Kiggavik Project
Final Environmental Impact Statement

Tier 3 Technical Appendix 6A:
Surficial Geology, Terrain and Shallow Geotechnical Conditions

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Table of Contents

List of Tables

List of Figures

Attachments

1 Introduction

1.1 Overview

This Technical Appendix of the Kiggavik Environmental Impact Statement (EIS) presents a summary of existing surficial geology, terrain and shallow geotechnical conditions for the Kiggavik Project area. The report includes the results of field investigations and laboratory analysis. Geotechnical field investigations were conducted at various sites in 1988, 2009 and 2010. Figure 1.1-1 shows the location map of shallow geotechnical boreholes in the Kiggavik Project area.

The purposes of field investigations consisted of the following.

- Geotechnical data collection for the selection of construction materials
- Geotechnical data collection for design criteria of the proposed mine infrastructures, the pit slope and stability of the proposed open pit mines, etc.
- Characterization of lakebed sediments
- Thermal data collection for the assessment of ground temperature and permafrost condition.

1.2 Purpose

The purpose of this Technical Appendix is to describe the existing terrain conditions and resources that may be affected directly or indirectly by the project, to provide sufficient information to support the environmental assessment, and develop measures for ongoing environmental monitoring of potential Project-related change.

1.3 Assessment Area

A Local Assessment Area (LAA) was developed for the baseline study and the extent of the assessment area is shown in Figure 1.3-1. This LAA occupies approximately 42,394 hectare of the Kiggavik Project area.

2 Data Collection

The presence of permafrost presents a number of technical difficulties in the process of collecting data in the Canadian Arctic. A geotechnical site investigation in permafrost regions is more complex and has always been a challenge due to potential presence of ice within the soil or rock whose properties are temperature and salinity dependent.

Both field and laboratory methods were used to collect geotechnical data of shallow ground conditions.

2.1 Field Investigation

In 1988, 2008, 2009 and 2010, field investigation and laboratory analysis were carried out to characterize the nature and geotechnical properties of the overburden and shallow bedrock. Field investigation included:

- Drilling
- Lithological and geotechnical logging
- Soil and rock sampling
- Borehole instrumentation
- Field intact rock strength testing
- Ground ice content determination
- Air photo interpretation
- Structural mapping of outcropping rocks
- Geophysical survey

In 1988, a custom built helicopter transportable Mobile B-40 drill rig was equipped for 160mm diameter solid stem flight angering and for soil sampling with 80mm diameter thin wall tubes and 50mm diameter Standard Penetration Test (SPT) apparatus. It was also equipped with a 100mm diameter Cold Regions Research and Engineering Laboratory (CRREL) type core barrel to collect Undisturbed Sample (US) of frozen overburden. The B-40 drill was also equipped with NQ wireline coring of the bedrock and also with a chiller unit for calcium chloride brine. Bradley Brothers Boyles-25 diamond drill rig was equipped with NQ wireline coring and with water flush return. In 2009 and 2010, Boart Longyear LF-70 diamond drill rig was used to drill shallow geotechnical boreholes at the Kiggavik site.

The summary of the geotechnical field program is tabulated in Table 2.1-1.

2.1.1 Drilling

A total of 106 boreholes and 3 test pits for a depth of 748.09m were drilled. Table 2.1-1 provides further detail of the drilling program.

In 1988, Bradley Brothers Boyles 25 drill commenced coring for the geotechnical investigation on July 16, 1988 and completed the work on July 31, 1988. After July 16, 1988, Mobile Augers B-40 was used primarily for overburden drilling and very limited coring. The geotechnical drilling of overburden, including the granular borrow sites, was completed on July 24, 1988. In 2009, two shallow geotechnical boreholes were advanced in locations corresponding to the proposed Mill site to confirm the historical results. The geotechnical investigation was further continued in 2010 field campaign and two additional geotechnical boreholes were drilled in the area. Boart Longyear LF-70 drill rig was used for overburden and shallow bedrock drilling in 2009 and 2010.

The borehole survey was done by Matthews and McGladrey in 1988. The boreholes at the Kiggavik site were surveyed by UTM grid co-ordinates and to geodetic elevation. Some boreholes drilled in the Jaeger Lake and Squiggly Lake areas were not surveyed and the co-ordinates and elevations for these boreholes were estimated from the aerial photographs and contour maps. The four boreholes drilled in 2009 and 2010 in the Kiggavik area were surveyed by UTM co-ordinates using GPS system.

2.1.2 Soil and Core Logging

Geotechnical logging was conducted for a total of 106 boreholes and 3 test pits with the generation of detailed stratigraphic logs. The borehole logs are included in Attachment A.

The logging included the field description of ground-ice content in frozen overburden materials in accordance with “Guide to a Field Description of Permafrost for Engineering Purposes” developed by National Research Council (Philainen and Johnston, 1963), visual observation and description of soil and its type in accordance with the ‘Modified Soil Classification System”, and shallow bedrock characterization. A lithological description in conjugation with the detail geotechnical logging of the drill core was also included. A total of seven drillholes (88-331, 88-332, 88-333, RMI-09-01, RMI-09-02, RMI-10-01, and RMI-10-01) were geotechnically logged to characterize the shallow bedrock conditions and recorded the following parameters (see Attachment A).

- Total Core Recovery (TCR)
- Rock Quality Designation (RQD)
- Fracture Frequency (FF) and Facture Spacing (FS)
- Weathering and alteration conditions
- Field estimate of rock strength
- Broken/Rubble Zone or Core Loss or Breccia Fault Zone or Gouge

- Individual discontinuities were described and the following parameters were recorded for these holes.
- Depth
- Type (foliation, joint, etc.)
- Dip with respect to the core axis
- Dip direction (where the core oriented)
- Shape
- Roughness
- Infilling type and character
- Discontinuity conditions for RMI holes
- Discontinuity set number for RMI holes
- Discontinuity alteration number for RMI holes

2.1.3 Sampling

Field sampling was conducted by Golder Associates during the 1988 field campaign. Auger and CRREL samples of overburden material were collected.

Undisturbed, frozen overburden samples obtained with the CRREL core barrel were tightly wrapped in thick plastic bags and temporarily stored at the drill site with freezer packs in Coleman cooler boxes. At the end of each shift, the CRREL samples were stored in a Kitchen freezer at the Kiggavik camp. The samples were then packed in corrugated cardboard boxes and periodically shipped by helicopter to Baker Lake, then by air cargo to Calgary in Coleman cooler boxes with ice packs. The cooler boxes were temporarily stored in Canadian Airlines' walk-in freezer at Winnipeg airport between connecting flights and similarly on arrival at Calgary airport. The frozen CRREL samples were then transferred to the walk-in freezer at Golder Associates' Calgary laboratory.

A total of 224 disturbed flight auger samples (AS), 6 chunk samples (CS) and 51 undisturbed core samples (CREEL) were obtained from 106 boreholes and 3 test pits. 224 AS samples were obtained using B-40 rig and the remaining 6 CS samples were taken by manual excavation of test pits. All undisturbed core samples were obtained using B-40 rig with exception of one sample from the borehole RMI-09-01 drilled in 2009.

A sample from 0.13 to 0.37m on the borehole RMI-09-01 was collected in 2009. In 2010, 20 samples of lakebed sediments in the area of the proposed Andrew Lake Pit dewatering structure and 5 samples in the End Grid area were collected for the field and laboratory analysis. Laboratory testing was undertaken on 7 of the 20 samples collected in the area of Andrew Lake Pit dewatering structure area and 4 out of 5 samples collected in the End Grid area. Please refer to Table 2.1-1 for the detail information about the sampling.

Sampling of overburden material was conducted to carry out grain size distribution analysis and compaction test, classify the soils, and determine the frozen bulk density, dry density, specific gravity of soil solids and moisture content.

A total of 23 bedrock samples were taken for laboratory testing during the detailed logging of fresh core from drillholes 88-331 (10 samples) , 88-332 (5 samples) and 88-333 (8 samples) in order to determine Uniaxial Compressive Strength (UCS), Young's Modulus, Poisson's Ratio, Brazilian Tensile Strength and Density.

2.1.4 Testing and Installation

Field rock peak test using a geology hammer was conducted to determine the field intact strength of shallow bedrock.

Installation of thermistor (T) and frost depth indicator (FDI) in selected boreholes was conducted to obtain ground temperature data and measure the thaw depth below ground surface, respectively. The instrumentation consisted of 8 thermistor strings and 14 frost depth indicators. Table 2.1-1 includes the detail of the borehole instrumentation. Figure 2.1-1 shows the location map of thermistors and frost depth indicators.

2.1.4.1 Thermistor

The thermistor strings were pre-fabricated by Cantech Controls Limited of Calgary, Alberta for temperature measurements at pre-determined depths below ground surface. Each thermistor string had 6 or 12 thermistor bids, depending on the type of proposed facility and the amount of temperature details. The thermistor strings were wired to an Amphenol connector at ground surface to facilitate the measurement of ground temperatures. Readings were obtained with a Fluke Model 27 Multimeter and a splitter box coupled to the Amphenol connector. Monitoring of ground temperature was conducted during the 1988 field program. Attachment D includes the ground temperature data recorded in thermistors.

In 2007, a shallow 30m thermistor string was installed in the borehole END-07-01 at End Grid site. A data logger (Lakewood Systems- Ultra Logger Data Storage Unit R-X) manufactured by M-Squared was attached to the thermistor for the continuous automatic reading with a reading frequency of 12 hours.

2.1.4.2 Frost Depth Indicator

Frost depth indicators, which actually do not provide ground temperature data rather directly measure the thaw depth below surface, were installed as follows. The flexible, transparent frost indicator tube was filled with a methylene blue solution which changed color from deep blue to clear when it was frozen. The 12mm diameter sealed indicator tube was installed inside a water tight 25mm diameter plastic pipe previously installed in the borehole. The top of the plastic pipe was sealed with a threaded plug. Thaw depth readings were obtained by removing the inner tube and measuring the distance from the upper end of the tube to the clear frozen indicator solution. Frost depth below ground surface was calculated to account for stick-up depth of the tube and plastic pipe. Frost depth indicator readings were obtained by Golder Associates on August 9, 1988 and another set of readings were taken by Urangesellschaft on August 31, 1988. Maximum thaw depths were recorded with Frost Depth Indicators and the detail can be found in geotechnical boreholes in Attachment A.

2.1.5 Mapping

Structural mapping of outcropping rocks was conducted as one of the geotechnical investigation programs during the field campaign in June/July 1988. Outcrop structural mapping was focused on the immediate vicinity of the Main and Centre Zones. Data recorded from bedrock outcrop included the following.

- Discontinuity type i.e. bedding, foliation, joint, etc.
- Dip
- Dip direction
- Persistence- being a measure of the continuity of the feature

The above allowed the delineation of the principle joint sets and general foliation trends. Geotechnical data such as joint aperture, roughness, spacing and infilling was not recorded on a systematic basis as all outcrops has been subjected to ice action over a considerable time and only general trends could be established.

2.1.6 Geophysical Survey

GPR geophysical surveys were conducted in 2008 and 2009 in the Kiggavik area. The objective of the survey was to delineate soil stratigraphy, bedrock contacts and bedrock surface condition as well as permafrost condition.

The first investigation in 2008 covered the proposed Kiggavik mill site. The second survey in 2009 covered additional portions of the proposed facility area and major open pit locations at Kiggavik and Andrew Lake.

Figure 2.1-2 shows Kiggavik area GPR coverage and locations of shallow geotechnical boreholes. Attachment E provides more detailed information on the geophysical survey results.

2.2 Laboratory Analysis

Laboratory program was undertaken to determine the properties of the frozen ground as well as engineering properties of soils and shallow bedrock unit. The laboratory program is summarized in Table 2.2-1. It included the following determinations:

- Moisture content, dry and bulk frozen densities of soil, and specific gravity of the soil solids
- Plasticity (Atterberg Limits) of soils
- Organic matter content
- Compaction test to determine the moisture-density relationship
- Grain size analysis (sieve and hydrometer analysis) of overburden unit
- Determination of Uniaxial Compressive Strength (UCS), Young's Modulus, Poisson's Ratio, Brazilian Tensile Strength and Density of the rock

2.2.1 Geotechnical properties of overburden unit

The following laboratory analyses were done to determine the geotechnical properties of overburden unit.

- Grain size distribution analysis and soil classification
- Atterberg's limit (Plasticity Index)
- Water (moisture) content
- Bulk frozen density
- Dry density
- Specific gravity
- Soluble sulphate
- Maximum dry density at optimum moisture content by conducting compaction test

Table 2.2.1 lists the geotechnical tests performed for overburden samples from all locations.

Table 2.2-2 summarizes the laboratory analysis for the selected areas, whereas Table 2.2-3 provides detail of the laboratory analysis conducted at the Kiggavik area, in general.

2.2.2 Geotechnical properties of shallow bedrock

Rock samples for laboratory testing were taken during the detailed logging of fresh core from drillholes 88-331, 88-332, and 88-333. Table 4.2-1 summarizes the laboratory testing results for the following parameters.

- Uniaxial compressive strength
- Young's Modulus
- Poisson's Ratio
- Brazilian Tensile Strength
- Density

3 Terrain and Site Conditions

3.1 Introduction

The Kiggavik project area consists of vast treeless plains called tundra. The area has been extensively glaciated and is dominated by flat lying or gently sloping terrain. The area has a rolling and hummocky topography with frequent bedrock outcrops. The steepest local topography occurs along the scarp faces or is associated with local features. In the Kiggavik area, elevation ranges from 140 masl near Pointer Lake to 265 masl at the peak of the hill northeast of the proposed site for the accommodation complex. In the Sissons area, elevations vary from 166 masl near Andrew Lake to 215 masl at the peak of the hill northeast of the End Grid area. The general trend of local drainage and glacial landforms is from the north-northwest to the south-southeast.

Ground surface features in the project area are indicative of underlying frozen ground conditions, which is mantled by glacial till with areas of organic debris in low lying areas. Bedrock outcrops occurs along the scarps or as large angular frost shattered boulder fields where bedrock is close to ground surface. Smaller, circular frost heaved (frost boils) zones are common on the flatter terrain.

Tundra vegetation typical of the Barren Lands occurs in the project area. The vegetation is influenced by soil and rock type, and by drainage. Well-drained glacial till supports vegetation consisting of low grass, some moss and low shrubs up to about 0.5m high. Sand and gravel deposits have sparse grass cover and local wind-eroded areas with no vegetation. Only thin moss and lichens grow on the boulder fields and shattered rock. Taller grass and moss grow in the poorly drained depressions and along the creeks.

The project site is located within the zone of continuous permafrost (NRCan 2007). The ground is generally frozen from late September to late June. The “active layer” is the shallow zone above the permafrost table that thaws and refreezes each year. The thickness of the active layer is highly variable, which normally increases gradually over the summer months during July, August and early September. In general, the active layer thickness at the project area ranges from 1m to 2m, except where it is dependent on factors including the type and thickness of the organic cover, the underlying mineral soils and bedrock.

The project is characterized by long cold winters and short summers with very short transition seasons. Prevailing winds are from the north and northwest.

3.2 Surficial Geology

The general surficial geology of the Kiggavik Project site and adjacent areas is relatively well described by the Geological Survey of Canada, presented Schultz Lake south, Nunavut, Map 2120A at scale 1:100,000 (McMartin, I., et al., 2008; Aylsworth, J.M., 1990); and Aylsworth, J.M. et al., 1990, 1989, 1985) and is accompanied by geotechnical data from over 100 boreholes chosen to represent shallow geotechnical conditions of the project areas. A surficial geological map of the Kiggavik mine Local Assessment Area was generated based on the above mentioned existing published regional surficial geology map (see Figure 3-1.1).

The surficial deposits consist mainly of glacial till and small local deltaic deposits. The glacial till varies in texture and composition from well graded silty sand with some gravel and trace of clay to well-graded gravelly sand with some silt and a trace of clay. The till also contains boulders and cobbles, but only minor amount of fine particles. The clay fraction of the glacial till exhibited little to no plasticity. Thin deposits of poorly graded sand and gravel, which locally occur on the till surface, are considered to have been produced by glacial melt-water and post glacial erosion. Fields of large, angular boulders occur where the glacial till is relatively thin or absent, and also where the finer constituents of the till have been removed by erosion. Thin organic layers have been developed on the till surface in poorly drained depressions. Thin soil profiles developed on well-drained glacial till.

Surficial deposits are underlain by bedrock, which is exposed along the fault controlled escarpments. The shallow bedrock mainly comprises sandstone conglomerate and orthoquartzite. For geotechnical investigation purposes, the most significant bedrock formations are the Thelon Formation, the orthoquartzite and the so called Dirty Quartzite. The Thelon Formation outcrops north of the escarpment between Ridge Lake and Cirque Lake areas, in the north of Main Zone and near Felsemeer Lake area. The Thelon Formation consists of siliceous sandstone and Orthoquartzite pebble conglomerate. The orthoquartzite outcrops in the escarpment, which extend from Cirque Lake eastward through the north of Centre Zone area and the northwest of Centre Zone area. The orthoquartzite is typically greyish white, hard, fine-grained and contains sericite and hematite. The Dirty Quartzite outcrops along the lower escarpment north of the Main Zone and Centre Zone areas.

Geological and geotechnical features associated with surficial geology are further discussed in Section 4.

3.3 General Geomorphology

The periglacial geomorphic processes in the Kiggavik Project site and adjacent areas are associated with the ground that is permanently affected by the cold climate, consisting of an active layer, excess ground ice and a layer of perennially frozen ground. Periglacial processes observed at and around the project site include frost wedging and frost shattering, thaw subsidence, and solifluction, which shaped various landforms. The characteristic relief- forming permafrost features are typically subdued in areas of thin overburden and dry conditions. Generally wet conditions exist locally associated with low-lying ground.

The surficial deposits at the proposed mine site and along most of the potential road corridors between the mine/mill site and Baker Lake comprise mainly glacial till overlying precambrian intrusive igneous and metamorphic bedrock that are typically quartzite, schist or granite. The eastern portions of the potential road alignments toward Baker Lake are below the most recent glacial marine transgression; consequently the lower elevations near Baker Lake are partly covered by marine and glaciomarine materials.

3.4 Surficial Materials

Surficial materials are sediments deposited by ice, water, wind and gravity during quarternary time – the ice ages through to the present (Aylsworth et. al., Geological Survey of Canada 2000). Surficial materials are unconsolidated sediments produced by specific processes of erosion, transportation, deposition, mass wasting and weathering and are classified according to their mode of formation. Continuous permafrost currently underlies the Kiggavik Project areas; as a result, surficial materials are generally frozen and frequently contain ground ice.

A typical top layer of surficial material profile in the Kiggavik Project area consists of a thin organic soil layer underlain by glacial till varying in thickness from less than a meter on ridges to several meters in depressions, overlying bedrock. Post-glacial frost action has shattered much of the exposed and near-surface bedrock. Large areas of boulders (boulder-fields) exist on the ground surface where the finer fraction of the glacial till has been removed by erosion or the boulders have been frost-jacked to surface by the repetitive freeze-thaw action of the active layer.

The surficial materials in the study area have originated as a result of glaciations by the Laurentide ice sheet, and marine offlap following its retreat. These changes are summarized as follows:

- Glacial deposition and erosion which prevailed during expansion and subsequent retreat of the Laurentide ice sheet, including localized readvances;
- Marine submergence which occurred when much of the terrain near Baker Lake was temporarily inundated by of an ancient sea (Tyrrel Sea); and

- More recent periglacial conditions established when isostatic rebound of the earth's crust resulted in exposure of the land surface as the margin of the Hudson Bay retreated eastward.
- The surficial materials in the project area have been historically grouped into six major deposits (BEAK Consultants Ltd. 1987 and Wickware & Associates Inc. 1989):
- Glacial till or morainal deposits;
- Glaciofluvial deposits;
- Glaciolacustrine deposits;
- Glaciomarine deposits;
- Organic deposits; and
- Bedrock

Minor deposits of lacustrine materials have been recognized in the Squiggly Lake area, and along shorelines of larger lakes where ice-pushed sandy materials may occur. Their occurrence is of limited areal extent. Immediately to the east of the study area, the landscape is dominated by reworked marine deposits. These deposits mask bedrock and glacial deposits; and mute the lowland topography. The primary materials associated with this marine transgression are foreshore and beach deposits of sand and gravel. Such deposits are found on the flanks of hills and bedrock knobs, often with associated terraces marking the stages of the gradual recession of waters from the area (BEAK, 1987). These deposits are characterized by a network of high centred ice-wedge polygons and by patterned peat deposits in the low poorly drained areas.

3.4.1 Glacial Till or Morainal Deposits

Glacial till is an unsorted material that has been deposited directly by a glacier, which consists of a mixture of clay, silt, sand, gravel, cobbles and boulders. Moraine is glacial till deposited in front, at the sides, or beneath the ice margins without modification by any other agents of transport. Glacial till and moraine often have an identical connotation and both terminologies can be found as an interchangeable word in literatures and publications. Glacial till deposits are the most widespread of surficial materials in the project area and were represented by two major till types (Wickware & Associates Inc. 1989):

1. A buff-coloured, sandy-textured till, which dominates the area north of the east-west trending escarpment in the Kiggavik area; the area between the Kiggavik site and Baker Lake (where the till has been extensively modified by post-glacial marine activity), and the area north of Aberdeen Lake to the limestone quarry; and
2. A reddish-coloured, coarse loamy-textured till with a relatively high silt component (17 to 37%), which dominates the area below the escarpment

Each of the tills represents two different phases of glaciation (BEAK Consultants Ltd. 1987). The sandy till results from an early east-west trending ice movement through the area and is typically a hard, compact till containing up to 30% material greater than 2 mm in size and 5% silt and clay. Thickness of the deposits varies from deep blankets tens of meters thick, to veneers less than one meter thick with bedrock knobs protruding. This latter condition is particularly evident in the area between the Kiggavik site and Baker Lake. In the Aberdeen Lake area, the till is moulded into east-west trending drumlins which were subsequently modified through glaciolacustrine activity. The till in the area between Baker Lake and the Kiggavik site has been extensively modified by a post-glacial marine transgression (up to 180m above sea level). Sandy foreshore and beach deposits are commonly associated with the till in this area.

Patterned ground, such as striping and stone circles, are common periglacial features associated with the till. Surface relief of the till is typically gently undulating, with numerous scattered lakes, ponds and streams occupying shallow, basin-like depressions.

The coarse loamy-textured till, occurring primarily in the Kiggavik area south of the escarpment, has been described by BEAK Consultants Ltd. (1987) as a clay till deposited by a late north westward flow of ice through the area. Although clay content of the till is relatively low (1% to 13%), silt content ranges from 17% to 35%. When classified according to the Canadian System of Soil Classification (CSSC) (1978), textures range from silty sand to sandy loam. In the Kiggavik study area, the till has been moulded into drumlins. Permafrost features associated with the till include circles, earth/moss hummocks, and striping.

BEAK Consultants Ltd. (1987) further recognized clay till deposits in the area, which was deposited during the last north-westward flow of ice in the area. This till, which dominates the central and eastern points of the study area, has been molded into drumlins in the south and south-eastern parts of the study area. Two types were recognized in the Squiggly Lake area; a fine-textured clayey till and a sandy till, each representing two different phases of glaciation. Both tills have been locally modified on the surface by postglacial meltwaters. In such circumstances, the surface of the till deposits have a heavy concentration of rocks and boulders. These deposits are recognized as “rock barrens” and have a different vegetation composition then unmodified till. In general, the boulders on the modified clay till are smaller than those on the modified sandy till.

During the 1986 field reconnaissance, a modified till was tentatively recognized in the south-eastern and eastern portions of the study area. It is not clear whether this material is marine or glaciofluvially modified. A judgement in this regard has not yet been made and he material has been mapped as a modified till (T).

3.4.2 Glaciofluvial Deposits

Glaciofluvial deposits occur most extensively on the east end of Aberdeen Lake and the south and west shores of Skinny Lake. The deposits, which are comprised of sub-angular to sub-rounded gravel and sand, are moderately well sorted and contain less than 5% silt and clay. The materials are loose to moderately compact, and generally have low ground ice content. Areas of dry permafrost (frozen material, but no ground ice) occur in some of the deposits. Small scattered deposits are found in the vicinity of the Kiggavik exploration camp and southwest of the Kiggavik site. Thickness of the deposits have not been accurately determined, however surface coring in most deposits reached at least 3 m. Active layer depths typically reach 1.0 m $\pm$ 0.2 m. Ice wedge polygons are the most commonly occurring surface patterns, particularly in the terrace deposits northeast of Squiggly Lake an in the outwash deposits east of Aberdeen Lake (Wickware & Associated Inc. 1989).

3.4.3 Glaciolacustrine Deposits

Glaciolacustrine deposits occur where materials are deposited in or along the margins of ice-dammed glacial lakes. They may include sediments released by the melting of floating ice on the glacial lakes.

Glaciolacustrine deposits occur primarily as the result of modification of previously developed landforms along the shores of Aberdeen and Squiggly Lakes. Terraces developed in the sandy glaciofluvial deposits at the east end of Aberdeen Lake and the wave-washed surfaces of the drumlins along the north shore of the lake are evidence of this activity (BEAK 1987).

It has been observed that glaciolacustrine sediments generally have high susceptibility to frost heaving, surface subsidence, gullying and drainage network disruption by combined hydraulic and thermal erosion, even on gentle slopes following vegetation removal. Sensitive slopes may be prone to active-layer detachments and consequent development of retrogressive-thaw flows or slides.

3.4.4 Glaciomarine Deposits

Glaciomarine deposits in the form of sandy beach and foreshore deposits, and sandy-gravelly raised shorelines around bedrock hills are characteristic of the terrain between Aniguq Lake and Baker Lake. Deposits are typical thin and feature ice-wedge polygon patterns (BEAK 1987).

3.4.5 Organic Deposits

Formed by the accumulation of organic material, organic deposits are composed of peat and other organic material (sphagnum and other mosses). The deposits are frequently thin, and overlay glaciofluvial or morainal deposits or rock. In a number of locations, they are associated with former meltwater channels or present day streams and creeks. The organic material typically overlays a boulder lag deposit (boulder pavement) which has had the fine matrix (till) material removed.

Organic deposits occur frequently throughout the project area, but are particularly significant in the Kiggavik site development area where they are associated with seepage zones along the escarpment. Poorly-drained depressions and drainage ways between lakes and ponds are other typical locations for organic material to occur. The area between Aniguq and Baker Lake, particularly west of the Qinguq River, exhibits extensive development of poorly-drained peaty terrain (Wickware & Associates Inc. 1989).

3.4.6 Bedrock

In the Project Study area, bedrock forms prominent ridges, scarps and hills.

3.5 Landforms

3.5.1 Depositional Landforms

The normal depositional and erosional processes associated with the various preglacial, glacial, marine, and the present day periglacial environments have resulted in the evolution of a variety of common landforms in the study area.

Major landforms have been subdivided into depositional landform types within the Local Assessment Area (LAA) and described below. The predominant common landforms in the LAA are shown in Figure 3.1-1. Table 3.5-1 shows the percentage coverage area of the following common depositional landforms in the LAA.

3.5.1.1 Alluvium or Outwash Sediments, Undiffentiated

With the exception of Kiggavik site and its north-northeast areas, undifferentiated alluvium or outwash sediments occur in all directions. However, this unit does not occur in the Sissons site and adjacent areas. This type of landform covers approximately 10% of the LAA or 3,786 ha.

3.5.1.2 Glaciofluvial

Glaciofluvial deposits occur when material is deposited by glacial meltwater streams either directly in front of, or in contact with, glacial ice. The material is typically comprised of unsorted and unstratified, moderately to well sorted and stratified gravel and sand. Glaciofluvial outwash materials occur randomly throughout the study area and are generally composed of granular soils. Percentage coverage of glacioflucial landform is less than 1% of the LAA or approximately 200 ha.

Ground ice content in glaciofluvial deposits is typically low. These deposits generally form stable unconsolidated deposits and may offer a source of aggregate where the material is gravel rather than sand.

3.5.1.3 Glacial Till or Moraine

Till ground moraine is the most common and widespread in both Kiggavik and Sissons site areas and their adjacent neighbourhoods. The till is generally unsorted, medium brown, silty, sandy and stony, with locally derived volcanic, sedimentary, and lesser granitic clasts. Clast sizes range from granule to boulder with a high proportion in the gravel-sized range. It consists mainly of till blanket, till veneer and hummocky till. The coarse-grained materials common in most of the channels between lakes and ponds are evidence of the finer sediments having been removed by water flow. This type of landform occupies majority (approximately 84% of the LAA or 30,356 ha) of the LAA.

In general, due to the fine texture of the morainal soils and poor drainage conditions they typically have high ground ice content. Ice-rich morainal deposits are susceptible to geomorphological processes associated with permafrost. These deposits are sensitive to changes in the thermal regime following the removal of surface vegetation, inundation, or tundra fires. These deposits may be susceptible to frost heaving, surface subsidence (consolidation settlement), gullying and drainage network disruption and slope stability. Also, active layer detachment slides and retrogressive thaw flows slides or slumps can occur.

3.5.1.4 Glaciomarine

Glaciomarine deposits occur where materials released from the glacial ice come in contact with marine water and deposits are typically thin and contain various forms of permafrost including ice wedge polygons and surface patterns.

Glaciomarine landforms deposited during postglacial emergence due to crustal rebound are insignificant in the mine site areas (a percentage of coverage for this type of landform is approximately 0.3% of the LAA or 108 ha), but widespread near Baker Lake. Wave action resulted in extensive reworking of the local ground moraine creating subdued raised beach ridges and depositing fine grained, near shore marine sediments. The beach ridges comprise granular, sand-sized, materials which are generally well drained. The fine-grained marine sediments are confined to low-lying areas and are often ice-rich.

3.5.1.5 Organic

Organic deposits are composed predominantly of organic materials resulting from accumulation of vegetative matter and contain at least 30% organic matter by weight. Organic deposits form a dominant terrain either as a veneer or blanket overlying the predominantly fine grained soils of moraine and glaciolacustrine plains. They are highly compressible and have low strength when thawed. When frozen, they may contain up to 100% ice by volume.

Thick organic landforms represent a relatively minor portion of the total study area, but small localized materials are widespread. Thick peat accumulations occur in low-lying areas. The materials are wet and ice-rich. These unfavorable areas have been avoided where possible during project design.

Changes in surface drainage conditions may result from warming and thawing of permafrost. Local flooding will significantly decrease the insulating value of the peat, thus increasing the permafrost degradation process as saturated peat is ten times more thermally conductive than dry peat. Disturbance of near surface seepage in peat terrain may lead to erosion on sloping approaches to streams, particularly where the peat forms a blanket over flat surfaces into which streams and major tributaries are disturbed. In areas where frost may build up as a result of construction or operation methods, near surface seepage may be disrupted.

3.5.1.6 Bedrock

Bedrock forms prominent ridges, scarps, and hills in the Project Study Area. Typically bedrock is generally freely drained with some poorly drained depressions. No records of segregated ice within the bedrock are available at this time, but the presence of ice is possible in joints and fracture zones. Segregated ice may be present in silt-filled depressions within the region.

Outcrops are widespread around the plant/mill site, characterized by a jointed or frost shattered upper surface (felsenmeer) resulting in a jagged micro- topography. Bedrock outcrops are also common around the Main Zone, Centre Zone and Purpose Built Pit areas. It also occurs in the north of the proposed overburden and permanent stockpiles. In the Sissons area, outcrops are common in the north-east of Mushroom Lake, east of End Grid Lake and south- west of Lunch Lake. Bedrock outcrop covers approximately 5% of the LAA or 1,790 ha.

3.5.2 Glacial Landforms

Landforms around the proposed mill site are dominated by hummocky bouldery glacial till and scattered boulder till moraines with frequent bedrock outcrops and shattered bedrock features in isolated exposures, elevated plateaus and elongated ridges (drumlins, and other glaciofluvial outwash features). The localized north-northwest-trending glacial drumlins preserve evidence of regional ice flow. Glaciofluvial kames and eskers form rare, isolated topographic features. The lower elevations near Baker Lake are partly covered by marine, glaciomarine and lacustrine materials.

3.5.3 Permafrost- Related and Sensitive Landforms

Permafrost-related and sensitive landforms are potentially ground-ice rich and fine grained, which contain ground-ice in several forms, ranging from coating on soil particles and individual ice inclusions to ice with soil inclusions. Hence, this type of landforms is assessed as sensitive to changes in thermal regime and surface conditions. In thawing, the ice will disappear, and for existing overburden pressures the soil skeleton must now adapt itself to a new equilibrium void ratio. The resulting thaw settlement phenomenon is important to slope stability which is closely associated with the design of permafrost support system, design of building foundations and road design on continuous permafrost. Silts and clayey silts generally contain high ground-ice and give rise to larger thaw settlements. Ground ice-rich landform is common in alluvial plains, some till deposits, and glacio-lacustrine basins (Andersland and Ladanyi 2004).

Thickness of surface frozen ground (active layer) in the permafrost terrain depends on various factors including proximity to lakes, slope, aspect, and many other site-specific conditions. Permafrost is reflected in well developed patterned ground and periglacial processes. Evidence of active cryoturbation was found in several locations, where boulders and platy stones were thrust upward to the tundra surface. Patterning is primarily sorted circles, sorted stripes, sorted nets, sorted steps and sorted polygons depending on slope and materials. Sorted circles, nets and steps occur on the glacial till material where there is enough fine material. Sorted polygons are confined to glaciofluvial materials likely due to the high proportion of stone and cobble sized material (Geomatics International 1991).

Ground-ice conditions in the Project area have been characterized as indicated in Figure 3.1-2, likely having less than 10% of ground-ice content. This low amount of ground-ice is likely applicable for most landforms in the Project area, except for the marine and localized fine-grained (high silt or clayey silt content) landforms which may contain more than 10% ground-ice. The higher ground-ice content within those localized landforms may result in greater sensitivity to changes in thermal regime, as melting or aggrading permafrost will cause greater changes in drainage conditions or volume (heaving or settlement).

The geocryological processes prevailing locally in the Project area are typical of permafrost conditions associated with excess ground-ice. Geocryological processes observed at and around the Project area include frost wedging and frost shattering, thaw settlement, and solifluction. Permafrost features are typically subdued in areas of thin overburden and dry conditions. Generally wet conditions, associated with low-lying ground, exist locally.

Permafrost sensitive landforms may be determined based on the following:

- A potential high water content;
- A potential high ground-ice content;
- A potential high frozen bulk density of soil;
- Fine grained strata with high silt content;
- Position in the landscape; and
- Slope types

3.5.4 Uncommon Landforms

Some of the landforms left behind by glaciation have played a significant role in the lives of local communities. The landforms having a high value in terms of traditional ecological knowledge and habitat potential for wildlife, rare plant species, and human are considered as uncommon landforms. The most prominent uncommon landforms in the Project area are eskers.

Eskers are identified as uncommon landforms or landforms of value separately from other glacial features based on the consultation with local communities, elders, regulators and existing scientific study. Eskers provided resources and aids to survival to hunter and trappers. Eskers have special attributes that were understood and incorporated into the ways that people traditionally used the land. The elevation of the eskers allowed people to survey the land for a great distance. Looking for caribou or other animals, or watching for other people. The smooth, flat surfaces made travelling much easier, and provided convenient and comfortable spot for camping along the way. When the winds are strong,, the sides of eskers can provide protection. The soft slopes along the sides were also used by Aboriginal people to bury dead. Many of the significant sites on eskers today are ancient graves or campsites. Animals use the esker in a number of ways. Caribou use them as migratory paths. The relatively clear and dry surface helps them avoid the streams and bogs of the tundra, and the higher winds help to keep insects away. The soft, sandy sides of the eskers are easily dug out and may species of animals depend on them for their dens including wolves, white foxes, bears, and wolverines. Many plants grow in the protected microclimates created at the sides of eskers. Three landforms that are believed to be related to eskers have been identified within the LAA. However, they occupy insignificant area of the LAA.

3.6 Observations along the Baker Lake to Kiggavik All-Season Road

The proposed All Season Road extends from the proposed Kiggavik Mine/Mill site to a proposed dock site on the north shore of Baker Lake, east of the community as shown in Figure 3.1-3. The proposed Northern All Weather Access Road is 114km in length from Kiggavik site to the proposed dock site. The road will be 10 meter wide gravel road, built with rock embankment (fill). Fill method avoids the removal of surface insulation protecting the surface from the exposure to direct sunlight that prevents increased thaw and degradation of permafrost. Ultimately, this can prevent and/or minimize adverse environmental effects (such as erosion) and the road maintenance required over the life of the mine and during closure and reclamation. There will not be earth cuts along the alignment, and the only cut sections will be through rock. Materials for the rock embankment and road surfacing material will be derived from rock quarries developed adjacent to the proposed road.

Numerous options and variations have been developed and evaluated to arrive at the preferred road alignment. The route has been located generally on higher ground. The reasons for this are as follows.

- Higher areas tend to be less ice-rich, which present fewer geotechnical issues when constructing the road;
- Higher areas tend to have fewer areas of diffuse drainage patterns which are hard to accommodate in construction;
- Higher areas are less prone to snow drifts, which can become a major maintenance issue;
- The higher areas tend to have more areas of bedrock which reduces the fill requirement when constructing the road embankment;
- The higher areas are nearer to suitable quarry locations.

Areas of geotechnical instability, environmental and archeological constraints also guided the route selection.

The surficial landforms (deposits) along the All Season Road between the Kiggavik mine/mill site and the north shore of Baker Lake comprise mainly glacial till overlying pre-cambrian intrusive igneous and metamorphic bedrock. The periglacial geomorphic processes in the area are typical of permafrost conditions associated with excess ground ice. It is estimated that the glacial landform covers approximately 63% of the All Season Road LAA. Alluvial, Marine, Glaciofluvial and Bedrock landforms cover 3.63%, 2.12%, 0.76%, and 30.30 % of the All Season Road LAA, respectively.

The eastern portion of the proposed alignment near Baker Lake is below the most recent glacial marine transgression; consequently the elevations near Baker Lake are covered by marine reworked sediments; the till deposits appear reworked by nearshore marine processes, forming flights of raised strandlines (McMartin, I., Dredge, L.A., and Aylsworth, J.M. 2008). Widespread areas of marine reworked sands are present near Baker Lake and along its shoreline.

Further inland, the glacial till overburden soils are interrupted by bedrock outcrops that are more prevalent inland (west). Widespread areas of thin till veneer are present and bedrock boulder fields frequent the route. – also called block field (or felsenmeer) – as surface layer of angular shattered rocks formed in either modern or Pleistocene periglacial environments More recent alluvial sediments occur as thin deposits of fine-grained sand and silt throughout the project area and present themselves locally in topographic depressions (low lying areas) and along stream channels. The general area is devoid of glaciofluvial sediments, although there are areas north of Judge Sissons Lake that show evidence of proglacial and subglacial meltwater erosion and deposition (McMartin, I., Dredge, L.A., and Aylsworth, J.M. 2008).

Bedrock outcrops available along the route are the best available source of fill material for constructing the road. Quarry sites are available inland along the route, and possible locations have been identified along the entire route.

Morainal/till materials generally provide suitable foundation conditions on which a road can be constructed. Morainal materials are typically moderately well drained and comprise a fraction of sand, gravels and cobbles. They present few limitations to road construction except in areas with steep slopes or where drainage is poor and ice-rich.

Alluvial and thick organic deposits comprise a small percentage of the materials that will be encountered along the route. These materials are transported and deposited by streams and gravity and are found along water courses and steeper slopes. From an engineering perspective, alluvial deposits could represent potential borrow sources, however, these materials are often finer grained, ice-rich, and located in sensitive areas, in close proximity to water bodies, and are of small volume and relatively unmapped, so should not be relied upon as significant material sources.

In general, the grades are gentle, in the order of 1 to 3%. There are some sections that reach the maximum end of the design criteria range of 5-6%. The longest section of this steep gradient (500m) is around KM 133.5.

Terrain conditions observed along the proposed All Season Road are described in Table 3.6-1. Percentage coverage area of the common depositional landforms along the All Season Road Local Assessment Area is shown in Table 3.6-2. Geometric design principles, criteria, cross-section for varying terrain conditions, design parameters for depth of embankment fill and detail route descriptions for the All Season Road can be found in the Technical Appendix 2L "All Season Road Report".

4 Geotechnical Conditions

Detailed geotechnical information is important to consider in the detailed design of the infrastructure at each site but it does not significantly change the design criteria for the infrastructure or mines. The geotechnical properties will result in small changes, if any, to the final design of the open pit mines, site drainage infrastructure, and ore and special waste pads. These facilities have preliminary designs which provide the basis for assessing the environmental effects of the project. During detailed design of each facility, the site specific geotechnical conditions will be incorporated into the design of the facilities to ensure that that they meet the design goals for the facility.

The final design of the site access and haul roads is expected to be an iterative process that includes geotechnical characterization along the proposed routes and modification to the design to minimize the impact on the local terrain. The route for either the winter road or all weather road option is not expected to change significantly from the current plan; however, additional investigations may lead to modifications to the design of the road design, construction and operation.

4.1 Overburden Characteristics

4.1.1 Overburden Profiles

A typical overburden profile comprises a thin, dark brown to black organic topsoil layer, 0.10m in thickness, underlain by glacial till varying in thickness from approximate a metre to several metres. The glacial till varies in texture and composition from well-graded silty sand with some gravel and a trace of clay to well-graded gravelly sand with some silt and a trace of clay. Oversize material in the till consists of boulders and cobbles which tend to be larger and more frequent with proximity of bedrock. In general, flight auger refusal was believed to be encountered on cobbles and boulders within the glacial till on some of the boreholes and hence the overburden thickness is expected to be more than the depth to auger refusal on these holes. Field observations and borehole logs indicated the thickness of the till to be more than 0.30 metres and reached up to 5.34m with the exception of 8.0m on the drillhole BH88-1T6 located west of BH88-1MHR6. Depth to bedrock ranged from 0.30 to 6.5m with the exception of 8.0m on the drillhole BH88-1T6. Table 4.1-1 presents the overburden conditions in the Kiggavik area. Figure 1.1-1 shows the location of the geotechnical boreholes and the cross-section.

A typical overburden profile in the Kiggavik Project area is shown in the cross-section X-Y (see Figure 4.1-1). Eight out of eleven boreholes reached the bedrock. Depth to bedrock ranged from 1.22 to 7.3m below ground surface. At those three holes that did not reach the bedrock, the overburden profile was interpolated based on the data on surrounding boreholes.

Ground Penetrating Radar survey results suggest that the overburden thickness is quite variable over the Kiggavik area with a depth to bedrock ranging from 2 to 20 m approximately (EBA, 2010).

4.1.2 Grain Size Distribution Analysis

Grain size distribution results in the permafrost terrain may be useful to analyze the possible occurrence of frost heaving and susceptibility for thaw settlement. Coefficient of uniformity (Cu) and Coefficient of curvature (Cc) values were calculated based on the D60, D30, and D10 values directly estimated from the Grain Size Distribution Curves where possible.

The overburden unit appeared to be granular tills with relatively well graded particle size distributions. Oversize material consisted of cobbles and boulders. Laboratory results showed that coefficient of uniformity (Cu) values were greater than 6 for all soil samples and ranged from 7.8 to 1500. Coefficient of curvature (Cc) values varied from 0.2 to 5.3.

Grain size analysis results generally indicated that the overburden unit at most of the sites consisted of soil types of clayey to silty sand (SM-SC), silty sand (SM) and gravely sand. Grain size analysis at Skinny Lake area and some of the analyses at Squiggly Lake area indicated that overburden comprised poorly graded gravels (GP) and non-plastic poorly graded gravel with silt (GP-GM).

Grain size distribution curves and the summary of the grain size distribution analysis for all sites are included in Attachment B and Attachment C, respectively.

4.1.3 Water Content and Plasticity

Water content in the permafrost terrain is used to obtain an indication of volumetric ground-ice content. In general, the water content of the glacial till ranged from 7.7 to 50.6% (see Figure 1.1-1 and Table 2.2-3). These water contents are higher than the estimated 7.1% optimum water content (OMC) determined from the compaction test conducted on the sample AS5 of BH88-1P8. The glacial till at the Main Zone and Centre Zone area exhibited analogous water content ranging from 4.4 to 54.2%. Sandy Gravel till with some silt and trace clay showed maximum water content of 54.2%. The overburden soil collected from RMI-09-01 drilled in 2009 exhibited water content of 18.2%. The laboratory analysis of four overburden samples from shallow test pits in the area of End Grid underground mine exhibited water content ranging from 3.1 to 22.5%. The water content of lakebed sediment samples varied from 19.9 to 44.8%.

The glacial till sample, characterized by well-graded silty sand with some gravel and a trace of clay to well-graded gravely sand with some silt and a trace of clay, exhibited little to no plasticity. The laboratory test results indicated that liquid limit (Wl) and plastic limit (Wp) in the area north of Main Zone and Centre Zone ranged from 18 to 54 and from 14 to 31, respectively. Plasticity index (Ip) of the overburden soils at these sites ranged from 3 to 23. The glacial till samples, mainly characterized by sand till with some clay and trace silt at the Main Zone and Centre Zone area exhibited no plasticity. The overburden soil in the borehole RMI-09-01 exhibited plasticity index of 6. One sample from shallow test pit END-OB-09 in the area of End Grid underground mine exhibited plasticity index of 1. Two lakebed sediment samples showed no plasticity.

A summary of the water content and plasticity is included in Table 2.2-3.

4.1.4 Soil Density

Frozen bulk density (γ_{bf}), dry density (γ_d) and specific gravity (SG) of overburden samples were determined in the laboratory. Frozen byulk density along with the water content is used to obtain an indication of volumetric ground-ice content. In general, frozen bulk density ranged from 1271 to 1982 kg/m^3. Dry density of the same samples ranged between 536 and 1405 kg/m^3. Specific gravity of soil solids varied from 2.64 to 2.69.

Minimum frozen bulk and dry densities were determined on overburden samples from the borehole BH88-1P9, whereas the maximum of those parameters were found on samples from the borehole BH88-4A2. Minimum and Maximum values of soil density in the Kiggavik area is tabulated below.

Value	γ_{bf} (kg/m^3)	γ_d (kg/m^3)	Site
Minimum	1271	536	BH88-1P9
Maximum	2468	2128	BH88-4A2

4.1.5 Ground Ice Conditions

With the exception of one borehole BH88-1MHR1, where depth to permafrost was not recorded, ground ice was encountered at a depth ranging from 0.60 to 1.00m below ground surface in 5 holes in the north of Main Zone area. Ground ice descriptions for the glacial till were typically non-visible, well bonded, no excess ice (Nbn) to excess ice (Nbe).

Ground ice was observed at depths of 0.15 and 0.76m below ground surface in boreholes BH88-1P9 and BH88-1P6, respectively. Ground ice descriptions for the glacial till ranged from non-visible, well-bonded (Nb) to visible stratified and crystalline ice (Vs and Vx). The non-visible ice included both non excess ice (Nbn) to excess ice (Nbe). The stratified ice was 1 to 3mm thick, clear and hard. Clear and hard ice with soil inclusions (0.10m thick) was observed at 1.20m below ground surface in BH88-1P5.

In the area north of Centre Zone, ground ice content was encountered at depths of 0.30 and 0.75m below ground surface. Ground ice descriptions for the glacial till ranged from non-visible, well-bonded with no excess ice (Nbn) to visible ice coatings on soil particles (Vc) and random ice formations (Vr) and stratified ice (Vs).

In the south of Centre Zone area, ground ice was observed at depths of 0.50 and 1.00m below ground surface. These thaw depths were encountered in the silty sand till and sand/gravel which were encountered in two boreholes. Ground ice in the silty sand till was described as non-visible, well-bonded, non-excess ice (Nbn), whereas ground ice in the sand and gravel was classified as non-visible, well-bonded, excess ice (Nbe).

In general, ground ice content was observed in most of the boreholes which were drilled by the flight auger. The field investigation was completed before the end of the thawing season and therefore the depth to ground ice observed in the flight auger boreholes are believed to be less that the depth of the active layer.

In the borehole RMI-09-01, drilling to a depth of 1.5m without using water indicated the presence of ground ice characterized by non-visible, poorly-bonded to well-bonded with an excess ice (Nf and Nbn). However, no ground ice was recovered below the depth of 1.5m with the use of minimum water possibly due to drilling induced thawing. In RMI-09-02, water was used during coring to a depth of 3.5m and hence ground ice condition could not be described. All fines were believed to be washed out. Drilling with the use of minimum water was advanced from 3.5 to 4.0m and ground ice in the silty gravel was described as non-visible, well-bonded, no excess ice (Nbn). Soil was observed as frozen and stiff within this depth interval. No ground ice was recovered in the boreholes drilled in 2010 as it thawed during coring.

Figure 3-1.2 shows the location of the Kiggavik project in area of continuous permafrost. The ground ice content of permafrost soil and rock in the project area is expected to be between 0 and 10 % (dry permafrost) based on regional scale compilation data (Brown, J., O.J. Ferrians Jr., J.A. Heginbottom, and E.S. Melnikov. 1998, revised Feb. 2001. Circum-arctic map of permafrost and ground ice conditions, Boulder, CO: National Snow and Ice Data Center/World Data Center for Glaciology). Excess ground ice is expected to be greater in areas such as lowlands that are characterized by poorly drained conditions commonly expressed as patterned ground and other periglacial process features. Ground ice content descriptions in Kiggavik project area are summarized in Attachment J based on the information available in the geotechnical borehole logs included in Attachment A.

The assumptions provided for the ground ice content are considered to be reasonable for the preliminary design of facilities. Additional data on ground ice content will be acquired to support the detailed design of specific facilities such as the stockpiles, roads, and mill site to ensure that facilities perform as described in the EIS. Detailed designs will include this data and be provided prior to licensing.

4.1.6 Shear stress

The shear strength of the soil is an important characteristic with respect to geotechnical design of the engineering structures. Typical shear stress values of rock types such as those found at the Kiggavik area are estimated in the order of 30º (apparent friction). With exception of summer time, field investigations suggested that soils at the site will be ice filled, which will significantly increase the shear strength of these surfaces (Golder, 1989)

The laboratory test results are included in Attachment C.

4.2 Shallow Bedrock Characteristics

4.2.1 Bedrock Profile

In general, shallow bedrock at the Kiggavik site consists of the following units.

- Sandstone conglomerate
- Orthoquartzite
- Granite/granitic gneiss
- Metasediment/Meta- arkose
- Intrusive such as lamprophyre and feldspar porphyry

In the north of Main Zone area, shallow bedrock comprises sandstone conglomerate and orthoquartzite. The sandstone conglomerate is typically light brown, siliceously cemented, and fine to medium grained. The orthoquartzite is typically white to light grey, hard and very fine grained with traces of hematite. Depth to bedrock ranged from 0.71 in BH88-1P3 to 4.60m in BH88-1P11. The upper part of the bedrock appears to be shattered by frost action and it is expected that the shattered rock contains significant amount of ground ice. The depth of the shattered rock was estimated based on the presence of ground ice recovery as well as from examination of the core in the absence of ground ice recovery. The bottom of the shattered bedrock was encountered from 3.35m in BH88-1P2 to 5.40m below ground surface in BH88-1P12. Estimated shattered bedrock thickness varied from 0.31 to 3.61m with a thickness ranging between 1.50 and 2.50m in general.

In the area north of Centre Zone, bedrock was characterized by greyish-white, hard, crystalline, sericitic and hematitic orthoquartzite. . Depth to bedrock at this site ranged from 0.30 in BH88-2P3 to 5.64m in BH88-2P4. The bottom of the shattered bedrock was encountered from 3.66m in BH88-2P1 to 9.45m below ground surface in BH88-2P4. Estimated shattered bedrock thickness varied from 2.44 to 4.04m. Sandstone conglomerate was observed in BH88-2P4. Depth to bedrock in this hole appears to be 8m, which is deeper than in other holes. Bottom of the shattered bedrock was found to be 10.36m below ground surface.

Bedrock was encountered at depths of 2.6m, 4.1m, 2.7m and 6.5m in the most recent boreholes RMI-09-01, RMI-09-02, RMI-10-01 and RMI-10-02, respectively.

Shallow bedrock conditions in the Kiggavik area is summarized in Table 4.1-1.

4.2.2 Core Recovery and Rock Quality

Main Zone and Centre Zone areas

Rock Quality Designation (RQD) values were estimated from three boreholes drilled in 1988. For the estimation of average value of RQD, the following borehole depth range was considered for the shallow bedrock conditions.

- 88-331: 9m (30 ft.)- 60m (197 ft.)
- 88-332: 6m (20 ft.)- 60m (197 ft.)
- 88-333: 9m (30 ft.)- 60m (197 ft.)

The average RQD estimated for two holes at Main Zone area ranged between 64 and 72% indicating fair rock quality as a blocky and seamy type of rock. However, the average estimated RQD at Centre Zone area revealed very poor quality rock with crushed nature.

4.2.3 Mill Area (North of Main Zone)

A total of four shallow geotechnical boreholes (RMI-09-01, RMI-09-02, RMI-10-01 and RMI-10-01) were drilled in 2009 and 2010. In general, Total Core Recovery (TCR) was very good with an average value of 98%. Rock Quality Designation (RQD) was estimated with an average value of 89% indicating the shallow bedrock as massive/moderately jointed with good rock quality rating.

Based on the detail geotechnical logging of boreholes, average TCR and RQD for each borehole were estimated greater than 87% and 82%, respectively. According to the RQD classification system, the estimated RQD data indicated that rock quality is good and the shallow bedrock is characterized by moderate jointing system. Figure 4.1-2 shows TCR and RQD profiles with depth on RMI boreholes. The RQD distribution in combination with the Fracture Frequency with depth on the recent geotechnical boreholes at the Mill area is presented in Figure 4.1-3. Figure 4.1-4 shows the TCR profile with depth.

4.2.4 Fracture and Joint Characterization

Detail geotechnical logging provided the basis for the estimation of Fracture Frequency (FF) and Fracture Spacing (FS). Number of fractures was counted for every meter of the drill core in RMI-09-01 and RMI-09-10, whereas it was counted for each run (3m) for RMI-10-01 and RMI-10-02.

Fracture Frequency was calculated as the total number of fractures (N_f) divided by the interval length (L).

$$FF = \frac{N_f}{L}$$

Fracture Spacing (FS) was calculated as a ratio of the interval length to the total number of fracture as below.

$$FS = \frac{L}{N_f + 1}$$

Average fracture frequency and fracture spacing for 2009 shallow geotechnical boreholes were calculated 5 per metre and 0.24m, respectively. For 2010 boreholes, the average fracture frequency and fracture spacing were calculated 9 per run (3m) and 0.39m, respectively. Fracture (joint) analysis indicated that the average fracture spacing in the drill cores of four shallow geotechnical boreholes was generally estimated between 0.2 and 0.6m, which may be described as moderately wide in accordance with the Rock Mass Rating 1979 system. However, wider fracture spacing is expected at depth.

The major steeply dipping joint set analysis was done at Main Zone and Centre Zone areas. This interpretation was based on the data collected in 1988 field campaign and all three joint

Sets were identified and presented as a series of stereographic projections as shown in Attachment K. These joint sets are referred to as J1, J2 and J3 for convenience. The most consistent and dominant set, J1, trends in an east-west direction and is characterized by quartz in-filling and veining. The J2 set is also well developed, and trends north-south. This set often crosscuts the J1 set. The J3 is less well developed, discontinuous and trends in a southeast-northwest direction. The J3 set generally terminates on J1 and J2.

Figure 4.1-5 shows the fracture frequency and fracture spacing versus depth on the most recent geotechnical boreholes drilled in 2009 and 2010 at Mill area. Figure 4.1-3 and Figure 4.1-4 also show their distribution in combination with other basic geotechnical parameters over depth.

Joint description was based on the field mapping of outcrops and detail geotechnical logging of drill core. Shallow bedrock at three geotechnical boreholes at Main Zone land Centre Zone areas typically exhibited planar joint shape with occasional curved and undulating character. Quartz and hematite were the most common joint infill type. Joint roughness typically varied from rough/very rough to smooth with occasional slickenside.

Based on the drill core observation in four holes drilled in 2009 and 2010, joint surface shape was found to be undulating and planar with very rough to smooth joint surface roughness. Chlorite, hematite and clay were the most common joint infill type. In general, joint infill was characterized by slight alteration, staining and coating. Joint set number (Jn) usually ranged from 2 joint sets and random to three joint sets and random with the rating ranging from 6 to 12. However, joint set rating of 15 (four and more joints) was occasionally noticed. Normally, the rating of Joint Roughness (Jr) ranges from 1 to 3 indicating planar-smooth to undulating-rough or irregular. Joint alteration was generally characterized by only coating (no mineral fillings) and thin mineral fillings. Rating of Joint Alteration Number (Ja) commonly ranged from 0.75 to 4.

4.2.5 Rock Strength

With the exception of the highly altered rocks of the ore zone, all rock types at the shallow depth exhibit strong rock characteristics. The field strength of shallow bedrock was estimated using the rock peak test. Rock strength was indexed from R0 to R6 and described in accordance with the International Society of Rock Mechanics (ISRM) Standard "Rock Characterization Testing and monitoring: ISRM Suggested Methods", developed by Brown 1981. It is an empirical determination of the rock strength. Attachment F includes the ISRM Standard for the determination of field strength of rock.

Typical field strength value of rock types at the Main Zone and Centre Zone area ranged from strong (R3) to very strong (R5) to a depth of 60m below ground surface. Drillcores from the borehole 88-333 at the Centre Zone area exhibited slightly weaker rock strength ranging from weak (R2) to strong (R4) depending on the rock type, alteration and mineralization.

In general, medium strong field rock strength (R3) was estimated in drillcores from the boreholes drilled in 2009 and 2010. However, the rock strength increased with depth and ranged from medium strong (R3) to very strong (R5). Figure 4.1-6 and Figure 4.1-7 show the field rock strength versus depth in four drillholes drilled in 2009 and 2010.

The results of laboratory rock strength tests in the Main Zone and Centre Zone area indicated that the Uniaxial compressive strength (UCS) values of the shallow bedrock ranged from 66.9 to 128.0 MPa, which is generally consistent with the estimated field rock strength. Hence, the orthoquartzite and the intrusive unit were found to be very strong rocks. The metasediment/ meta-arkose do not always appear to have the same strength, but are still very competent in nature. Rock strength testing was conducted on thawed core. The strength characteristics of rock types tested are unlikely to differ significantly in a frozen condition due to very low moisture content and void ratios. The results of laboratory rock strength tests are presented in Table 4.2-1.

It is important to point out that degradation of the rock mass generally impacts the strength and geotechnical character of the rock. Weathering on the shallow bedrock in boreholes drilled in 2009 and 2010 typically varied from fresh to slightly weathered. In general, a greater degree of rock weathering was observed near to the surface and it decreased with depth. The cross section X-Y in Figure 4.1-7 shows the weathering Index (WI) and Field Intact Rock Strength (IRS) versus depth in these boreholes.

Point load tests (PLT tests) were carried out on the Main Zone and Centre Zone rock. The point load tests were converted to rock strength in MPa using correlation coefficients determined from the laboratory Unconfined Compressive Strength (UCS) test results. The results for the Kiggavik and Andrew Lake areas are shown as histograms in Attachment L. There are no histogram plots for the End Grid deposit since the point load data could not be converted due to poor statistical correlation with the laboratory UCS results. Summaries of the main geotechnical properties measured in each drillhole in the 2009 drilling campaign are also shown in Attachment L for the End Grid, Andrew Lake and Kiggavik sites. Properties measured were total core recovery (TCR) and rock quality designation (RQD). Rock quality rating was done on a scale from 1 to 6 as follows:

1-strong competent rock; 2-strong moderately fractured rock;3-strong highly fractured rock; 4-intermittent moderately leached rock; 5-moderately leached rock; 6-highly leached rock.

On average, the laboratory strength testing confirmed the field strength estimates, except when samples failed along a pre-existing feature within the rock sample, producing slightly lower strengths than field estimates.

4.2.6 Rock Density

The rock density was determined for the shallow bedrock unit at the Main Zone and Centre Zone area to a depth of 60 metre below ground surface. The average density values for meta-arkose (Main Zone), lamprophyre (Main Zone) and orthoquartzite (Centre Zone) were estimated 2.69, 2.77 and 2.63 gm/cm^3, respectively.

4.3 Observation at the proposed Dock Site Area

The proposed dock site 1 is located approximately 5 km east of the hamlet of Baker Lake along the north shore of Baker Lake (See Figure 4.1-10). The area is characterized by a relatively narrow and abruptly rising shoreline which has been extensively terraced by gradually declining lake levels since deglaciation.

The area between the proposed dock sites and Baker Lake is characterized by gradually slopping gravelly/sandy beach deposits which grade more steeply up a bedrock slope covered by a veneer of terraced marine sand and gravel. Numerous former beach ridges occur on the valley slope and on the upland. The beach ridges and the present beach are composed of rounded gravel and small cobles which underlain by sand. The dock site is well-drained because of the permeable soils and step slopes.

Four boreholes were drilled in the vicinity of the proposed dock sites using Mobile Augers B-40 rig. Rotary and NQ wireline coring equipment with water flush return was used in two boreholes drilled in ice. Standard Penetration Test (SPT) driven-open samples and wash samples were

Obtained in the overburden and NQ size core was recovered from the underlying bedrock. Solid stem flight auger and NQ wire coring equipment was used on the two boreholes drilled on land. Flight auger cutting samples were obtained from the overburden and NQ size core was recovered from the bedrock. The borehole logs are included in Attachment A.

The laboratory program consisted of testing selected overburden samples for grain size distribution, plasticity and water content. Two direct shear tests were conducted on combined samples of sand from Borehole BH88-D101 which was drilled on the frozen lake. The grain size distribution test results are included in Attachment B and the laboratory test results for the overburden samples are included in both on the borehole logs. The direct shear test results are included in Attachment C.

4.3.1 Overburden

The overburden surface encountered at depths of 5.15 and 4.20m below ice surface in boreholes BH88-D100 and BH88-D101, respectively. The ice thickness was approximately 2m. The overburden in BH88-D100 was 3.69m thick and consisted of 2.75m of medium brown, very fine to fine, sub-angular and very loose sand with trace silt and trace fine gravel underlain by 0.92m of sand and gravel with occasional cobble. The overburden in BH88-D101 was 6.62m thick and consisted of 3.69m of fine to coarse, sub-angular, loose to very loose sand with trace silt underlain by 2.13m of multicoloured, loose sand and gravel.

SPT “N” values of 0 to 8 blows per 300mm on the sand stratum in both boreholes indicated that the state of compaction of the sand is very loose to loose. However, SPT “N” value of 4 blows per 300mm on the underlying sand-gravel stratum indicated that the sand and gravel is in a loose condition. The direct shear test results for combined samples of the sand from Borehole BH88-D101 indicated effective angles of shearing resistance of 36 to 40.8 degrees.

Boreholes BH88-D102 and BH88-D103 were located on the land. Overburden thicknesses were 8.81 and 2.93m, respectively in these two boreholes. In BH88-D102, the overburden consisted of 0.60m of gravely sand underlain by 8.51m of glacial till. In BH88-D103, the overburden consisted of 0.60m of gravely sand underlain by 2.33m of glacial till.

Grain size distribution test results for the surficial sand and gravely sand and for the glacial till are included in Attachment B. The glacial till is typically silty sand till with some fine to coarse gravel and some non-plastic clay. Oversize material in the glacial till consisted of cobbles and boulders. Water content of samples of the till ranged from 7 to 14 %.

4.3.2 Shallow Bedrock

The overburden was underlain by meta-sandstone and meta-arkose bedrock in the four boreholes. The bedrock was cored to depths of 0.56 to 3.65m below the bedrock surface. Meta-sandstone was observed light pinkish red with dark green on foliation contacts, fine to coarse grained, foliated, chloritic, and minor hematite staining with trace calcite on joints and foliation breaks. Meta-arkose was noticed black to red to white alternating bands of biotite quartz and feldspar, fine grained, heavily hematized with micro-cyrstalline foliation, and sheared with abundant micro-folds.

4.3.3 Permafrost

No permafrost was encountered in the boreholes at the dock site. The absence of permafrost is attributed to the thawing effect of the nearby lake.

4.3.4 Surficial Deposits

Glacial deposit is the most common and widespread surficial deposits in the proposed dock site area (Figure 4.1-10). Till veneer and till blanket appear to be major glacial depositional units in the area. Marine deposits (primarily littoral sediments and/or its combination with bedrock) are generally noted in the south and south-east part of the proposed dock area. Bedrock outcrops are mainly observed in the northern and eastern parts of the area. Two of the proposed dock sites appear to be located within the marine deposits in combination with bedrock outcrops, whereas the proposed dock site #1 is likely located in the glacial (till veneer), marine and bedrock units.

5 Shallow Thermal Conditions

The Kiggavik Project site is located within the zone of continuous permafrost. The shallow “Active Layer” is generally characterized by its limited thickness and continuity. The active layer possesses a seasonal nature as it melts during summer period (June to September) and refreezes for rest of the time of each year. Hence, the active layer thickness, also known as the “Thaw Depth”, increases gradually over the summer months and is believed to reach its maximum depth in August and September. However, the thaw depth depends on various factors including the presence of type and thickness of vegetation cover, organic soils insulation, slope aspect and orientation, the nature of the underlying soil and rock, weather, proximity to water bodies and human disturbance.

Permafrost was observed in most of the boreholes drilled in the Project area. However, field investigations were completed before the end of the thawing season and therefore the depths to permafrost observed in the flight auger boreholes are believed to be less than the depth of the active layer. Thermistors and frost depth indicators were installed in selected boreholes to collect ground temperature data and maximum thaw depths.

The thaw depths observed in flight auger holes varied with soil or rock type, vegetation cover and surface drainage. In general, permafrost was observed and described in most of the boreholes in the Kiggavik area (refer to Attachment J for permafrost conditions). The thaw depths were estimated from temperature profiles recorded with seven shallow thermistors and the maximum thaw depths measured with 14 frost depth indicators. The maximum thaw depth estimated from temperature profiles ranged from 1.4 to 2.7m with the exception of 6.3m in BH88-1T3 in the Ridge Lake area. The maximum thaw depth measured with frost depth indicators ranged from 0.88 to 3.1m with the exception of 2.13m in BH88-1T4 in the Ridge Lake area. The shallowest and the deepest thaw depths were measured in the boreholes BH88-1P5 and BH88-1L2, respectively. The depths in BH88-1T3 and BH88-1T4 are believed to be affected by adjacent water bodies and not included to analyze and interpret the active layer. In general, the thaw depth ranged from 0.88 to 3.10m in the Kiggavik Project area. Figure 5.1-1 shows the map of thaw depth (active layer) in the proposed Kiggavik Project area. In order to produce this map, an occurrence of 1m of thaw depth (active layer) was assumed within the pockets of glaciofluvial deposits in the project area was assumed. Table 5.1-1 includes the summary of thermal condition monitoring and provides maximum estimated and measured thaw depths at the Kiggavik area. Temperature profiles in all seven thermistors are included in Attachment D and the measured maximum thaw depths with frost depth indicators are shown in geotechnical borehole logs in Attachment A.

It is apparent from the observations at temperature and thaw depth monitoring stations that the thaw depth increases adjacent to water bodies or where the coarse textured overburden and/or shattered bedrock occur at shallow depths (i.e. less than about 1.5m). It is believed that increased thaw depth may result from the water movement as well as conduction of heat down into the shattered bedrock relative to the overburden. Eleven of the 18 thermistors/frost depth indicators, which were not installed adjacent to water bodies or in shattered bedrock, indicated the maximum thaw depths of 0.88 to 1.76m with an average value of about 1.35m. This measured thaw depth is likely overestimated because of ground surface and subsurface disturbance caused by the drilling operation.

Ground temperature data recorded from September 29, 2007 to June 21, 2008 in the shallow thermistor string inside the drillhole END-07-01 at the End Grid area suggested that the zero annual amplitude, which is the depth at which the ground temperature are not affected by seasonal changes in surface temperatures, is in the order of about 20m below ground surface. At the Meadowbank Project site, located about 100 km northwest of the Kiggavik Project area, the depth of the zero amplitude was estimated to be between 20 and 25m below ground surface (Golder, 2003). Therefore, this estimate of the zero amplitude depth is considered reasonable. Figure 4.1-8 and Figure 4.1-9 show the distribution of the ground temperature as a function of time and depth, respectively. The estimated thaw depth based on the dataset is not fully conclusive since the recorded period does not include the months of August and September for which the active layer reaches its maximum thickness. The apparent thaw depth shown in Figure 4.1-9 most likely reflects either the heat that was introduced in the ground during the drilling or faulty nature of thermistor itself. However, based on the existing record and shallow thermistor data collected at the Meadowbank Project, the thickness of the active layer is expected to be between 1 and 5 m below ground surface.

At this time, a thaw depth contour map has not been generated for the remainder of the Mine LAA, the Road LAA, and the Dock and Storage LAA, but will be included as part of the site investigation for the detailed design phase of the project.

6 Summary

Geotechnical investigations were conducted in 1988, 2009 and 2010 in the Kiggavik Project area to characterize the shallow ground conditions.

Data collection methodology included both field and laboratory investigation programs to characterize overburden and shallow bedrock conditions. The field investigation included drilling of 106 shallow geotechnical boreholes and 3 test pits with a total drilling meterage of 748.1m. In 1988 and 2007, 8 shallow thermistors and 14 frost depth indicators were installed in selected boreholes as a part of the ground temperature and thaw depth monitoring program. In 2008 and 2009, GPR geophysical surveys were conducted in the Kiggavik area to delineate soil stratigraphy, bedrock contacts and bedrock surface condition as well as permafrost condition. The laboratory program included sampling and testing of soil and rock. A total of 230 disturbed fight auger samples and 51 undisturbed samples were analyzed, which were collected in 1988 and 2009. Additionally, 5 samples in the End Grid area and 20 lakebed samples in the Andrew Lake area were collected and tested in 2010. Laboratory tests on 23 bedrock samples were also performed to determine the bedrock characteristics.

Field and laboratory programs provided geotechnical data, which included rock quality designation, discontinuity characteristic, rock strength, rock density, grain size distribution, water content, plasticity, soil density, ground ice content, thaw depth, permafrost conditions, etc.

The following findings are generated from the review of geotechnical data collected in 1988, 2008, 2009 and 2010.

- In general, the overburden profile comprises a thin, dark brown to black organic topsoil layer, 0.10m in thickness, underlain by glacial till varying in thickness from approximate a metre to several metres. The glacial till varies in texture and composition from well graded silty sand with some gravel and a trace of clay to well graded gravelly sand with some silt and a trace of clay. In most cases, overburden thickness ranges from 0.30 to 6.5m.
- Ground Penetrating Radar (GPR) survey results suggest that the overburden thickness is quite variable over the Kiggavik area with a depth to bedrock ranging from 2 to 20 m approximately.
- The water content of the glacial till generally ranged from 7.7 to 50.6%. Sandy Gravel till with some silt and a trace of clay showed maximum water content value. In general, the glacial till samples exhibited little to no plasticity with the plasticity index value ranging from 1 to 6.

- Laboratory analysis of the overburden till material indicated that the frozen bulk density ranged from 1271 to 1982 kg/m^3, dry density between 536 and 1405 kg/m^3, and specific gravity of soil solids varied from 2.64 to 2.69.
- Ground ice was generally encountered at a depth ranging from 0.15 to 1.00m below ground surface. Ground ice descriptions for the glacial till were generally non-visible, well bonded, no excess ice (Nbn) to excess ice (Nbe). In general, the thaw depth ranged from 0.9 to 3.1m. The ground ice content of permafrost soil and rock in the project area is expected to be between 0 and 10%.
- In general, shallow bedrock at the Kiggavik site consists of sandstone conglomerate, orthoquartzite, granite/granitic gneiss, metasediment/Meta- arkose, and intrusive units. The sandstone conglomerate is typically light brown, siliceously cemented, and fine to medium grained. The orthoquartzite is generally white to light grey, hard and very fine grained with traces of hematite. Depth to bedrock commonly ranged from 0.30 to 6.5m below ground surface. The upper part of the bedrock appears to be shattered by frost action and its bottom was found to be ranging from 3.35 to 9.45m below ground surface.
- The Rock Quality Designation (RQD) value was estimated for four shallow geotechnical holes drilled in 2009 and 2010 and ranged from 65 to 100% with an average value of 89% indicating the shallow bedrock as moderately jointed with good rock quality rating.
- Average fracture frequency and fracture spacing values in four shallow geotechnical boreholes drilled in 2009 and 2010 were calculated 3m^{-1} and 0.39m, respectively. Fracture (joint) analysis indicated that the average fracture spacing in the drill cores of these holes was generally estimated between 0.2 and 0.6m, which may be described as moderately wide in accordance with the Rock Mass Rating 1979 system. In general, joint surface shape was found undulating and planar with very rough to smooth joint surface roughness. Chlorite, hematite and clay were the most common joint infill types. Joint infill was characterized by slight alteration, staining and coating. Joint set number (Jn) usually ranged from 2 joint sets and random to three joint sets and random with the rating ranging from 6 to 12. Joint Roughness (Jr) value ranged from 1 to 3 indicating the joint character as planar-smooth to undulating-rough or irregular. Joint alteration was generally characterized by only coating (no mineral fillings) and thin mineral fillings. Rating of Joint Alteration Number (Ja) commonly ranged from 0.75 to 4.
- Typical field strength value of the shallow bedrock at the Main Zone and Centre Zone area ranged from strong (R3) to very strong (R5). The results of laboratory rock strength tests in the Main Zone and Centre Zone area indicated that the Uniaxial compressive strength (UCS) values of the shallow bedrock ranged from 66.9 to 128.0 MPa, which is generally consistent with the estimated field rock strength. In general, medium strong field rock strength (R3) was estimated in drillcores from the boreholes drilled in 2009 and 2010. However, it was observed that the rock strength increased with depth and ranged from medium strong (R3) to very strong (R5).
- The average density values of the shallow bedrock for meta-arkose (Main Zone), lamprophyre (Main Zone) and orthoquartzite (Centre Zone) were determined 2.69, 2.77 and 2.63 gm/cm^3, respectively.

- Overburden thickness in the vicinity of the proposed dock site area ranges from 2.9 to 8.8m, which comprises sand, sand gravel and glacial till strata. The glacial till is typically silty sand till with some fine to coarse gravel and some non-palstic clay. The water content of the glacial till generally ranged from 7 to 14%. An effective angle of shearing resistance for the combined samples of the sand varied from 36 to 40.8 degrees. The overburden was underlain by meta-sandstone and meta-arkose bedrock. No permafrost was encountered in the boreholes. The absence of permafrost is attributed to the thawing effect of the nearby lake. Glacial deposit is the most common and widespread surficial deposits in the proposed dock site area. Till veneer and till blanket appear to be major glacial depositional units in the area.
- The surficial landforms (deposits) along the Northern All Weather Access Road between the Sissons and Kiggavik mine/mill sites and the north shore of Baker Lake comprise mainly glacial till overlying precambrian intrusive igneous and metamorphic bedrock. In general, the grades are gentle, in the order of 1 to 3% with the exception of some sections that reach the rage of 5-6%. Morainal/till materials generally provide suitable geotechnical conditions on which a proposed road can be constructed. Alluvial and thick organic deposits comprise a small percentage of the materials that will be encountered along the proposed access road.
- The surficial materials in the project area are grouped into five major deposits: Glacial till, Glaciofluvial, Glaciolacustrine, Glaciomarine, and Organic deposits. The normal depositional processes associated with the various preglacial, glacial, marine, and the present day periglacial environments have resulted in the evolution of a variety of the following common landforms in the study area.
  - Alluvium or Outwash Sediments
  - Moraine
  - Glaciofluvial
  - Glacial
  - Marine
  - Organic
  - Bedrock

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8 Tables

Table 2.1-1: Summary of Geotechnical Field Program

Site Location	Type of drilling	No. of BH/TP/SL	Rig Type				Depth (m)		Samples			Instrumentation		Remarks
			Boart Longyear LF-70	B40	Boyles 25	Manual	Total	Range	AS	CRREL	Cored (m)	T	FDI	
Plantsite No.1	BH	8		X			36.22	1.02-16.16	15	4	16.73	1		
	BH	8			X		94.23	10.38-14.02	-	-	76.82		2	
Plantsite No.2	BH	2		X			3.05	1.20-1.85	6	1	-			
	BH	5			X		89.68	12.35-21.64	-	-	77.04	1	1	
Talings Dam- Cirque Lake/Ridge Lake	BH	3		X			17.13	1.25-10.38	9		7.61		2	B-40 Auger and core BH88-1T4
	BH	7			X		116.38	12.50-21.64	-	-	94.85	3		
Living Quarters	BH	1		X			8.32	1.20-7.12	1	1	2.33			B-40 Auger and Core BH88-1L3
	BH	2			X		21.79	9.29-12.50	-	-	19.66	1	1	
Pumphouse Sites 1 and 2	BH	2		X			7.75	2.45-5.30	5	2	-			
Mine Haul Road	BH	6		X			11.84	1.45-2.80	15	1	-			
Pointer Lake Airstrip	BH	6		X			20.63	1.78-4.90	19	8	-		2	
Skinny Lake Airstrip	BH	16		X			54.16	1.40-6.40	50	16	-	1	2	
Drumlin Airstrip	BH	9		X			21.68	1.22-6.20	32	12	-		2	
Jaeger Lake Airstrip	BH	1		X			2.25	2.25	3	-	-			
Skinny Lake Borrow	BH	11		X			45.18	1.20-7.20	33	1	-		1	
Skinny Lake Borrow	TP	3				X	3.10	0.80-1.20	6	-	-			AS- 6large bag samples from test pits
Squiggly Lake (East) Borrow	BH	3		X			11.30	2.80-4.70	10	-	-			
Other Borrow Sites-Sleek Lake/Rhyolite Lake	BH	3		X			12.20	3.80-4.10	12	-	-			
Talings Management-Main Zone	BH	4		X			3.70	1.40-2.30			-	2	1	
Tailing Management-Centre Zone	BH	2		X			1.85	1.85	14	4	-	1		
Waste Dump	BH	3		X			4.15	1.20-1.70			-			
Road and Mine Infrastructure	BH	4	X				161.50	29.50-57.00	-	1	145.60			
Andrew Lake Pit Dewatering Structure Area	SL	20				X								Lakebed sediments sampling
End Grid Underground Mine Area	TP	5				X								
Subtotals		**4**	**LF-70**				**161.50**		**0**	**1**	**145.60**			
		80		**B40**			**261.41**		**224**	**50**	**26.67**			
		22			**Boyles 25**		**322.08**		**0**	**0**	**268.37**			
		3				**Manual**	**3.10**		**6**	**0**	**0.00**			
Project Total		**109**				**Total**	**748.09**		**230**	**51**	**440.64**	**10**	**14**	

Note: Sampling locations in the area of Andrew Lake Pit Dewatering Strcuture area, test pits in the area of End Grid Underground Mine area and boreholes in the vicinity of the proposed dock sites are not included in the project total.

AS- Flight Auger Sample, CRREL- Core Barrel Sample, T- Thermistor, FDI- Frost Depth Indicator, SPT- Standard Penetration Test *BH- Borehole* SL- Sampling Location

Core length from top of bedrock to total depth of borehole *Boyles 25 total depth drilled includes overburden* *TP- Test Pit*

Table 2.2-1: Summary of Laboratory Program

Site Location	Visual Classfication	Water Content	Atterberg's Limit	Grain Size Analysis		Compaction Test	Density		Specific Gravity (SG)	Direct Shear	Soundness (MgSO4)	Organic Matter (%)	Remarks
				Sieve	Hydrometer		γ_{bf}	γ_d					
Plantsite No.1	4	10	5	6	6	1	3	3	2	-	1		
Plantsite No.2	1	3	2	2	2	-	1	1	1	-			
Talings Dam- Cirque Lake/Ridge Lake	-	4	3	4	4	-	-	-	-	-			
Living Quarters	1	1	1	1	1	-	-	-	-	-			
Pumphouse Sites 1 and 2	2	5	2	3	3	-	2	2	-	-			
Mine Haul Road	1	7	-	4	4	-	1	1	-	-			
Pointer Lake Airstrip	8	19	3	7	7	-	8	8	1	-			
Skinny Lake Airstrip	-	3	-	3	-	-	-	-	-	-			
Drumlin Airstrip	-	9	1	1	1	-	-	-	-	-			
Jaeger Lake Airstrip	-	-	-	-	-	-	-	-	-	-			
Skinny Lake Borrow	-	8	-	7	-	-	-	-	-	-	1		
Squiggly Lake (East) Borrow	-	9	-	7	-	-	-	-	-	-			
Other Borrow Sites-Sleek Lake/Rhyolite Lake	-	-	-	-	-	-	-	-	-	-			
Quarry Prospects	5	-	-	-	-	-	-	-	-	-			
Talings Management-Main Zone													
Tailing Management-Centre Zone	3	9	9	9	9	-	3	3	-	-			
Waste Dump													
Road and Mine Infrastructure	-	1	-		-	-	-	-	-	-			
Andrew Lake Pit Dewatering Structure Area		7	2	7	5							5	Split-Washed and Air-Jet Cup Dispersion method used
End Grid Underground Mine Area		4	2	4									Split-Washed and Stirring Dispersion method used
Project Total	**25**	**99**	**30**	**65**	**42**	**1**	**18**	**18**	**4**	**0**	**2**	**5**	

γ_{bf} - Frozen bulk density, γ_d - Dry density

Table 2.2-2: Summary of Laboratory Test Results of Overburden in the Selected Kiggavik Project Areas

Site	Borehole ID	Sample ID	Sample Depth (m)		Grain Size Distribution (%)									Plasticity			Soil Type (USCS)	Water Content (%)	Density		SG	Soluble Sulphate (%)	Direct Shear	Compaction Test		Remarks
			From	To	Gravel	Sand	Silt	Clay	D60	D30	D10	Cu	Cc	W_l	W_p	I_p			γ_{bf} (kg/m^3)	γ_d (kg/m3)				OMC (%)	MDD (kg/m3)	
Plantsite No.1	BH88-1P5	AS2	0.46	0.85	18	47	22	13	0.450	0.050	0.0013	346.2	4.3	19	14	5	SM-SC	8.8	-	-	-	-	-	-		Sand Till, some Silt, some Gravel, some Clay
	BH88-1P5	AS3 (CRREL)	0.85	1.20	21	44	23	12	0.550	0.035	0.0015	366.7	1.5	21	17	4	SM-SC	33.9	1882	1405	2.64	-	-	-		Sand Till, some Silt, some Gravel, some Clay
	BH88-1P6	AS1	0.00	1.12	13	45	30	12	0.250	0.023	0.0016	156.3	1.3			-	-	10.2	-	-	-	<0.10				Silty SAND Till, some Gravel, some Clay
	BH88-1P7	AS4	0.76	1.06	5	51	34	10	0.230	0.018	0.0020	115.0	0.7	21	18	3	SM	13.7								Silty SAND Till, some Clay, trace Gravel
	BH88-1P8	AS2	0.62	1.25												-										
	BH88-1P8	AS4	1.48	1.55												-										
	BH88-1P8	AS5	0.10	1.50	11	50	29	10	0.315	0.027	0.0020	157.5	1.2	Non Plastic			SM	7.7			2.68			7.1	2140.0	Silty SAND Till, some Gravel, some Clay
	BH88-1P9	AS2 (CRREL)	0.36	0.42												-		46.3	1982	1355						γbf-Organic
	BH88-1P9	AS3 (CRREL)	0.42	0.76												-		132.2	1271	536						γbf-Organic
	BH88-1P9	AS4	0.76	0.92	6	36	26	32	0.085	0.001	NA			54	31	23	OH	137.2								Oraganic Clayey, Silty Sand Till, trace fine Gravel
Plantsite No.2	BH88-2P2	AS1	0.52	0.90	13	45	29	13	0.300	0.020	0.0013	230.8	1.0	18	14	4	SM-SC	11.9								Silty SAND TILL, some Clay, some Gravel
	BH88-2P4	AS4 (CRREL)	1.70	1.85	15	35	34	16	0.160	0.007	0.0011	145.5	0.2	19	16	3	SM	50.6	1953	1297	2.69					Silty SAND TILL, some Clay, some Gravel
	BH88-2P4	AS2	0.50	1.65												-		20.7								
Mine Haul Road	BH88-1MHR1	AS3	0.92	1.50	17	45	26	12	0.420	0.026	0.0015	280.0	1.1			-	SM-SC	9.5				-	-	-		Silty SAND TIL, some Clay, some Gravel
	BH88-1MHR2	AS2	0.90	1.45												-		13.1								
	BH88-1MHR3	AS1	0.00	0.60												-		9.2								
	BH88-1MHR3	AS3 (CRREL)	1.35	1.46	32	38	22	8	1.300	0.075	0.0027	481.5	1.6			-	SM-SC	23.2	1324	1074						Gravelly SAND TILL, some Silt, trace Clay
	BH88-1MHR3	AS4	1.45	1.95												-		8.4								
	BH88-1MHR5	AS2	0.92	1.35	22	41	24	13	0.250	0.027	0.0010	250.0	2.9			-	SM-SC	10.5								SAND TILL, some Silt, some Gravel, some Clay
	BH88-1MHR6	AS3	1.25	2.80	25	41	22	12	0.630	0.040	0.0015	420.0	1.7			-	SM-SC	9.1								Gravelly SAND TILL, some Silt, some Clay
Main Zone Area	BH88-MZ1	AS3 (CRREL)	0.70	1.25	13	73	1	13	0.510	0.230	NA			Non plastic			SM	23.7	1920	1552						Sand TILL, some Gravel, some Clay, trace Silt
		AS4 (CRREL)	1.49	1.60	40	30	24	6	3.500	0.070	0.0043	814.0	0.3	Non plastic			GM	54.2	1640	1064						Sandy GRAVEL TILL, some Silt, trace clay
		AS5	1.67	2.30	21	48	22	9	0.850	0.069	0.0020	425.0	2.8	Non plastic			SM	9.0								Sand TILL, some Gravel, some Clay, trace Silt
	BH88-MZ2	AS2	0.51	1.25	17	32	40	11	0.160	0.015	0.0018	88.9	0.8	Non plastic			ML	10.5								Sandy SILT TILL, some Gravel, some Clay
Centre Zone Aea	BH88-CZ1	AS2	0.42	0.92	16	43	30	11	0.280	0.022	0.0017	164.7	1.0	Non plastic			SM	6.4								Silty SAND TILL, some Gravel, some Clay
		AS3 (CRREL)	0.92	1.14	30	39	21	10	1.250	0.063	0.0017	735.3	1.9	Non plastic			SM	22.8	2109	1717						Gravellly SAND TILL, some Silt, some Clay
		AS4	1.13	1.85	15	44	30	11	0.315	0.030	0.0017	185.3	1.7	Non plastic			SM	6.6								Silty SAND TILL, some Gravel, some Clay
Waste Dump	BH88-1WD1	AS2	0.53	1.29	17	45	25	13	0.600	0.022	<0.001			Non plastic			SM	7.7								Silty SAND TILL, some Gravel, some Clay
	BH88-1WD2	AS3	1.25	1.50	35	56	5	4	1.900	0.450	0.0800	23.8	1.3	Non plastic			SP	4.4								Gravelly SAND TILL, trace Silt, trace Clay
Mill Area	RMI-09-01	SL1492	0.13	0.37										24	18	6		18.2								

γ_{bf} - Frozen bulk density, γ_d - Dry density, SG- Specific Gravity of soil solids, UCS- Uniaxial Compressive Test, OMC- Optimum Moisture Content, MDD- Maximum Dry Density

Table 2.2-3: Summary of Laboratory Test Results of Overburden in the Kiggavik Project Area

Site	Borehole ID	Sample ID	Sample Depth (m)		Grain Size Distribution (%)									Plasticity			Soil Type (USCS)	Water Content (%)	Density		SG	Soluble Sulphate (%)	Direct Shear	Compaction Test		Organic Matter (%)	Remarks
			From	To	Gravel	Sand	Silt	Clay	D60	D30	D10	Cu	Cc	W_l	W_p	I_p			γ_{bf} (kg/m^3)	γ_d (kg/m3)				OMC (%)	MDD (kg/m3)		
Plantsite No.1	BH88-1P5	AS2	0.46	0.85	18	47	22	13	0.450	0.050	0.0013	346.2	4.3	19	14	5	SM-SC	8.8	-	-	-	-	-	-			Sand Till, some Silt, some Gravel, some Clay
	BH88-1P5	AS3 (CRREL)	0.85	1.20	21	44	23	12	0.550	0.035	0.0015	366.7	1.5	21	17	4	SM-SC	33.9	1882	1405	2.64	-	-	-			Sand Till, some Silt, some Gravel, some Clay
	BH88-1P6	AS1	0.00	1.12	13	45	30	12	0.250	0.023	0.0016	156.3	1.3			-	-	10.2	-	-	-	<0.10					Silty SAND Till, some Gravel, some Clay
	BH88-1P7	AS4	0.76	1.06	5	51	34	10	0.230	0.018	0.0020	115.0	0.7	21	18	3	SM	13.7									Silty SAND Till, some Clay, trace Gravel
	BH88-1P8	AS2	0.62	1.25												-											
		AS4	1.48	1.55												-											
		AS5	0.10	1.50	11	50	29	10	0.315	0.027	0.0020	157.5	1.2	Non Plastic			SM	7.7			2.68			7.1	2140.0		Silty SAND Till, some Gravel, some Clay
	BH88-1P9	AS2 (CRREL)	0.36	0.42												-		46.3	1982	1355							γbf-Organic
		AS3 (CRREL)	0.42	0.76												-		132.2	1271	536							γbf-Organic
		AS4	0.76	0.92	6	36	26	32	0.085	0.001	NA			54	31	23	OH	137.2									Oraganic Clayey, Silty Sand Till, trace fine Gravel
Plantsite No.2	BH88-2P2	AS1	0.52	0.90	13	45	29	13	0.300	0.020	0.0013	230.8	1.0	18	14	4	SM-SC	11.9									Silty SAND TILL, some Clay, some Gravel
	BH88-2P4	AS4 (CRREL)	1.70	1.85	15	35	34	16	0.160	0.007	0.0011	145.5	0.2	19	16	3	SM	50.6	1953	1297	2.69						Silty SAND TILL, some Clay, some Gravel
		AS2	0.50	1.65												-		20.7									
Ridge Lake Area	BH88-1T4	AS3	1.25	2.30	22	35	29	14	0.340	0.009	0.0010	340.0	0.2	20	17	3	SM	13.7				-	-	-			Silty SAND Till. Some clay, some gravel
	BH88-1T5	AS5	1.30	1.40	7	45	37	11	0.180	0.013	0.0018	100.0	0.5	23	19	4	SM-SC	8.7									Silty SAND TILL, some Clay, some Gravel/ Water Content questionable as sample was damged
	BH88-1T7	AS2	0.52	0.85	25	38	25	12	0.550	0.036	0.0010	550.0	2.4			-		6.2									Silty SAND TILL, some Clay, trace Gravel/ Water Content questionable as sample bad damged
		AS4	1.25	2.30	22	41	29	8	0.420	0.033	0.0024	175.0	1.1	19	16	3	SM	10.0									Silty SAND TILL, some Clay, trace Gravel
Living Quarters Area	BH88-1L3	AS2 (CRREL)	0.50	1.20	17	36	40	7						Non Plastic			SM	60.6	1469	915							Sandy SILT TILL, some Clay, trace Gravel
Pumphouse Sites 1	BH88-1PH1	AS1	0.00	0.50														18.6									
		AS2	0.50	1.20	60	36	1	3	10.500	1.900	0.5300	19.8	0.6	Non Plastic			GW	4.8									Sandy GRAVEL, trace Silt and Clay
		AS5 (CRREL)	4.85	5.00	25	68	1	5	1.700	0.600	0.2000	8.5	1.1	Non Plastic			SP-SM	18.6	2176	1835	2.67						Gravelly SAND TILL, trace Silt and Clay
Pumphouse Sites 2	BH88-2PH1	AS2 (CRREL)	0.80	1.20	23	44	28	5	0.270	0.059	0.0050	54.0	2.6	Non Plastic			SM	43.3	1629	1137							Silty SAND, some Gravel and trace Clay
Mine Haul Road	BH88-1MHR1	AS3	0.92	1.50	17	45	26	12	0.420	0.026	0.0015	280.0	1.1			-	SM-SC	9.5				-	-	-			Silty SAND TILL, some Clay, some Gravel
	BH88-1MHR2	AS2	0.90	1.45												-		13.1									
	BH88-1MHR3	AS1	0.00	0.60												-		9.2									
	BH88-1MHR3	AS3 (CRREL)	1.35	1.46	32	38	22	8	1.300	0.075	0.0027	481.5	1.6			-	SM-SC	23.2	1324	1074							Gravelly SAND TILL, some Silt, trace Clay
	BH88-1MHR3	AS4	1.45	1.95												-		8.4									
	BH88-1MHR5	AS2	0.92	1.35	22	41	24	13	0.250	0.027	0.0010	250.0	2.9			-	SM-SC	10.5									SAND TILL, some Silt, some Gravel, some Clay
	BH88-1MHR6	AS3	1.25	2.80	25	41	22	12	0.630	0.040	0.0015	420.0	1.7				SM-SC	9.1									Gravelly SAND TILL, some Silt, some Clay

Site	Borehole ID	Sample ID	Sample Depth (m)		Grain Size Distribution (%)									Plasticity			Soil Type (USCS)	Water Content (%)	Density		SG	Soluble Sulphate (%)	Direct Shear	Compaction Test		Organic Matter (%)	Remarks
			From	To	Gravel	Sand	Silt	Clay	D60	D30	D10	Cu	Cc	W_l	W_p	I_p			γ_{bf} (kg/m^3)	γ_d (kg/m3)				OMC (%)	MDD (kg/m3)		
Pointer Lake Airstrip	BH88-4A1	AS2/AS3	0.58	1.10	26	39	21	14	0.720	0.033	0.0010	720.0	1.5	22	17	5	SM-SC	13.5				-	-	-			Gravelly SAND TILL, some Silt, some Clay/ samples AS2 and AS3 were combined for the lab. test
		AS4	1.40	1.90	13	48	28	11	0.380	0.024	0.0015	253.3	1.0			-		12.5									Gravelly SAND TILL, some gravel, some Clay
		AS5 (CRREL)	1.95	2.09												-		14.8	2393	2085							Nbn
	BH88-4A2	AS2	0.66	1.08												-		9.1									
		AS3 (CRREL)	1.19	1.50												-		16.0	2468	2128							Nbn/water content 17.5% is indicated as a second test
		AS4	2.08	2.50												-		11.7									
	BH88-4A3	AS1	0.00	0.60	12	48	28	12	0.315	0.027	0.0012	262.5	1.9	24	18	6	SM-SC	13.7									Silty SAND TILL, some Gravel,some Clay
		AS3	1.06	1.40												-		12.4									
		AS4	1.55	1.95												-		27.4									
		AS5 (CRREL)	1.92	2.35	5	30	53	12	0.045	0.008	0.0015	30.0	0.9			-		78.9	1597	893	2.69						Sandy SILT TILL, some Clay, trace Gravel; Vs/Vc
		AS6 (CRREL)	2.51	3.05												-		36.7	2149	1572		-	-	-			Vs 2-5mm
		AS7	3.60	4.60												-		20.0				-	-	-			
	BH88-4A4	AS1	0.00	0.38												-		14.1									
		AS3	1.07	1.37												-		10.0									
	BH88-4A5	AS2	0.55	0.83	28	40	17	15	0.820	0.053	0.0010	820.0	3.4			-		26.0									Gravelly SAND TILL, some Silt, some Clay
		AS2 (CRREL)	0.83	1.20	32	34	15	19	1.500	0.017	0.0010	1500.0	0.2			-		20.8	2054	1701							Gravelly SAND TILL, some Silt, some Clay/Nbn/water content 20.7% is indicated as a second test
		AS4 (CRREL)	1.86	2.27												-		103.9	1707	837							Vs 1-3mm
	BH88-4A6	AS1	0.00	0.50	17	53	25	5	0.420	0.075	0.0050	84.0	2.7	Non plastic			SM	14.1									Silty SAND
		AS3 (CRREL)	1.23	1.46												-		21.5	2147	1767							Vx/Vc
		AS4 (CRREL)	2.25	2.60												-		44.3	1691	1172							Vs 1-5mm
Skinny Lake Airstrip	BH88-1A1	AS1	0.00	1.22	53	44	3	0	9.800	1.350	0.3150	31.1	0.6	Non plastic			GP	3.9									Sand and Gravel, trace Silt and Clay
	BH88-1A10	AS1	1.20	2.60	52	39	9	0	12.000	0.520	0.0970	123.7	0.2	Non plastic			GP-GM	5.3									Sandy GRAVEL. Trace Silt and Clay
	BH88-1A14	AS1	0.00	1.40	42	51	7	0	5.300	0.980	0.1600	33.1	1.1	Non plastic			GP-GM	5.2									Sand an Gravel, trace Silt and Clay
Drumlin Airstrip	BH88-2A1	AS1 (CRREL)	0.30	0.92												-		12.9									
		AS2 (CRREL)	0.92	1.70												-		16.5									
		AS3	1.70	2.45												-		11.3									
	BH88-2A5	AS2	0.45	0.92	19	51	21	9	0.700	0.075	0.0025	280.0	3.2	16	14	2	SM	6.7									SAND TILL, some Silt, some Gravel, trace Clay
		AS3	1.82	2.75												-		5.1									
		AS4	2.75	4.26												-		8.5									
	BH88-2A8	AS2 (CRREL)	0.50	1.00												-		9.2									
		AS5	1.60	1.80												-		43.5									
		AS6	1.80	2.70												-		6.9									

Site	Borehole ID	Sample ID	Sample Depth (m)		Grain Size Distribution (%)									Plasticity			Soil Type (USCS)	Water Content (%)	Density		SG	Soluble Sulphate (%)	Direct Shear	Compaction Test		Organic Matter (%)	Remarks
			From	To	Gravel	Sand	Silt	Clay	D60	D30	D10	Cu	Cc	W_l	W_p	I_p			γ_{bf} (kg/m^3)	γ_d (kg/m3)				OMC (%)	MDD (kg/m3)		
Jaeger Lake Airstrip	No lab test done																										
Skinny Lake Borrow	TP88-1B1	CS1/CS2	0.00	0.80	48	49	1	0	8.900	1.550	0.5800	15.3	0.5	Non plastic			GP/SP	0.0									Sand and Gravel, trace Silt/ combined sample 2% cobbles to 127mm dia./FM 1.5
	TP88-1B2	CS1/CS2	0.00	1.10	57	39	1	0	12.000	1.900	0.8000	15.0	0.4	Non plastic			GP	1.6				7.65 (ST)					Sandy GRAVEL, trace Silt/ combined sample 3% cobbles to 112mm dia./FM 4.3
	TP88-1B3	CS1/CS2	0.00	1.20	45	51	1	0	7.500	1.450	0.6400	11.7	0.4	Non plastic			SP	0.3									Sand and Gravel, trace Silt/ combined sample 3% cobbles to 112mm dia./FM 4.0/ water content taken as an average value of 0.2 and 0.4
	BH88-1B2	Bulk Samp	0.00	1.98	41	50	3	0	6.300	1.800	0.5800	10.9	0.9	Non plastic			SW	4.2									Sand and Gravel, trace Silt/ bulk sample 6% cobbles to 112mm dia./FM 4.0/ water content taken as an average value of 3.6 and 4.7
	BH88-1B4	AS2	1.50	2.50	32	56	12	0	2.100	0.730	0.0500	42.0	5.1	Non plastic			SP-SM	6.9									Gravelly SAND, some Silt/ No cobbles./FM 3.4/ water content taken as an average value of 6.9 and 6.8
	BH88-1B9	AS1	0.05	0.60	57	36	7	0	12.000	1.300	0.1500	80.0	0.9	Non plastic			GP	3.7									Sandy GRAVEL, trace Silt/No cobbles/FM 3.2/ water content taken as an average value of 3.5 and 3.9
Squiggly Lake (East) Borrow	BH88-8B1	AS1	0.00	1.10	56	42	2	0	17.000	1.700	0.5300	32.1	0.3	Non plastic			GP	3.8				-	-	-			Sand and Gravel, trace Silt/No cobbles/FM 3.8/ water content taken as an average value of 4.0 and
		AS2	1.10	2.40	19	76	5	0	1.800	0.730	0.2300	7.8	1.3	Non plastic			SW	8.1									Sand, some Gravel, some Silt/ No cobbles/FM 4.4
		AS3	3.00	4.20	7	76	17	0	0.730	0.290	NA						SM	12.5									Sand, some Silt and Clay (?), trace Gravel/ FM 2.3
	BH88-8B2	AS2	1.50	2.40	32	58	10	0	2.300	0.730	0.0900	25.6	2.6				SW-SM	5.9									Gravelly SAND, some Silt/ No cobbles./FM 3.4
		AS3	3.00	3.80	27	58	15	0	1.800	0.370	NA						SM	11.2									No cobbles./FM 2.8
	BH88-9B1	AS1	0.00	0.40	86	12	2	0	32.000	17.000	1.7000	18.8	5.3	Non plastic			GP	1.2				-	-	-			FM 3.8
		AS2	2.00	2.45	40	54	6	0	3.300	0.480	0.1400	23.6	0.5	Non plastic			SP-SM	2.8									No cobbles./FM 2.7
Quarry Prospects	No lab test done																										
Main Zone Area	BH88-MZ1	AS3 (CRREL)	0.70	1.25	13	73	1	13	0.510	0.230	NA			Non plastic			SM	23.7	1920	1552							Sand TILL, some Gravel, some Clay, trace Silt
		AS4 (CRREL)	1.49	1.60	40	30	24	6	3.500	0.070	0.0043	814.0	0.3	Non plastic			GM	54.2	1640	1064							Sandy GRAVEL TILL, some Silt, trace clay
		AS5	1.67	2.30	21	48	22	9	0.850	0.069	0.0020	425.0	2.8	Non plastic			SM	9.0									Sand TILL, some Gravel, some Clay, trace Silt
	BH88-MZ2	AS2	0.51	1.25	17	32	40	11	0.160	0.015	0.0018	88.9	0.8	Non plastic			ML	10.5									Sandy SILT TILL, some Gravel, some Clay
Centre Zone Area	BH88-CZ1	AS2	0.42	0.92	16	43	30	11	0.280	0.022	0.0017	164.7	1.0	Non plastic			SM	6.4									Silty SAND TILL, some Gravel, some Clay
		AS3 (CRREL)	0.92	1.14	30	39	21	10	1.250	0.063	0.0017	735.3	1.9	Non plastic			SM	22.8	2109	1717							Gravellly SAND TILL, some Silt, some Clay
		AS4	1.13	1.85	15	44	30	11	0.315	0.030	0.0017	185.3	1.7	Non plastic			SM	6.6									Silty SAND TILL, some Gravel, some Clay
Waste Dump Area	BH88-1WD1	AS2	0.53	1.29	17	45	25	13	0.600	0.022	<0.001			Non plastic			SM	7.7									Silty SAND TILL, some Gravel, some Clay
	BH88-1WD2	AS3	1.25	1.50	35	56	5	4	1.900	0.450	0.0800	23.8	1.3	Non plastic			SP	4.4									Gravelly SAND TILL, trace Silt, trace Clay
Mill Area	RMI-09-01	SL1492	0.13	0.37										24	18	6		18.2									

Site	Borehole ID	Sample ID	Sample Depth (m)		Grain Size Distribution (%)									Plasticity			Soil Type (USCS)	Water Content (%)	Density		SG	Soluble Sulphate (%)	Direct Shear	Compaction Test		Organic Matter (%)	Remarks
			From	To	Gravel	Sand	Silt	Clay	D60	D30	D10	Cu	Cc	W_l	W_p	I_p			γ_{bf} (kg/m^3)	γ_d (kg/m3)				OMC (%)	MDD (kg/m3)		
Andrew Lake Pit Dewatering Structure Area		SD1	0.00	0.00	0	91.5	8.5											19.9								0.6	Lakebed sediments
		SD2	0.00	0.00	0.2	90.5	9.3											20.7								0.6	Lakebed sediments
		SD3	0.00	0.00	2.2	91.5	6.3											23.6									Lakebed sediments
		SD4	0.00	0.00	0.8	89.5	10.2							Non plastic				26.3								2.3	Lakebed sediments
		SD5	0.00	0.00	0.7	91.9	7.4											24.1								1.1	Lakebed sediments
		SD11	0.00	0.00	0.9	90.1	9							Non plastic				29.6								1.9	Lakebed sediments
		SD12	0.00	0.00	0.2	78	21.8											44.8									
End Grid Lake Area	END-OB-09	1		0.30														22.5									
	END-OB-10	2	0.20	0.30										Non plastic				11									
	END-OB-11	3	0.20	0.30										16	15	1		15									
	END-OB-12	4	0.20	0.30														3.1									

γ_{bf} - Frozen bulk density, γ_d - Dry density, SG- Specific Gravity of soil solids, OMC- Optimum Moisture Content, MDD- Maximum Dry Density

FM- Fineness Modulus of saple fraction passing 10mm Sieve, ST- Magnesium Sulphate Soundness Test result for Natural Fine Aggregatres

Table 3.5-1: Coverage Area of the Common Depositional Landforms in the Local Assessment Area (LAA)

GLACIATION PERIOD	DEPOSITIONAL LANDFROMS	CODE	LAA COVERAGE AREA		
			Area of Landform (ha)		% of Total LAA*
Post-Last	Alluvial	AO	3786	3786	10.45%
Last	Glaciofluvial	Gk	40	200	0.55%
		Go	160		
Post-Last	Marine/Littoral	Mr	108	108	0.30%
Pre-quarternary	Bedrock	R1	758	1790	4.94%
		R2	1032		
Last	Glacial	Tb	22918	30356	83.76%
		Th	205		
		Tv	7233		
Total			**36240**	**36240**	**100.00%**

* The surface covered by water has not been included in the calculations of landform surface percentage coverage of the LAA

Table 3.6-1: Terrain Conditions along the Proposed Northern All Weather Road Alignment

Kilomtre		Description of Terrain Conditions
From	To	
100.0	106.5	The proposed North all-weather road alignment departs the Kiggavik site at an elevation of about 215m and travels along rolling till moraine terrain gradually climbing in elevation to a pronounced rock outcrop at KM 106.5, an elevation of 260 m. This is the location of the first of many proposed rock quarries along the route.
106.5	109.7	The alignment then descends at grades of 2 to 5 % for about 3 km to the south end (outflow) of Kavisilik Lake (about elevation 170 m). The terrain grades to the southeast towards Siamese Lake.
109.7		Between KM 109 and KM 110 the road traverses a topographic low along the south end of Kavisilik Lake, separating Kavisilik Lake from Siamese Lake. Open channel water crossing requiring a bridge structure is located at about KM 109.7.
110.0	111.0	111 At KM 110 the road climbs in elevation at grades of 3 to 5 % to a topographic high. An initial route along lower elevations near Siamese Lake was initially investigated, but was judges to be a more difficult alignment because it crossed very wet terrain with many drainage channels that originated from the higher ground. It was decided that a better route would traverse along the higher terrain that avoided the less favorable wet, sensitive ground with significant cross drainage concerns.
111.0	121.5	At km 111 the road travels along a topographic high ridge top for about 11 km, varying in elevation from 205 m to 230 m. The section of road from KM 116 to KM 121.5 is particularly smooth
121.5	125.0	From KM 121.5 to KM 122.5 the terrain becomes more irregular and then begins a long descent from KM 212.5 to KM 125.0 along grades of 2 to 6 % to an elevation of about 125 m at KM 25.0. The alignment crosses a quarry prospect at KM 122.6 km.
125.0	132.5	From KM 125 to KM 132.5 the route further decreases in elevation from about 125 m to about 90 m at KM 132.5, and crosses two significant stream crossings and several other drainage channels that will require culverts or other cross drainage measures.
127.4		Alignment crosses an open water channel requiring a bridge structure.
129.1		Alignment crosses an open water channel requiring a bridge structure
132.5	135.0	At 132.5 km, the route begins a 3 to 6 % climb from elevation 90 m to 180 m over a distance of about 2.5 km.
135.0	138.0	From km 135.0 to 136.5 km the route traverses a ridge top and then descends along the southeast side of the ridge at a grade of about 2% to km 38. The alignment passes by another quarry prospect at about KM 135

Kilomtre		Description of Terrain Conditions
From	To	
138.0	143.5	From KM 138 to KM 143.5 the route traverses relatively flat ground with cross slope from an area of topographic high to the lowlands at KM 143.5.
143.5	149.0	From KM 143.5 to 144.6 the route decreases in elevation and across a stream crossing at approx KM 145.1 at an elevation of about 100 m, and then climbs away from the topographic low to about an elevation of 130 m at KM 164 and continues along rolling terrain to about KM 149.
145.1		Stream crossing will require a bridge structure.
147.5		Stream crossing will require a bridge structure.
149.0	157.2	The route decreases along relatively smooth terrain for 1 km and then travels along level to gradually rolling terrain weaving around several lakes to the next major crossing at KM 157.2. At 156.2 the route travels by another quarry.
157.2		Bridge Crossing
157.2	170.0	The route continues along relatively favorable, rolling terrain to the Thelon River (KM 174) varying in elevation from 90 m to 110 m. At 160.5 and 163.5 the quotes passes by two quarry prospects. 170.5 km another site
170.0	174.4	At KM 170.0, the route begins a general decent towards the Thelon River.
174.4	174.8	The Thelon River is the most significant crossing along route with a channel width of about 400 m
174.8	177.0	After crossing the Thelon River, the route ascends gradual slopes to irregular rolling terrain. The route connects to a network of existing ATV trails that follow dry ridge tops and more favorable terrain from the Thelon River towards Baker Lake. The proposed all-weather road follows the general direction of the ATV trails but along favorable horizontal and vertical lines. The Thelon River is the most significant crossing along route with a channel width of about 400 m.
177.0	182.5	From KM 177 to KM 182.5 the elevations typically vary from an elevation of 90 m to 110 m. Quarry prospects are located at about KM 177.8, KM 182.5.
182.5	185.0	The route passes by two lakes and topographic low areas that are wet.

Kilomtre		Description of Terrain Conditions
From	To	
185.0	192.0	The route increases in elevation onto more favorable, dry, stable terrain. The route follows the topography of the terrain through this section of the road. From km 85 to km 92.0 the route follows relatively dry stable terrain with few lakes. The route crosses low-lying sections from 187.4 to 187.9, and cross drainage depressions at 189.6, 190.4 and 191.4 km. Quarry prospects are located at about KM 186.3 m and near KM 191.6
192.0	195.0	At km 192.0, the route begins descending to a dispersed drainage crossing at km 193 and continues along low-lying terrain to another stream crossing at km 195.
193.0		Bridge Crossing
195.0		Bridge Crossing
195.0	200.5	Beyond about km 95, the frequency of water bodies increases and the route is forced to navigate around these bodies of water. The elevation of the terrain from KM 195 to KM 200.5 the terrain varies in elevation from 70 to 90 m. Quarry 99.2.
197.3		Bridge Crossing
200.5		The route climbs in elevation and begins decreasing in elevation over a distance of 1 km before coming to a section of wet terrain from KM202.5 to KM 203.5 and between KM 207 and KM 208 the route crosses a lowland section that connects a series of lakes that is wet with no defined flow. The route continues along progressively decreasing terrain to a proposed port site at about KM 213.5 and passes by a rock quarry site at KM 211.3, as shown on the alignment sheets.

Table 3.6-2: Coverage Area of the Common Depositional Landforms in the Northern All Weather Access Road (NAWAR) Local Assessment Area (LAA)

PERIOD	DEPOSITIONAL LANDFORMS	CODE	NAWAR LAA COVERAGE AREA		
			(ha)		(%)
Quarternary	Alluvial	Ao	264	264	3.63%
	Marine	Mr	154	154	2.12%
	Glaciofluvial	Go	55	55	0.76%
	Glacial	Tb	2899	4586	63.18%
		Tv	1687		
Pre-Quarternary	Bedrock	R1	2099	2199	30.30%
		R2	101		
Total			**7258**	**7258**	**100.00%**

Table 4.1-1: Summary of the overburden and shallow bedrock conditions in the Kiggavik Project area

Site	Borehole ID	Till (m)				Bedrock		Remarks
		From	To	Thickness	Type	Depth to (m)	Type	
Plantsite No.1	BH88-1P1	0.00	0.89	0.89	Gravelly	0.89	Sandstone Conglomerate	
	BH88-1P2	0.00	1.83	1.83	Gravelly	1.83		
	BH88-1P3	0.00	0.71	0.71	Sandy gravelly	0.71		
	BH88-1P4	0.00	1.22	1.22	Glacial?	1.22		
	BH88-1P5	0.10	2.28	2.18	Sand	2.28		
	BH88-1P6	0.00	4.11	4.11	Silty sand	4.11		
	BH88-1P7	0.15	1.78	1.63	Silty sand	1.78		
	BH88-1P8	0.10	1.55	1.45	Silty sand	?		Auger refusal on cobbles and bouders
	BH88-1P9	0.15	1.25	1.10	sand	?		Auger refusal on cobbles and bouders
	BH88-1P10	0.00	2.32	2.32	sand	2.32	Orthoquartzite	
	BH88-1P11	0.00	4.60	4.60	Silty sand	4.60		
	BH88-1P12	0.00	3.50	3.50	Gravelly sand	3.50	Sandstone Pebble Conglomerate	
	BH88-1P13	0.00	1.98	1.98	Gravelly sand	1.98		
Plantsite No.2	BH88-2P1	0.00	1.22	1.22	Silty sand	1.22	Orthoquartzite	
	BH88-2P2	0.10	1.90	1.80	Silty sand	1.90		
	BH88-2P3	0.00	0.30	0.30	Silty sand	0.30		
	BH88-2P4	0.30	5.64	5.34	Silty sand	5.64		
	BH88-2P5	0.00	3.58	3.58	Gravelly sand	3.58		
Ridge Lake Area	BH88-1T6	0.00	8.00	8.00	Gravelly sand	8.00	Sandstone Conglomerate	
Mine Haul Road	BH88-1MHR1	0.10	1.52	1.42	Silty sand	?		Auger refusal on cobbles and bouders
	BH88-1MHR2	0.00	1.45	1.45	Silty sand	?		Auger refusal on cobbles and bouders
	BH88-1MHR3	0.10	1.95	1.85	Gravelly sand	?		Auger refusal on cobbles and bouders
	BH88-1MHR4	0.10	1.52	1.42	Silty sand	?		Auger refusal on cobbles and bouders
	BH88-1MHR5	0.10	2.60	2.50	Sand	?		Auger refusal on cobbles and bouders
	BH88-1MHR6	0.10	2.80	2.70	Silty sand	?		Auger refusal on cobbles and bouders

Site	Borehole ID	Till (m)				Bedrock		Remarks
		From	To	Thickness	Type	Depth to (m)	Type	
Main Zone Area	BH88-MZ1	0.10	2.30	2.20	Sand	?		Auger refusal on cobbles and bouders
	BH88-MZ2	0.10	1.40	1.30	Sandy silt	?		Auger refusal on cobbles and bouders
Centre Zone Area	BH88-CZ1	0.10	1.85	1.75	Silty sand	?		Auger refusal on cobbles and bouders
Waste Dump Area	BH88-1WD1	0.10	1.25	1.15	Silty sand	?		Auger refusal on cobbles and bouders
	BH88-1WD2	0.10	1.70	1.60	Gravelly sand	?		Auger refusal on cobbles and bouders
	BH88-2WD1	0.10	1.20	1.10	Gravelly	?		Auger refusal on cobbles and bouders
Mill Area	RMI-09-01	0.10	2.60	2.50	NA	2.60	Granite/metasediment	
	RMI-09-02	0.12	4.10	3.98	NA	4.10	Granite	
	RMI-10-01	NA	2.70	NA	NA	2.70	Granitic gneiss	
	RMI-10-02	NA	6.50	NA	NA	6.50	Granite	

Table 4.2-1: Summary of the laboratory rock strength test for Main Zone and Centre Zone Areas

Site	Borehole ID	Sample No.	Sample Depth (m)			UCS (MPa)	Young's Modulus (MPa)	Poissons Ratio	Brazillian Tensile Strength (MPa)	Density (gm/cm3)	Sample Description and Remarks
			From	To	Length						
Main Zone Area	88-331	1	21.79	22.19	0.40	128.0	7.53E+04	0.24	28.00	2.67	Silicified foliated meta-arkose
		2	50.60	50.93	0.34	-	-	-	-	-	Foliated Meta-arkose
		3	66.60	66.87	0.27	117.0	-	-	-	2.77	Lamprophyre
	88-332	1	17.37	17.59	0.21	-	-	-	33.10	-	Mafic meta-arkos
		2	38.01	38.22	0.21	66.9	-	-	-	2.71	Mafic meta-arkos
Centre Zone Area	88-333	1	43.68	44.01	0.34	120.0	-	-	-	2.63	Orthoquartzite

UCS- Unified Compressive Strength

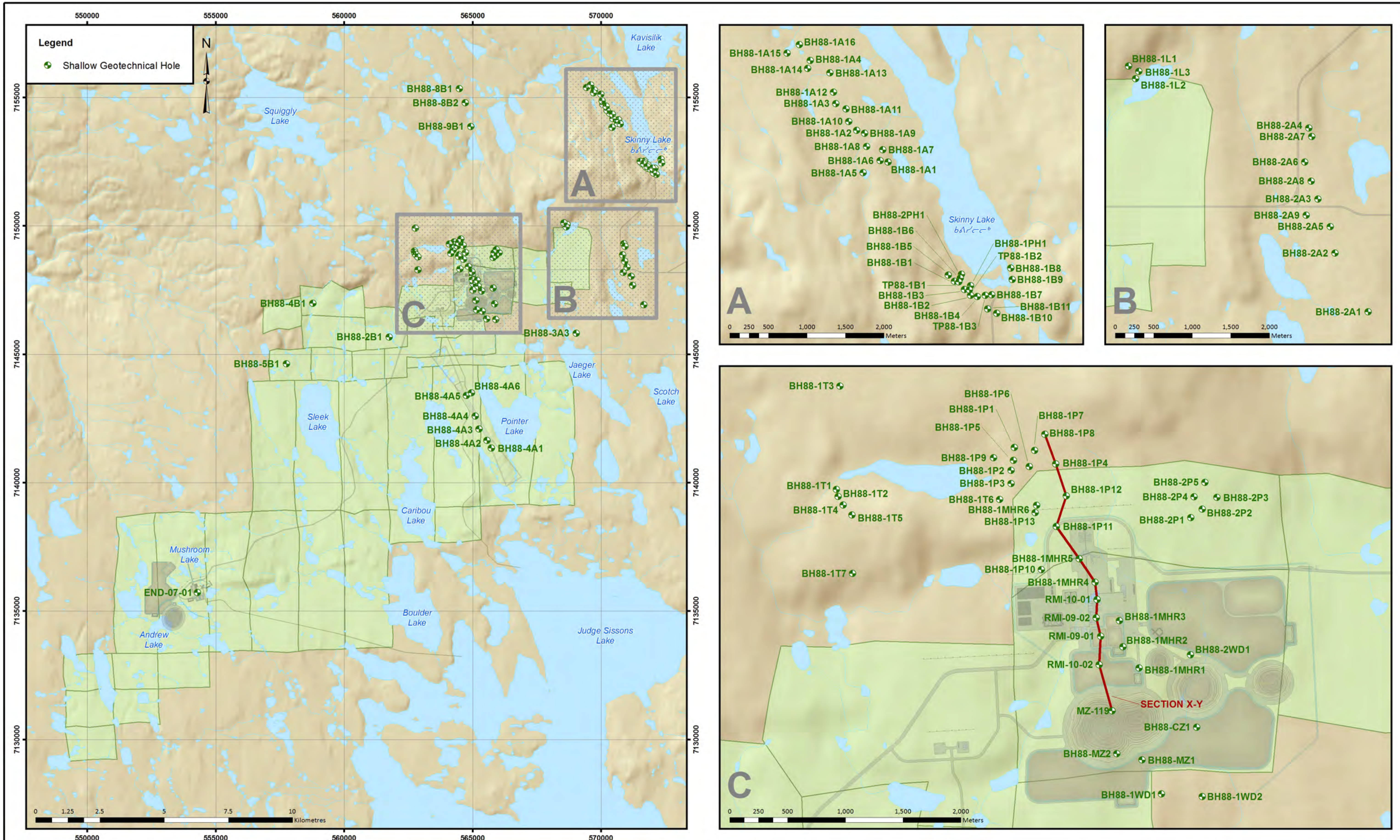
Table 5.1-1: Summary of Thermal Condition Monitoring Data in the Kiggavik Area

Site Location	Borehole ID	Depth Along Hole (m)	Instrumentation		Max. Recorded Thaw Depth (m)		Depth to Shattered Rock (m)	Remarks
			T	FDI	T	FDI		
Plantsite Area No.1	BH88-1P1	15.00	1		2.7		0.89	
	BH88-1P3			1		2.64	0.71	
	BH88-1P5			1		0.88	>2.1	
Plantsite Area No.2	BH88-2P2	10.00	1		1.1		1.90	
	BH88-2P3			1		2.82	0.30	
Ridge Lake Area	BH88-1T1	12.00	1		2.3		1.09	
	BH88-1T3	20.00	1		6.3		3.35	Thaw depth affected by adjacent water bodies
	BH88-1T4			1		2.13	2.77	Thaw depth affected by adjacent water bodies
	BH88-1T5	15.00	1		1.4		>1.25	
	BH88-1T7			1		1.76	>3.20	
Living Quarters Area	BH88-1L1	12.00	1		1.7		1.68	
	BH88-1L2			1		3.10	0.45	
Pointer Lake Area	BH88-4A1			1		1.20	>4.50	
	BH88-4A5			1		1.33	>3.90	
Skinny Lake Area	BH88-1A5			1		1.48	>3.20	
	BH88-1A10	6.00	1		1.4		>6.40	
	BH88-1A14			1		1.59	>3.65	
Drumlin Area	BH88-2A7			1		1.21		
	BH88-2A8			1		1.00		
Skinny Lake Arera	BH88-1B4			1		1.92		
Main Zone Area	88-331	199.02	1					
	88-332	169.06	1					
	BH88-MZ1	168.57		1		1.01	>2.30	
Centre Zone Area	88-333		1					
Project Total			10	14				

T- Thermistor, FDI- Frost Depth Indicator

"Maximum" thaw depths are those recorded on August 31, 1988

9 Figures



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Date: 09/01/2011
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Data Sources: *Natural Resources Canada, Geobase®, Nation Topographic Database, AREVA Resources Canada Inc.*

FIGURE 1.1-1
LOCATION MAP OF SHALLOW GEOTECHNICAL BOREHOLES

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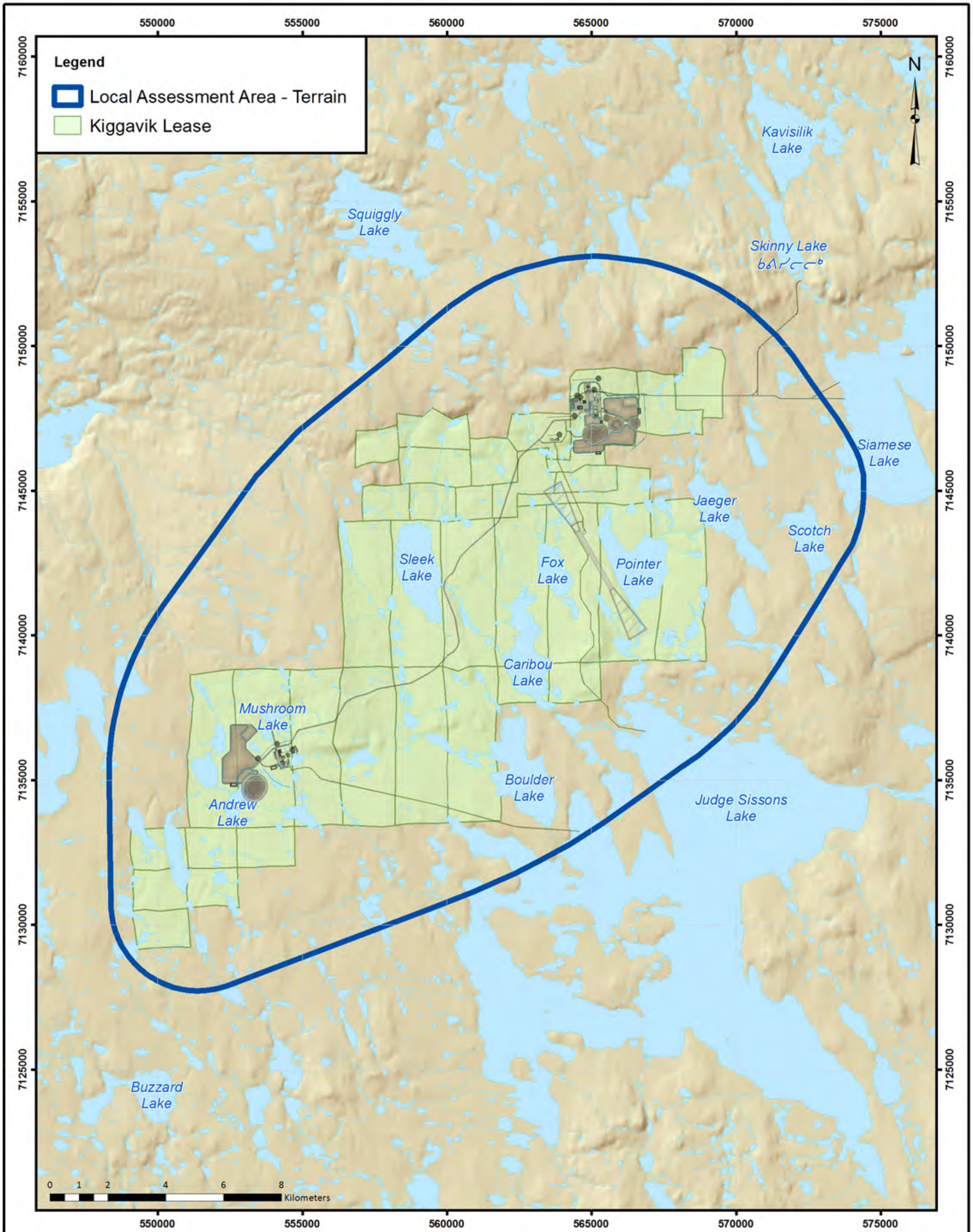

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FIGURE 1.3-1
KIGGAVIK LOCAL ASSESSMENT AREA

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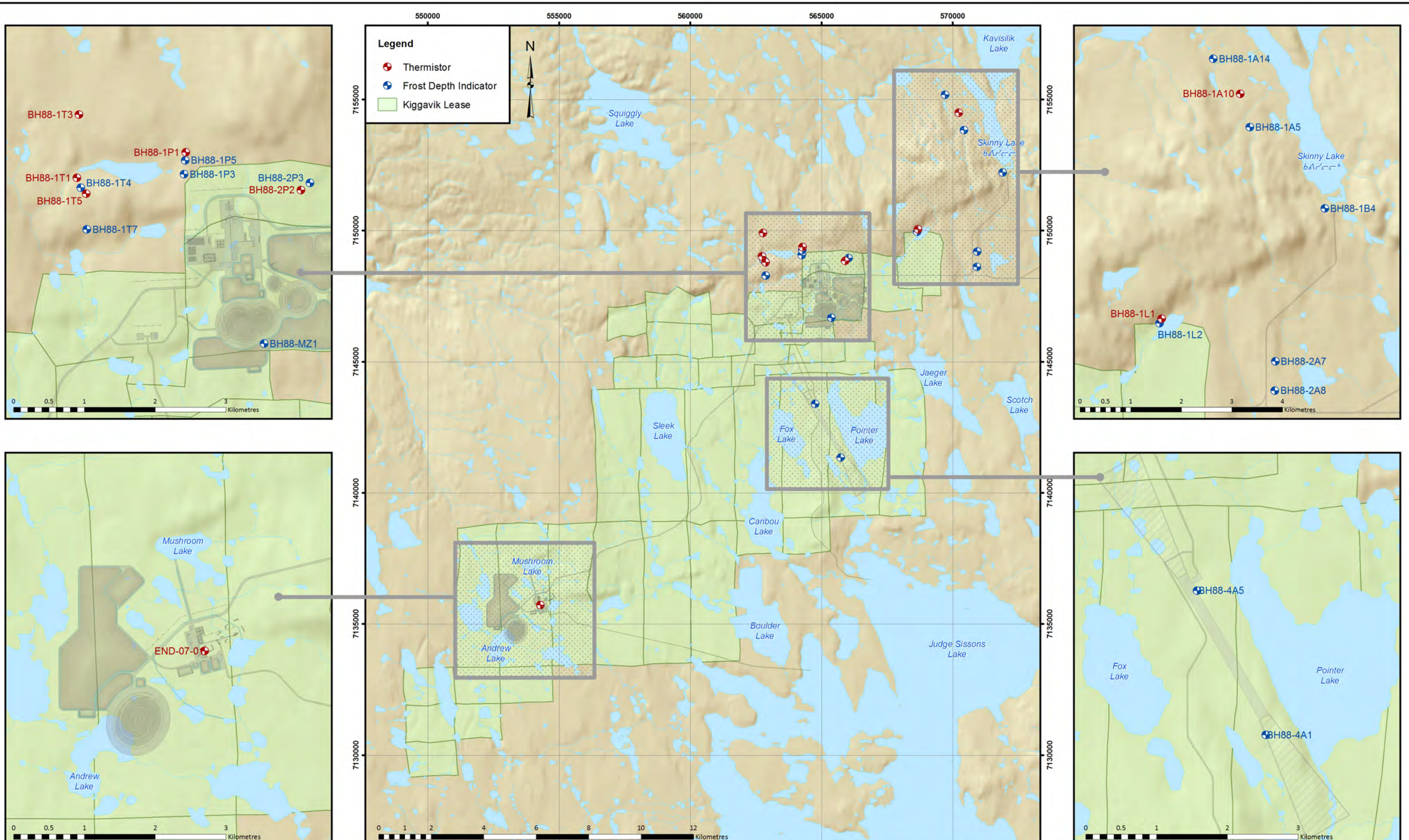

Projection: NAD 1983 UTM Zone 14N
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Date: 09/01/2011
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Data Sources: *Natural Resources Canada, Geobase®, Nation Topographic Database, AREVA Resources Canada Inc.*

FIGURE 2.1-1
LOCATION MAP OF THERMISTORS AND FROST DEPTH INDICATORS

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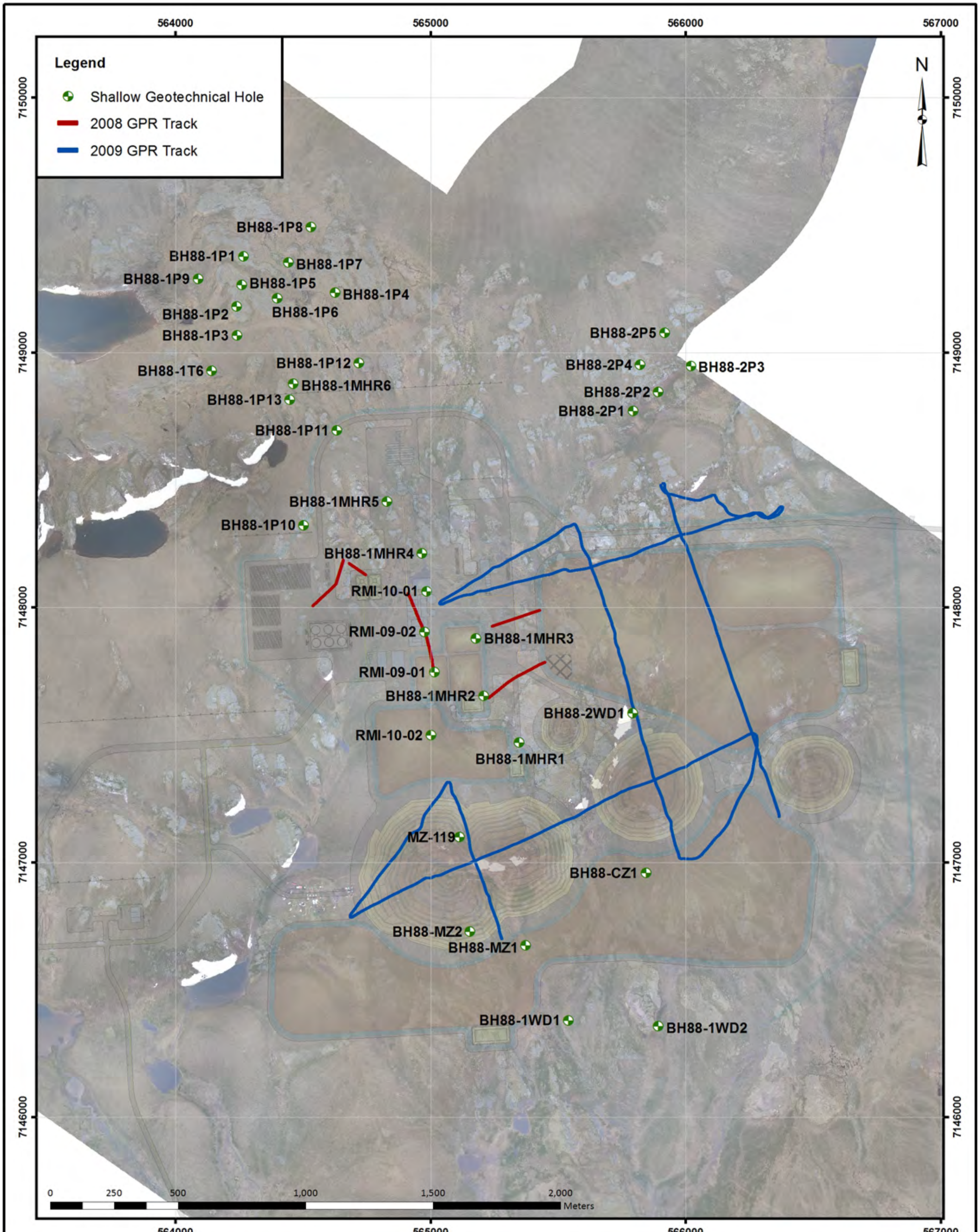

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Data Sources: *Natural Resources Canada, Geobase®, Nation Topographic Database, AREVA Resources Canada Inc.*

FIGURE 2.1-2
KIGGAVIK AREA GPR COVERAGE AND LOCATIONS OF SHALLOW GEOTECHNICAL BOREHOLES

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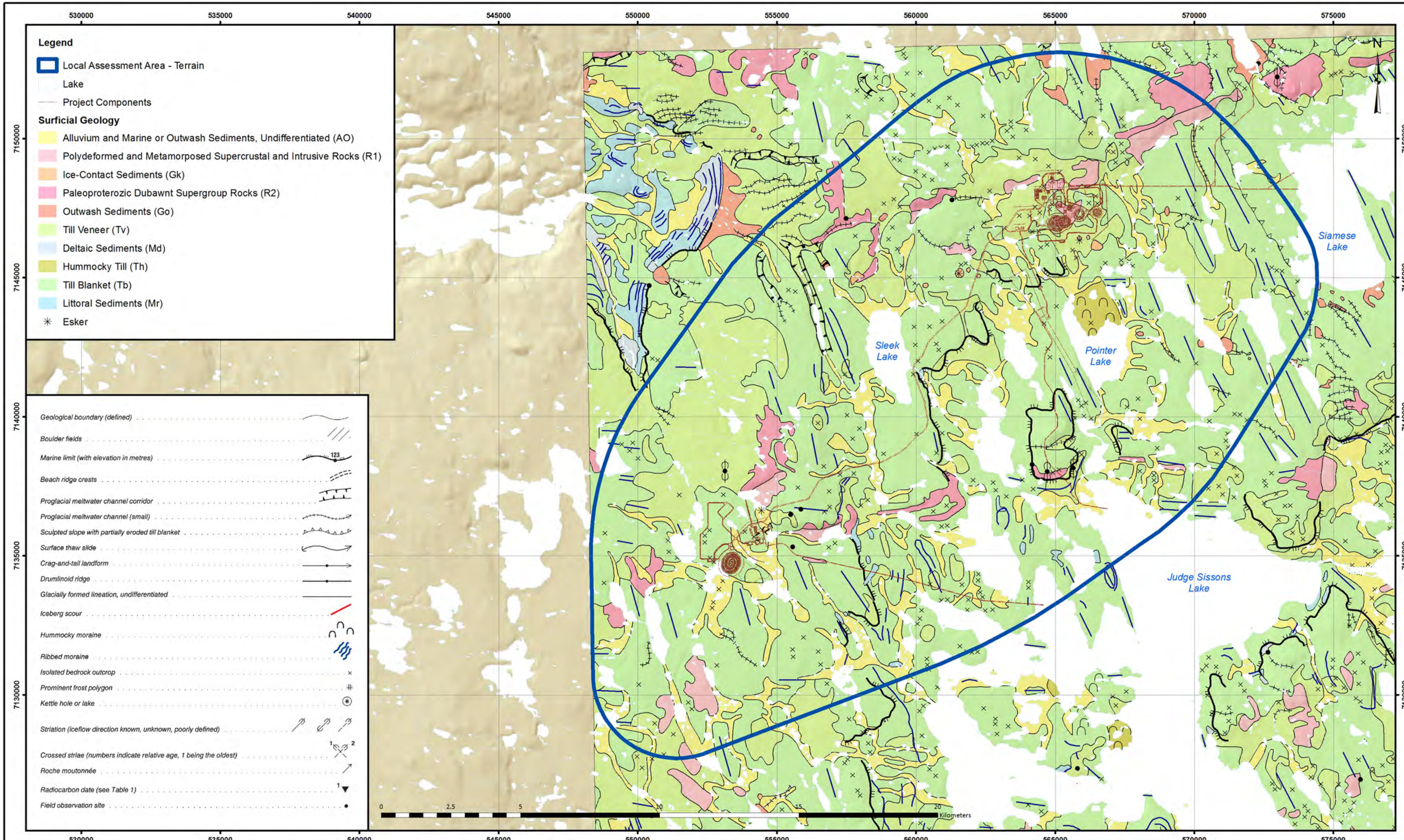

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Data Sources: *Natural Resources Canada, Geobase®, Nation Topographic Database, AREVA Resources Canada Inc, Geological Survey of Canada Map 2120A*

FIGURE 3.1-1
SURFICIAL GEOLOGY IN THE KIGGAVIK LOCAL ASSESSMENT AREA

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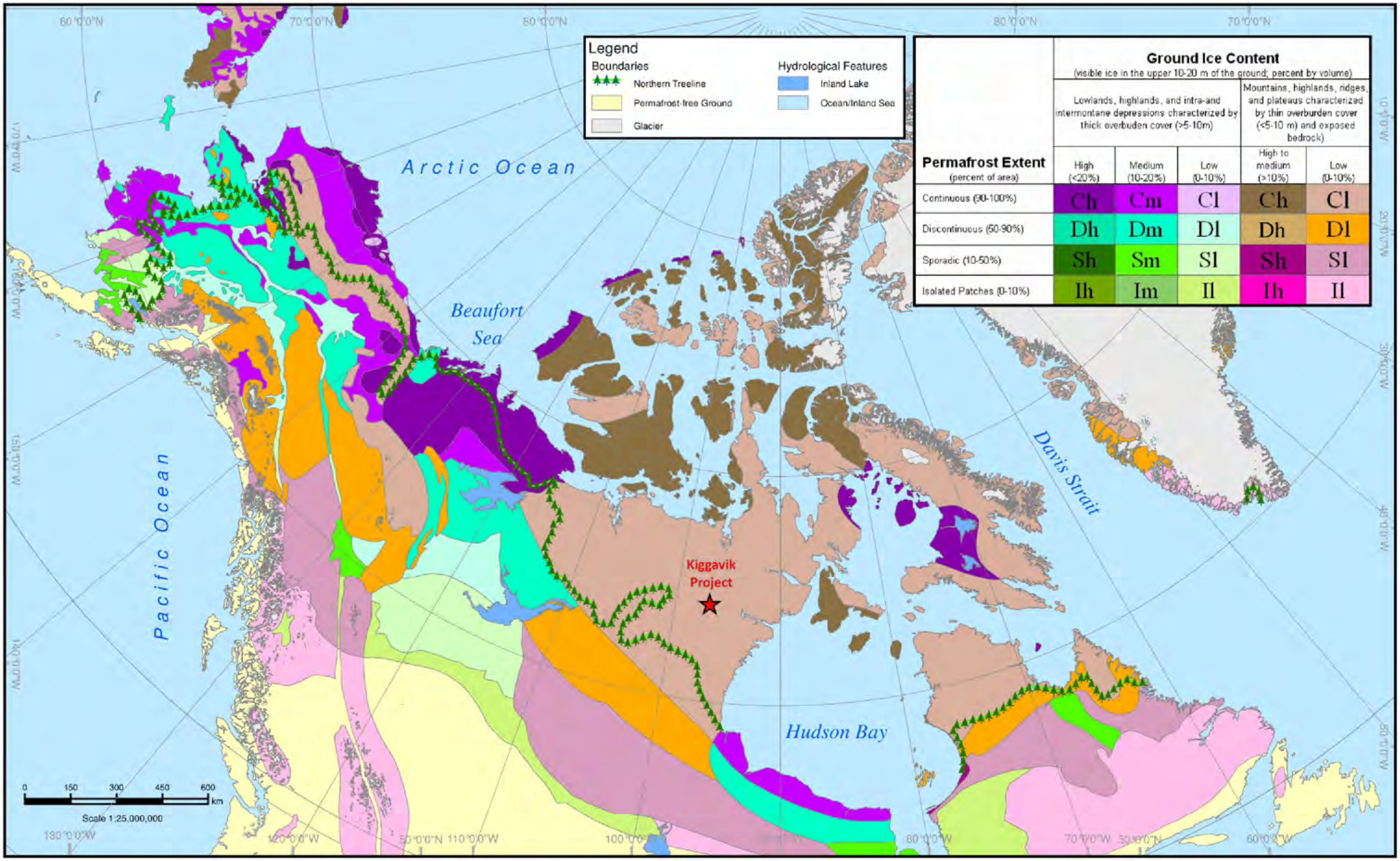

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FIGURE 3.1-2
PERMAFROST AND GROUND-ICE CONDITIONS MAP OF CANADA

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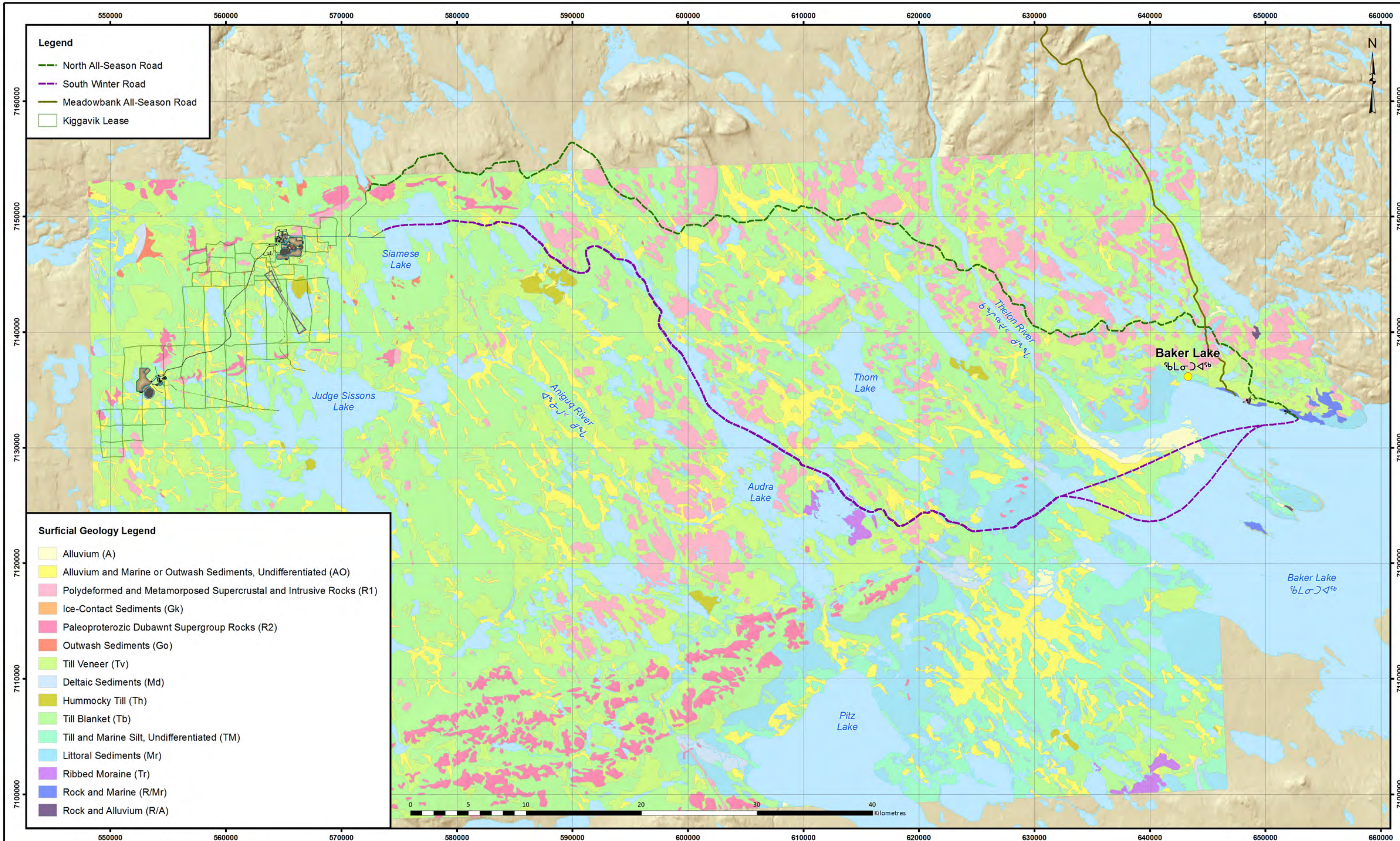

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FIGURE 3.1-3
PROPOSED ROAD ALIGNMENTS IN THE KIGGAVIK PROJECT AREA

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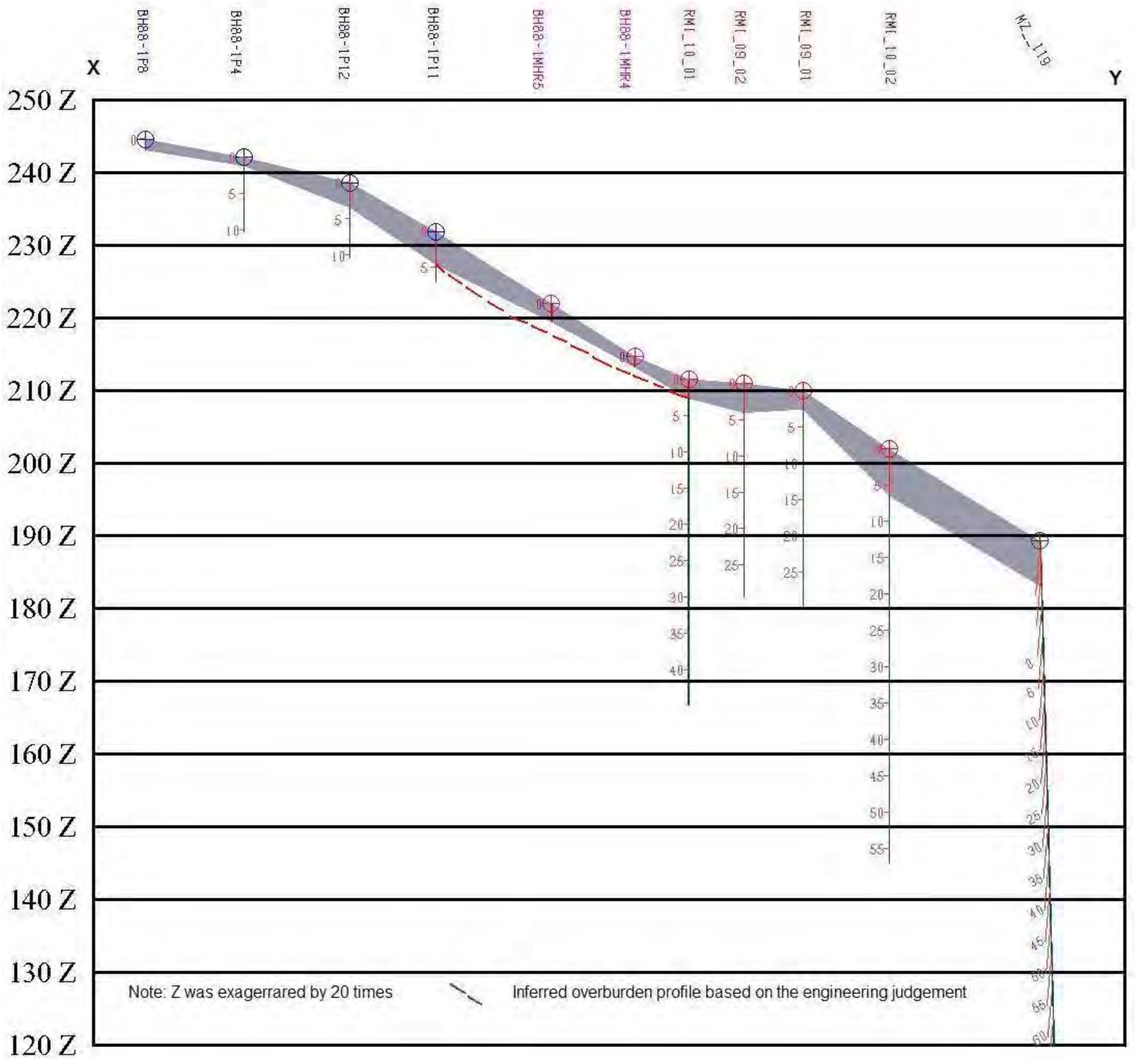


Figure 4.1-1
Overburden profile along X-Y in the Kiggavik Project area

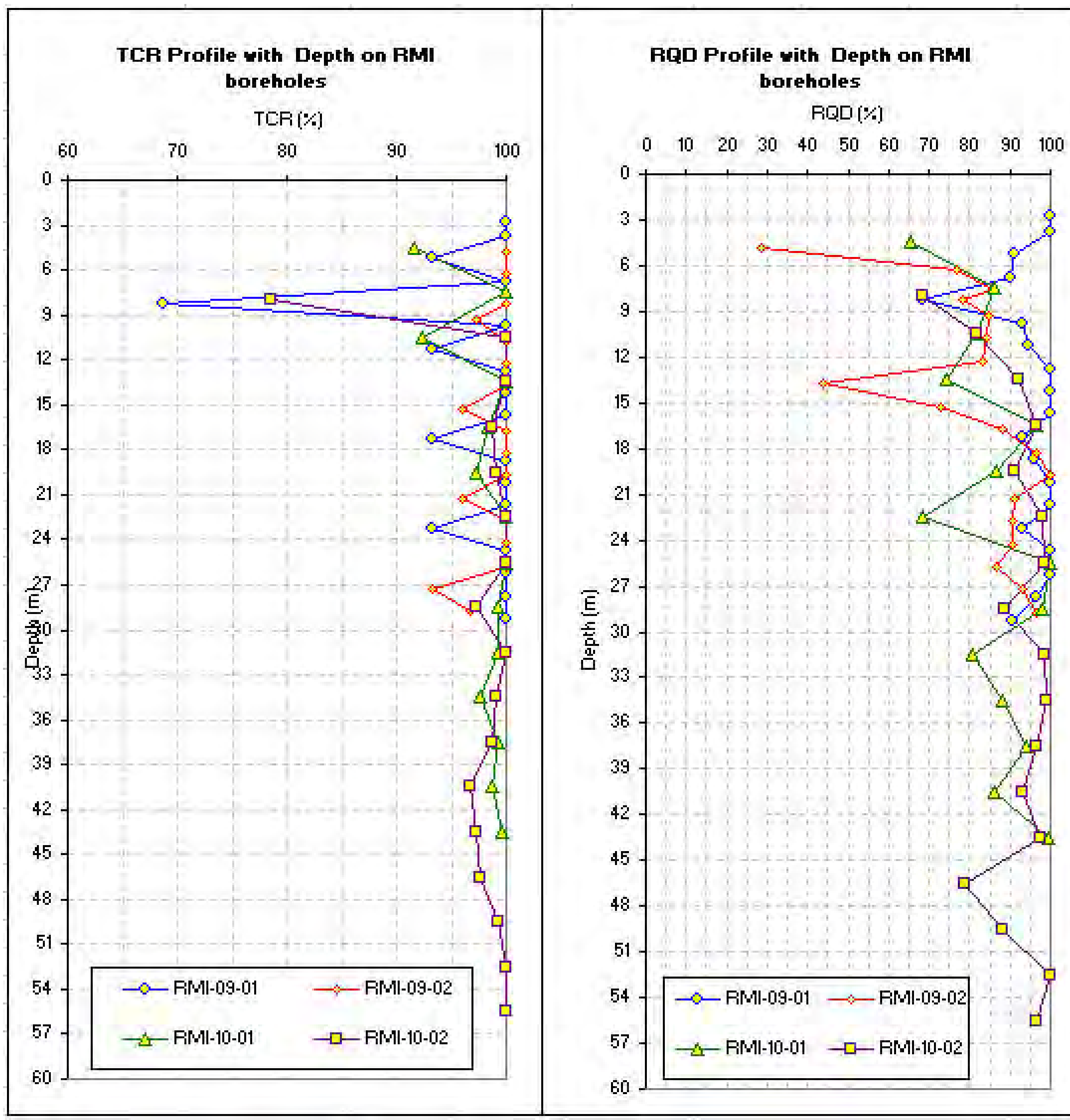


Figure 4.1-2
TCR and RQD profiles with depth - 2009 and 2010 boreholes

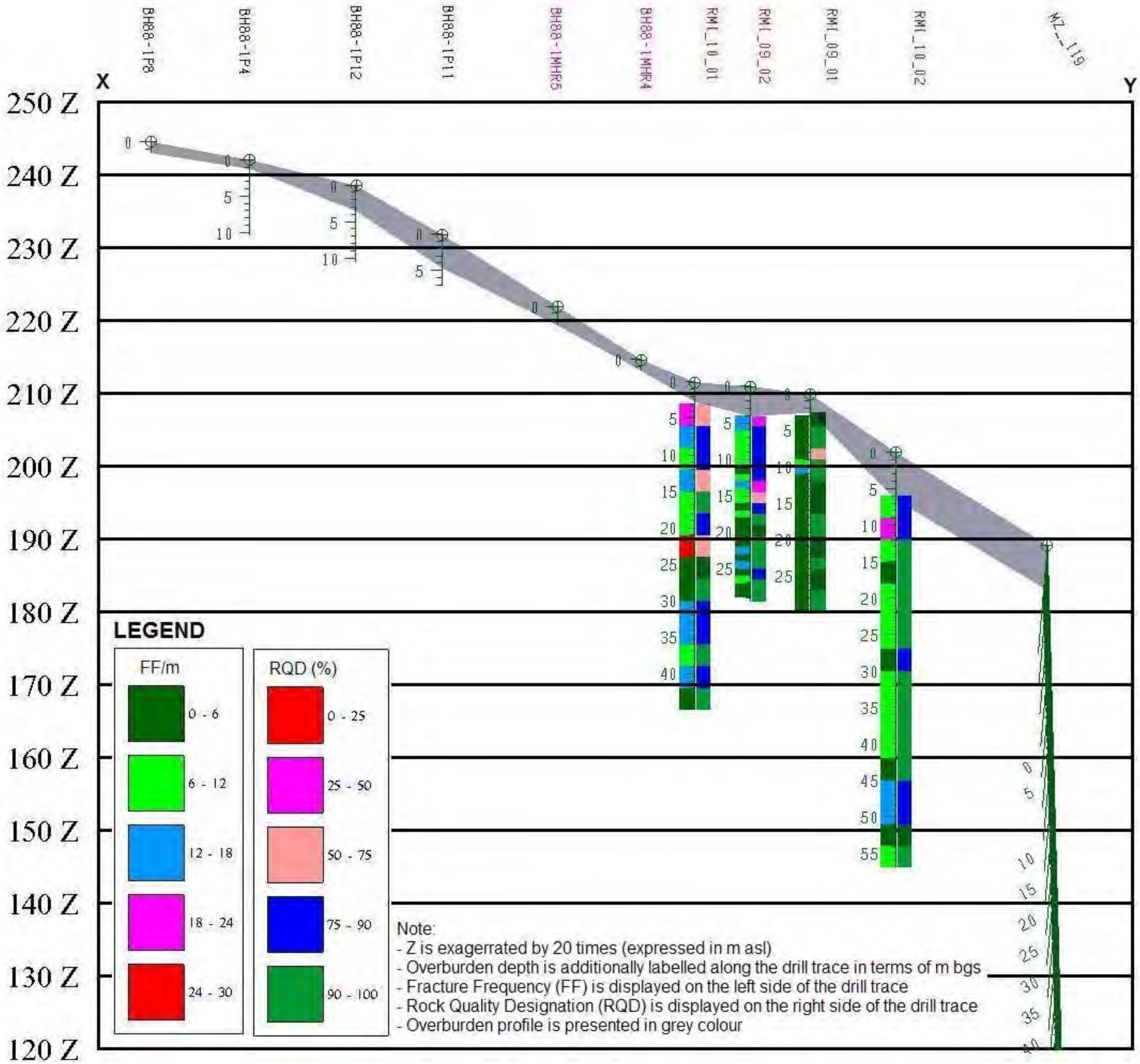
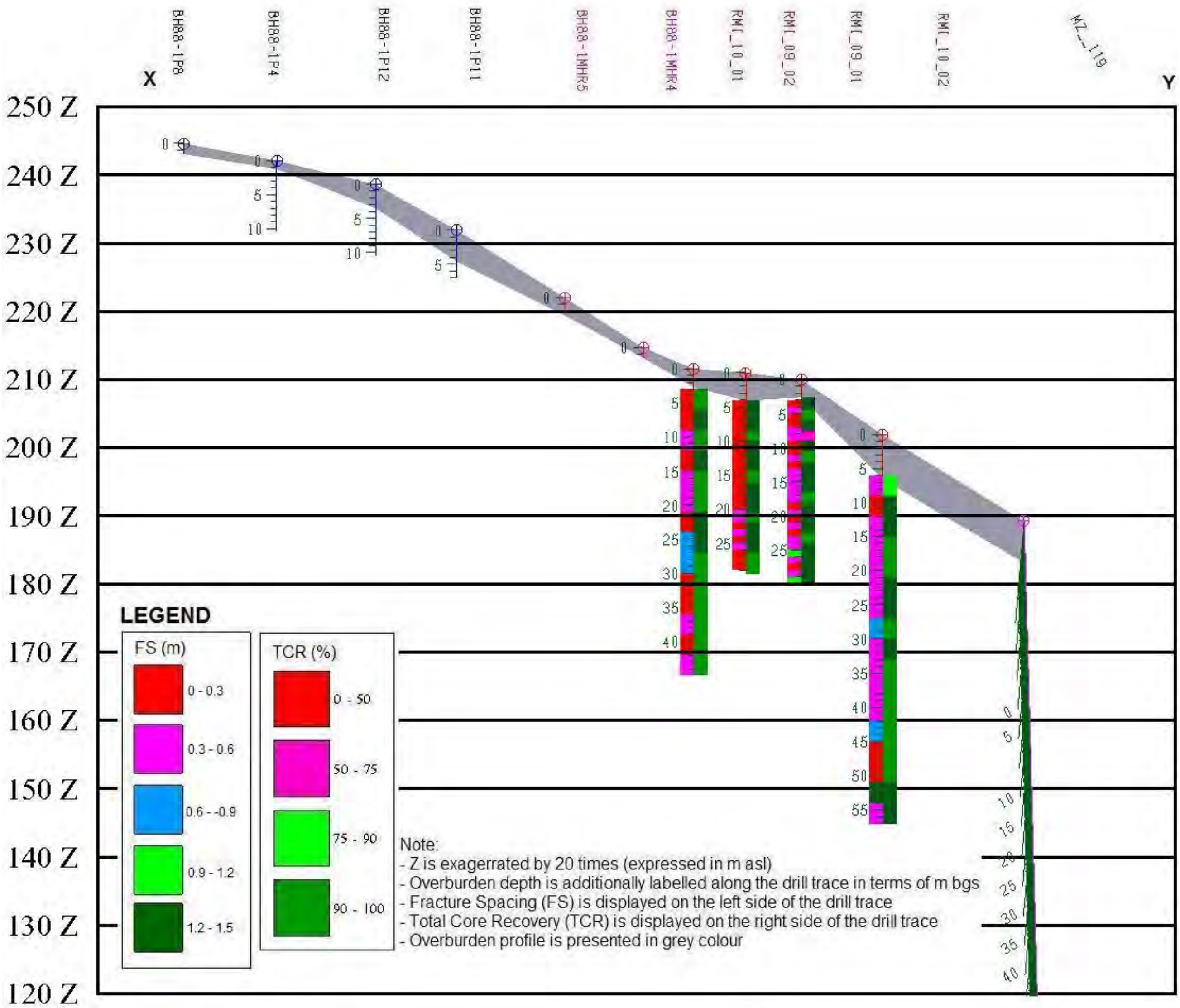


Figure 4.1-3
FF and RQD with depth - 2009 and 2010 boreholes



Technical Appendix 6A
Surficial Geology and Terrain
Date 15/09/2011

Figure 4.1-4
FS and TCR with depth - 2009 and 2010 boreholes

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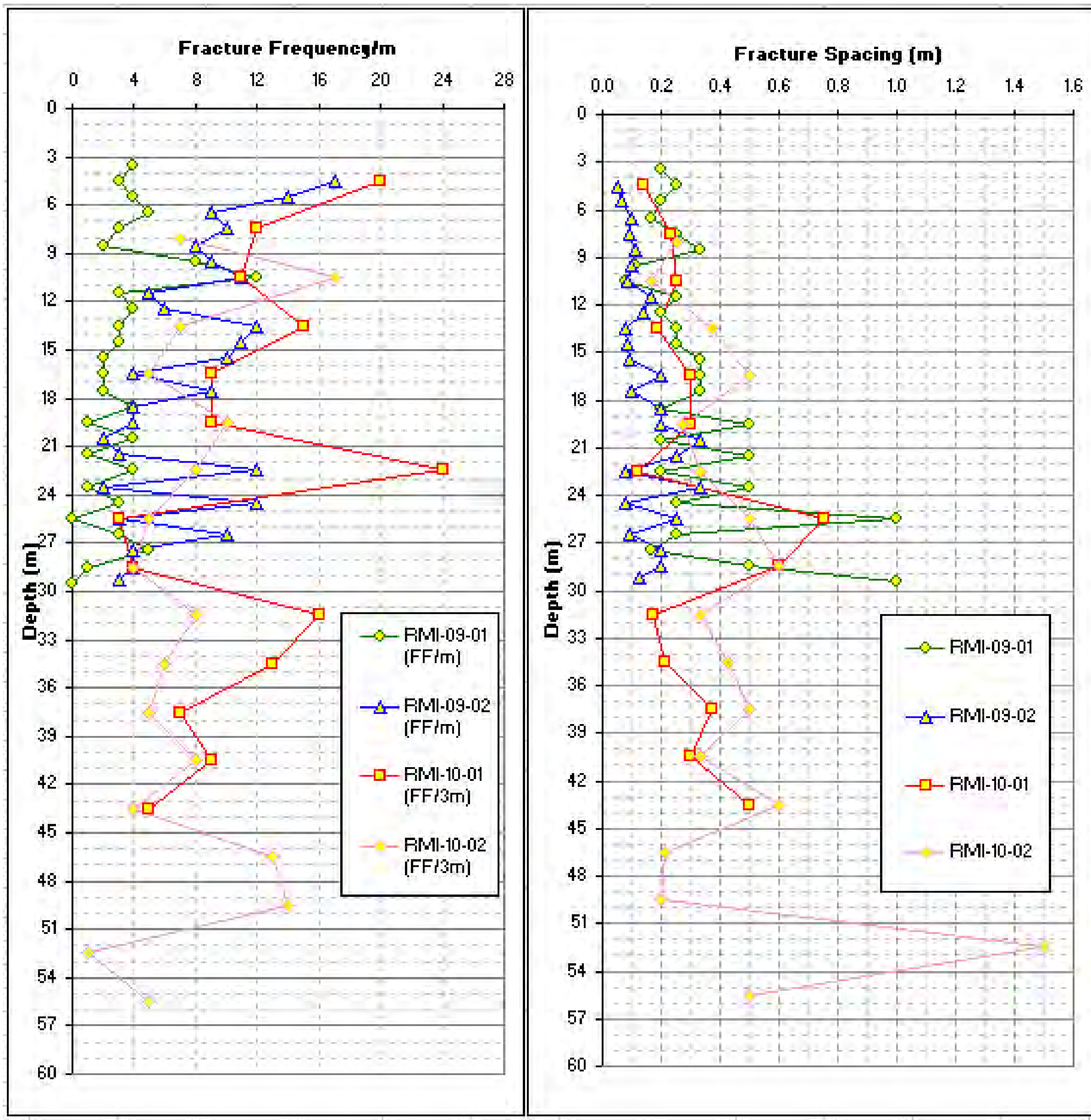

Figure 4.1-5
FF and FS versus depth - 2009 and 2010 boreholes

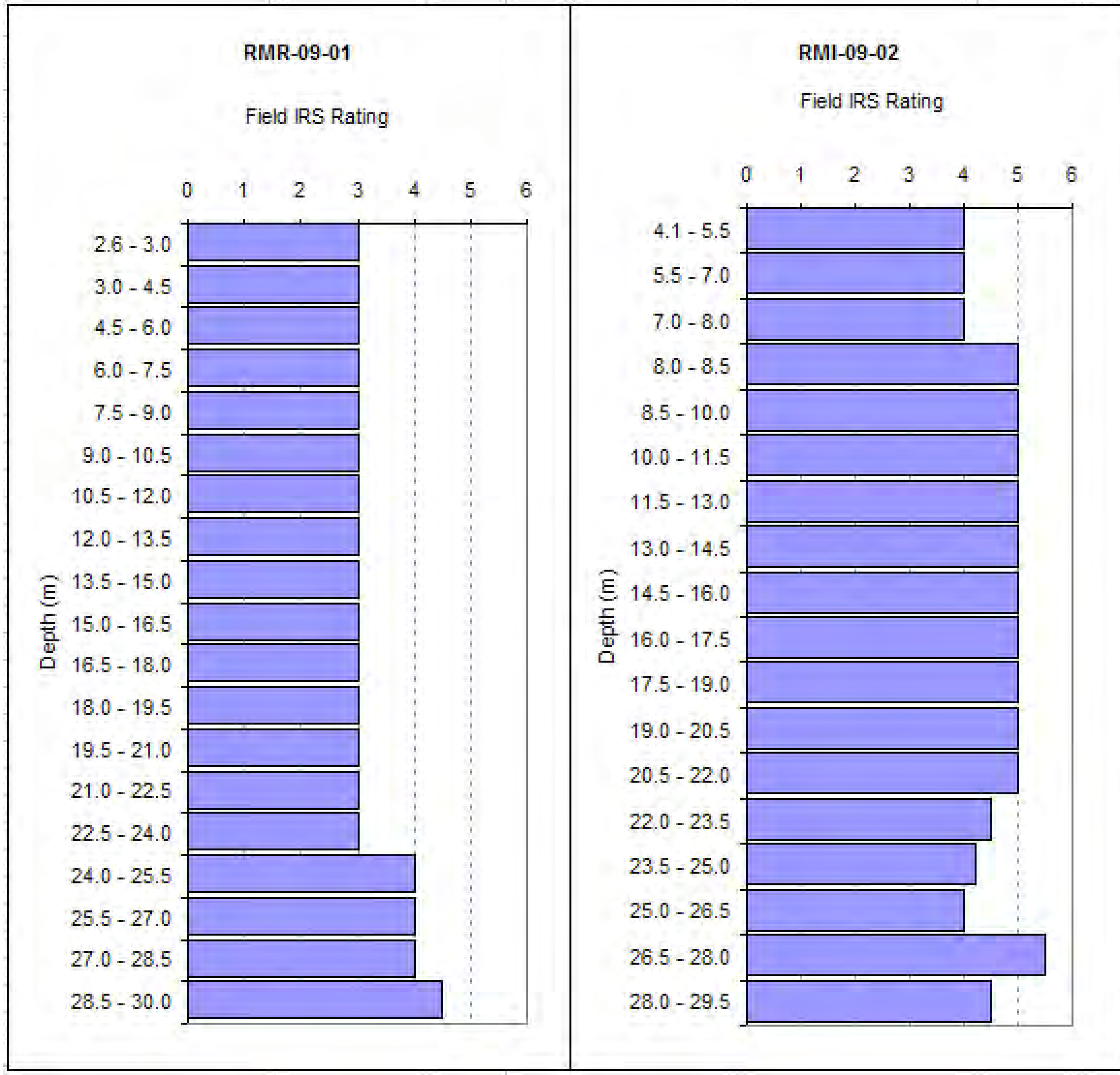

Figure 4.1-6
Field Rock Strength (R0-R6) versus depth in RMI-09-01 and RMI-09-02

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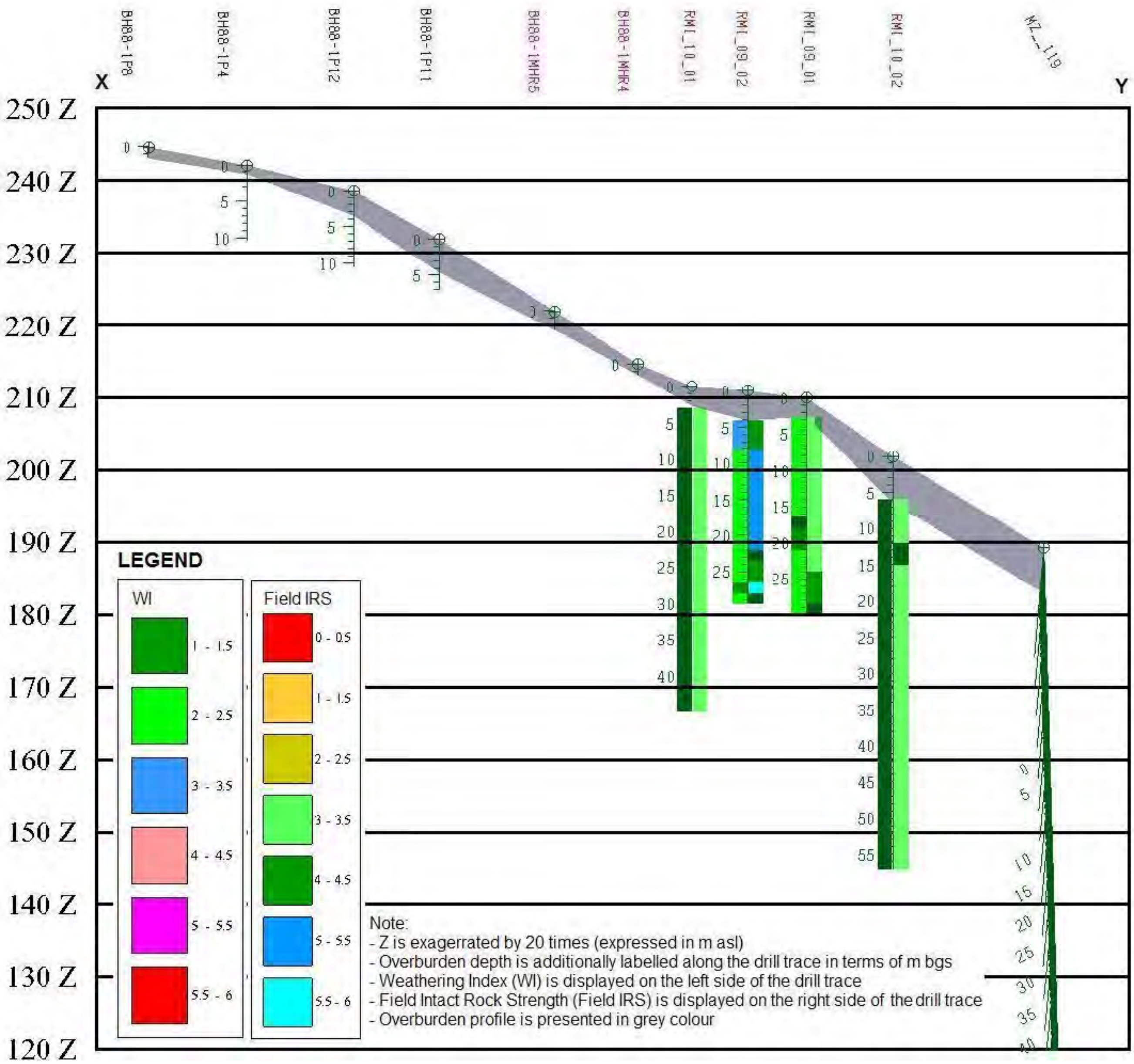

Technical Appendix 6A
Surficial Geology and Terrain
Date 15/09/2011

Figure 4.1-7
WI and IRS with depth - 2009 and 2010 boreholes

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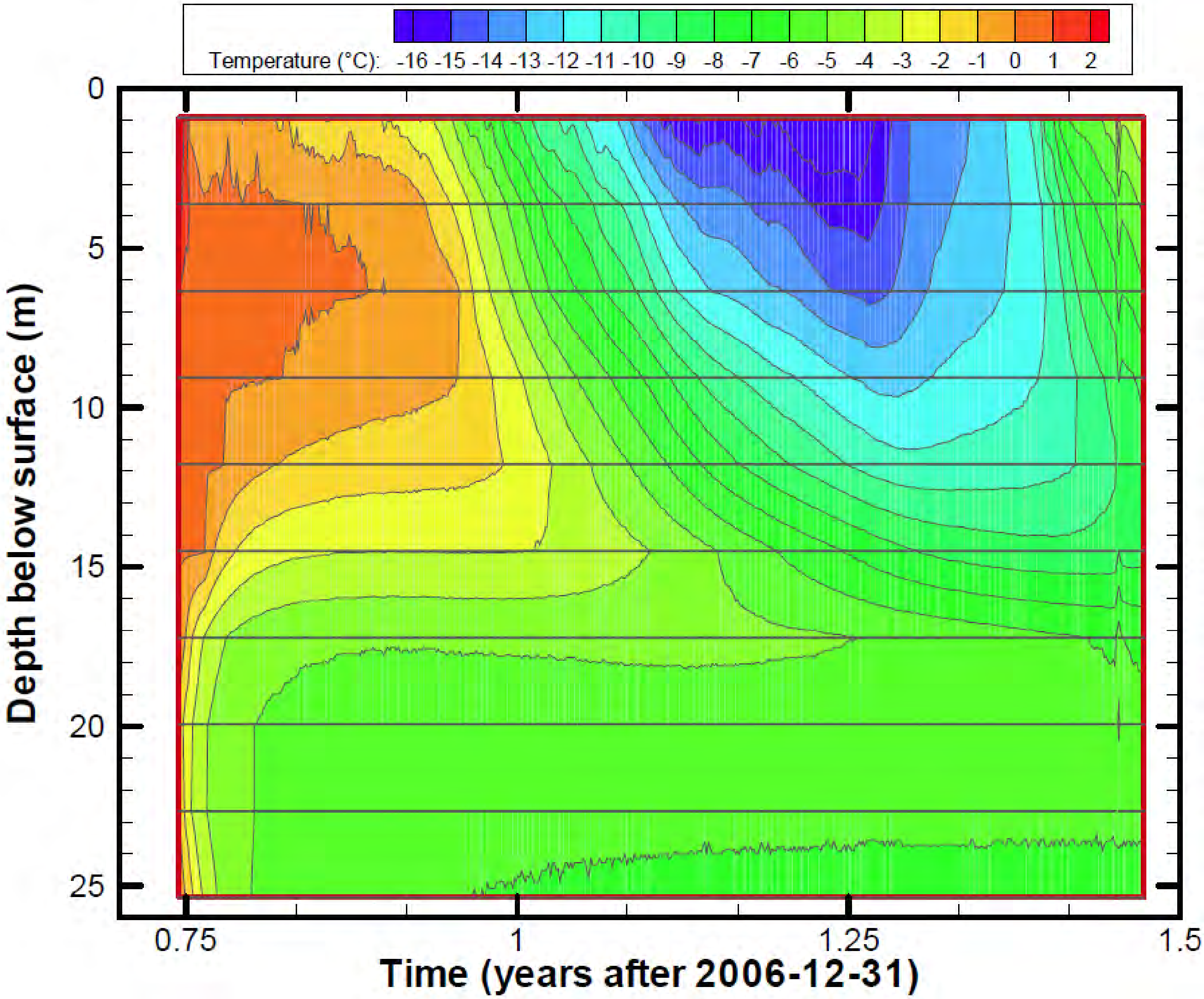
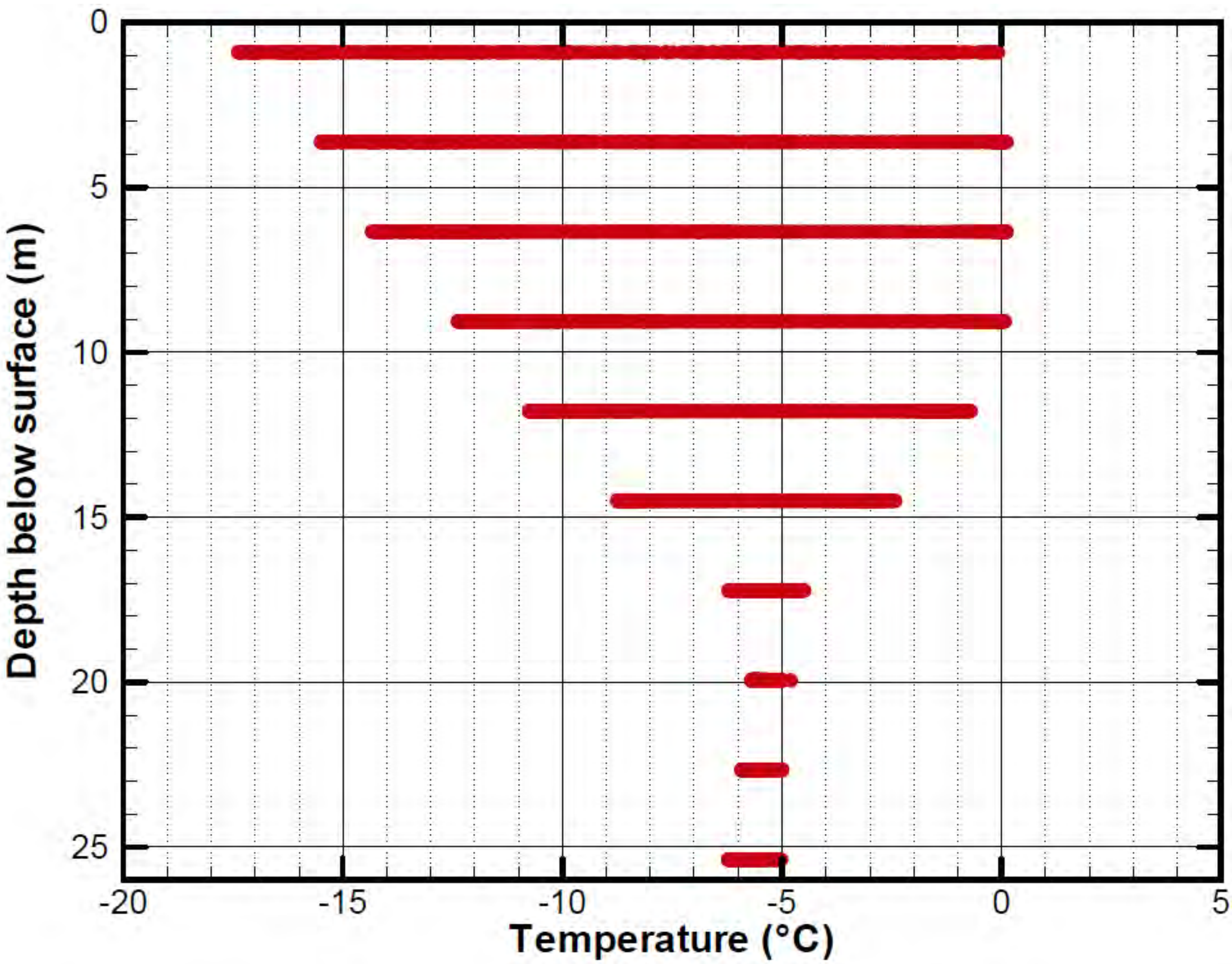


Figure 4.1-8
Ground temperature variation over time - END-07-01, End Grid area



Technical Appendix 6A
Surficial Geology and Terrain
Date 15/09/2011

Figure 4.1-9
Ground temperature variation versus depth - END-07-01, End Grid area

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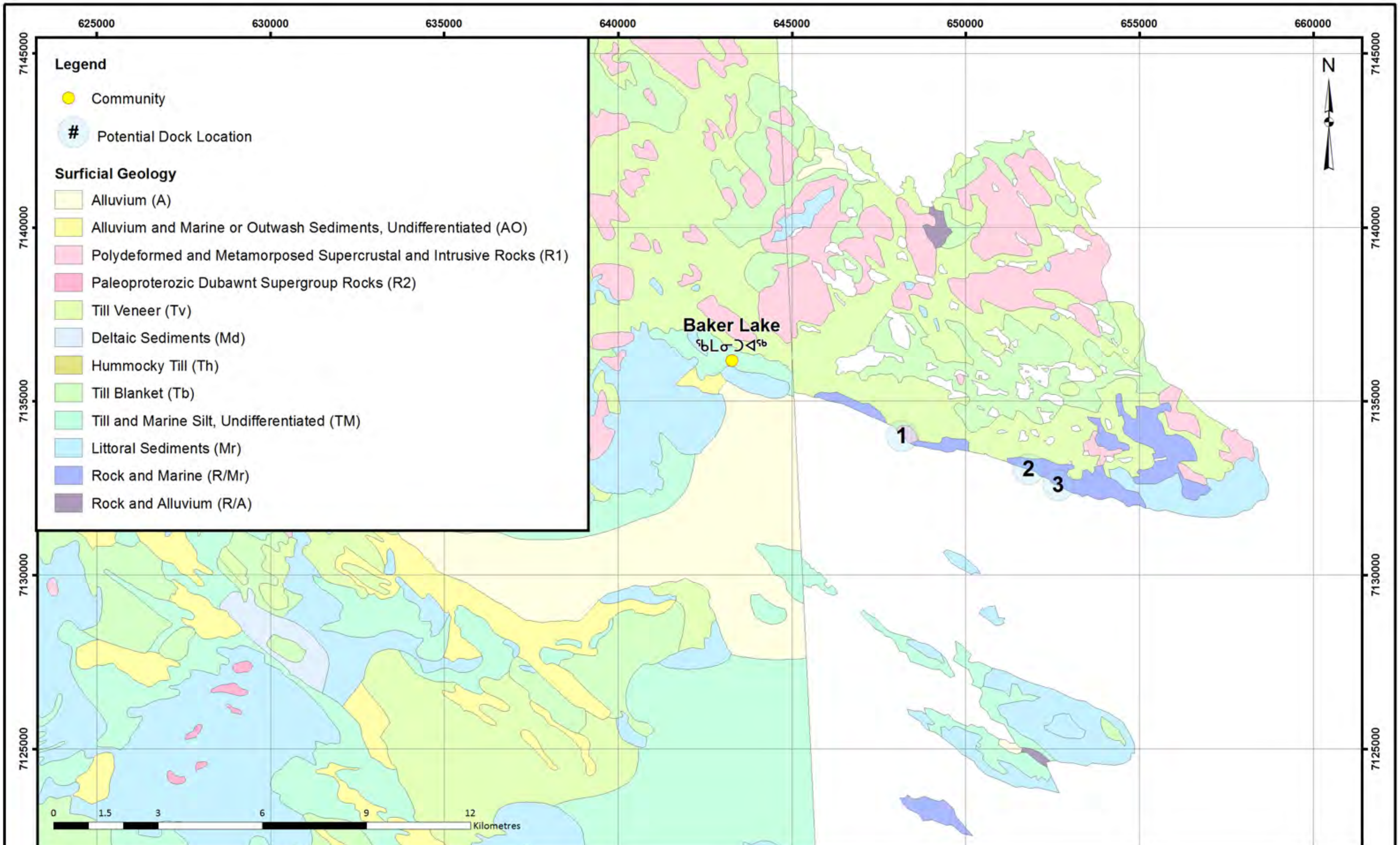

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File:
Data Sources: *AREVA Resources Canada Inc, Geological Survey of Canada Map 2120A*

FIGURE 4.1-10
SURFICIAL GEOLOGY IN THE PROPOSED DOCK SITE AREA

ENVIRONMENTAL IMPACT STATEMENT
APPENDIX 6A

Kiggavik Project
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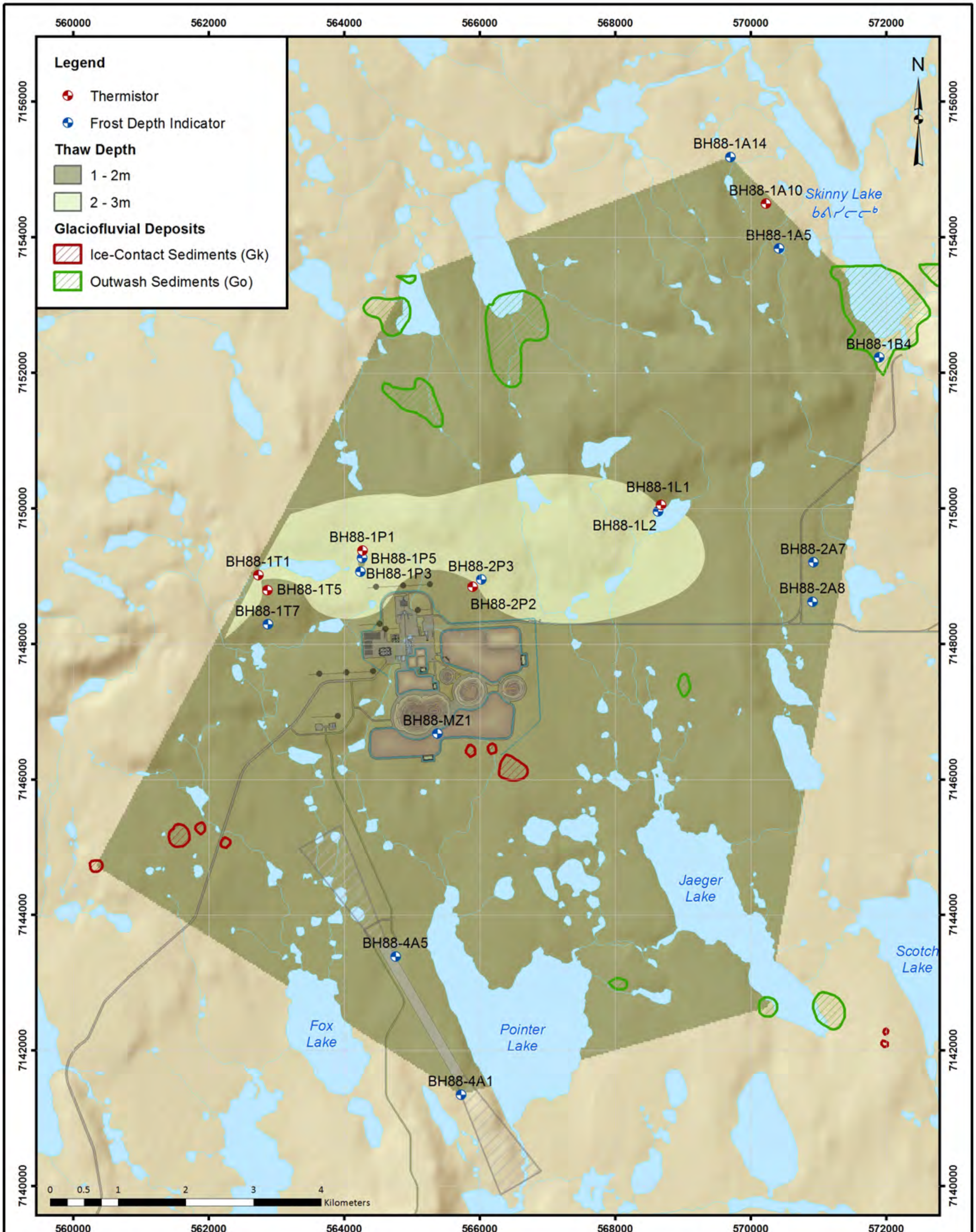

Projection: NAD 1983 UTM Zone 14N
Creator: CDC
Date: 09/14/2011 Scale: 1:75,000
File:
Data Sources: *Natural Resources Canada, Geobase®, Nation Topographic Database, AREVA Resources Canada Inc.*

FIGURE 5.1-1
THAW DEPTH IN THE KIGGAVIK PROJECT AREA

ENVIRONMENTAL IMPACT STATEMENT
APPENDIX 6A

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