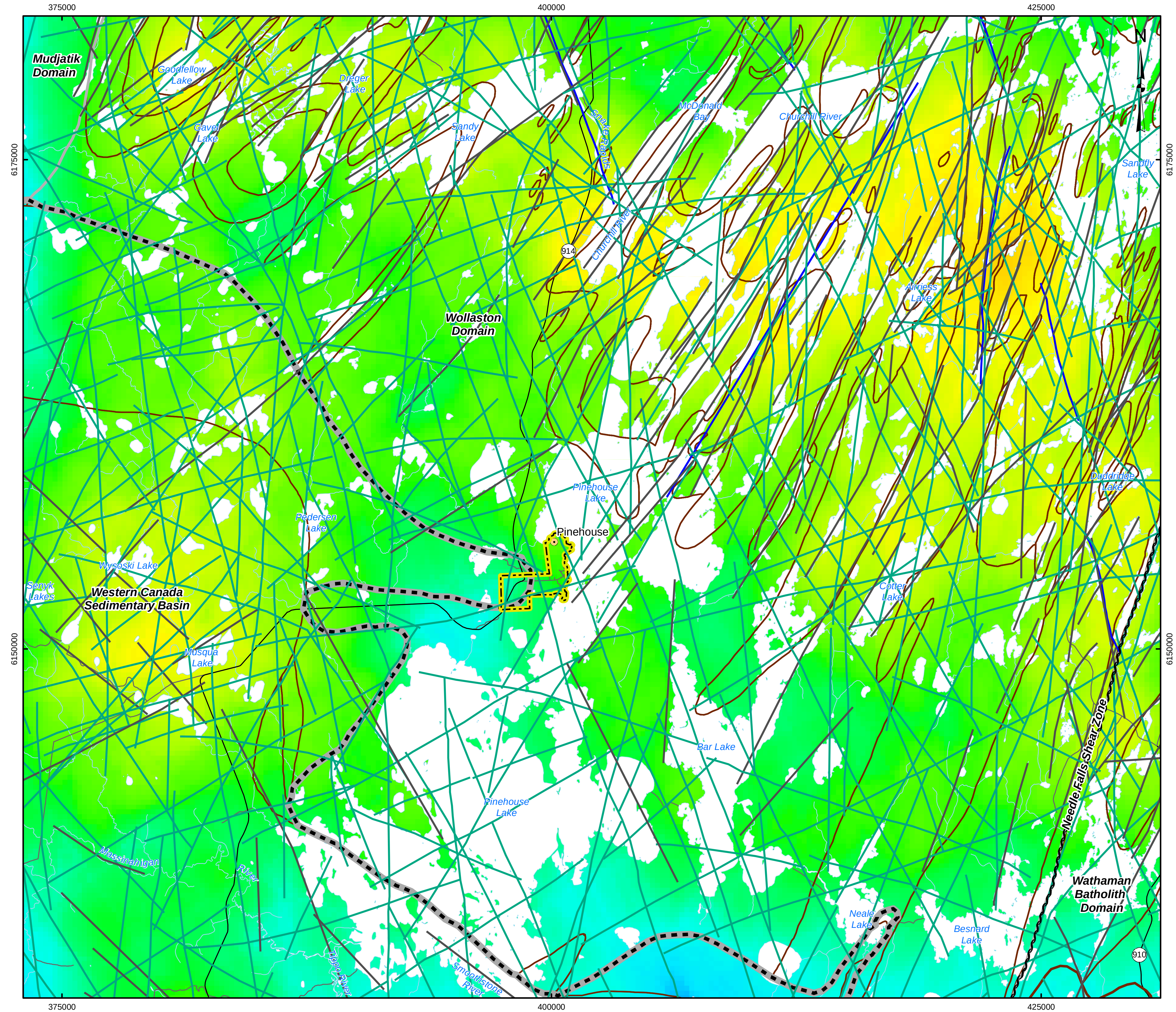

LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Metasedimentary Rock
- Wathaman Batholith
- Geophysical Lineament (>5 km)
- Surficial Lineament (>5 km)
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Lineament Density (km/km²)

High : 4

Low : 0

REFERENCE

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

5 2.5 0 5 10

SCALE 1:200,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Brittle Lineament Density Calculated for Lineaments >5 km in the Pinehouse Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	8 Jun. 2012		
GIS	PM/JB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		

FIGURE: 3.15

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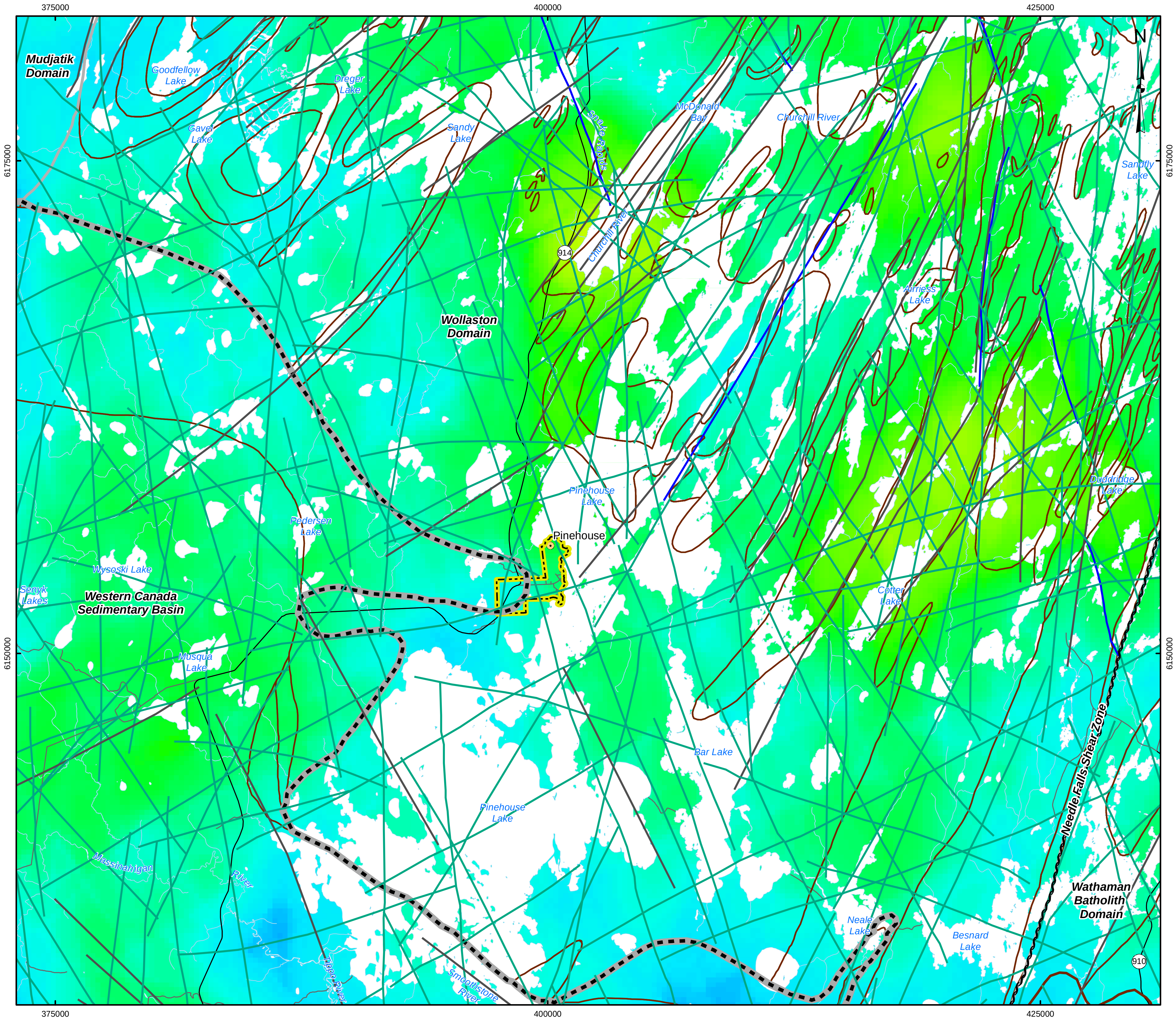


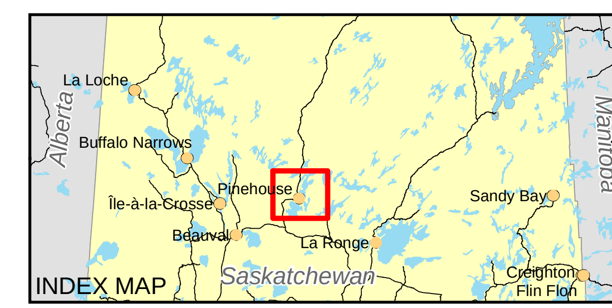
LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Metasedimentary Rock
- Wathaman Batholith
- Geophysical Lineament (>10 km)
- Surficial Lineament (>10 km)
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin

Lineament Density (km/km²)

High : 4

Low : 0



REFERENCE

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

5 2.5 0 5 10

SCALE 1:200,000 KILOMETERS

PROJECT

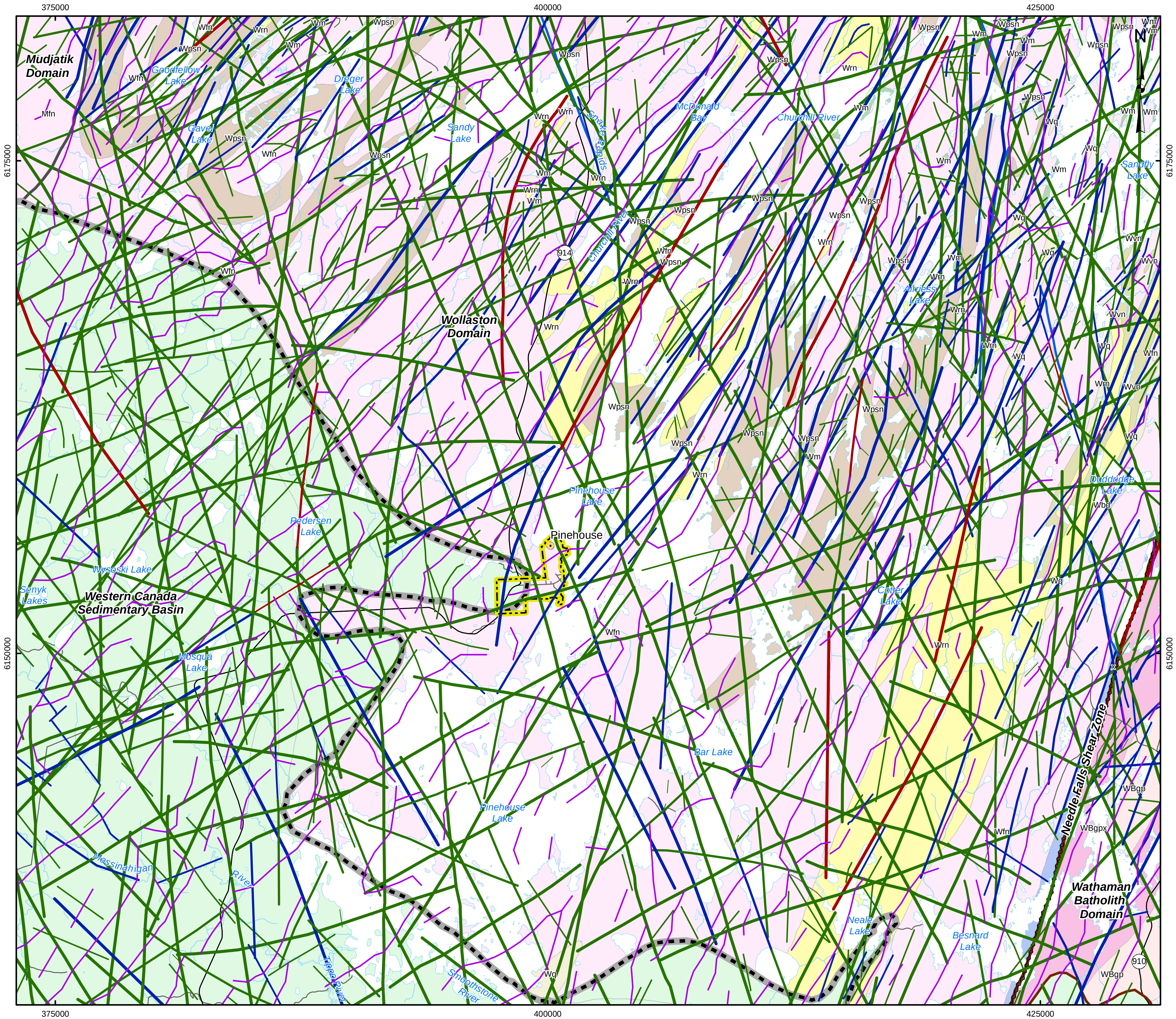
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Brittle Lineament Density Calculated for Lineaments >10 km in the Pinehouse Area

Golder Associates
Saskatoon, Saskatchewan

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PRM	8 Jun. 2012	FIGURE: 3.16	
GIS	PM/JB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Mapped Fault
- Mapped Shear Zone
- Wathaman Batholith
- Ductile Lineament

Lineament Length

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

Lineament Reproducibility

- 1
- 2
- 3
- 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

REFERENCE

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

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Combined Structural Features of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT No. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 3.17	
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

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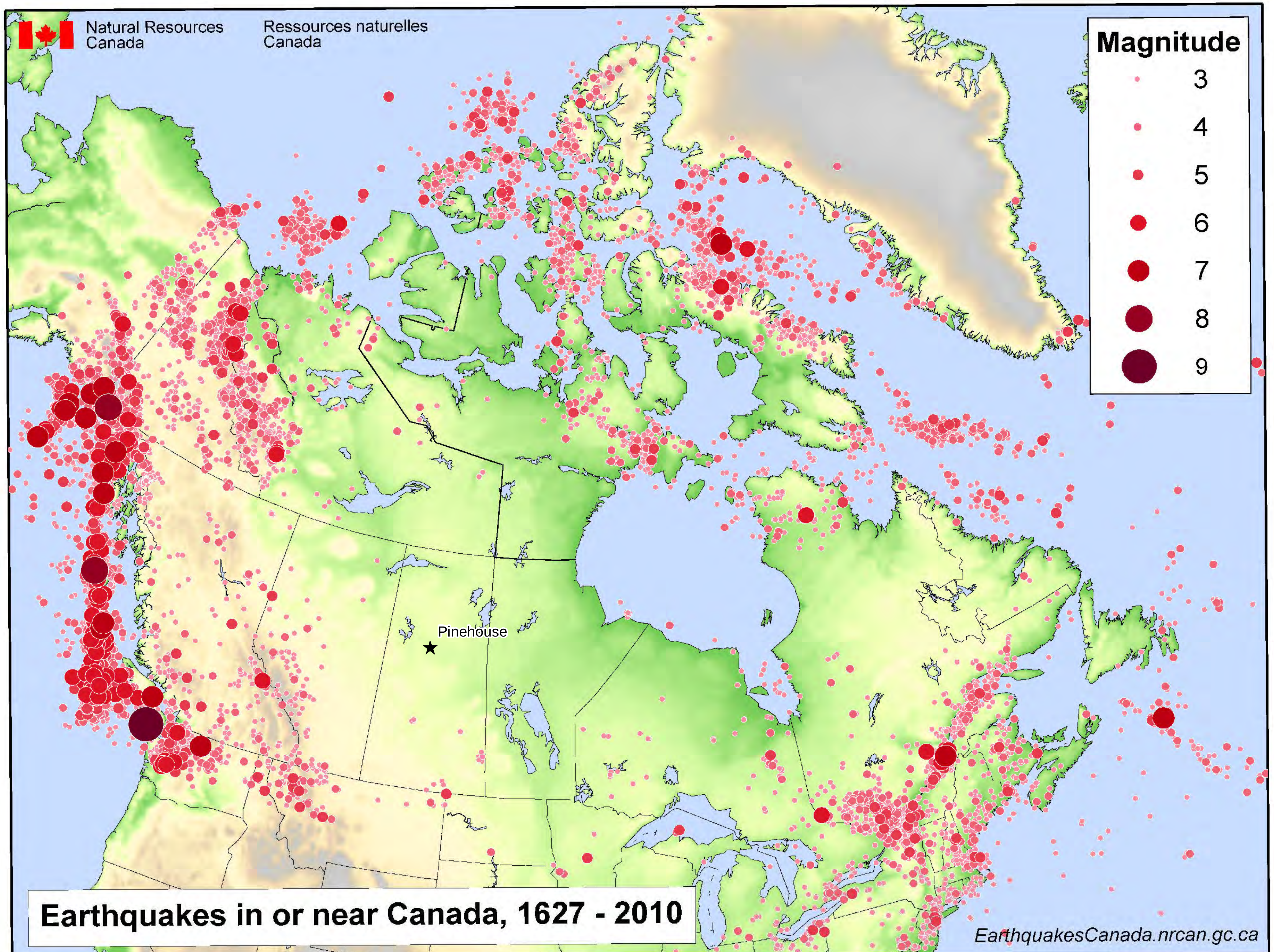

LEGEND

★ Pinehouse

REFERENCE

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

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Earthquakes Map of Canada 1627-2010

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	17 May. 2012	FIGURE: 3.18	
GIS	PM/JB	23 Sep. 2013		
CHECK	AM	23 Sep. 2013		
REVIEW	GWS	23 Sep. 2013		

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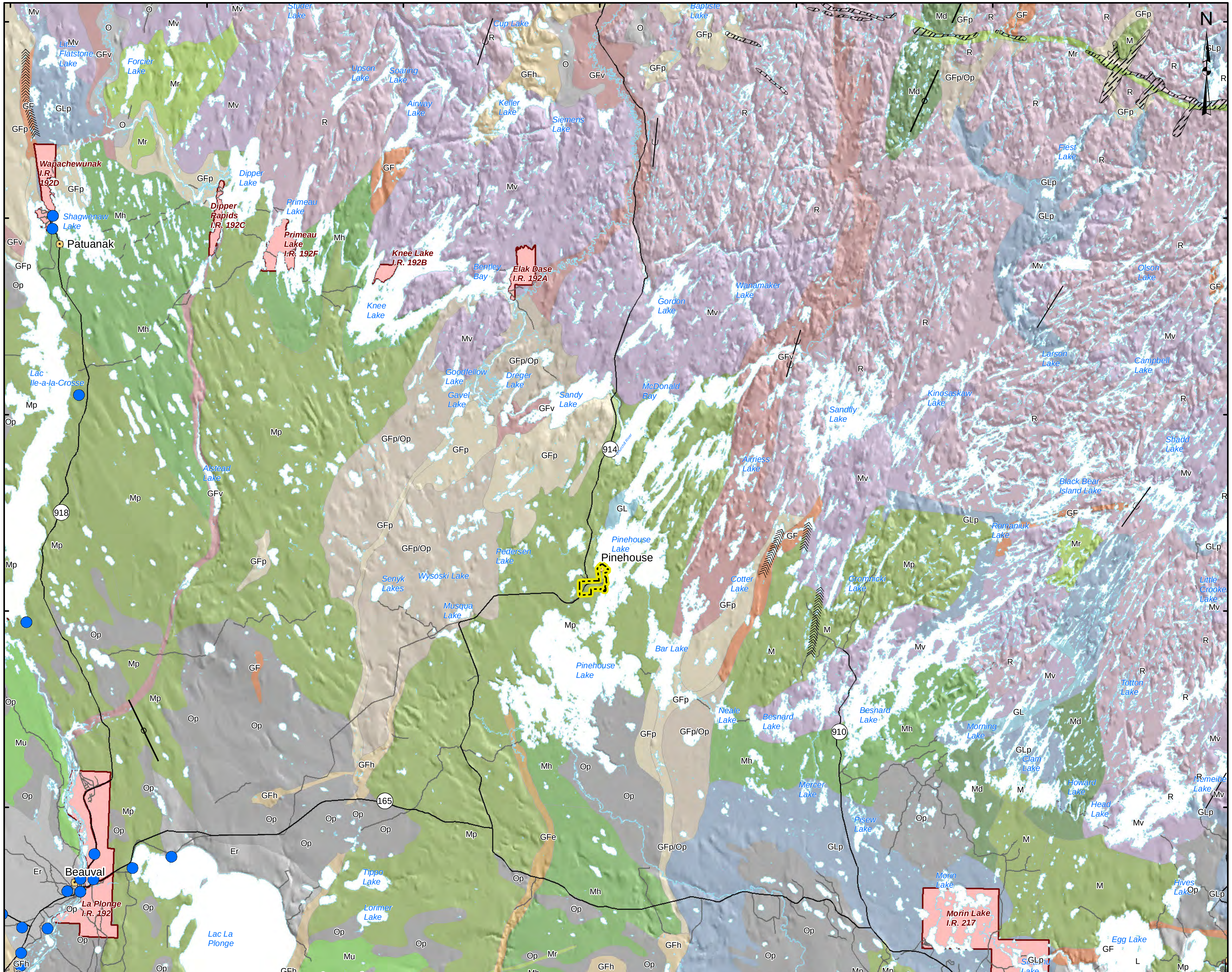


LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Waterbody
- Federal Land - Indian Reserve
- Groundwater Well
- Drumlin
- Striation
- Esker
- Moraine

Landform

- Op - Organic plain
- GF - Glaciofluvial
- GFe - Glaciofluvial eroded
- GFh - Glaciofluvial hummocky
- GFp - Glaciofluvial plain
- GFp/Op - Glaciofluvial/organic plain
- GFv - Glaciofluvial veneer
- GL - Glaciolacustrine
- GLv - Glaiolacustrine veneer
- GLp - Glaciolacustrine plain
- M - Morainal
- Md - Morainal drumlinoid
- Mh - Morainal hummocky
- Mp - Morainal plain
- Mr - Morainal ridged
- Mu - Morainal undulating
- Mv - Morainal veneer
- R - Rock

REFERENCE

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

10 5 0 10 20 30

SCALE 1:500,000 KILOMETRES

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

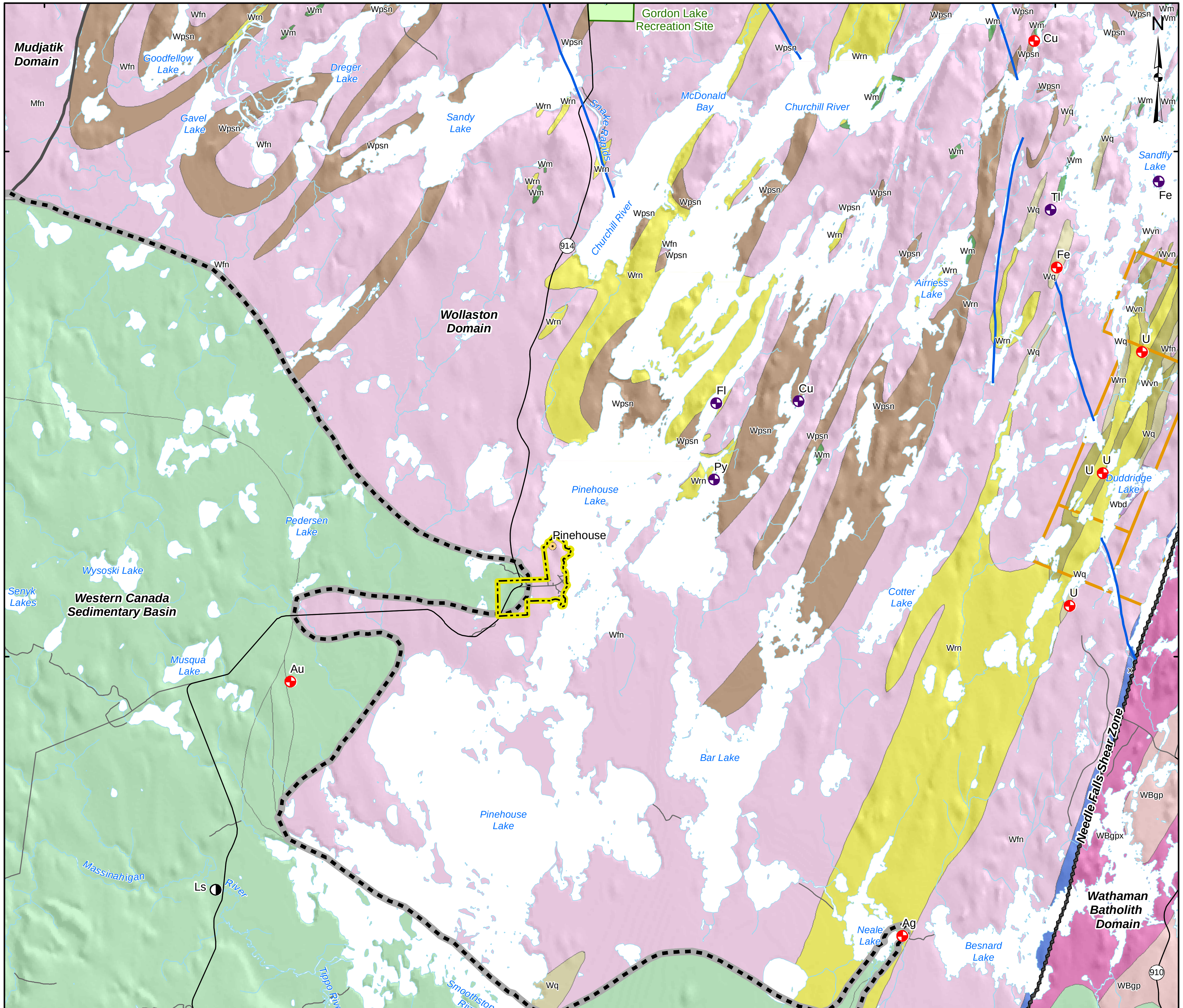
TITLE

Groundwater Wells near the Pinehouse Area

Golder Associates
Mississauga, Ontario

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

FIGURE: 4.1



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Park and Recreation Area
- Potential Mineral Deposit with Reserves
- Showing Mineral Potential
- Showing Mineral Potential with No Assay
- Mapped Fault
- Mapped Shear Zone
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Mining Claims

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

REFERENCE

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

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

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Mineral Showings and Dispositions of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 5.1	
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

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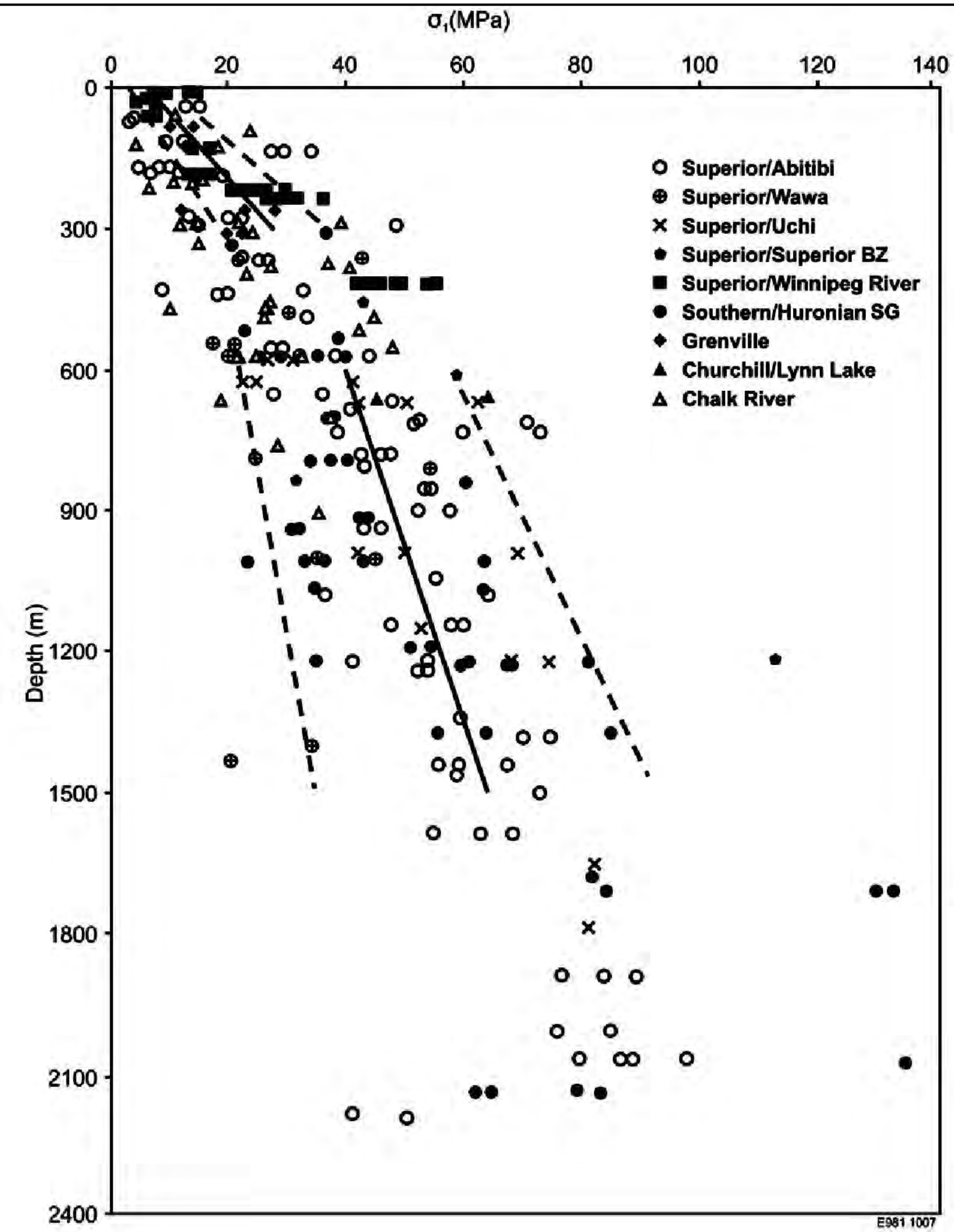


REFERENCE

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

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

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

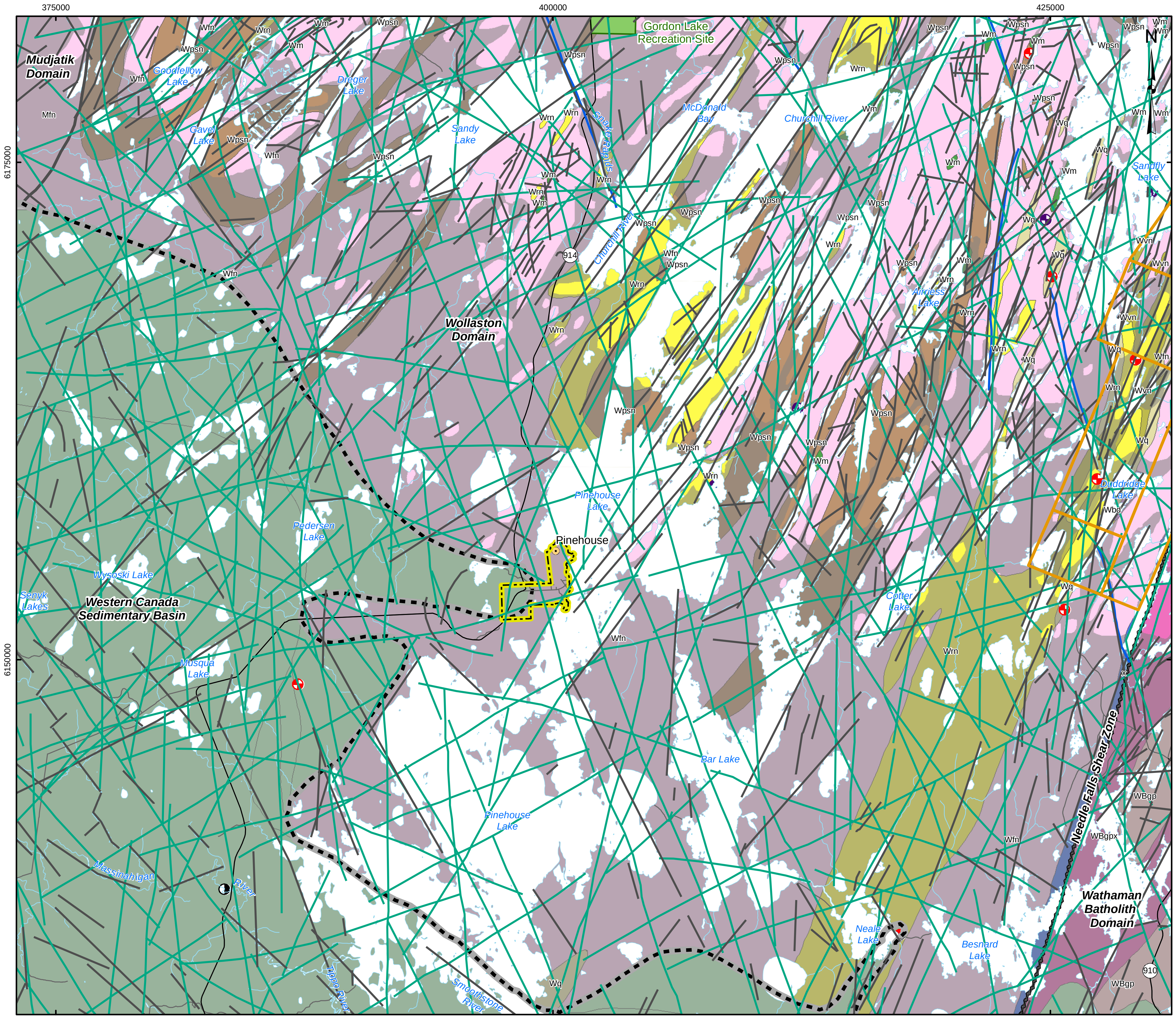
Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026		
DESIGN	PM	6 Nov. 2012
GIS	PM/JB	23 Sep. 2013
CHECK	AM	23 Sep. 2013
REVIEW	GWS	23 Sep. 2013

SCALE AS SHOWN

REV. 0.0

FIGURE: 6.1



LEGEND

- Municipal Boundary (Northern Village of Pinehouse)
- Pinehouse
- Main Road
- Local Road
- Watercourse
- Waterbody
- Protected Area
- Potential Mineral Deposit with Reserves
- Showing Mineral Potential
- Showing Mineral Potential with No Assay
- Mapped Fault
- Mapped Shear Zone
- Geophysical Lineament
- Surficial Lineament
- Mining Claims
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Thick Overburden

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

Approximate Size of Repository Footprint

3 km × 2 km

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Lineaments - Lineament Interpretation, Pinehouse, Saskatchewan (JDMA, 2013)
Thick Overburden - Munday, R.J.C., 1978b. The Shield Geology of the Ile-a-la-Crosse (East) Area Saskatchewan. Part of the NTS Area 73-0. 1:100,000 Sheet 1, Map 189A, SGS
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Mining Claims - Geological Atlas of Saskatchewan (Mar. 2013)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

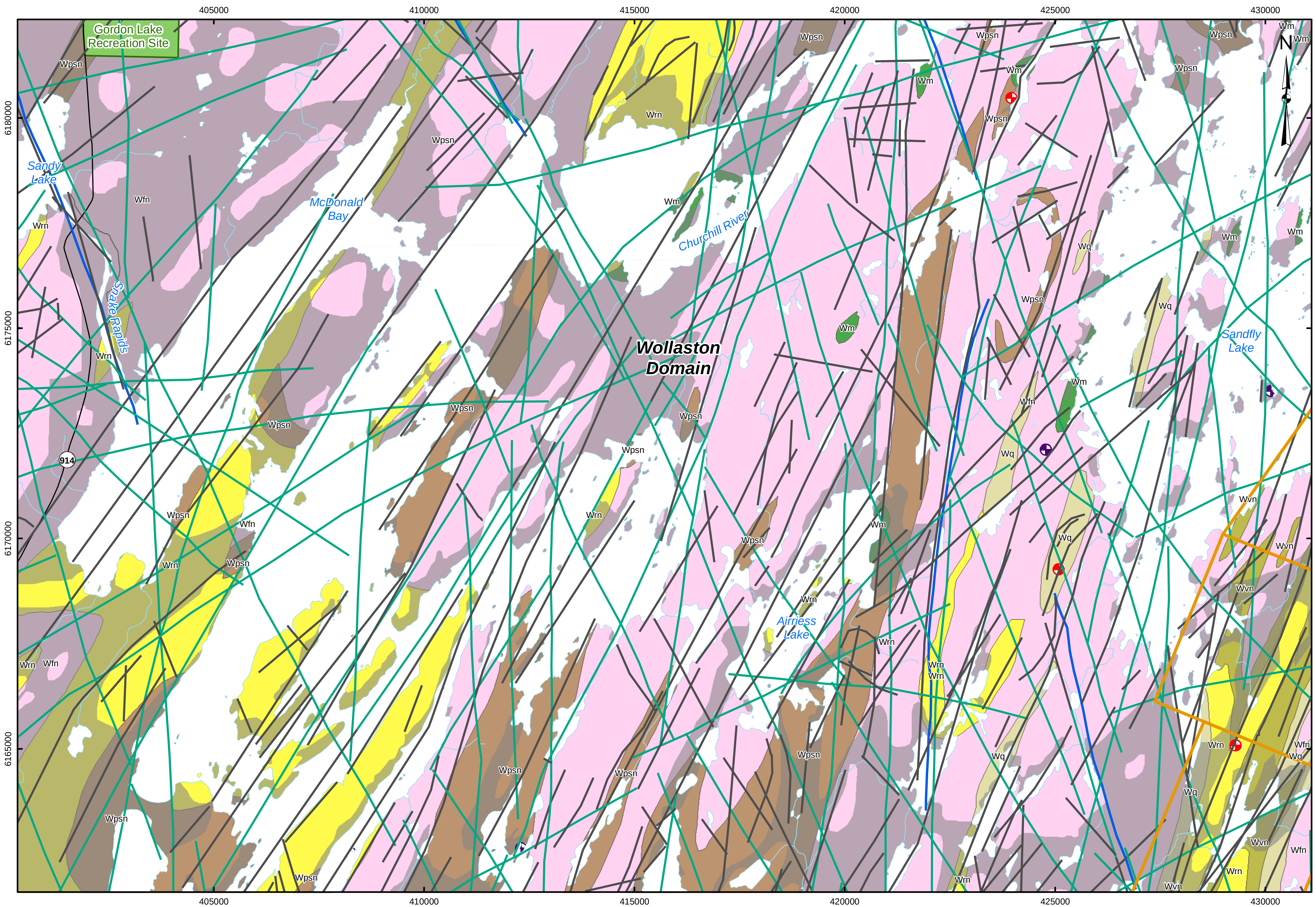
5 2.5 0 5 10
SCALE 1:200,000 KILOMETERS

PROJECT
PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE
Key Geoscientific Characteristics of the Pinehouse Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012	FIGURE: 7.1	
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		



LEGEND

- Main Road
- Local Road
- Watercourse
- Waterbody
- Protected Area
- Showing Mineral Potential
- Showing Mineral Potential with No Assay
- Mapped Fault
- Mapped Shear Zone
- Geophysical Lineament
- Surficial Lineament
- Mining Claims
- Domain Boundary
- Boundary between Precambrian Shield and Western Canada Sedimentary Basin
- Thick Overburden

Wollaston Domain

- Wfn - Felsic gneiss
- Wm - Amphibolite
- Wpsn - Pelitic, psammopelitic gneiss
- Wq - Metaquartzite
- Wrn - Psammitic to meta-arkosic gneiss
- Wvn - Biotitic mafic gneiss

Approximate Size of Repository Footprint

3 km

2 km

REFERENCE

Basedata - CANVEC V10 Topographic Mapping of Canada (1:50000)
Lineaments - Lineament Interpretation, Pinehouse, Saskatchewan (JDMA, 2013)
Thick Overburden - Munday, R.J.C., 1978b. The Shield Geology of the Ile-a-la-Crosse (East) Area Saskatchewan. Part of the NTS Area 73-0. 1:100,000 Sheet 1, Map 189A, SGS
Administrative Boundaries - Information Services Corporation of Saskatchewan, Administrative Boundary Overlays (2012)
Bedrock Geology - Saskatchewan Geological Atlas (1:250,000)
Mining Claims - Geological Atlas of Saskatchewan (Mar. 2013)
Projection: Universal Transverse Mercator
Datum: NAD 83 Coordinate System: UTM Zone 13

2.5 1.25 0 2.5 5

SCALE 1:100,000 KILOMETERS

PROJECT

PRELIMINARY ASSESSMENT OF GEOSCIENTIFIC SUITABILITY
PHASE 1 DESKTOP STUDY

TITLE

Key Geoscientific Characteristics of the North Pinehouse Lake Area

Golder Associates
Mississauga, Ontario

PROJECT NO. 12-1152-0026			SCALE AS SHOWN	REV. 0.0
DESIGN	PM	3 May. 2012		
GIS	PM/JB	25 Sep. 2013		
CHECK	AM	25 Sep. 2013		
REVIEW	GWS	25 Sep. 2013		

FIGURE: 7.2

APPENDIX A

Geoscientific Factors

Table A-1: Safety Factors, Performance Objectives and Geoscientific Factors

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

Safety Factors	Performance Objectives	Evaluation Factors to be Considered
Repository construction, operation and closure	**3.** The surface and underground characteristics of the site should be favourable to the safe construction, operation, closure and long-term performance of the repository.	**3.1** The strength of the host rock and in situ stress at repository depth should be such that the repository could be safely excavated, operated and closed without unacceptable rock instabilities. **3.2** The soil cover depth over the host rock should not adversely impact repository construction activities. **3.3** The available surface area should be sufficient to accommodate surface facilities and associated infrastructure.
Human intrusion	**4.** The site should not be located in areas where the containment and isolation functions of the repository are likely to be disrupted by future human activities.	**4.1** The repository should not be located within rock formations containing economically exploitable natural resources such as gas/oil, coal, minerals and other valuable commodities as known today. **4.2** The repository should not be located within geological formations containing exploitable groundwater resources (aquifers) at repository depth.
Site characterization	**5.** The characteristics of the site should be amenable to site characterization and site data interpretation activities.	**5.1** The host rock geometry and structure should be predictable and amenable to site characterization and site data interpretation.
Transportation	**6.** The site should have a route that exists or is amenable to being created that enables the safe and secure transportation of used fuel from existing storage sites to the repository site.	**6.1** The repository should be located in an area that is amenable to the safe transportation of used nuclear fuel. **6.2** The repository should be located in an area that allows appropriate security and emergency response measures during operation and transportation of the used nuclear fuel.

APPENDIX B

Geoscientific Data Sources

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

Map Product	Title	Author	Source	Scale	Date	Coverage	Additional Comments
Rep 2010-7	Geological Atlas of Saskatchewan	SGS	SIR	1:1,000,000	2010	Full (SK)	Regional bedrock and surficial geology mapping of Saskatchewan
Map 183A	Geology of the Dipper Lake Area	Scott, B.P.	SGS	1:63,360	1977	Dipper Lake, Primeau Lake and Knee Lake areas	Detailed bedrock lithology, mapped faults, structural measurements, areas with thick overburden
Map 189A	Shield Geology of the Ile-a-la-Crosse (East) Area	Munday, R.	SGS	1:100,000	1978	Knee Lake and Elak Dase areas, to the Needle Falls shear zone	Detailed bedrock lithology, mapped faults, structural measurements, areas with thick overburden
Map 221 A	Quaternary Geology of the Precambrian Shield, Saskatchewan	Schreiner, B.T.	SGS	1:1,000,000	1984	Full (SK)	Quaternary geology up to the Saskatchewan-Manitoba border
Open File 84-5	Quaternary Geology of the Ile-a-la-Crosse Area	Schreiner, B.T.	SGS	1:250,000	1984	Entire area	Quaternary geology, areas with veneer
Map 245A	Ile-a-la-crosse, NTS Area 73O	Thomas, M.W and W.L. Slimmon	SGS	1:250,000	1985	Knee Lake to Elak Dase	Compilation bedrock geology series
Prelim. Geology Map, Part of NTS 73O-9	Duddridge Lake	Delaney, G.D.	SEM	1:12,500	1993	Duddridge Lake area	Preliminary bedrock geology
Map 213-11	Geology of the Duddridge-Meyers Lakes Area	Coombe, W.	SEM	1:50,000	1994	West boundary	Bedrock geology, structural data near Needle Falls shear zone.

SGS = Saskatchewan Geological Survey
SIR = Saskatchewan Industry and Resources
SEM = Saskatchewan Energy and Mines

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

Product	Source	Type	Line Spacing/ Sensor Height	Line Direction	Coverage	Date	Additional Comments
Saskatchewan #8	GSC	Fixed wing magnetic	1609 m / 305 m	0°	W margin of area	1952	Geological Survey of Canada Regional Magnetic Compilation, lowest resolution dataset
Saskatchewan #9	GSC	Fixed wing magnetic	805 m / 305 m	90°	Entire area except small portion of west margin	1969	Geological Survey of Canada Regional Magnetic Compilation
GSC National Gravity Compilation	GSC	Ground gravity measure-ments	10 to 15 km	-	Entire area	1960-1995	Bouguer gravity field, first vertical derivative, horizontal gradient and the isostatic residual gravity field were extracted from the GSC gravity compilation. Station locations were extracted from the point data.
GSC Radiometric Coverage	GSC	Fixed wing radiometric	5000m / 120m	90°	Entire area	1976	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

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

Database	Description	Scale (Regional/Local)	Used? (Yes/No)
Geological Atlas of Saskatchewan	GIS maps and data for download. Includes all online geoscience data for Saskatchewan such as: surficial geology, bedrock geology, mine locations, mineral deposits index, crown dispositions, reserves, land claims, mineral assessment file maps, drill holes, EM conductors, kimberlite occurrences, lithogeochemistry, LITHOPROBE lines, aeromagnetic surveys, topographical base maps, dykes, faults. Surficial and bedrock geology is available at a scale of 1:250,000 and dyke and fault information is available at a scale of 1:1,000,000.	Regional and Local	Yes
SMAD, (MARS)	Saskatchewan Mineral Assessment Database (SMAD), after December 12, 2012 to be compiled in the Mineral Administration Registry Saskatchewan (MARS): contains active claims, alienations and dispositions. Data includes: links to available geological information. (http://www.er.gov.sk.ca/smad)	Regional	Yes
Drill Holes	SGS Diamond Drill Hole Database: contains information on surface and underground drilling done as outlined by assessment files. Data includes: company name, company hole number, township and a link to available drill hole records and/or reports.	Regional and Local	Yes
Earthquakes Canada	Geological Survey of Canada Earthquake Search (On-line Bulletin): http://www.earthquakescanada.nrcan.gc.ca/index-eng.php	Regional	Yes

Database	Description	Scale (Regional/Local)	Used? (Yes/No)
Geoscience Publications	SGS Geoscience Publications Database. Includes: geophysical index maps, annual reports, base maps, cross-sections, economic information.	Regional and Local	Yes
Summary of Investigations	SGS Summary of Investigations Database. Consists of a summary of SGS field work from 1972 to the present.	Regional and Local	Yes
CDED	Geobase (http://www.geobase.ca) Canadian digital elevation data.	Regional	Yes
SPOT	Geobase (http://www.geobase.ca) Orthoimage.	Regional	Yes
SWA (Water Wells)	Saskatchewan Watershed Authority (SWA) Database containing water well records throughout Saskatchewan (https://gis.wsask.ca)	Regional	Yes

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