AREVA

Kiggavik Project
Final Environmental Impact Statement

Tier 3 Technical Appendix 5B:
Geology and Hydrogeology Baseline

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Abbreviations

°	degrees
°C	degrees Celsius
DF	difference factor
km	kilometre
LiDAR	Light Detection and Ranging
LSA	local study area
m	metre
m/s	metres per second
masl	metres above sea level
mbgs	metres below ground surface
MDL	method detection limit
mg/L	milligrams per litre
mm	millimetre
NTS	National Topographic System
QA/QC	quality assurance/quality control
RPD	relative percent difference
RSA	regional study area
TDS	total dissolved solids
TSS	total suspended sediments
VW	vibrating wire

Glossary

Technical Term	Definition
Bathymetry	Lake bottom mapping.
Dyke	A sheet-like body of igneous rock which cuts across the bedding of the host rock.
Gneiss	Banded metamorphic rocks formed during regional metamorphism.
Hydraulic Conductivity	A parameter which characterizes the degree of resistance to groundwater flow in a porous media.
Hydraulic Head	A specific measurement of water pressure above a geodetic datum.
Intrusive rocks	Igneous rocks that intrude into pre-existing rocks, along some structure.
Metasediments	Sedimentary rocks that have been metamorphosed.
Packer	A device used in performing downhole tests in a borehole to seal off intervals of the borehole.
Vibrating Wire Piezometer	A device that converts pore pressure at the location of installation to an electronic signal via a diaphragm, a tensioned steel wire, and an electromagnetic coil. Changes in pore pressure create changes in the tension of the wire, and the vibration of the wire near the coil produces a signal that is transmitted to a readout device at the ground surface.
Slug Test	A test that involves the instantaneous injection or withdrawal of water over the test interval of a borehole during hydrogeologic testing.
Talik	Unfrozen ground surrounded by permafrost which forms beneath lakes that do not freeze to the bottom in winter.
Multi-Level Thermistor String	Temperature probes generally installed at regular intervals beneath the ground surface, along a drillhole.
Total Dissolved Solids (TDS)	The solid material in a solution.
Tracer	In this instance, a substance added to drill water used to tag the drill water, and to indicate when purging of the well was complete.

Glossary References:

Fetter, C.W. 1994. *Applied Hydrogeology 3rd Edition*. Prentice-Hall, Inc., Upper Saddle River, New Jersey

Poehls, D.J., and Smith, G.J., 2009. *Encyclopedia Dictionary of Hydrogeology*. Elsevier Inc.

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1 Introduction

1.1 Overview

The objective of this baseline report is to provide information on geology and hydrogeology in the area of the Kiggavik Project. This information will be used to assess the effects of the mines proposed by AREVA. The Project is located about 75 kilometres (km) west of the community of Baker Lake, Nunavut, which is west of Chesterfield Inlet and Hudson Bay (Figure 1.1-1). The Kiggavik Project includes three open pit mines and one underground mine. The Main Zone, Centre Zone and East Zone Pits are near each other and the Andrew Lake Pit and End Grid Underground Mine are located about 15 km to the southwest (Figure 1.1-2).

Collection of geologic data for the Project site was initiated during the nineteen-seventies. More specific structural and geotechnical data were collected from 1988 to 1997, and during the 2007, 2008, 2009, and 2010 field seasons. Hydrogeologic data for the Project site were collected from 1988 to 1997, and during the 2007, 2008, 2009, and 2010 field seasons. This baseline integrates information collected during all geologic and hydrogeologic investigations. In doing so, it presents the current understanding of geological and hydrogeological conditions in the area of the Kiggavik Project, as it is relevant to the assessment of the Project effects.

This report is organized as follows:

- Section 2 describes the general setting;
- Section 3 describes the surficial geology;
- Section 4 describes the bedrock geology;
- Section 5 describes the ground temperature conditions;
- Section 6 presents the groundwater quality conditions;
- Section 7 presents the hydrostratigraphy;
- Section 8 presents the groundwater flow conditions;
- Section 9 presents a summary of key baseline results;
- Section 10 presents references cited in this report; and
- Section 11 presents a glossary of terms used in this report.

1.2 Purpose

This purpose of this report is to document geologic and hydrogeologic data prior to the operational period of the proposed mines and to describe clearly and succinctly the existing groundwater quality, quantity, and use near the Kiggavik Project. A description of the groundwater quality, hydrostratigraphy, and groundwater flow patterns prior to development of the Kiggavik Project is included.

1.3 Scope

The scope of work for description of baseline geology and hydrogeology included field studies, interpretation, and synthesis to determine a conceptual model of baseline conditions.

The presentation of the geology baseline is based on data collected in the Project area since the 1970s, including recent data collected from 2007 to 2010.

The assessment of hydrogeologic conditions includes historic data collected at the Kiggavik and Sissons sites from 1988 to 1997, and recent data collected from 2007 to 2010.

Field investigations conducted from 1988 to 1991 consisted of temperature-depth profiles in eight boreholes. No permeability tests were conducted over this period. From 1989 to 1997, samples of drill return waters were collected to investigate groundwater quality. For comparison, water samples were also collected from Andrew Lake and End Grid Lake from 1995 to 1997.

Field investigations conducted from 2007 to 2010 included temperature-depth profiles in six boreholes, hydraulic testing of 11 boreholes, hydraulic heads measured beneath the permafrost in three boreholes, and one groundwater quality sample.

The focus of these investigations was to derive an understanding of the current groundwater flow regimes at the Project site. These data were collected to document baseline conditions and to be used in support of assessments of groundwater pressures and groundwater inflows (both quantity and quality) that may be encountered during mining and after decommissioning. These assessments include the development of a conceptual and numerical groundwater flow model of the Project area (see Technical Appendix 5D “Groundwater Flow Model”), the assessment of the long-terms effects related to tailings management (see Technical Appendix 5J “Tailings Characterization, Assessment, and Management”).

2 General Setting

2.1 Study Area

A Regional Study Area (RSA) and Local Study Area (LSA) were developed for the hydrogeological baseline and assessment and the extent of these study areas are presented in Figure 2.1-1. This RSA is equivalent to the one selected for the baseline hydrology which is based on surface water divides. The reason for this is that the elevations of large lakes provide the driving force for groundwater flow; therefore, surface drainage patterns provide a reasonably conservative approximation of the extent of the potential effects.

The LSA for hydrogeology is presented in Figure 2.1-2. The LSA covers an area of approximately 740 km^2. The extent of the LSA was selected based on observed topography, location of surface waterbodies, surface water drainage patterns and Project activities. The LSA includes the following key features:

- The Lower Lake, Boulder Lake, Caribou Lake and Willow Lake surface drainage basins, where most of the Project development will occur, are entirely included.
- A portion of the Kavisillik Lake and Siamese Lake sub-basins is included.
- A portion of the largest lakes in the area of Andrew Lake and End Grid is included. These lakes are Aberdeen Lake, Gerhard Lake, and Judge Sissons Lake.

2.2 Topography

Topography data near the project site were obtained from the Canadian Digital Elevation Data (CDED) published by Government of Canada, Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information (2004) and, where available, from the LSI and ARKeX Light Detection and Ranging (LiDAR) surveys that were conducted in July of 2009.

The LSI survey covered the Kiggavik area, Sissons area, the proposed Kiggavik-Sissons haul road and a potential access-road from Baker Lake to Kiggavik site (northern corridor). The deliverables of this survey included orthophotography with 18 cm raw pixel size and classified LiDAR point clouds. The ARKeX survey covered the Kiggavik Leases, Sissons Leases, and the St. Tropez Leases. The deliverables of this survey included bare earth and full featured LiDAR point clouds.

Figure 2.2-1 shows the extent of the LiDAR coverage in the Kiggavik Project area.

The regional topography is expected to control the groundwater flow system under both current and post-decommissioning conditions. For the most part, the Project area has a gently rolling topography with a few low escarpments associated mainly with east-west trending faults in the Kiggavik area. Ground surface elevations vary from 140 m near Pointer Lake to 265 m at the peak of the hill northeast of the proposed accommodation and mill sites. In the Sissons area, ground surface elevations vary from 166 m near Andrew Lake to 215 m at the peak of the hill northeast of the End Grid area (Figure 2.2-2).

2.3 Lake Elevations and Bathymetry

2.3.1 Data

Approximate elevations of lakes near the Project site were obtained from the Canadian Digital Elevation Data (CDED) published by Government of Canada, Natural Resources Canada, Earth Sciences Sector, Centre for Topographic Information (2004) and, where available, from the 2009 LiDAR surveys.

Collection of lake bathymetry data (lake bottom elevation) was initiated during field programs in 1988, 1989, and 1991 at the Project site. Lake bathymetry data was also collected during the 2007, 2008, and 2009 field programs. These data are summarized in the hydrology baseline report (Technical Appendix 5A).

2.3.2 Lakes Potentially Supporting Open Taliks

In areas of continuous permafrost, unfrozen ground conditions can develop beneath lakes that do not freeze to the bottom in winter. This unfrozen ground is referred as “talik”. If a lake is large and deep enough, the talik extends down to the deep groundwater regime (“open talik”).

To support a talik, a lake must be deep enough to maintain an unfrozen bottom throughout the winter. A two metre thick ice coverage is assumed to be developed in lakes at the Project site during the winter months (Prowse and Ommaney, 1990); therefore, lakes must be greater than two metres deep to support a talik.

The depth of the talik formed beneath a lake is dependent on the size of the lake. When the size of a lake is above a critical value, the talik beneath the lake will be an open talik, which connects to the deep groundwater flow regime beneath the permafrost. Beneath smaller lakes, which do not freeze to the bottom over the winter, a talik bulb that is not connected to the deep groundwater flow system will form. Using the formulas published by MacKay (1962) and Smith (1976) to determine the minimum size of lakes supporting an open talik, a circular unfrozen lake requires a minimum radius of about 145 m to support an open talik, while an elongated lake requires a half-width of about 80 m. These calculations assume a mean annual lake temperature of 4^{o}C and mean annual temperature of undisturbed permafrost of -8^{o}C.

Most lakes in the Kiggavik Project area are relatively shallow and many freeze to the bottom in winter. However several lakes near the Project site satisfy both the minimum dimensional and depth requirements to support a talik extending to the deep groundwater flow system. Figure 2.3-1 and Table 2.3-1 include the lakes that satisfy these requirements. Lakes that are large enough to support an open talik, but for which bathymetric data are unavailable, are also identified. Further information on the lakes analyzed to determine if a talik could exist is provided in Technical Appendix 5D Section 2.2.2.

Table 2.3-1 Lakes Potentially Supporting Open Talik Formation

Lake ID	Surface (km2)	mean Depth (m)	max Depth (m)	Estimated total volume (10^6 m3)	Average Lake elevation (masl)	Source Data For lake elevation
#1	2.59	na	na	na	182.3	#2
#2	1.08	na	na	na	158.1	#2
#3	1.16	na	na	na	182.6	#2
Aberdeen	>11.2	na	na	na	79	#1
Boulder	4.78	na	na	na	135	#2
Buzzard	3.19	na	na	na	160	#1
Caribou	3.41	1.4	2.7	4.91	136.9	#2
Cirque	0.056	2.6	4	0.146	211.3	#2
Escarpment	0.127	2.2	8	0.279	182.4	#2
Felsenmeer	0.208	2	6	0.423	222.8	#2
Fox	1.28	1.7	2.6	2.17	142.8	#2
Gerhard	10.73	na	na	na	185.1	#2
Jaeger	2.81	1.6	4	4.62	150.64	#2
Judge Sissons	95.5	4.6	20	439	132.4	#2
Lin	0.48	1.3	na	0.632	164.5	#2
Mushroom	0.32	1.89	8.9	0.59	173.2	#2
Pointer	3.93	1.39	2.9	5.45	141.9	#2
Ridge	0.167	2.3	7.1	0.384	230.7	#2
Rock	0.324	0.707	1.45	0.21	134.3	#2
Scotch	0.195	3.6	6	7.1	155.8	#2
Siamese	27.92	4.1	11.6	114.6	160.5	#2
Skinny	1.97	3.1	12	6.11	167.7	#2
Sleek	3.76	na	na	na	149.7	#2
Squiggly	6.38	6	14	38.3	213	#1
Willow	0.549	1.4	na	0.766	133	#2

Source data for lake elevation
#1 Canadian Digital Elevation Data (CDED), Gvt of Canada, Natural Resources Canada (www.geobase.ca)
#2 2008/2009 LiDAR survey

2.4 Regional Geology

The Kiggavik Project is located in the Rae Province (Hoffman, 1990), at the southwest termination of the Woodburn Group. The Archean Woodburn Group is a typical “greenstone belt” or supracrustal sequence consisting of a lower (mafic/ultramafic) metavolcanic assemblage and an upper metasedimentary (metagreywacke and quartzite) assemblage (Ashton, 1982). The supracrustal rocks are in tectonic contact with and structurally overlie Archean basement gneisses which are predominantly granitic with a minor amphibolitic component. The Woodburn Group is, in Kiggavik, unconformably overlain by the Paleo-Proterozoic metavolcanosedimenary Ketyet River Group and then by the non-metamorphosed Mesoproterozoic detritics of the supracrustal Dubawnt Supergroup (i.e. Thelon basin).

Most of the uranium exploration activity in east-central part of Nunavut has been associated with the Proterozoic sedimentary basins because of their geological similarity to the uranium-hosting Athabasca and Martin Basins of northern Saskatchewan. Thus, the Mesoproterozoic Dubawnt Supergroup supracrustal rocks, including the Thelon Formation, and immediately underlying basement lithologies have been the focus of uranium exploration because the Athabasca, Martin, Baker, and Thelon Basins are spatially and temporally-related intracratonic basins (Hiatt et al., 2003). The Archean basement rocks in these regions all belong to the Churchill geotectonic province.

A bedrock geology map which covered the Kiggavik Project area is available from the Geological Survey of Canada (Hadlari et al., 2004). An extract from the regional geological map is presented in Figure 2.4-1 and a list of lithologies, including lithologic groups and formations, is provided as Table 2.4-1. Archean rocks form the basement in this region and belong to both the Rae and Hearn domains of the Western Churchill geotectonic Province. These rocks are composed of dominant gneissic dioritic to granodioritic to monzonitic to granitic plutonic material intrusive into a polydeformed quartzofeldspathic banded gneiss interpreted to be a mixed paragneiss (supracrustal) and orthogneiss sequence (Peterson, 2006).

The Amer Group consists of eight sedimentary units comprising metaquartzite, feldspathic sandstone/meta-arkose (metapsammites), and lesser chloritic schist (metapelite). These rocks are found from Amer Lake in the north, through Aberdeen Lake in the east-central, to Dubawnt Lake in the southwest, in a 100 km by 50 km wide west-southwest-trending syncline that plunges to the southwest (Miller and LeCheminant, 1985). The most common lithology is white metaquartzite with lesser quartz pebble metaconglomerate and muscovite schist. The age of these rocks is poorly constrained by underlying Archean basement (~2600 Ma) and crosscutting intrusions (1833 Ma).

Metamorphosed supracrustal rocks, formerly called the Judge Sissons Lake Belt (JSLB) in the Kiggavik region, are present ~90 km south of the Amer Group exposures, underlie the region south of Schultz Lake and east of Aberdeen Lake (Miller and LeCheminant, 1985), overlie Archean granitic to granodioritic orthogneiss, and host the Kiggavik deposit. These rocks are considered to be part of the Woodburn Group, a typical "greenstone belt" or supracrustal sequence consisting of a lower (mafic/ultramafic) metavolcanic assemblage and an upper metasedimentary (metagreywacke and quartzite) assemblage. This clastic sequence is interpreted to be Paleoproterozoic in age. The JSLB strata consist of a lower section containing greywacke with minor intercalated volcanic strata and iron formation, a middle section containing interbedded immature feldspathic and lithic wackes and mudstone, and an upper section made up of more compositionally-mature sediments, such as micaceous orthoquartzite. The JSLB metasedimentary rocks were intruded by fluorite-bearing granites, syenites, and biotite lamprophyres related to the Dubawnt Supergroup and by northwest-trending Mackenzie swarm diabase dykes. The Thelon Formation of the Dubawnt Supergroup unconformably overlies the northern edge of the JSLB. The Kiggavik Main Zone uranium deposit is hosted by the feldspathic wacke unit and fluorite granite, near the level of the unconformity with the Thelon Formation.

Table 2.4-1 Lithologies and Geochronology (after Miller et al., 1986; Peterson, 2006)

Lithology			comments	geochronology
Mackenzie swarm			diabase dikes	1276 Ma
Dubawnt Supergroup	Barrensland Group	Lookout Point Fm	dolostone	
		Kuungmi Fm	volcanic flows, potassic tuff	
		Thelon Fm	sandstone and conglomerate	1720 ± 6 Ma
	Wharton Group	Nueltin granite	plutons and dikes; also basaltic dikes	1750-1765 Ma
		Pitz Fm	rhyolite to rhyodacite, red lithic interflow sandstone and siltstone [debris flow and stream channel deposits]	1750-1765 Ma
		Amarook Fm	eolian sandstone	
	Baker Lake Group	Kunwak Fm	lithic sandstone, siltstone, and conglomerate [alluvial fan and braided river/lacustrine deposits]	1785 ± 3 Ma
		Christopher Island Fm	felsic [potassic alkaline] lava flows and pyroclastics; ultrapotassic syenite/quartz syenite (Martell Syenite) stocks, sills, and dikes; interflow fluvial siltstone, sandstone, conglomerate; lamprophyre lava flows, tuffs, breccia; basal conglomerate	1833 ± 3 Ma
		Kazan Fm	red arkose, arkosic wacke, siltstone [basal clastic succession]	
		South Channel Fm	polymictic conglomerate [basal clastic succession]	
Hudsonian intrusions			granite to monzonite	~1840 Ma
Amer Group			quartzite; chloritic schist	~2100-1900 Ma
Archean			biotite/horneblende leucogranite	2602 ± 2 Ma
			megacrystic monzonite/granite	2605 ± 5 Ma
			granodiorite/diorite	
			pelitic to psammitic gneiss	
			iron formation	
			melanocratic orthogneiss	
			granitic paragneiss, schist	

The Dubawnt Supergroup fills the Baker Lake Basin in a series of structurally separated intracratonic sub-basins (Baker Lake, Yathkyed Lake, and Angikuni Lake Basins). The Baker Lake Basin is the largest of these basins being over 300 km in length, from Baker Lake to Tulemalu Lake, and averaging 50 km in width. These basins developed in a continental extensional setting between 1850 and 1700 Ma in response to the Trans-Hudson Orogeny (THO). The Dubawnt Supergroup is subdivided into three Groups and a total of nine Formations plus the Nueltin granites (Peterson, 2006).

The Baker Lake Group consists of the South Channel and Kazan Formations, the Christopher Island Formation, and the Kunwak Formation. In the Kiggavik region, the Lone Gull lamprophyre phases, along with abundant lamprophyre and syenite dykes, may be the intrusive equivalent of the Christopher Island Formation. The other formations cited are sedimentary redbeds, which are not exposed near the project area.

The Wharton Group, which unconformably overlies the Baker Lake Group (or Archean basement where the Baker Lake Group is not present), consists of the Pitz Formation (felsic volcanic rocks) and fluorite-bearing granite. In the Kiggavik region, there are no exposures of the Pitz Formation. The fluorite-bearing granite at Kiggavik has been informally named the Lone Gull granite (LGG). It was renamed the Shultz Lake Intrusive Complex by Miller (1996). Its stratigraphic position has been a point of discussion, and at Sissons, Kiggavik, and St. Tropez the fluorite-bearing granite is interpreted to be older than the Wharton Group (Miller, 1996).

The Barrensland Group unconformably overlies the Wharton Group, but commonly rests directly over Archean rocks. It contains mainly the sandstone and conglomerate of the Thelon Formation. The sandstone is exposed north of the Kiggavik deposit. The Archean rocks have gently dipping foliations (usually ~330/250) and show evidence of small-scale recumbent folding and low angle thrusting. Mylonitic textures in both the basement gneisses and Woodburn Group mark the location of these thrusts. In contrast, brittle deformation zones (syn-mineralization) are steeply-dipping and principally trend ENE and NNE and are interpreted to be a conjugate set. The main faults in the area are referred to as the Judge Sissons, Thelon, and the Andrew Lake Fault. Numerous other second and third-order brittle structures are parallel or conjugate to these main directions.

The youngest rocks in the project area are the ~1270 Ma NE-trending Mackenzie diabase dykes.

2.4.1 Regional Geology Update (2010-2014)

Since the original geology section was compiled, many new studies have better elucidated both the regional and local geology associated with the Kiggavik deposit. Although the essential characteristics of the geology of the Kiggavik area remain the same, their interpretation has undergone a re-evaluation. A major new initiative known as Geo-Mapping for Energy and Minerals (GEM) has been instituted in the north to research major continental basins and understand how they were formed to give a better understanding of the underlying geology of Northern Canada. Importantly for the Kiggavik project, mapping was carried out in and around the Thelon Basin and other northern basins to provide better maps and extrapolate uranium source units as well as key basement units beneath the basins. Further efforts were made to track and date basin development including uranium related alteration, sources and pathways (Jefferson et al. 2011a, Jefferson et al. 2011b, Jefferson et al. 2011c).

On a regional scale, work by Pehrsson et al. (2013) has investigated the Western Churchill Province. Detailed mapping, structural analysis and geochronology have better constrained the tectonometamorphic evolution of the Rae craton in the Woodburn Lake area of Nunavut. Initial work by Zaleski et al. (2000) divided the Woodburn Lake Group (WLG) into upper and lower Archean packages. The upper quartzite package was believed to be interbedded with a circa (ca.) 2630 Ma felsic volcanic rock. However, re-evaluation of field relationships by Pehrsson et al. (2010) caused the removal of the quartzite from the Woodburn Lake group. Now the WLG has been divided into six discrete assemblages (Pehrsson et al., 2010; Jefferson et al., 2011a) and it has been restricted to the Archean, after identifying that is separated everywhere from Paleoproterozoic quartzite by basal conglomerate or schist representing paleoweathered unconformity, or a structural break (Pehrsson et al. 2010, Scott et al. 2010 and Tschirhart et al. 2011). The greywacke-dominated Amarulik Wacke overlaps sequences 1 and 3 of the WLG and sequence 3 hosts the Meadowbank gold mine and appears to be the sequence hosting the Kiggavik deposits.

The ca. 2.56–2.30 Ga Arrowsmith and 2.56–2.50 MacQuoid orogenies reworked the Neoarchean greenstone belts and their basement at moderate to high pressures (Berman, 2010; Berman et al., 2013; Pehrsson et al., 2011). The Rae cover sequence, composed of four Paleoproterozoic assemblages was subsequently deposited and is preserved in a number of structural basins, including the Amer, Penrhyn and Ketyet River (Rainbird et al., 2010). The Amer and Ketyet groups have recently been much more closely correlated and their stratigraphy has been resolved to be consistent with structure. Unconformities separate four epicontinental sequences. The first three sequences were tightly infolded with the Archean during east-vergent D1 nappe tectonics. The fourth sequence is a foreland basin, a product of northwest-vergent tight D2 folding which is related to uplift along the Snowbird Tectonic Zone. The Fourth sequence is itself folded by the late D2 folding (Pehrsson et al. 2013)

More generally, Jefferson et al 2010 and Peterson et al. 2010 present recent research into the Dubawnt Supergroup Large Igneous Province (LIP) and BLIP (small mafic igneous events). Lithospheric extension driven by mantle upwelling is associated with most LIPs. Lithosphere plateau collapse and strike-slip deformation rather than plumes is likely to have driven the Dubawnt Supergroup LISP (large intracontinental sedimentary province) which contains two LIPs and a BLIP of mantle-sourced magmatism. The mafic/ultrapotassic Christopher Island Formation (LIP #1), was intercalated from 1845 ± 12 to 1785 ± 3 Ma with siliciclastic rocks of the trans-extensional Baker Lake Basin. The Baker Lake Basin partly covers the 1828 ± 29 Ma Lac Cinquante U deposit, which is vein-style (Jefferson et al. 2013a). The Baker Lake Basin also correlates temporally with the Martin

Basin of Saskatchewan's Beaverlodge district. The granite/gabbro/basalt/rhyolite of the 1.75 Ga Nueltin Suite (LIP #2), which is mineralized in the Main Zone of the Kiggavik deposits, was intercalated with siliciclastic rocks of the Wharton Group, invaded pre-Thelon Basin faults, and prepared the ground for basement hosted, unconformity associated U deposits (Jefferson et al. 2013a). The Nueltin granites are distinguished from regional Hudson suite rocks (which are not mineralized in any of the Kiggavik deposits) and contribute to a broader understanding of the evolution of the regional geology during the Paleoproterozoic. The emplacement the Nueltin suite indicates a major anorogenic event, signifying the last region-wide pulse of igneous activity across the Rae and Hearne domains of the western Churchill Province which followed a period of relative quiescence. The ca. 1750 Ma Nueltin event is marked by the bimodal extrusion of commonly porphyritic rhyolite and basalt lavas, and the intrusion of megacrystic and rapakivi granite plutons (Scott, 2012). The thin BLIP of ultrapotassic mafic Kuungmi lavas cap the Thelon Basin and provide a 1540 ± 30 Ma (micro-baddeleyite) upper age for the LISP (Jefferson et al. 2013a) The 1.27 Ga Mackenzie event, proposed to be plume-related, caused a re-set of unconformity U deposits in the Athabasca and Thelon basins, and developed new alteration vectors, such as chlorite, in the Athabasca Basin. Sandstone U mineralization is thought to be driven by the Mackenzie event drove as indicated by U-rich phosphate minerals in the Hornby Bay Basin dated as 1282 ± 11 and 1158 ± 80 Ma.

Generally, up until 2010, the majority of studies of the Thelon Basin were large in scope and included the entire basin and surrounding units. Subsequently, the Kiggavik host rocks were specifically targeted with locally detailed mapping of the Kiggavik camp by Pehrsson et al. (2010), Jefferson et al. (2011c), and McEwan et al. (2011). This mapping shows that most of the ore is in Neoarchean quartzofeldspathic metagreywacke with minor iron formation and metapelite. These units are unconformably overlain in succession by 2.6 Ga quartz-feldspar porphyritic rhyolite (also an ore host and locally known as "quartzeye quartzite") and early Paleoproterozoic quartzite that is barren of U. Highly micaceous quartzite was identified as the basal subunit, which is locally identified as sericite schist. Along the south side of the Thelon Fault and in a north-south panel west of the Bong deposit multiple structural intercalations in an east-west panel are formed by the three-part sequence of greywacke-rhyolite and quartzite. Past work has infered that the closest outcrops of the Thelon Formation are on the north side of the Thelon Fault, 2 km to the north of the Kiggavik Main Zone because closer deposits of sandstone and conglomerate of the Thelon Formation, which once covered the Kiggavik deposits, was removed by erosion (Fuchs and Hilger, 1989). This theory is strengthened by one of the new discoveries by Cameco Corp. (R. Hunter, oral presentation, Nunavut Mining Symposium, April 5, 2011) where the Ayra occurrence is overlain by an outlier of the Thelon Formation, supporting the unconformity association for the basement-hosted uraninite. The border phases of the porphyritic Lone Gull granite intrusion, hypabyssal Nueltin granite that is part of the Kiggavik igneous suite is another host rock for U (ca. 1750 Ma zircon U/Pb: Scott et al., 2010; Scott, 2012; Peterson et al., 2010). The ductile deformation and igneous history described was overprinted by hydrothermal alteration that was most strongly developed along steeply dipping, intersecting brittle fault zones. The east-northeast-trending Thelon Fault, some 2 km north of Kiggavik, and the Judge Sissons fault, about 8.5 km to the south are two of the most prominent regional faults.

However, these are only two of many of such faults, one or more of which trend directly through the Kiggavik deposits. These fault systems were recognized soon after discovery (Fuchs and Hilger, 1989) and their study continues (R. Hunter, oral presentation, Nunavut Mining Symposium, April 5, 2011). They are of primary importance because the intersections of these faults with northeast- and northwest trending faults localizes the deposits (Robinson et al. 2014)

2.5 Hydrogeologic setting

The Kiggavik Project lies within the Canadian Shield in an area of continuous permafrost. In areas of continuous permafrost, there are generally two groundwater flow regimes: a deep groundwater flow regime beneath permafrost and a shallow groundwater flow regime located in the active (seasonally thawed) layer near the ground surface. Because of the thick, low permeability permafrost, there is little to no hydraulic connection between the two groundwater flow systems.

2.5.1 Shallow Groundwater Flow Regime

From the late spring to early autumn, when temperatures are above 0 degrees Celsius (˚C), the active layer becomes thawed. Within the active layer, the water table is expected to be a subdued replica of topography, and is expected to parallel the topographic surface. Groundwater gradients would therefore be similar to topographic gradients. Groundwater in the active layers flows to local depressions and ponds that drain to larger lakes.

Permafrost reduces the hydraulic conductivity of the rock by one to two orders of magnitude (Anderson and Morgenstern 1973; Burt and Williams 1976). Consequently, the permafrost in the rock at Kiggavik would be virtually impermeable to groundwater flow. The shallow groundwater flow regime, therefore, has little to no direct hydraulic connection with the groundwater regime located below the permafrost.

2.5.2 Deep Groundwater Flow Regime

Taliks (unfrozen ground surrounded by permafrost) exist beneath lakes which have sufficient depth such that they that do not freeze to the bottom over the winter. Taliks beneath larger lakes extend down to the deep groundwater regime. The elevations of these lakes provide the driving force for deep groundwater flow. The presence of thick permafrost beneath land masses results in negligible recharge to the deep groundwater flow regime from these areas. Consequently, recharge to the deep groundwater flow regime is predominantly limited to areas of talik beneath large, surface waterbodies. Generally, groundwater will flow from higher-elevation lakes to lower-elevation lakes. To a lesser degree, groundwater beneath the permafrost is influenced by density differences due to the upward diffusion of deep-seated brines (density-driven flow).

The host rock lithology is expected to exhibit a very low primary (matrix supported) hydraulic conductivity, with the main flow related to secondary conductivity (i.e.: open fractures, faults, etc.).

2.5.3 Groundwater Usage

Groundwater sources from both the active layer and from the deep groundwater below the permafrost are generally not presently used for drinking water in continuous permafrost regions. Due to the presence of deep permafrost, the seasonal nature of the active layer, and the availability of good quality drinking water from surface water sources near the Project site, it is unlikely that groundwater will be used as a drinking water source in the near future.

2.5.4 Potential Geological Effects on Hydrogeologic Setting

Relatively competent rock is expected to comprise the majority of the rock domain. The hydraulic conductivity of the deep bedrock at the project site is expected to be low and to decrease at greater depths as observed at other sites in the Canadian Shield, Europe, and the USA (Stober and Bucher, 2007); however, the profile of hydraulic conductivity with depth will be site-specific, dependent on the site geology.

In a competent bedrock environment, enhanced permeability zones (i.e., zones of greater permeability than the surrounding rock) are observed in association with fractures. When connected, enhanced permeability zones are considered to be of potential importance for governing the groundwater flow both prior to mining, during mining, and after decommissioning. For instance, if the mines were to intersect an enhanced permeability zone beneath permafrost, the dominant groundwater flow pattern induced during mining would likely be near parallel to the features.

Zones of enhanced permeability can be composed of sparsely spaced, highly permeable discontinuities within a lower permeability pseudo-matrix. Depending on the orientation of a borehole drilled within such a zone, none or many permeable fractures may be intersected. Identification of these zones can be difficult with geotechnical logging and single well response testing alone.

In End, Andrew, and Bong deposits, permeability barriers formed by huge quartz-silica breccia fault zones have been identified.

3 Surficial Geology

3.1 Data

The general surficial geology of the Project area is relatively well described by the Geologic Survey of Canada, 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).

In addition to regional information, site specific data were collected in 1988 by Golder Associates Ltd. (Golder, 1988) as part of the Project feasibility study. Over 100 shallow boreholes were drilled in the summer of 1988 for the purpose of evaluating site foundations, waste dump foundations, and overburden stripping in the vicinity of the open pits and haul road design (Golder, 1989). Samples from flight auger cuttings and frozen samples were tested for grain size distribution, plasticity, and water content.

Subsurface geophysical investigations using ground-penetrating radar (GPR) technology were performed in 2008 and 2009 in order to delineate soil stratigraphy and/or bedrock contacts, bedrock surface condition, and permafrost conditions up to depths of approximately 15 m. The first investigation was conducted between September 16 and September 20, 2008, and covered the proposed Kiggavik mill site. A second survey, performed on April 27, 2009, covered additional portions of the proposed facility area and the major open pit locations at Kiggavik and Andrew Lake (EBA, 2009).

In the summer of 2009, two shallow geotechnical boreholes were advanced in locations corresponding to the Kiggavik mill site to confirm historical data. Similarly, two shallow geotechnical boreholes were advanced in 2010 at the Kiggavik mill site location.

The locations of the shallow geotechnical holes drilled since 1988 are shown on Figure 3.1-1. Figure 3.1-2 provides an overview of the locations of all GPR profiles collected to date. The shallow holes drilled in 1988, 2009, and 2010 are also shown on this figure. A summary of surficial geology information is included in the following sections. More detailed information regarding the surficial geology and soils can be found in the Technical Appendices 6A "Surficial Geology and Terrain Baseline" and 6B "Soils and Vegetation Baseline".

3.2 General Geomorphology and Soils

The surficial deposits in the Kiggavik Project area comprise mainly glacial till. 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. The glacial till samples exhibited little to no plasticity. The water content of the glacial till ranged from 8 to 15 percent, approximately.

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

A typical soil profile in the Kiggavik Project area consists of a thin organic 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.

Soils within the Project area are primarily Cryosolic soils (permafrost affected soils). Cryosolic soils are defined as soils that have been formed in either mineral or organic materials that have permafrost either within 1 m of the surface or within 2 m if the soil has been strongly cryoturbated laterally within the active layer, as indicated by disrupted, mixed, or broken horizons.

3.3 Surficial Deposits and Landforms

Landforms in the Project area are dominated by hummocky bouldery glacial till and scattered boulder till moraines with frequent 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 or 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 deposits.

The surficial deposits in the Project 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 erosion and deposition 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 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 normal depositional and erosional process associated with 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:

- Moraine – Till ground moraine is the most common and widespread across the Project area. 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. 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.
- Glaciofluvial – Glaciofluvial outwash deposits occur randomly throughout the study area and are generally composed of granular soils.
- Marine – Marine landforms deposited during postglacial emergence due to crustal rebound are 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.
- Organic – Thick organic landforms represent a relatively minor portion of the Project area, but small localized deposits are widespread. Thick peat accumulations occur in low-lying areas. The deposits are wet and ice-rich.
- Bedrock – Outcrops are widespread within the Project area, characterized by a jointed or frost shattered upper surface (felsenmeer) resulting in a jagged micro-topography.

3.4 Permafrost Conditions and Related Landforms

The Kiggavik Project area is located within the zone of continuous permafrost (NRC, 2007).Permafrost thickness 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 deposits likely due to the high proportion of stone and cobble sized material (Geomatics International 1991).

The periglacial geomorphic processes in the area are typical of permafrost conditions associated with excess ground ice. Periglacial processes observed in the Project area include frost wedging and frost shattering, thaw subsidence, 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.

The thickness of the active layer (the top layer of soil that thaws during the summer and freezes again during the winter) is variable. In general, the active layer thickness at the Project area is in the order of 1 m to 2 m, except where bedrock is found close to surface or is outcropping. Where bedrock outcrops, the active layer could be as thick as 5 m. The thickness of the active layer is dependent on many factors including the type and thickness of the organic cover and the underlying mineral soils and bedrock. Where frost fracturing has occurred below the depth of the active layer, the fractures are typically ice filled, and high ice contents govern geotechnical design. Competent bedrock is typically found at depths of 3 m to 4 m into bedrock.

The glacial till overburden soils often contains amounts of visible ice in the form of ice lenses. These high ice-content till materials are sensitive and prone to considerable settlement if thawed. The sensitivity of these materials to disturbance can be clearly seen along the Thelon River where numerous thaw flow sides are visible.

The ground ice content of permafrost soil and rock in the Project area is expected to be between 0% and 15% (dry permafrost) based on regional scale compilation data. 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.

More detailed information on the thermal conditions at the Kiggavik and Sissons sites are provided in Section 5.

4 Bedrock Geology

4.1 Structural Geology

4.1.1 Regional Stress Regime

The assumed regional stress regime for the Baker Lake area is based on data collected as part of the World Stress Map Project (based at the Heidelberg Academy of Sciences and Humanities). Available data are plotted in Figure 4.1-1, with detail of the site enlarged. From these data, the assumed current regional stress direction (sigma 1) is approximately NE. This will tend to close the faults lying normal to this direction. In contrast, faults that are quasi-parallel to the stress fields may be reactivated or opened due to this stress.

Information on the presence and characteristics of faults associated with mine development has been preliminarily described based on available geotechnical and hydrogeologic data for the mines. As additional information becomes available and as progress is made on detailed designs of each facility, the interpretation of the site geology and fault characteristics will continue to be updated. Additional site characterization will be completed for each open pit or underground mine prior licencing and construction of the facilities.

4.1.2 Regional Structures

Several airborne geophysical surveys were conducted in the Project area for exploration purposes. Regional structures as shown on Figure 4.1-2 and 4.1-3 are based on geophysical anomalies that were interpreted to be potential fault traces. Therefore, the location of these regional features may not be accurate at the deposit/pit scale.

A structural geology program was conducted by AREVA from 1994 to 1996. The program focused on structural analysis of major fault systems with emphasis on hydrothermal events. The program included structural mapping at the outcrop level, regional mapping from airborne data and kinematic analysis. Two main phases of brittle deformation were identified during the program.

The first and main phase of brittle deformation is labeled D_{bh1} (deformation-brittle-hydrothermal #1). This phase is associated with extensive silica flooding and hematitic alteration extending deep (>400m) into the basement. During this phase, a NNE compression event created a network of 080^o to 035^o trending strike-slip faults. This event is considered to be intimately linked to uranium deposition. For instance, it is considered that the Judge Sissons fault (JS) has been a major mobile zone during the D_{bh1} phase. The JS fault is a 075^o to 080^o trending fault 1 km north of the Andrew

Lake deposit. Topographically, it stands out as a ridge of faulting and is associated with erosion-resistant quartz veins and silicified breccias. In airborne geophysics, it is marked by well defined resistivity and magnetic lows. In plan view, the regional structure appears as a 400-1000 m wide corridor. The main fault plan is observed at several microtectonic observation stations. It dips 65^o to the North and is marked by a 25 m wide silicified breccia. The latest movement is sinistral and shows a minor reverse vertical component with slickensides consistently dipping at 20-30^o to the East.

The second phase of brittle deformation in hydrothermal conditions (D_{bh2}) occurred during a phase of NW-SE compression that postdates the main movement on the JS fault. In the central and eastern part of the Sissons area, the JS fault is truncated by two sets of conjugate strike-slip faults. The 125^o set displays a dextral displacement in the order of 50-300 m. The 160^o trending set shows sinistral offsets of at least 50-300 m. Airborne data suggests that further east, the displacement could be in the order of a kilometer. At the outcrop scale, younger NW trending sets of quartz veins and NNW trending minor sinistral faults postdate the D_{bh1} EW trending structure. Both families of faults are associated with moderate to locally strong hydrothermal alteration and deformation. For instance, in the Siamese area N160 faults show several tens of meters of massive quartz-cemented hydraulic breccia.

Outcrop observations suggest that most fractures from the D_{bh1} and D_{bh2} phases are characterized by fault breccias, veins, or fault gouges. A summary of observations conducted on microtectonics stations is included in Attachment A.

4.2 Geology of the Deposits

4.2.1 Kiggavik Area

4.2.1.1 *Data*

Historical drilling (1977 to 1988)

Diamond drilling at Main Zone began in 1977. All drilling was done by coring; BQ from 1977 to 1982 then NQ from 1985. No drilling was carried out in Main Zone in 1981, 1983 and 1984. In 1988, fifteen additional holes were drilled in the general Main Zone area. Of these 15 holes drilled, eight were targeted to test for potential mineralization in areas designated for use as waste rock piles north and south of the then planned open pit (holes 327-330, 345-347 and 352). Two holes (331 and 332) were also drilled to obtain geotechnical and thermal information. Five holes were drilled to investigate a local diabase and the continuity of mineralization in strike direction.

Diamond drilling at Centre Zone began in 1978. All drilling was done by coring; BQ from 1978 to 1983 then NQ from 1986. No drilling was carried out in Centre Zone in 1981, 1984 and 1985. In 1988, three additional holes were drilled. Two holes (343 and 344) were drilled west of the Centre Zone in areas of potential waste rock piles. One hole (333) was also drilled to test the geotechnical and thermal characteristics of the Centre Zone. In addition, this hole was targeted to provide information on a local dyke and for a comparison of observed versus predicted mineralization.

Recent drilling (2007 to 2010)

The main objective of the 2007 drilling campaign was to collect ore samples from the deposits to conduct metallurgical bench-scale tests. A second objective of the 2007 drilling campaign was to collect geotechnical, hydrogeological, and thermal data to confirm mine design assumptions as part of a pre-feasibility study. Six holes were drilled (four at Main Zone and two at Centre Zone) using NQ sized diamond core equipment.

The main objective of the 2008 drilling campaign was to collect ore samples from the deposits to conduct metallurgical pilot tests. In 2008, drilling was carried out using NQ and HQ sized diamond core equipment. Ten holes were drilled: eight at Main Zone, one at Centre Zone, and one at East Zone.

The main objective of the 2009 drilling campaign at Main Zone was to collect additional geotechnical data for pit slope stability analysis and additional hydrogeological and thermal data. Drilling was carried out using HQ and NQ sized diamond core equipment. In total, 5 drillholes were geotechnically core logged and 4 of these had core orientation.

The main objective of the 2010 drilling campaign was to collect additional hydrogeological data and to validate the geological and mineralization model. All holes were geotechnically logged. Drilling was carried out using NQ sized diamond core equipment. In total, two drillholes were completed at Main Zone and one at East Zone.

The locations of exploration, delineation, and geotechnical holes drilled in the Kiggavik area since 1977 are shown on Figure 4.2-1. In total, more than 320 holes have been drilled.

4.2.1.2 *Local Geology*

The geology of the Kiggavik deposits has been relatively well described during the nineteen-nineties (see for instance Fuchs et al., 1986, Weyer and al., 1987, Hilger, 1988, and Fuchs and Hilger, 1989). Drilling and ore sampling activities conducted since 2007 have essentially confirmed the local geological conditions and previous interpretations in terms of distribution of grade and lithology. A regional geologic cross-section for the Kiggavik area is shown in Figure 4.2-24.

The Main Zone, Centre Zone, and East Zone deposits are located between two regional fault zones. The Thelon fault is located to the north, while the Sissons fault is located to the south. The Main and Center zones are located 600 m apart and follow the same 65 degrees (^{o}) east-northeast trending shear zone. The East Zone is located approximately 500 m further to the east of Center Zone.

Basement host rocks are composed of metasediments, and to a lesser extent altered granite and intrusive rocks. Metasediments are sedimentary rocks that have been metamorphosed (altered by heat, pressure, or chemically active fluids). Intrusive rocks are igneous rocks that intrude into pre-existing rocks, along some structure. Uranium mineralization in the Kiggavik area is hosted for the most part in altered metasedimentary rocks (mainly metaarkose, metapelites, and sericite schist), and to a much lesser extent in altered granite and intrusive rocks.

The general deposit model includes lithological and structural features. The host lithology is typically Woodburn Lake Group metasediment (metagreywacke and micaceous quartzofeldspathic gneiss) that is traversed by regional faults, local faults, and fracture zones. The mineralization locally crosses lithologies and can also be found in fractures within granite. Orebodies are tabular to irregular in shape, following local structures and/or foliation directions. They are up to 600 m in length and 100 m in width. The deposits have been found from bedrock surface (Kiggavik) to 500 m below the surface (End Grid). Uranium minerals fill voids in breccias and vein stockworks and along foliation planes. Mineralization often occurs at or near structures associated with sites of rheology contrasts (granite-metasediment contacts, quartz breccia units, etc.) and/or at intersections of fault sets. The location of mineralization emplacement is controlled and bounded by conjugate sets of high-angle faults and hydraulic brecciation zones. Fluids associated with the mineralization were guided by earlier ENE/WSW structures, low-angle foliation, and parallel-to-foliation ductile to brittle-ductile shear zones. The precipitation of the relatively low-grade (<2% U) pitchblende mineralization occurred through redox reactions within regions of relatively reduced host material, likely through fluid-rock interaction and the coupled Fe-U redox reaction. Uranium deposition is accompanied by Au enrichment. The mineralization is also associated with hematization and is surrounded by a clay mineral host-rock alteration halo composed of sudoite and illite, with bleaching and quartz dissolution (argillization) features.

The metasediments in the Kiggavik area are late Archean in age and belong to the Woodburn Lake Group (pelitic to psammitic gneiss in Table 2.4-1).

The granites in the Kiggavik and Andrew Lake areas are not Archean; rather they are variably Hudson (~1840 Ma) or Nueltin (~1760 Ma) in age (see Table 2.4-1), depending on which granite body is being discussed.

Main Zone

The Main Zone deposit consists of two parallel running major lenses, which are elongated along strike and are generally 20 to 30 metres (m) thick (ranging between 20 to 50 m). Two minor lenses have also been identified. The main lenses sub-crop to the west and plunge at approximately 25° in the 65° ENE direction, each with a strike length of approximately 300 m. The lenses are controlled by the intersection of the shear zone with a 95° E fault dipping 55° N. The lithology in the Main Zone deposit consists of granite and metasediments, with this fault serving as the contact between the two units. The main mineralized lenses occur in metasedimentary rocks and terminate at a depth of approximately 150 to 190 m below surface. Uranium mineralization also occurs within the granite to a depth of over 300 m. There is currently no evidence to suggest that the ore is terminated or significantly displaced by faulting. At the Main Zone deposit, a northwest-southeast trending dyke cuts through the middle of the deposit, and is non-mineralized. A dyke is a sheet-like body of igneous rock which cuts across the bedding of the host rock.

The drill plan and a surface projection of the Main Zone orebody are presented in Figure 4.2-2. Sections through the Main Zone deposit are presented in Figures 4.2-3 to 4.2-5. A three-dimensional view of the mineralized lenses is presented in Figure 4.2-6.

Centre Zone

The Centre Zone deposit is located about 600 m to the east of the Main Zone deposit, along the strike of the shear zone. The mineralized body appears to be folded around a center core of orthoquartzite, with an Upper lens in the hanging wall and a Lower lens in the footwall of the orthoquartzite horizon. The lenses closely follow the shallow dip of the orthoquartzite unit and appear to merge and form a fold closure to the north. The mineralization reaches a thickness of 30 m in each lens. The lateral extents of the ore lenses are approximately 150 m along strike by 100 m wide. Almost all of the mineralization lies within 100 m from surface.

The drill plan and a surface projection of the Centre Zone orebody are presented in Figure 4.2-7. Sections through the Centre Zone deposit are presented in Figures 4.2-8 and 4.2-9. A three-dimensional view of the mineralized lenses is presented in Figure 4.2-10.

East Zone

The East Zone deposit is a small deposit located about 500 m to the east of the Centre Zone deposit, along strike of the shear zone. Mineralization within the East Zone deposit is similar to that of the Centre Zone deposit, and occurs up to 60 m below ground surface.

The drill plan and a surface projection of the East Zone orebody are presented in Figure 4.2-11. A section through the East Zone deposit is presented in Figures 4.2-12.

4.2.1.3 *Petrography, Mineralogy, and Mineralization*

From Farkas (1984), Fuchs et al. (1986), and unpublished AREVA petrographic determinations, the mineralogical compositions of the various rock types are typically:

1. meta-arkose (fine- to medium-grained, psammopelitic to psammitic gneiss; impure/"dirty" quartzite)

Mineral	**Original**		**altered**
Quartz	30-50%		0-30%
Feldspar (plagioclase + K-feldspar)	30-50%		nil
Biotite/chlorite	15-30%	chlorite	5-40%
Muscovite/sericite	5-40%	illite/sericite	30-90%
Garnet	<5%		nil
Pyrite	<5%		<5%
Carbonate	<5%		<5%
Tourmaline	accessory		accessory
Zircon	accessory		accessory
Fluorite	accessory		accessory
Hematite	accessory		0-15%
Epidote	accessory		nil

2. Lone Gull granite (medium-grained, pinkish, non-foliated, holocrystalline-granular)

Mineral	**Original**		**altered**
Quartz	35-55%		5-40%
K-Feldspar	25-45%		nil
Plagioclase	15-25%		nil
Biotite/chlorite	15-25%	chlorite	5-40%
Muscovite/sericite	5-20%	illite/sericite	30-60%
Fluorite	accessory		accessory
Pyrite & Molybdenite	accessory		<5%
Carbonate	accessory		0-40%
Zircon & Titanite	accessory		accessory
Epidote	accessory		nil
Apatite	accessory		accessory

3. Chlorite-sericite schist

Quartz	10-30%
Chlorite/sericite	70-90%

4. Metaquartzite ("orthoquartzite")

Quartz	>98%
Sericite	trace
Andalusite	accessory

The Kiggavik mineralization is monometallic (U ± Au, Pt) and occurs in both metasediments and granite. The two major uranium minerals are pitchblende [UO2] and coffinite [USiO4(OH)4]. This mineralization is present as finely-disseminated granules located along foliation planes and/or as colloform aggregates and rosettes in veinlets parallel to the foliation. It is also found as fracture fillings and coatings along cross-cutting structures (Fuchs et al., 1986) and rarely in brecciated metasediments (Farkas, 1984). Fracture-controlled mineralization is more frequently observed in granite than metasediment. The uranium minerals are often associated with brownish Fe-oxide/hydroxides (hematite/limonite). Coffinite surrounds and replaces pitchblende. Gangue minerals are illite, with minor dusty hematite, and variable amounts of chlorite.

Secondary uranium minerals are uncommon, although fine-grained uranophane occurs in weathered rocks at surface and also occasionally at greater depth. Pitchblende and coffinite are often associated with and replace marcasite and pyrite. Other sulphides or accessory metals are present only in minor amounts, resulting in the monometallic composition characteristic of the Kiggavik ore zones.

4.2.1.4 *Physical Properties*

Measurements of density, porosity, electrical resistivity, magnetic susceptibility, and acoustic velocity were conducted on core samples from the Main Zone area (University of Saskatchewan, 2011, see Table 4.2-1).

With the exception of two samples taken from hole MZ-09-01A, the core samples used to determine the physical properties are quite fresh. In contrast, the two samples from MZ-09-01A are clay-altered. MZ-09-1A/246.60 is strongly clay-altered, bleached white, soft, friable, and clayey. MZ-09-1A/257.00 is also clay-altered, but not as strongly as the other sample, being bleached, somewhat friable, and somewhat clayey. The density, porosity, and resistivity data (Table 4.2-1) mirror the degree of clay alteration of the samples, with a lower density, higher porosity, and lower resistivity associated with the clay-altered granite.

Table 4.2-1 Kiggavik Host Rock Physical Properties

Site	Hole / depth	Total porosity (%)	Dry density (g/cc)	SG (calc)	Thermal conductivity (W/m*deg. K)	Specific Heat (MJ/m^3*deg. K)
Kiggavik Main Zone	MZ-07-03 / 236.0 m	0.29	2.596	2.60	3.45	2.13
	MZ-08-02 / 255.0 m	0.74	2.765	2.79	2.33	2.22
	MZ-08-04 / 142.2 m	0.49	2.581	2.59	3.39	2.01
	MZ-08-04 / 170.3 m	1.83	2.567	2.61	3.39	1.95
	MZ-09-1A / 215.5 m	0.29	2.665	2.67	3.46	1.85
	MZ-09-1A / 216.3 m	0.39	2.602	2.61	3.20	1.75
	MZ-09-1A / 246.6 m	13.94	2.242	2.60	3.58	1.62
	MZ-09-1A / 257.0 m	8.53	2.400	2.62	2.91	1.80
	MZ-09-1A / 300.5 m	0.48	2.597	2.61	3.58	1.64
	MZ-09-03 / 227.0 m	0.31	2.634	2.64	3.34	1.51
	MZ-09-03 / 236.0 m	0.42	2.608	2.62	3.23	1.59
	MZ-09-03 / 240.2 m	0.98	2.560	2.58	3.58	1.51
	MZ-09-03 / 247.8 m	0.41	2.602	2.61	3.11	1.91
	MZ-09-04 / 239.0 m	0.52	2.609	2.62	3.91	1.45
	MZ-09-04 / 240.1 m	0.85	2.611	2.63	3.91	1.73
	MZ-09-04 / 241.5 m	0.60	2.618	2.63	3.93	1.86
	LG88-329 / 72.5 m	0.47	2.628	2.64	3.00	1.95
	LG88-352 / 36.6 m	0.89	2.587	2.61	3.45	1.80
Kiggavik Mill Site	RMI09-02 / 19.0 m	13.51	2.299	2.66	2.26	1.88
	RMI09-02 / 23.5 m	0.40	2.592	2.60	3.15	1.92

Site	Hole / depth	P-wave velocity (km/sec)	S-wave velocity (km/sec)	Magnetic susceptibility (x10^{-6} c.g.s.)	Resistivity (Ω-m)
Kiggavik Main Zone	MZ-07-03 / 236.0 m	5.909	3.427	70	17,650
	MZ-08-02 / 255.0 m	5.749	3.169	173	14,568
	MZ-08-04 / 142.2 m	5.621	3.126	8.7	8,030
	MZ-08-04 / 170.3 m	5.039	3.001	21.3	952
	MZ-09-1A / 215.5 m	5.843	3.366	28	14,415
	MZ-09-1A / 216.3 m	5.700	3.188	17	6,345
	MZ-09-1A / 246.6 m	4.227	2.011	12	243
	MZ-09-1A / 257.0 m	4.264	2.379	9	196
	MZ-09-1A / 300.5 m	5.768	3.288	25	13,474
	MZ-09-03 / 227.0 m	5.680	3.350	43	10,997
	MZ-09-03 / 236.0 m	5.178	3.207	156	8,667
	MZ-09-03 / 240.2 m	5.757	3.256	40	9,077
	MZ-09-03 / 247.8 m	5.584	3.185	534	15,057
	MZ-09-04 / 239.0 m	5.567	3.364	29	5,101
	MZ-09-04 / 240.1 m	5.522	3.330	23	3,148
	MZ-09-04 / 241.5 m	5.680	3.408	30.6	4,395
	LG88-329 / 72.5 m	5.966	3.454	22.3	20,535
	LG88-352 / 36.6 m	5.692	3.265	32.4	6,877
Kiggavik Mill Site	RMI09-02/19.0 m	4.309	2.352	28.1	235
	RMI09-02/23.5 m	5.832	3.323	46.2	9,176

4.2.1.5 *Faults and Shear Zones*

The faults and major shear zones identified to date in the Kiggavik area are shown on Figure 4.2-1. The dominant fault systems are interpreted to strike at 065° and 095° respectively. The 065° faults generally appear to dip steeply to the south, while the 095° system is inferred to dip at approximately 60° to the north. The intersection of these fault zones apparently controls the mineralization and linear shape of the orebodies. There is an apparent weakening and alteration of the rock mass up to several metres on either side of the inferred fault trace.

In the Centre Zone, 065° faulting is combined with postulated low angle shearing parallel to the bedding/foliation of the quartzite meta-arkose contact.

Cross cutting faults which dip steeply and trend north-northwest or north-northeast have also been observed. These faults are considered to be relatively minor as they apparently do not affect the ore bodies except for possible minor variations in plunge. The north-northwest trending fault system has a similar trend to the diabase dykes.

4.2.2 Andrew Lake Area

4.2.2.1 *Data*

Historical drilling (1988 to 1997)

Diamond drilling at Andrew Lake began in 1988. All drilling was done by coring, most of which is NQ. In a few holes, drilling difficulties (i.e., blocky, highly fractured rocks, etc…) made it necessary to reduce from NQ to BQ core. Exploration and delineation drilling on the Andrew Lake deposit comprised 85 holes totaling 22,707 meters from 1988 to 1993 and 30 holes totaling 8,627 meters from 1994 to 1997.

Recent drilling (2007 to 2010)

The main objective of the 2007 drilling campaign was to collect ore samples from the Andrew Lake deposit to conduct metallurgical bench-scale tests. A second objective was to collect geotechnical, hydrogeological, and thermal data to confirm mine design assumptions. In 2007, diamond drilling at Andrew Lake was carried out using NQ sized diamond core equipment. Two holes were drilled.

The main objective of the 2008 drilling campaign was to collect ore samples from the Andrew Lake deposit to conduct metallurgical pilot tests. Drilling was carried using NQ, HQ, and HQ3 sized diamond core equipment.

The main objective of the 2009 drilling campaign was to collect additional geotechnical data for pit slope stability analysis and additional hydrogeological and thermal data. In 2009, drilling was carried out using NQ and NQ3 sized diamond core equipment. Three holes were drilled and geotechnically core logged, all with core orientation.

Three holes were completed at the Andrew Lake site in 2010 using NQ sized diamond core equipment. Two holes were drilled to validate the ore model and one hole was drilled to test a gravity low below Andrew Lake. This hole was also used to collect geotechnical data.

The locations of exploration, delineation, and geotechnical holes drilled in the Andrew Lake area since 1988 are shown on Figure 4.2-13. In total, more than 120 holes have been drilled.

4.2.2.2 *Local Geology*

The Andrew Lake deposit is located in metasediments overlying granitic gneiss (banded metamorphic rocks) and granodiorite (an igneous rock). Within the Kiggavik project, granite is the dominant igneous rock (monzo-granite to syeno-granite) as alkali feldspar content is more dominant. These formations have been strongly metamorphosed and altered, tectonized, and intruded. The rocks have gently dipping foliation, small scale recumbent folding, and low angle thrusting. The Andrew Lake deposit is located on a major east-northeast structure. This region has seen several episodes of hydraulic brecciation, mainly within the granite and syenite rocks, and to a lesser extent in the metasediment units. The subvertical faulting associated with the Andrew Lake deposit governs the extension of the mineralization.

Three main mineralized lenses have been identified at the Andrew Lake deposit. These are associated with strongly altered metasediments, altered paragneiss (gneiss metamorphosed from a sedimentary parent), and less altered metasediments. The zones overlie each other, and are separated by a quartz breccia (a poorly sorted rock commonly containing rock fragments), and paragneiss. Mineralization within the Andrew Lake area occurs between 70 and 300 m below ground surface.

Abundant interspersions of syenite and lamprophyre intrusive units are common throughout the Andrew Lake deposit area. The entire deposit area is overlain by approximately 10 to 20 m of unconsolidated overburden material.

The drill plan and a surface projection of the Andrew Lake orebody are presented in Figure 4.2-13. Sections through the Andrew Lake deposit are presented in Figures 4.2-14 to 4.2-16. A three-dimensional view of the mineralized lenses is presented in Figure 4.2-17.

4.2.2.3 *Fault and Shear Zones*

Regional fault traces as shown on Figure 4.1-3 sub-parallel the regional trend on which the End Grid and Andrew Lake deposits occur.

At the Andrew Lake deposit, the regional Andrew Lake Fault, which is steeply dipping and trends northeast at 030°, is interpreted to lie within the footprint of the proposed pit. It is possible that four dominant north-northeast trending faults mapped from historical core data are related to the Andrew Lake fault.

Numerous structural features including fault zones and breccia units were noted during exploration and delineation of the deposit. Four dominant structures are interpreted to be the main controls on the lateral extents of the uranium mineralization found at Andrew Lake. The main control is exercised by north-northeast trending, sub-parallel, steeply dipping (i.e. 70-75°) features that strike in the same orientation as the uranium mineralization at Andrew Lake. There is also indirect evidence of structural features which cross-cut these faults, although there is limited drill core data to support this. It is estimated that these cross-cutting features run sub-parallel to the north-northeast trending faults, and may have an influence on the mineralization at Andrew Lake. It has been estimated these cross cutting features dip steeply to the southwest.

The last phase of brittle deformation that occurred in the Andrew Lake deposit area is considered to coincide with uranium deposition. This period of brittle deformation would have created the conduits through which silica-rich and uranium-rich fluids would have propagated through the deposit area. Because the dominant silica-rich fault structure and Quartz-Breccia marker horizon appear to act of barriers to the uranium mineralization, it is assumed that the uranium deposition would post-date this initial hydrothermal event.

The dominant faults at the deposit scale, as well as the regional fault trends for Andrew Lake are plotted on Figure 4.2-18.

4.2.3 End Grid Area

4.2.3.1 *Data*

Historical drilling (1987 to 1996)

End Grid deposit was first drilled in 1987. In total, 71 holes were drilled from 1987 to 1996. No drilling was conducted in 1990, 1994, and between 1997 and 2006.

Recent drilling (2007 to 2010)

Drilling activities at End Grid resumed in 2007. One hole was drilled with the objective of collecting ore samples and geotechnical, hydrogeological and thermal data.

The main objective of the 2008 drilling campaign was to collect ore samples from the deposit to conduct metallurgical pilot tests. Four holes were drilled.

The main objective of the 2009 of 2010 drilling campaigns was to improve the understanding of the End Grid deposit, from a resource and mining perspective. In total, 17 holes were drilled in 2009. Fifteen drillholes were geotechnically core logged, nine of which had core orientation, eight drillholes were also relogged to assess degradation with time and three historical holes from 1995 were core logged for data infill purposes. Most of the drilling in 2010 focussed on the North Pod of End Grid deposit and all of these holes except three were within, or on the edge of this pod. They either confirmed or delineated the known mineralization in this area. In total, 14 holes were drilled using NQ sized diamond core equipment.

The locations of exploration, delineation, and geotechnical holes drilled in the End Grid area since 1987 are shown on Figure 4.2-19.

4.2.3.2 *Local Geology*

The End Grid deposit is located in metasediments, intruded by granite, porphyries, syenites, and lamprophyres. The mineralization within the deposit is related to an East/North East quartz healed breccia. Most of the mineralization is observed along fracture planes, associated with quartz veins and locally leached out along foliation with no significant vertical offsets.

Two main mineralized pods (North Pod and South Pod) have been identified at the End Grid deposit. These are located in strongly altered metasediment that are tectonized, with steeply dipping tension faults and hydraulic breccias. Mineralization at the End Grid deposit occurs between 75 m and 450 m below ground surface.

The 2009 drilling program on the North Pod confirmed that a thick oxidised horizon is encountered from surface to 80-300 m below the surface. It was traditionally interpreted as a paleoweathering profile emplaced before the sub-Thelon formations deposit. The mineralization envelopes are limited upwards by this oxidised horizon, which is interpreted to postdate the hydraulic silica breccias and granitic veins.

The primary low grade mineralization is disseminated within the foliation and in association with microfractures. Several examples show an association of granitic to quartzic small intrusions with the mineralization. The global trend of the primary mineralization is ENE/WSW. This trend is parallel to a former quartz breccias trend. No direct relation between breccias and mineralization has been observed. The secondary medium to high grade mineralization is associated with a late tectonic event. NNW/SSE faults are formed and the ENE/WSW silica breccias trend is reactivated by brittle faults cutting across the primary mineralization and oxidising fluids have remobilized it. Fractures with pitchblende are encountered around the main deformation fault zone and in association with Red-Ox fronts surrounding the late faults. Red-Ox fronts and associated mineralization are also common along foliation and former ductile shear zones parallel to foliation.

The drill plan and a surface projection of the End Grid North Pod orebody are presented in Figure 4.2-19. Sections through the End Grid North Pod deposit are presented in Figures 4.2-20 and 4.2-21. A three-dimensional view of the mineralized lenses is presented in Figure 4.2-22. A plan view map show in the proposed mine development footprint with the geology and faults is provided in Figure 4.2-25.

Unpublished internal petrographic determinations have been made on altered quartzo-feldspathic metasediment material from End Grid. This metasediment appears to be similar in mineralogy to that observed at Kiggavik (original: 35-50% quartz, 20-40% feldspar, 10-25% mica [biotite, muscovite], trace zircon; altered: 40-80% clay [illite, chlorite], 15-50% quartz, 0-5% Fe-oxides).

4.2.3.3 *Fault and Shear Zones*

Nine 2009 drillholes with oriented cores have been studied in detail to implement a data orientation analysis. The trend of the primary mineralization is ENE/WSW, and is disseminated within the foliation and in micro-fractures. The overall foliation is oriented N170° and dips 10° to 30° eastward. This orientation is consistent with the foliation measured on outcrop NE of the Project area (N160°.18°E). The second mineralization is associated with a late tectonic event that has formed NNW/SSE trending faults. These faults are referred to as late faults because of their association with a late tectonic event. Within the deposit area, zones of greater fracturing associated with late faults appear to be infilled with late fluid flows from the secondary mineralization. The NNW/SSE trending faults oriented N160 offset the entrie deposit area, but are considered birittle dry faults with little to no fluid associated with them. These N-S fault zones are observed to be rubbly/blocky intervals with little to no alteration. The N130 trend has numerous examples of the remobilized fluids through them; however, they are never associated with mineralization directly, suggesting that the N130 was a fluid conduit. Fractures infilled with pitchblende are found surrounding late faults. In addition, fault gouge and quartz veins are also typically found in these faults.

Fractures and faults measured define three sets of structures (Figure 4.2-23). The first is oriented N40 to N70. It is consistent with the main ENE/WSW trend defined by the quartz breccias structures, late faulting parallel to this trend and with the formerly modelled mineralized envelopes trend. The second set is oriented N160. This set is consistent with the N140 to N170 faults observed and measured on outcrop and with N140 faults. The third set is oriented N110-120. This orientation has not been observed on outcrop.

Orientation measurements show that faults and fractures with mineralization are oriented N140/150, N00/N20 and N70. Those orientations are correlated to the N140/150 and N00/N20 late faults orientations and with the N70 orientation defined by the silica breccias and the late reactivation along this trend.

On average, there were 124 fractures per hole in the eight holes logged at End Grid that are shown in Figure 4.2-23. The average length of these holes was 395 m. No bias correction was applied to these measurements, and fracture dip angles were recorded.

4.3 Bedrock Geotechnical Conditions

4.3.1 Kiggavik

4.3.1.1 *Material Properties*

Representative samples for the Kiggavik Main and Centre Zone pits were collected as part of the 2009 geotechnical investigation, and strength tested in the laboratory. The testing was conducted at the University of Saskatchewan's Rock Mechanics Laboratory. A total of 16 Unconfined Compressive Strength (UCS) tests were carried out for the Main Zone and Centre Zone samples. The measured material parameters included:

- UCS;
- Young's Modulus;
- Poisson's Ratio; and
- Bulk Density (based on physical measurements of the sample dimensions and weight prior to testing).

To complement the laboratory testing program, a field estimate for rock strength according to the International Society for Rock Mechanics (ISRM) standards for assessing rock hardness (ISRM 1981) was undertaken during geotechnical core logging. Also, point load tests (PLT) for the estimation of the PLT index strength (Is(50)) were carried out at the site on selected rock intervals. A total of 244 valid PLT tests were carried out on the Main Zone and Centre Zone rock types.

Based on the results of the assessment, alteration is assumed to be the main control on rock strength, particularly in zones where faulting and ore zone halo alteration are more pronounced. The Main and Centre Zones show substantially less alteration, resulting in considerably stronger rock conditions. An example figure illustrating the measured material density with UCS strength is shown on Figure 4.3-1. The density determinations shown in Figure 4.3-1 show that there is a noticeable decrease in strength with decreasing density. The wall rocks for the Kiggavik Main and Centre pits are generally competent to very competent rocks and exhibit brittle rock characteristics. The unaltered granites and metasediment rock units showed similar strengths, ranging from strong to very strong. The metasediments were shown to be slightly weaker than the granites, but are still very competent with respect to providing a stable wall for an open pit. Altered zones related to faulting or ore zone halo alteration are expected to reduce the rock strengths considerably. The ISRM weathering index (ISRM 1981) as assessed during the borehole investigation was used for assessment of weathering/alteration at the MZ/CZ. The potentially altered zones on the final pit walls were assessed for rock mass stability considerations. Results from the laboratory strength testing program are summarised in Table 4.3-1.

Table 4.3-1 Main Zone & Centre Zone - Summary of UCS Tests by Rock Type and Alteration

Rock Type	Alteration (SRM)	# Tests	UCS (MPa)	Youngs Modulus (GPa)	Density (g/cm^{3})	Poissons Ration
Metasediments	Highly altered (W5)	1	21.8	6.6	2.37	0.01
	Fresh (W1)	8	98.4 +/-26.1	44.6+/-6.3	2.69+/-0.10	0.17+/-0.02
Granite	Slightly to Moderately altered (W2 to W3)	3	55.9+/-27.0	23.9+/-18.2	2.42+/-0.22	0.10+/-0.03
	Fresh (W1)	4	112.3+/-28.5	45.1+/-3.4	2.64+/-0.05	0.15+/0.01
NOTES: MPa=mega pascal, GPa=giga pascal, g/cm^{3}=grams per cubic centimetre						

All rock strength testing was conducted on thawed core. The strength characteristics of rock types tested are unlikely to differ significantly in a frozen state due to very low moisture content/void ratios. The highly altered rocks such as the ore zone materials have a relatively high void ratio which implies that they are likely to be significantly stronger in a frozen state than in an unfrozen condition. The potential reduction in strength with thawing may contribute to unravelling of the rock on the slope face, which would be exacerbated in the blocky rock conditions associated with high alteration.

4.3.1.2 *Rock Mass Quality*

An assessment of rock mass quality was carried out for the geotechnical data obtained from the 2009 borehole program. Little historic information was available with regards to the engineering geology of the various rock units at the two sites. The rock mass quality assessment was carried out by calculating a Rock Mass Rating (RMR) index value (0 to 100) on a per run basis (typically 3 m in length).

Recommendations for RMR and strengths for the rock units at Kiggavik Main and Centre are given in Table 4.3-2. Rock mass qualities for the majority of the pit walls are generally fair to good, with strong to very strong intact rock strength. Some rock mass stability concerns might however be considered where faulting or mineralization alteration transects the pit boundaries, as the presence of moderately to highly altered rock reduces the strengths considerably.

Table 4.3-2 Main Zone and Centre Zone - Recommended RMR and Strengths Parameters

Rock Unit	RMR (1976)	Comment	Strength	Comment
Upper Metasediments (approximately less than 75 m depth)	46 to 66 (fair to good)	Range of RMR from lower to upper bound limits for the 2009 Upper Metasediment data.	R4/R5 (strong to very strong)	Average UCS =93.4 MPa and average $Is_{(50)}$=7.9 MPa for slightly altered
Lower Metasediments (approximately greater than 75 m depth)	62 to 71 (good)	Range of RMR from lower to upper bound limits for the 2009 Lower Metasediment data.	R4/R5 (strong to very strong)	Average UCS=93.4 MPs and average $Is_{(50)}$=8.4 MPa for fresh rock
Granites	62 to 76 (good)	Range of RMR from lower to upper bound limits for the 2009 Granite data.	R4/R5 (strong to very strong)	Average UCS=112.3 and average $Is_{(50)}$=10.0 MPa for fresh rock
Fault or Mineralization Altered Zones	46 to 62 (fair to good)	Lower Bound RMR for all 2009 lithology data.	R3 (moderately strong)	Average UCS=21.8 MPa for highly altered metasediments, and average UCS=55.9 for slightly too moderately altered granites.

4.3.2 Andrew Lake

4.3.2.1 *Material Properties*

An assessment of mineral alteration (argilization and chloritization) and its effect on the intact strength and density of the rock were carried out for the Andrew Lake rock samples. Alteration indices were logged and an index value was assigned to reflect the relative degree of alteration (0 = non-altered and 4 = intensely altered). The strength testing results show a good correlation between the degree of alteration, related decrease in material density, and decrease in strength.

Based on the results of the assessment, alteration is assumed to be the main control on rock strength at the Andrew Lake site, where faulting and ore zone halo alteration are more pronounced. An example figure illustrating the measured material density with UCS strength is shown on Figure 4.3-1. The density determinations presented in Figure 4.3-1 show that there is a noticeable decrease in density with increasing alteration.

Little factual information is known about the wall rocks at Andrew Lake, other than that which has been determined from the geotechnical holes drilled in 2009, and other information available from exploration holes that incidentally intersect wall rock slope toes. Reasonably conservative interpretation of available information suggests that some of the pit slopes may be entirely comprised of weak, deformable rock masses due to a combination of regional faulting and clay and chlorite alteration. Similarly, the lower portions of all rock slopes are interpreted to also intersect weak, deformable rock masses. Away from the faulting and alteration halos, competent rocks are interpreted to occur. The granites and metasediments at depth (gneisses) away from zones of alteration are shown to be moderately strong to strong. Results from the laboratory strength testing program are summarized in Table 4.3-3.

Table 4.3-3 Andrew Lake - Summary of UCS testing by rock type and alteration

Rock Type	Alteration	# Tests	UCS (MPa)	Young Modulus(GPa)	Density (g/cm^3)	Poissons Ration
Metasediments <200 m depth	Low to Mod Alt (Af=1 to2)	8	29.9+/-13.2	11.3+/6.5	2.46+/-0.17	0.08+/-0.04
	Mod. To High Alt (Af=3 to 6)	3	15.9+/-1.7	2.8+/-1.5	2.39+/0.17	0.09+/0.05
Granite	Low to Mod Alt (Af=1 to 2)	2	66.5+/-20.4	22.4+/-2.5	2.53+/-0.10	0.15+/-0.02
	Mod to High Alt (Af=3)	1	24.7	6.1	2.45	0.24
Inferred Fault	Low to High Alt (Af=1 to 6)	2	7.4+/-3.5	1.4+/-1.4	2.03+/-0.08	0.05+/-0.01
Quartz Breccia	Low Alt (Af=1)	1	35.0	19.9	2.63	0.16

NOTES:
MPa=mega pascal, GPa=giga pascal, g/cm^3=grams per cubic centimetre, Af=alteration factor

4.3.2.2 *Rock Mass Quality*

At Andrew Lake, considerable variability in RMR was observed in the boreholes due to improved ground conditions with depth, as well as due to the inferred proximity to faulting and mineralization zones. The data was grouped by geology and alteration in order to make a better assessment of the varying geotechnical qualities for the various rock mass domains. The recommended RMR and strengths based on the statistical significant intervals of quality and strength for the upper metasediments, granitics, lower metasediments, and alteration zones and summarised in Table 4.3-4. The ranges in RMR reflect the variability in values for the upper bound, lower bound, and average cumulative distributions of the data. A number of comments are included on this table to substantiate the recommended values.

Table 4.3-4 Andrew Lake - Recommended RMR and strengths parameters

Rock Unit	RMR (1976)	Comment	Strength	Comment
Upper Metasediments (approximately less than 200 m depth)	42 to 62 (fair)	Range of RMR for lower to upper bound limits for 2009 Upper Metasediments data. Average RMR of nil to moderately altered ground.	R2/R3 (weak to moderately strong)	Average UCS=29.9 MPa and average $Is_{(50)}$=2.2 MPa for upper metasediments
Granites (all)	52-65 (fair to good)	Range of RMR for lower to upper bound limits for the 2009 Granite data. Average RMR of nil to moderately altered ground.	R3/R4 (moderately strong to strong)	Average UCS=66.5 MPa and $Is_{(50)}$ =5.5 MPa
Lower Metasediments/Paragneiss (approximately greater than 200 m depth)	52-74 (fair to good)	Range of RMR for lower to upper bound limits for the 2009 Lower Metasediments data. Average RMR of nil to slightly altered ground.	R4 (strong)	Average $Is_{(50)}$=7.3 MPa
Fault or Mineralization Altered Zones	42 to 52 (poor to fair)	Lower Bound RMR of all 2009 lithology data. Average RMR of 2009 highly altered data.	R2 (weak)	Average UCS =7.4 to 24.7 MPa for moderate to highly altered rock or fault related zones

4.3.3 End Grid

A preliminary geotechnical model has been developed based primarily on data collected during the 2007, 2008, and 2009 field programs. Data collected during the 2010 field program was used for confirmation purposes. A systematic review and analysis of the data within the footprint of the deposit was carried out and common patterns emerged.

Relatively consistent rock quality is observed in five distinct groups:

- metasediments above the hematite alteration surface;
- rock subject to short term degradation above the ore zones;
- mineralized zone consisting of both low and medium to high grade ore zones;
- rock to the NW of the mineralized zone below the hematite alteration surface; and
- fresh metasediments below the hematite alteration surface to the SE of the ore zones.

4.3.3.1 *Hematite Altered Metasediments*

Above the hematite alteration surface, rock is generally of fair quality with some poor to very poor intervals. This zone is characterized by pervasive hematite alteration; rock is generally moderately altered, red in colour and finely crystalline. Localized highly altered zones appear to be associated with some form of structural weakness such as increased fracturing, or the presence of clay alteration. There is potential for medium to long-term degradation of rock within this zone.

4.3.3.2 *Short-Term Degredation Zones*

The 'short-term degredation' zone refers to intervals of rocks which have been observed to degrade over a relatively short time period of days to weeks. These zones are located above the ore zones and beneath the hematite alteration surface, are characterized by fair rock of weak to medium strength with some poor to very poor intervals and are commonly associated with chloritization, argillization, and bleaching. Unlike the rock above the hematite alteration surface this zone is susceptible to short term degradation within days to weeks of exposure to air.

Late brittle faulting associated with tectonic breccias, clay gouges, and bleaching has been observed both within silica-breccia zones and parallel to them. This regional ENE/WSW trend was reactivated by brittle faults which both cross cut and remobilized the breccias creating shear zones parallel to the foliations. While the late transverse faults which offset the silica breccia and the uranium envelopes, the faults do not appear to impact rock quality. The late faults parallel to the ore zones do appear to be related to short term degradation trends observed in the rock core. No other trends have been identified other than the relatively consistent presence of these zones above and occasionally between areas of mineralization.

4.3.3.3 *Mineralized Zone*

Rock within the mineralized zone is generally fair quality, medium strong rock to strong rock with some localized weak zones. The mineralized zone is usually less altered than the short-term degradation 'cap' above. However, remnant chlorite hematite and clay alteration are interspersed throughout and alteration adjacent to zones with visible mineralized veins is more intense. The mineralization trends ENE/WSW; this trend is parallel to a former quartz breccias trend.

4.3.3.4 *NW of the Mineralized Zone*

Rock to the NW of the mineralized zone below the hematite alteration surface is generally described as fair quality rock with some poor quality intervals. This area has not been associated with significant levels of long term or short term degradation of rock quality.

4.3.3.5 *Fresh Metasediments*

The fresh metasediments are generally characterized as strong to very strong rock with fewer visible alteration minerals. The zone is described as fresh to slightly weathered, laminated to thinly foliated, grey in colour, finely crystalline and strong to very strong. Alteration is generally only associated with discontinuity surfaces. No visible degradation of fresh metasediments has been observed in either the historical holes or during the 2009 drilling program. Consistently strong, moderately fractured, good quality rock was encountered in boreholes intersecting this zone.

4.3.3.6 *Intact Rock Strength*

ISRM strength estimates for intact rock strength were recorded for each individual 3m interval along 15 boreholes of the 2009 geotechnical field program. Additional holes drilled in the 2010 field program were used for verification purposes.

The North Pod of the End Grid deposit is characterized by an oxidized horizon above a paleoweathered surface. The intact rock strengths in this horizon are generally between R2 and R3 values (5-50 MPa) with isolated areas of weaker material (R1, 1-5 MPa). Below the paleoweathered surface and within the mineralized zones, the intact rock strengths appear to increase to between R3 and R4 values (25-100 MPa) with isolated areas of weaker rock (R2, 5-25 MPa) and stronger rock (R5, 100-250 MPa).

4.3.3.7 *In Situ Stress*

No in-situ stress measurements have been taken to date. No estimate of in-situ stress was used in the mine design and any reasonable assumption on in-situ stress conditions would not impact the design of the End Grid underground mine.

4.3.3.8 *Rock Mass Quality*

Rock quality was logged as a dry RMR_{76} where the parameter that accounts for the influence of groundwater in the quality of the rock mass was assumed to be that of dry conditions. Typical RMR values seen within the End Grid deposit are between 40-80% (fair to very good rock). There are numerous short intervals that have values less than 40% and a few short intervals in the footwall of the deposit that have values above 80%.

5 Ground Temperature

5.1 Field Data

Historical thermal data were collected at the Project site from 1988 to 1991, and recent data was collected from 2007 to 2011. In these investigations, multilevel thermistor strings were installed in select drillholes to determine the temperature profile of the ground beneath the Project site, and, therefore, the thickness of the active layer and the permafrost. The multilevel thermistor strings consist of temperature probes installed at regular intervals along the drillhole. The locations of multi-level thermistor strings installed at the Kiggavik and Sissons sites are presented in Figures 5.1-1 and 5.1-2.

5.1.1 Historical Data

In 1988, in the area of the Main Zone, Centre Zone, and East Zone deposits, three deep multilevel thermistor strings (88-331, 88-332, and 88-333) were installed at the Project site to a maximum depth of about 170 m below ground surface. In 1990 and 1991, in the area of the Andrew Lake deposit and the End Grid deposit, five deep multilevel thermistor strings were installed to a maximum depth of about 330 m below ground surface. Data from these thermistors strings were recorded periodically for between three weeks and seven weeks after installation.

5.1.2 Recent Data

2007 Field Season

In 2007, the field program (SRK, 2007) consisted of installation of the following probes and multi-level thermistor strings.

- Four single point temperature probes with dataloggers were installed during the field program. A first unit was attached outside the office cabin at the Kiggavik camp, 1.8 m above ground and recorded the ambient air temperatures. The second unit was inserted at 15 cm depth into tundra soil in a relatively flat area. The third unit was placed between large boulders in a prominent boulder field near Main Zone ore zone. The last sensor was placed in a shallow lake south-west of the Kiggavik camp, in about 1.5 m of water.
- A shallow thermistor cable was installed to a depth of 25.4 m inside drillhole END-07-01. The 10 sensor cable was connected to a datalogger which recorded temperature data at 12 hour intervals.

- Two deeper multilevel thermistor strings (up to 300 m length) were installed in boreholes MZ-07-03, and ANDW-07-01 to ultimate depths of about 210 m below ground surface and 270 m below ground surface, respectively.

Temperature readings from the thermistors strings were collected by field staff in August and September of 2007 and 2008 (SRK, 2009).

2009 Field Season

During the 2009 field season, thermistors were installed in four boreholes: END-09-01, ANDW-09-03, MZ-09-02, and MZ-09-04 to depths of up to 300 m below ground surface (Golder, 2009). Temperature readings from these instruments were recorded by field staff periodically, approximately every five to ten days, while on site.

2010 Field Season

Monitoring of all existing thermistors and vibrating wire piezometrers was conducted during the 2010 field season. Readings were taken from six thermistors/vibrating wire piezometers: one at End Grid, two at Andrew Lake and three at Kiggavik Main Zone deposits.

2011 Field Season

During the 2011 field season, multilevel thermistor strings were installed in two boreholes at Kiggavik: GW-11-01 and GW-11-02 to depths of up to 250 m below ground surface (Golder, 2011). Temperature readings were collected from these instruments and from thermistors installed at the site during the previous investigations.

5.2 Active Layer and Surface Conditions

The temperature data collected from the four single point temperature probes with built-in dataloggers is shown in Figure 5.2-1. This figure shows the range in temperatures depending on the surface conditions. As the ambient air temperature shows the largest scattering, the shallow overburden is less affected by the snow cover while the temperatures measured in the boulder field are dampened considerably. This is probably due to snow and ice entrapped between the boulders that acted as insulation. The unit in the shallow lake did not freeze over the recorded period but is apparently responding to warm temperatures. The collected temperature data collected to date clearly show the importance of boundary conditions, which are valuable for thermal modeling. A longer monitoring period would be required to complete the interpretation of the temperature data.

Figure 5.2-2 shows the entire collected dataset at borehole END-07-01, where the vertical axis is the depth, the horizontal axis the time and the contours show the ground temperature distribution. The dataset covers the period from September 29, 2007 to June 21, 2008. Figure 5.2-3 shows the distribution of the ground temperature as a function of depth. Data suggests that the zero annual amplitude, which is the depth at which the ground temperatures are not affected by seasonal changes in surface temperatures, is probably about 20 m below ground surface. At the Meadowbank Project site, located about 100 km of northwest of the Kiggavik Project site, the depth of the zero amplitude was estimated to be between 20 and 25 mbgs (Golder, 2003). Therefore, this estimate of the zero amplitude thickness is considered reasonable.

It should be noted that due to equipment malfunction, shallow thermistor was not collected for the months of August and September, for which the active layer is expected to reach its ultimate depth; therefore, the depth of the active layer cannot conclusively be estimated from site data. 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 mbgs.

5.3 Deep Thermal Conditions - Kiggavik Area

Figures 5.3-1 and 5.3-2 show the historical and recent temperature profiles recorded in the Kiggavik area. Multilevel thermistor data collected suggests that the depth of permafrost near the Main Zone, Centre Zone, and East Zone deposits is slightly shallower than in the area of the Andrew Lake and End Grid deposits (Table 5.3-1). Multi-level-thermistor data collected from 2007 to 2011 indicate that permafrost extends to a depth of about 210 m to 230 m below ground surface in the area of the Main Zone, Centre Zone, and East Zone deposits. This is somewhat shallower, but generally consistent with data from historical thermistor installations, which suggests permafrost depths at the site ranging from 220 m to 240 m below ground surface.

Table 5.3-1 Estimated Permafrost Depths at Multi-Level Thermistor Locations

Area	Deposit	Borehole	Permafrost depth (m below ground surface)	Operator
Kiggavik	Main Zone	MZ-07-03	215	SRK, 2007
Kiggavik	Main Zone	MZ-09-02	210	Golder, 2009
Kiggavik	Main Zone	MZ-09-04	215	Golder, 2009
Kiggavik	North of Main Zone	GW-11-01	280	Golder, 2011
Kiggavik	South of Main Zone	GW-11-02	230	Golder, 2011
Kiggavik	*Main Zone*	*88-331*	*160*	*Golder, 1989*
Kiggavik	*Main Zone*	*88-332*	*240*	*Golder, 1989*
Kiggavik	*Main Zone*	*88-333*	*220*	*Golder, 1989*
Sissons	Andrew Lake	ANDW-07-01	260	SRK, 2007
Sissons	Andrew Lake	ANDW-09-03	250	Golder, 2009
Sissons	*Andrew Lake*	*ANDW-030*	*260*	*UG, 1990/91*
Sissons	*Andrew Lake*	*ANDW-033*	*270*	*UG, 1990/91*
Sissons	*Andrew Lake*	*ANDW-041*	*270*	*UG, 1990/91*
Sissons	*Andrew Lake*	*ANDW-050*	*280*	*UG, 1990/91*
Sissons	End Grid	END-09-01	240	Golder, 2009
Sissons	*End Grid*	*END-019*	*260*	*UG, 1990/91*

NOTE:

The permafrost depth from 88-331 is inconsistent with all other results, and is likely due to installation problems or malfunctioning temperature probes.

The permafrost depth from GW-11-01 is questioned. The thermistor string installed in borehole GW-11-01 did not extend past the base of permafrost. The permafrost depth is based on a linear interpolation past the last datum to reach the 0 degree temperature.

5.4 Deep Thermal Conditions - Sissons Area

Figures 5.4-1 and 5.4-2 show the historical and recent temperature profiles recorded in the Sissons area. Multi-level-thermistor data collected in transducers from 2007 to 2010 indicate that permafrost extends to between 240 m and 260 m depth below ground surface in the area of the Andrew Lake and End Grid deposits. This is somewhat shallower, but generally consistent with data from historical thermistor installations, which suggests permafrost depths at the site ranging from 260 m to 280 m below ground surface.

6 Groundwater Quality

6.1 Field Data

Groundwater sampling in a low hydraulic conductivity environment is challenging because of the longer time required to obtain the volume of water necessary for sampling. In continuous permafrost areas, the difficulties increase due to concerns regarding freezing of the drill hole. Only one groundwater sample was successfully collected at the Kiggavik site, using packer equipment, in 2009. In 2010 and 2011 samples were also collected from artesian flowing exploration boreholes at the Bong site. Several drill return waters were collected during historical drilling programs and a rig tank sample was collected in 2008.

6.1.1 Historical Data

Samples of drill return water were collected during the drilling programs conducted from 1989 to 1997. The majority of the drill return water samples (24 out of 30) were filtered at the site before preservation. Samples were sent for analysis at Saskatchewan Research Council (SRC) analytical laboratory.

For comparison, samples of lake water from Andrew Lake and End Grid Lake were also collected over the period of 1995 to 1997.

6.1.2 Recent Data

2008 Field Season

Water sampling was attempted at borehole END-08-02 during the 2008 field season. During drilling, the borehole had been observed to be flowing; however, when water sampling was attempted, no groundwater flow from the borehole was observed and sampling was not possible. Instead, a sample was taken from the rig circulation tank. About nine hours before sampling, one bag of calcium chloride had been mixed into the tank by the drillers to reduce the chance of freezing of the drilling brine.

The circulation tank represents a mixture of lake water, which is relatively fresh water, and bags of calcium chloride to produce a brine that would remain unfrozen while drilling through permafrost. Due to environmental concerns at the borehole location, all drill water from the borehole was collected and pumped to a separator, which removed solids, after which the water was returned to the drill circulation tank for reuse. The tank was only topped up with lake water, and additional bags of calcium chloride when necessary, when drill water was lost down the hole.

The sample was shipped to SRC analytical laboratory in Saskatoon.

2009 Field Season

The groundwater sampling location was selected based on relatively high hydraulic conductivity values encountered during the testing program. In this manner, the vertical borehole, MZ-09-04, was drilled through permafrost and into the sub-permafrost groundwater in the area intercepted by the inclined borehole MZ-09-03, which had relatively high calculated hydraulic conductivity values. Figure 5.1-1 shows the location of these two boreholes.

Drilling

The borehole MZ-09-04 was drilled as an HQ-size borehole (96 millimetre [mm]) diameter) to accommodate the equipment required for the groundwater sample collection. The drilling fluid used while advancing MZ-09-04 was heated fresh water. A rhodamine tracer was added to the drill water once the drillhole had extended past the base of permafrost. This tracer was added to assist in the monitoring process during development of the sampling interval prior to sample collection. If the sample water indicated a very low rhodamine concentration then the sample was considered to be relatively undiluted by drill fluid and to be representative of the groundwater quality.

Sampling

Field staff sampled groundwater beneath permafrost in MZ-09-04 using the following procedure.

A HQ-size packer was lowered on dedicated BQ-size (60 mm) test rods to about 220 m below ground surface. A datalogger programmed to a one minute sampling frequency was installed below the packer tool to record pressure and temperature during the sampling process.

To prevent freezing of the BQ test rods in the drillhole, the annular space outside the BQ test rods above the packer was continuously flushed with warm, saline water. Two one-quarter inch PVC tremie pipes were attached to the rods while the packer was lowered into the drillhole to allow circulation. One pipe outlet was placed a few metres above the packer, the second was placed half way down (Figure 6.1-1).

The packers were inflated to hydraulically isolate the sampling interval. After packer inflation, water began to flow from the BQ test rods, indicating that the groundwater pressure over the depth interval to be sampled was above the ground surface. A stuffing box was attached at the top of the BQ rods and connected with the flow board. Using the valve on the flow board, the system was closed (shut-in), and the pressure build-up was monitored with a manual pressure gauge.

The valve was opened and the drillhole was allowed to flow. The discharge rate and the standard field chemical parameters were monitored at about 30 minute intervals. These parameters were also monitored in the water being circulated outside the test rods to check for leakage through the packers. For comparison, one groundwater sample was collected from the water circulated outside the test rods during this purging period.

Groundwater samples from the sample interval were collected when the field parameters became stable after about 44 hours of flow, and the tracer could not be visually detected in the discharge. These samples, which consisted of one sample, one duplicate, and one sample of the purge water collected from water circulated outside the test rods, were collected in dedicated bottles and preserved as required.

Immediately after collection of the groundwater sample, a dissolved radon sample was collected using a pressurized stainless steel container suspended through the test rods on nylon tubing. The container was equipped with custom-made valves that kept the container pressurized after it was recovered from the drillhole.

Groundwater samples were shipped to SRC analytical laboratory in Saskatoon, and analyzed for major ions, total and dissolved metals, uranium, radium 226, total dissolved solids, deuterium, and oxygen 18.

2010 and 2011 Field Seasons

In 2010 and 2011 samples were collected from two artesian flowing exploration boreholes at the Bong site (BONG-45 and BONG-052, see also section 8.1-1). Figure 5.1-3 shows the location of these two boreholes. Water samples were collected on surface. Following sampling the holes were sealed after and permanently capped. The sample were shipped to SRC analytical laboratory in Saskatoon, and analyzed for major ions, total and dissolved metals, uranium, radium 226 and total dissolved solids.

6.2 Results

2009 Samples

Three groundwater samples were collected in MZ-09-04 during the 2009 field program. These samples, which consisted of one groundwater sample, one duplicate of that sample, and one sample of the purge water collected from water circulated outside the test rods, show similar chemistry (with the exception of the pH of the purge water during development). They have similar concentrations of major elements including calcium, sodium, magnesium, chloride and alkalinity, and similarly low concentrations of dissolved trace elements. The three samples also show similar enrichment and proportions of the heavy isotopes of water (oxygen-18 and deuterium). This corroborates with the high groundwater flows and artesian conditions of the well, suggesting that well water quality became stable and was representative of formation water shortly after initiating well development.

The concentration of major elements, principally calcium, sodium, and chloride, and corresponding electrical conductivity and total dissolved solids (TDS) concentration are considerably higher than those of local lake waters. The concentration of major elements is likely attributed to the natural calcium-sodium-chloride salinity of the deep bedrock. This is encountered at numerous other locations within the Canadian Shield (Clark *et al*, 2000; Frape and Fritz, 1987). The groundwater sample is considered to be representative of the formation water because: 1) the high purge volume of the well by natural formation water prior to sampling, 2) the consistency of water quality during development and sampling, and 3) the concentration of sodium in groundwater which is associated with bedrock salinity but present in only trace amounts in the calcium chloride drilling water additive (DowFlake product MSDS) that was circulated above the top packer to prevent freezing of the drill rods.

Cross-plots of major elements chloride vs. calcium and chloride vs. sodium were used to compare the groundwater sample collected from MZ-09-04 with the rig circulation tank sample collected in END-08-02 in 2008, historic drill return samples collected from 1989 to 1997, and lake water samples collected from 1995 to 1997, and are presented in Figure 6.2-1. There is a distinct chemical signature, indicated from the presence of major ions (i.e., calcium, chloride and sodium), in the groundwater samples, compared to the lake samples, rig circulation tank sample, and historic drill return samples, which all have very low major element concentrations. TDS for the groundwater sample and the historic samples were calculated with the principal major element contributors to TDS (*i.e.,* calcium, magnesium, sodium, alkalinity, potassium, sulphate, and chloride). Attachment B tabulates the results of the calculated TDS and shows that the groundwater sample has over an order of magnitude greater, calculated TDS than the historic drill return and lake water samples.

The TDS resulting from laboratory analysis of the groundwater sample (Table 6.2-1), collected at about 250 m below ground surface, is 3,500 milligrams per liter (mg/L). This TDS is consistent with the composition of deep groundwater in the Canadian Shield (Frape and Fritz 1987) at the depth that the sample was collected.

The chemical signature from the water isotope is similar to that of arctic precipitation (Clark and Fritz 1997). The isotopic signature of the groundwater may be suggestive of dilution with surface water, for example, through a hydrogeologically conductive fracture system as documented elsewhere (Clark et al. 2000; Frape and Fritz 1987). This could have an attenuating effect on groundwater salinity (the deep groundwater away from the effect of water-conductive fractures may be more saline than measured). The isotopic signature of surface water would be required to allow a comparison between these water sources.

In addition to groundwater samples collected at MZ-09-04, dissolved radon gas samples were collected. One sample and one duplicate sample for dissolved radon gas analyses were collected. Results are shown on Table 6.2-1.

A comparison of the groundwater sample results in MZ-09-04 with the duplicate sample results was undertaken as a QA/QC measure. The relative percent difference (RPD, the absolute difference between the two values divided by the mean) of duplicate analyses was used to evaluate the sample result variability. An RPD value of less than 20% was considered an indication of acceptable sample variability, and therefore was considered to represent a good correlation between the duplicate samples. Where the concentration of a given parameter was less than five times the method detection limit (MDL), the results were expected to be less precise (more variable) and the RPD was not calculated. For parameters with concentrations less than five times the MDL, if the absolute difference between the samples was less than two times the MDL, they were considered to meet acceptable sample variability. This is represented by a calculated Difference Factor (DF) of less than 2.0, where the DF is defined as the absolute difference between two values, divided by the MDL. Quality Assurance / Quality Control (QA/QC) results for the groundwater sample analysis are shown on Table 6.2-2.

2010 and 2011 Samples

A summary of the groundwater samples results from the two artesian flowing exploration boreholes at the Bong site (BONG-045 and BONG-052) is included in Table 6.2-3. A comparison of the Bong groundwater sample results with the MZ-09-04 results and water quality guidelines is also shown on Table 6.2-3.

The major ions (i.e., calcium, chloride, sodium) have relatively similar concentrations in BONG-052 and MZ-09-04, suggesting that the two samples are representative of the sub-permafrost groundwater quality. However there is a distinct chemical signature in BONG-052, indicated from the presence of higher metal concentrations in the sample, compared to MZ-09-04. These higher metal concentrations may be representative of the groundwater quality in the vicinity of the Bong mineralization. They may also be related to some contamination from the drilling equipment due to the low purge volume of the borehole by natural formation water prior to sampling.

A comparison of the groundwater sample results with Canadian water quality guidelines (Table 6.2-3) suggests that iron concentrations in the vicinity of the Bong and Main Zone deposits exceed the CCME water quality guideline of 0.3 mg/L for the protection of aquatic life while radium-226 concentrations exceed the Health Canada guideline of 0.5 Bq/L for drinking water quality.

Table 6.2-1 Groundwater Sampling in MZ09-04 Analytical Results

Sample	Parameter/ Units	Method Detection Limit	MZ09-04A	MZ09-04A Precision (+/-)	MZ09-04B	MZ09-04B Precision (+/-)	MZ09-04C	MZ09-04C Precision (+/-)
Sample Collection Date			12/8/2009		12/8/2009		12/8/2009	
Sample Description			Original		Duplicate		Purge Water	
Field pH	-	-	7.77	-	7.77	-	10.55	-
Field Temperature	^{O}C	-	2.4	-	2.4	-	5.4	-
Field Total Dissolved Solids	ppm	-	2	-	2	-	51.1	-
Field Conductivity	mS	-	4.07	-	4.07	-	102.6	-
Inorganic Chemistry								
Bicarbonate	mg/L	1	144	10	144	10	145	10
Calcium	mg/L	0.1	370	20	367	20	354	20
Carbonate	mg/L	1	<1	-	<1	-	<1	-
Chloride	mg/L	5	1280	5	1280	5	1220	5
Hydroxide	mg/L	1	<1	-	<1	-	<1	-
Magnesium	mg/L	0.1	126	3	128	3	120	3
pH	pH units	0.07	7.63	0.1	7.66	0.1	7.67	0.1
Potassium	mg/L	0.1	7.3	1	7.3	1	7.1	1
Sodium	mg/L	0.1	129	4	128	4	124	4
Specific Conductivity	µS/cm	1	3710	60	3720	60	3590	60

Table 6.2-1 Groundwater Sampling in MZ09-04 Analytical Results

Sample	Paramete r/ Units	Method Detection Limit	MZ09-04A	MZ09-04A Precision (+/-)	MZ09-04B	MZ09-04B Precision (+/-)	MZ09-04C	MZ09-04C Precision (+/-)
Sample Collection Date			12/8/2009		12/8/2009		12/8/2009	
Sample Description			Original		Duplicate		Purge Water	
Sulfate	mg/L	0.2	<0.2	-	<0.2	-	<0.2	-
Sum Of Ions	mg/L	1	2060	40	2050	40	1970	40
Total Alkalinity	mg/L	1	118	4	118	4	119	4
Total Hardness	mg/L	1	1440	30	1440	30	1380	30
Nitrate	mg/L	0.04	0.13	0.07	0.13	0.07	0.13	0.07
Aluminum	mg/L	0.0005	0.0012	0.0008	0.0009	0.0007	0.0018	0.0009
Aluminum, Dissolved	mg/L	0.0005	0.0008	0.0006	0.0018	0.0009	0.0023	0.001
Antimony	mg/L	0.0002	<0.0002	-	<0.0002	-	<0.0002	-
Antimony, Dissolved	mg/L	0.0002	<0.0002	-	<0.0002	-	<0.0002	-
Arsenic	µg/L	0.1	0.3	0.1	0.3	0.1	0.3	0.1
Arsenic, Dissolved	µg/L	0.1	0.3	0.2	0.3	0.2	0.3	0.2
Barium	mg/L	0.0005	1.90	0.02	1.90	0.02	1.81	0.02
Barium, Dissolved	mg/L	0.0005	1.88	0.02	1.92	0.02	1.83	0.02
Beryllium	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Beryllium, Dissolved	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Boron	mg/L	0.01	0.17	0.04	0.17	0.04	0.17	0.04
Boron, Dissolved	mg/L	0.01	0.17	0.04	0.17	0.04	0.17	0.04
Cadmium	mg/L	0.0001	<0.0001	-	<0.0001	-	<0.0001	-
Cadmium, Dissolved	mg/L	0.0001	<0.0001	-	<0.0001	-	<0.0001	-
Chromium	mg/L	0.0005	<0.0005	-	<0.0005	-	<0.0005	-
Chromium, Dissolved	mg/L	0.0005	<0.0005	-	<0.0005	-	<0.0005	-
Cobalt	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

Table 6.2-1 Groundwater Sampling in MZ09-04 Analytical Results

Sample	Parameter/ Units	Method Detection Limit	MZ09-04A	MZ09-04A Precision (+/-)	MZ09-04B	MZ09-04B Precision (+/-)	MZ09-04C	MZ09-04C Precision (+/-)
Sample Collection Date			12/8/2009		12/8/2009		12/8/2009	
Sample Description			Original		Duplicate		Purge Water	
Cobalt, Dissolved	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Copper	mg/L	0.0002	0.0004	0.0003	0.0004	0.0003	0.0004	0.0003
Copper, Dissolved	mg/L	0.0002	0.0004	0.0003	0.0005	0.0003	0.0005	0.0003
Iron	mg/L	0.0005	0.52	0.01	0.52	0.01	0.50	0.01
Iron, Dissolved	mg/L	0.0005	0.52	0.01	0.52	0.01	0.49	0.01
Lead	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0003	0.0001
Lead, Dissolved	mg/L	0.0001	0.0002	0.0001	0.0001	0.0001	0.0004	0.0002
Manganese	mg/L	0.0005	1.56	0.002	1.56	0.002	1.51	0.002
Manganese, Dissolved	mg/L	0.0005	1.55	0.02	1.57	0.02	1.52	0.02
Molybdenum	mg/L	0.0001	0.0094	0.001	0.0094	0.001	0.011	0.001
Molybdenum, Dissolved	mg/L	0.0001	0.0089	0.0008	0.0090	0.0008	0.011	0.0009
Nickel	mg/L	0.0001	0.0005	0.0003	0.0005	0.0003	0.0006	0.0003
Nickel, Dissolved	mg/L	0.0001	0.0006	0.0002	0.0006	0.0002	0.0006	0.0002
Selenium	mg/L	0.0001	<0.0001	-	<0.0001	-	0.0001	0.0001
Selenium, Dissolved	mg/L	0.0001	<0.0001	-	<0.0001	-	<0.0001	-
Silver	mg/L	0.0001	<0.0001	-	<0.0001	-	<0.0001	-
Silver, Dissolved	mg/L	0.0001	<0.0001	-	<0.0001	-	<0.0001	-
Strontium	mg/L	0.005	9.5	0.2	9.5	0.2	9.1	0.2
Strontium, Dissolved	mg/L	0.005	9.5	0.2	9.6	0.2	9.1	0.2
Thallium	mg/L	0.0002	<0.0002	-	<0.0002	-	<0.0002	-

Table 6.2-1 Groundwater Sampling in MZ09-04 Analytical Results

Sample	Parameter/ Units	Method Detection Limit	MZ09-04A	MZ09-04A Precision (+/-)	MZ09-04B	MZ09-04B Precision (+/-)	MZ09-04C	MZ09-04C Precision (+/-)
Sample Collection Date			12/8/2009		12/8/2009		12/8/2009	
Sample Description			Original		Duplicate		Purge Water	
Thallium, Dissolved	mg/L	0.0002	<0.0002	-	<0.0002	-	<0.0002	-
Tin	mg/L	0.0001	<0.0001	-	<0.0001	-	<0.0001	-
Tin, Dissolved	mg/L	0.0001	<0.0001	-	<0.0001	-	<0.0001	-
Titanium	mg/L	0.0002	<0.0002	-	<0.0002	-	0.0002	0.0002
Titanium, Dissolved	mg/L	0.0002	<0.0002	-	0.0002	0.0002	0.0002	0.0002
Uranium	µg/L	0.1	3.4	0.4	3.3	0.4	3.8	0.4
Uranium, Dissolved	µg/L	0.1	3.2	0.2	3.3	0.2	3.8	0.3
Vanadium	mg/L	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002	0.0001
Vanadium, Dissolved	mg/L	0.0001	0.0002	0.0001	0.0002	0.0001	0.0002	0.0001
Zinc	mg/L	0.0005	0.018	0.005	0.016	0.004	0.018	0.005
Zinc, Dissolved	mg/L	0.0005	0.018	0.003	0.029	0.003	0.019	0.003
Fluoride	mg/L	0.01	1.15	0.1	1.16	0.1	1.18	0.1
Total Dissolved Solids	mg/L	5	3500	100	3310	100	3250	100
Radio Chemistry								
Deuterium	--	0	-184.9	-	-186.5	-	-188.4	-
Oxygen-18	--	0	-22.69	-	-23.38	-	-24.19	-
Radium-226	bq/L	0.005	9.9	0.7	8.6	0.6	8.8	0.6
Radon-222	bq/L	3	3000	3	3100	3	-	3

NOTE:

Radon results are corrected for decay to the midpoint of sample collection, Deuterium and Oxygen-18 analysis is subcontracted to the Saskatchewan Isotope Laboratory, Department of Geological Sciences at the University of Saskatchewan.

°C = degrees Celsius; mS = milliSiemens; ppm = parts per million; mg/L = milligrams per litre; µS/cm = microSiemens per centimetre; µg/L = micrograms per litre; bq/L = Bequerels per litre

Table 6.2-2 Quality Assurance / Quality Control Results Based on MZ09-04 Analytical Results

Sample	Parameter / Units	Method Detection Limit	MZ09-04A	MZ09-04B	RPD (%)*	DF	P/F
Sample Collection Date			12/8/2009	12/8/2009			
Sample Description			Original	Duplicate			
Field pH	-	-	7.77	7.77	-	-	-
Field Temperature	^{o}C	-	2.4	2.4	-	-	-
Field Total Dissolved Solids	ppm	-	2	2	-	-	-
Field Conductivity	mS	-	4.07	4.07	-	-	-
Inorganic Chemistry							
Bicarbonate	mg/L	1	144	144	0.00	-	P
Calcium	mg/L	0.1	370	367	0.81	-	P
Carbonate	mg/L	1	<1	<1	-	DL	-
Chloride	mg/L	5	1280	1280	0.00	-	P
Hydroxide	mg/L	1	<1	<1	-	DL	-
Magnesium	mg/L	0.1	126	128	1.57	-	P
pH	pH units	0.07	7.63	7.66	0.39	-	P
Potassium	mg/L	0.1	7.3	7.3	0.00	-	P
Sodium	mg/L	0.1	129	128	0.78	-	P
Specific Conductivity	µS/cm	1	3710	3720	0.27	-	P
Sulfate	mg/L	0.2	<0.2	<0.2	-	DL	-
Sum Of Ions	mg/L	1	2060	2050	0.49	-	P
Total Alkalinity	mg/L	1	118	118	0.00	-	P
Total Hardness	mg/L	1	1440	1440	0.00	-	P
Nitrate	mg/L	0.04	0.13	0.13	-	0.00	P
Aluminum	mg/L	0.0005	0.0012	0.0009	-	0.60	P
Aluminum, Dissolved	mg/L	0.0005	0.0008	0.0018	-	2.00	P
Antimony	mg/L	0.0002	<0.0002	<0.0002	-	DL	-
Antimony, Dissolved	mg/L	0.0002	<0.0002	<0.0002	-	DL	-
Arsenic	ug/L	0.1	0.3	0.3	-	0.00	P
Arsenic, Dissolved	ug/L	0.1	0.3	0.3	-	0.00	P

Table 6.2-2 Quality Assurance / Quality Control Results Based on MZ09-04 Analytical Results

Sample	Parameter / Units	Method Detection Limit	MZ09-04A	MZ09-04B	RPD (%)*	DF	P/F
Sample Collection Date			12/8/2009	12/8/2009			
Sample Description			Original	Duplicate			
Barium	mg/L	0.0005	1.90	1.90	0.00	-	P
Barium, Dissolved	mg/L	0.0005	1.88	1.92	2.11	-	P
Beryllium	mg/L	0.0001	0.0001	0.0001	-	0.00	P
Beryllium, Dissolved	mg/L	0.0001	0.0001	0.0001	-	0.00	P
Boron	mg/L	0.01	0.17	0.17	0.00	-	P
Boron, Dissolved	mg/L	0.01	0.17	0.17	0.00	-	P
Cadmium	mg/L	0.0001	<0.0001	<0.0001	-	DL	-
Cadmium, Dissolved	mg/L	0.0001	<0.0001	<0.0001	-	DL	-
Chromium	mg/L	0.0005	<0.0005	<0.0005	-	DL	-
Chromium, Dissolved	mg/L	0.0005	<0.0005	<0.0005	-	DL	-
Cobalt	mg/L	0.0001	0.0001	0.0001	-	0.00	P
Cobalt, Dissolved	mg/L	0.0001	0.0001	0.0001	-	0.00	P
Copper	mg/L	0.0002	0.0004	0.0004	0.00	-	P
Copper, Dissolved	mg/L	0.0002	0.0004	0.0005	22.22	-	F
Iron	mg/L	0.0005	0.52	0.52	0.00	-	P
Iron, Dissolved	mg/L	0.0005	0.52	0.52	0.00	-	P
Lead	mg/L	0.0001	0.0001	0.0001	-	0.00	P
Lead, Dissolved	mg/L	0.0001	0.0002	0.0001	-	1.00	P
Manganese	mg/L	0.0005	1.56	1.56	0.00	-	P
Manganese, Dissolved	mg/L	0.0005	1.55	1.57	1.28	-	P
Molybdenum	mg/L	0.0001	0.0094	0.0094	0.00	-	P
Molybdenum, Dissolved	mg/L	0.0001	0.0089	0.0090	1.12	-	P
Nickel	mg/L	0.0001	0.0005	0.0005	0.00	-	P
Nickel, Dissolved	mg/L	0.0001	0.0006	0.0006	0.00	-	P

Table 6.2-2 Quality Assurance / Quality Control Results Based on MZ09-04 Analytical Results

Sample	Parameter / Units	Method Detection Limit	MZ09-04A	MZ09-04B	RPD (%)*	DF	P/F
Sample Collection Date			12/8/2009	12/8/2009			
Sample Description			Original	Duplicate			
Selenium	mg/L	0.0001	<0.0001	<0.0001	-	DL	-
Selenium, Dissolved	mg/L	0.0001	<0.0001	<0.0001	-	DL	-
Silver	mg/L	0.0001	<0.0001	<0.0001	-	DL	-
Silver, Dissolved	mg/L	0.0001	<0.0001	<0.0001	-	DL	-
Strontium	mg/L	0.005	9.5	9.5	0.00	-	P
Strontium, Dissolved	mg/L	0.005	9.5	9.6	1.05	-	P
Thallium	mg/L	0.0002	<0.0002	<0.0002	-	DL	-
Thallium, Dissolved	mg/L	0.0002	<0.0002	<0.0002	-	DL	-
Tin	mg/L	0.0001	<0.0001	<0.0001	-	DL	-
Tin, dissolved	mg/L	0.0001	<0.0001	<0.0001	-	DL	-
Titanium	mg/L	0.0002	<0.0002	<0.0002	-	DL	-
Titanium, dissolved	mg/L	0.0002	<0.0002	0.0002	-	DL	-
Uranium	µg/L	0.1	3.4	3.3	2.99	-	P
Uranium, dissolved	µg/L	0.1	3.2	3.3	3.08	-	P
Vanadium	mg/L	0.0001	0.0002	0.0002	-	0.00	P
Vanadium, dissolved	mg/L	0.0001	0.0002	0.0002	-	0.00	P
Zinc	mg/L	0.0005	0.018	0.016	11.76	-	P
Zinc, dissolved	mg/L	0.0005	0.018	0.029	46.81	-	F
Fluoride	mg/L	0.01	1.15	1.16	0.87	-	P
Total dissolved solids	mg/L	5	3500	3310	5.58	-	P
Radio chemistry							
Deuterium	--	0	-184.9	-186.5	0.86	-	P
Oxygen-18	--	0	-22.69	-23.38	3.00	-	P

Table 6.2-2 Quality Assurance / Quality Control Results Based on MZ09-04 Analytical Results

Sample	Parameter / Units	Method Detection Limit	MZ09-04A	MZ09-04B	RPD (%)*	DF	P/F
Sample Collection Date			12/8/2009	12/8/2009			
Sample Description			Original	Duplicate			
Radium-226	bq/L	0.005	9.9	8.6	14.05	-	P
Radon-222	bq/L	3	3000	3100	3.28	-	P

NOTES:

RPD = relative percent difference, DF = Difference Factor, DL = detection limit, P = pass, F = fail; °C = degrees Celsius; mS = milliSiemens; ppm = parts per million; mg/L = milligrams per litre; µS/cm = microSiemens per centimetre; µg/L = micrograms per litre; bq/L = Bequerels per litre

Table 6.2-3 Summary of Groundwater Sample Results and Water Quality Guidelines

Analyte	Units	BONG045 (2010)	BONG052 (2011)	MZ-09-04 (2009)	CCME guidelines	Health Canada Drinking water Guidelines	
pH (laboratory)	pH units	6.93	7.2	7.63	6.5 to 9.0	6.5 - 8.5	AO or OG
Specific conductivity	uS/cm	23	4,740	3,710			
Aluminum	mg/L	0.034	55	0.0008	0.005-0.1	0.1 / 0.2	AO or OG
Antimony	mg/L	<0.0002	0.004	<0.0002		0.006	MAC
Arsenic	ug/L	0.2	29	0.3	5	10	MAC
Barium	mg/L	0.032	3.7	1.88		1	MAC
Beryllium	mg/L	<0.0001	0.003	0.0001			
Boron	mg/L	<0.01	0.4	0.17		5	MAC
Cadmium	mg/L	0.00001	0.0005	<0.0001	0.000017	0.005	MAC
Chromium	mg/L	<0.0005	0.088	<0.0005	0.001 (Cr(VI)) - 0.0089 (Cr(III))	0.05	MAC
Cobalt	mg/L	<0.0001	0.11	0.0001			
Copper	mg/L	0.0031	0.061	0.0004	0.002-0.004	1	AO or OG
Iron	mg/L	0.074	13.3	0.52	0.3	0.3	AO or OG
Lead	mg/L	0.0006	0.048	0.0002	0.001-0.007	0.01	MAC
Manganese	mg/L	0.010	0.24	1.55		0.05	AO or OG
Molybdenum	mg/L	<0.0001	0.57	0.0089	0.073		
Nickel	mg/L	0.0007	0.11	0.0006	0.025-0.150		
Selenium	mg/L	<0.0001	0.015	<0.0001	0.001	0.01	MAC
Silver	mg/L	0.00001	0.0045	<0.0001	0.0001		
Strontium	mg/L	0.013	22.7	9.5			
Thallium	mg/L	<0.0002	<0.002	<0.0002	0.0008		
Tin	mg/L	0.0001	<0.001	<0.0001			
Titanium	mg/L	<0.0002	0.22	<0.0002			
Uranium	ug/L	<0.1	500	3.2	15 (long-term)	20	MAC
Vanadium	mg/L	<0.0001	0.25	0.0002			
Zinc	mg/L	0.012	0.07	0.018	0.03	5	AO or OG
Radium-226	Bq/L	n.a	2.7	9.9		0.5	MAC
Bicarbonate	mg/L	n.a	41	144			
Calcium	mg/L	n.a	461	370			
Carbonate	mg/L	n.a	<1	<1			
Chloride	mg/L	n.a	1,670	1,280		250	AO or OG
Hydroxide	mg/L	n.a	<1	<1			
Magnesium	mg/L	n.a	148	126			
Potassium	mg/L	n.a	25	7.3			
Sodium	mg/L	n.a	182	129		200	AO or OG
Sulfate	mg/L	n.a	2.8	<0.2		500	AO or OG
Sum Of Ions	mg/L	n.a	2,530	2,060			
Total Alkalinity	mg/L	n.a	34	118			
Total Hardness	mg/L	n.a	1,760	1,440			
Nitrate	mg/L	n.a	<0.04	0.13	13	45	MAC

CCME - Canadian Water Quality Guidelines for the Protection of Aquatic Life (2011)
Health Canada - Guidelines for Canadian Drinking Water Quality (December 2010)
MAC - Maximum Acceptable Concentration
AO - Aesthetic Objectives or Operational Guidance Values (OG)

7 Hydrostratigraphy

7.1 Field Data

Hydrogeological testing was conducted in 13 boreholes (Figures 5.1-1, 5.1-2 and 5.1-3). Six of these tests were conducted in the area of the Main Zone, Centre Zone and East Zone deposits. The remainder were conducted in the area of the Andrew Lake deposit and End Grid deposit.

2008 Field Season

During the 2008 field season, hydraulic testing beneath permafrost was completed in three boreholes: MZ-08-04, ANDW-08-01, and ANDW-08-04. Testing was conducted using a hydraulically inflated wireline packer system, which was used to isolate a section of the drillhole below the base of the permafrost to obtain bulk hydraulic parameters for each test interval.

2009 Field Season

During the 2009 field season, hydrogeologic testing consisted of packer testing in seven boreholes, and a shut-in test in one borehole. Testing was conducted using a single packer wireline tool, which was used to isolate a section of the drillhole below the base of the permafrost to obtain bulk hydraulic parameters for each test interval. To prevent freezing of the drilling rods, the drillhole was flushed with heated water for about two hours prior to testing, and tests were limited to four hours in length.

A slug (withdrawal or injection) test was initiated by either removing or adding an instantaneous slug of water from inside the test rods. The hydraulic head inside the test rod was monitored until it recovered to the pre-test level. If full recovery from the slug test was relatively rapid, the slug test was followed by a constant rate injection test. The constant rate injection test consisted of injecting water into the test interval at a constant rate for a minimum of 30 minutes. Flow rate and injection pressure were recorded during the test.

A shut-in test was conducted in borehole MZ-09-04, following groundwater sampling at this location. A single wireline packer was used to isolate the interval for the test (between 220 m and 270 m depth), and after packer inflation, a continuous flow of water was observed from the test rods. The interval was allowed to flow for 44 hours before the system was closed, and the pressure build-up over the interval was monitored.

2010 Field Season

The scope of work for collection of hydrogeological data in 2010 included single-well response testing of the sub-permafrost aquifer at two new locations within the Project area. Hydraulic conductivity tests were carried out in geotechnical boreholes EZ-10-01 (East Zone area) and MZ-10-01 (Main Zone area) after they were completed to final depth. The testing was conducted using a single packer tool in a wireline configuration.

2011 Field Season

The scope of work for collection of hydrogeological data in 2011 included single-well response testing of the sub-permafrost aquifer at two new locations within the Project area. Hydraulic conductivity tests were carried out in geotechnical boreholes GW-11-01 (North of Main Zone) and GW-11-02 (South of Main Zone) after they were completed to final depth. The testing was conducted with a single wireline packer tool that consisted of two packers connected by a seating cone. Locations of the two test boreholes are shown in Figure 5.1-1.

7.2 Hydraulic Conductivity Distribution

7.2.1 General

The deep groundwater flow regime was characterized during hydrogeological testing undertaken in deep boreholes drilled through permafrost to the unfrozen ground below. A compilation of the hydraulic conductivity values derived from the tests conducted during the 2008, 2009 and 2010 field program is presented in Figure 7.2-1.

Hydraulic tests conducted to data indicate that the hydraulic conductivity (K) of the rock at the Project site is low. The hydraulic conductivity values appear to be somewhat related to the rock type, with syenitic gneiss (located at ANDW-09-03 in the area of the Andrew Lake deposit) and granitic rock (located at MZ-08-04, MZ-09-03 and MZ-09-04 in the area of the Main Zone deposit, and CZ-09-01 in the area of the Centre Zone deposit) having an apparent higher K than the metasediments (Table 7.2-1).

Figure 7.2-1 presents the results of K testing versus the depth of the measurements along with hydraulic conductivity versus depth profiles derived from hydrogeologic testing data at other sites located in the crystalline bedrock of the Canadian Shield. These results indicate that, with the exception of the one hydrogeologic test conducted at Andrew Lake in borehole ANDW-09-03 in syenitic gneiss, the hydraulic conductivity measured at the project site is within the average range of hydraulic conductivity measured at other sites at similar depths. Neretnieks (1990) provides data representative of gneissic and granitic rocks over a similar depth range to the tests conducted for the

Kiggavik Project and the Meadow Bank data set provides data for a relatively close mining site. The comparison to other sites provides supporting data that the tests conducted for this project are representative and typical of similar rock types.

Table 7.2-1 Results of Hydrogeologic Testing

Location	Borehole	Interval Top (m below ground surface)	Interval Bottom (m below ground surface)	Vertical Interval Length (m)	Hydraulic Conductivity (m/s)	Unit	Operator
Andrew Lake	ANDW-08-01	241.3	255.0	13.7	8.E-08	Metasediment	SRK, 2008
Andrew Lake	ANDW-08-04	227.0	260.0	33.0	< 1E-9	Metasediment	SRK, 2008
Andrew Lake	AND09-01	271.0	320.5	49.5	1.E-09	Metasediment	Golder, 2009
Andrew Lake	AND09-03	279.6	307.3	27.6	1.E-06	Syenitic Gneiss	Golder, 2009
End Grid	END09-01	272.5	432.0	159.5	6.E-11	Metasediment	Golder, 2009
End Grid	END09-05	253.5	383.4	129.9	7.E-11	Metasediment	Golder, 2009
End Grid	END09-11	281.4	439.3	157.9	6.E-10	Metasediment	Golder, 2009
Main Zone	MZ-08-03	210	234	24	< 1E-9*	Granite, Metasediment	SRK, 2008
Main Zone	MZ08-04	279.4	312.9	33.5	< 1E-9	Granite, Diabase Dyke	SRK, 2008
Main Zone	MZ09-03	205.9	229.8	23.9	4.E-08	Granite	Golder, 2009
Main Zone	MZ09-04	200.0	250.0	50.0	1.E-07	Granite	Golder, 2009
Main Zone	MZ10-01	222.1	247.9	25.8	7.E-08	Granite	Golder, 2010
North Main Zone	GW-11-01	218.7	252.0	33.3	9.E-10	Metasediment	Golder, 2011
South Main Zone	GW-11-02	224.9	252.0	27.1	2.E-10	Gneiss, Metasediment	Golder, 2011
Centre Zone	CZ09-01	220.8	260.8	40.0	1.E-08	Granite, Metasediment	Golder, 2009

Location	Borehole	Interval Top (m below ground surface)	Interval Bottom (m below ground surface)	Vertical Interval Length (m)	Hydraulic Conductivity (m/s)	Unit	Operator
East Zone	EZ10-01	222.1	250.9	28.8	< 3E-11	Metasediment	Golder, 2010
NOTES: m – metres; m/s = metres per second							

7.2.2 Kiggavik area

At the Main Zone and Centre Zone deposits, near-surface rock consists of moderately weathered metasediments. From about 200 m below ground surface (near the bottom of permafrost) to the depth of the investigations, the rock type is identified as granite. The results of hydraulic testing indicate that the hydraulic conductivity of this granite generally ranges from 1 x 10^{-8} m/s to 1 x 10^{-7} m/s. Testing conducted in one packer interval in this unit indicated a much lower hydraulic conductivity at approximately 1 x 10^{-9} m/s. This test took place over a packer interval that included granite and a thin (about 5 m wide) diabase dyke. This result indicates that there does not appear to be a zone of enhanced permeability associated with the contact between the granite and the diabase dyke in this location.

One packer test was carried out in permafrost at Main Zone (MZ-08-03). This test resulted in a hydraulic conductivity value less than 1 x 10^{-9} m/s. Another test was also conducted in permafrost North of Main Zone (GW-11-01), resulting in a low hydraulic conductivity of 9 x 10^{-10} m/s. The temperature data collected from the thermistor string in this borehole indicate that the test was conducted within the permafrost section of the borehole. Therefore it is considered that the measured hydraulic conductivity likely represents a thawed zone within permafrost created around the borehole during drilling and flushing. Packer testing conducted in permafrost tends to overestimate the hydraulic conductivity due to partial melting of permafrost near the borehole. Nevertheless, these results confirm that the frozen rock has low hydraulic conductivity.

The major lithology at East Zone includes metasediments intruded by syenite sills and dykes, Alteration within the metasediments appears to be predominantly consist of hematite and limonite with local argilization and weak-trace chloritization and bleaching. The hydraulic test conducted at East Zone (EZ-10-01) straddled an interval from 221 m to 248 m, approximately, below the permafrost. The packer test carried out at East Zone resulted in a hydraulic conductivity value less than 1 x10^{-11} m/s. The pressure response in borehole EZ-10-01 corresponded to a very tight interval with low hydraulic conductivity such that the test could not be analyzed numerically. Therefore a maximum transmissivity was estimated based on the pressure responses experienced on projects in similar conditions.

7.2.3 Sissons area

The deposits in the Andrew Lake and End Grid area are located in pelitic and arenitic metasediments overlying granite gneisses, and granodiorites. Hydraulic testing conducted in the metasediments at the Andrew Lake deposit, and the End Grid deposit indicates that the hydraulic conductivity of the metasediments from the base of the permafrost (approximately 240 m below ground surface) to approximately 50 m beneath the permafrost ranges from 1×10^{-9} m/s to 8×10^{-8} m/s. Testing in metasediments below this depth indicates that the hydraulic conductivity (K) is less, with K values ranging from 6×10^{-11} m/s to 6×10^{-10} m/s in packer intervals extending to about 400 m below ground surface. One of these hydraulic tests, in END-09-11, was conducted across one of the lat faults, striking NNW/SSE, which have been interpreted to pass through the End Grid deposit. The hydrogeology test yielded a low hydraulic conductivity value of 6×10^{-10} m/s. Although the data are limited (3 tests), this result is about one order of magnitude higher than the other two tests located at End Grid.

At the Andrew Lake deposit, testing in one packer interval located in syenitic gneiss indicated a much higher hydraulic conductivity of 1×10^{-6} m/s. There is no data to assess whether the higher permeability in the syenitic gneiss is a function of rock type of localized fracturing unrelated to rock type. A packer test conducted in one borehole drilled in 2008, ANDW-08-04, appears to intersect the inferred location of a fault based on the location of geophysical anomaly. However, a fault was not identified in the log for this borehole. Consequently, the hydraulic conductivity determined from this test is not considered representative of a fault.

7.2.4 Structural features

The main structure that was intercepted through packer-testing is the Main Zone diabase dyke, which could correspond to the NW-SE lineament shown on Figure 4.1-3. At some locations, faults logged in individual boreholes but not interpreted to extend laterally, intersected the test intervals, without translating to an increased hydraulic conductivity. Also geotechnical logging of boreholes has resulted in the local identification of fracture systems in both of the areas of the planned mines. These fracture systems may correspond to zones of enhanced permeability; however where fractures are in filled by fault breccias, veins or fault gouge this may not be the case. Gouge refers to rock that has been ground to a fine grain size, while breccia refers to angular fragments of rock. Veins are minerals which have been intruded a joint or fissure.

8 Groundwater Flow

8.1 Sub-Permafrost Hydraulic Heads

8.1.1 Field Data

8.1.1.1 *Historical Data*

In 1989 Golder reported artesian flow at ground surface during drilling of some deep boreholes extending below the permafrost depth. However, the field observations are regarded as anecdotal since borehole locations, flow rates and pressure head at the collar are not provided and it is not known if the rate of flow remained unchanged or rapidly decreased soon after completing the borehole. Importantly, the available information does not indicate if flowing conditions were detected while drilling was advancing downward, or if surface flow was evident only upon reaching the ultimate drilling depth (*i.e.*, below permafrost depth).

Other anecdotal information suggests similar artesian conditions are present at the Sissons site, although there are no known recorded observations of artesian flow in deep boreholes in that area. Accordingly, it is expected the reference to artesian conditions at the Sissons site have been inferred from the previous Kiggavik report (Golder, 1989).

8.1.1.2 *Recent observations from exploration boreholes*

In 2008, artesian flow conditions were observed in the Bong and Kiggavik Main Zone areas. The first artesian flow was observed in drill hole BONG-041 at a depth of approximately 300 mbgs with a flow rate of approximately 2.5L/s (150L/min). The hydraulic head measured at BONG-041 was estimated at 1m above ground surface. Flow stopped after several hours. The second artesian flow was encountered in drill hole MZ-08-04, with an estimated flow rate of 4.5L/min.

Flowing artesian conditions were also encountered in two exploration boreholes during the 2010 exploration field program: The first artesian flow was encountered on Friday June 18th at BONG-045 at a depth of 320m. The flow rate was estimated to be 12 L/min. The second artesian was encountered on June 27th at BONG-047 at a depth of 282m. An estimate of the water flow was not conducted; however upon visual inspection the drillers and project geologist on site noted that the flow was less than BONG0-45.

It should be noted that groundwater flowing from boreholes could be the result of hydraulic influences encountered during drilling that are not related to deep groundwater pressures.

Maintaining circulation of drilling fluids, such as heavy brines, during borehole advancement requires continuous application of hydraulic pressure through the down-hole assembly. Prior to removing the drill head from the borehole casing, for any purpose, all pressure is normally relieved using a bypass valve that provides controlled relief and safe venting. However, if the drill assembly is detached from the casing prior to opening the bypass, and the applied hydraulic pressure is fully or partly maintained, the system will rapidly vent at the casing-head contact and cause brine to momentarily flow over the top of the brine-filled casing. An observer could interpret this to indicate the presence of artesian conditions. The effect could be more pronounced if the drill head is held directly over the borehole while the brine pump continues to operate, which would cause pumped brine to continuously flow over the casing, thus reinforcing the interpreted artesian flow scenario. This observation could occur anytime during drilling, but would likely be more pronounced when the borehole is relatively deep and the brine volumes are corresponding increased.

Apparent artesian conditions might also be observed at ground surface during drilling when a zone(s) of heavy brackish water is encountered within permafrost. Specifically, if the drill bit is advanced into a zone hosting saline groundwater that is denser than the drilling brine, the in-situ water could enter the drilling assembly and slightly displace the lighter brine upward in the borehole. The observed effect might be quite modest at ground surface, but could lead to the conclusion that the response is related to natural artesian conditions.

8.1.1.3 *Recent Vibrating Wire Piezometers*

During the 2009 field season, thermistors were installed in four boreholes: END-09-01, ANDW-09-03, MZ-09-02, and MZ-09-04 to depths of up to 300 m below ground surface. A vibrating wire (VW) piezometer was installed beneath each deep multilevel thermistor string to determine the hydraulic head in the deep groundwater flow regime. About 2 months after installation of the VW piezometers, three out of the four piezometers were considered to be providing reliable hydraulic heads measurements. The exception was the VW piezometer installed in MZ-09-02, which had a hydraulic head measurement inconsistent with other data. This sensor was likely damaged during grouting; therefore, data from this sensor is not discussed in the later sections of this report.

During the 2011 field season, multilevel thermistor strings and VW piezometers were installed in two boreholes: GW-11-01 and GW-11-02. The VW piezometer installed in borehole GW-11-02 achieved steady state conditions about one month after installation and was considered to be providing reliable hydraulic heads measurements. In contrast the static hydraulic heads of the sub permafrost layer could not be measured in GW-11-01 because the VW piezometer was found to be located within the permafrost layer.

8.1.1.4 *Recent observations during borehole instrumentation or packer tests*

In drill hole MZ07-03, the pressure transducer near bottom of permafrost recorded a small increase in pressure. The borehole was filled with brine and froze after several days, possibly due to dilution by fresher water below the permafrost. The pressure increase suggests artesian conditions below permafrost, however; it could also be caused by volume expansion in the borehole cavity as the water freezes.

Artesian conditions were noted while conducting a packer test on MZ-10-01 during the 2010 field program. The pressure response of the interval tested indicated artesian conditions at the borehole collar.

8.1.2 Results

In general hydraulic heads measured beneath permafrost at the site were near to or above ground surface in all three deposits. The hydraulic head measured in the piezometer located beneath the permafrost in the area of the End Grid deposit, END-09-01, was about 9 m above ground surface (175.5 masl), while in the area of the Andrew Lake deposit the hydraulic head measured in a piezometer, ANDW-09-03, was about 3 m above the ground surface (169.7 masl). The hydraulic head measured in the one piezometer located in the area of the Main Zone deposit, MZ-09-04, was about 25 m above ground. Similarly the pressure response of the interval tested in borehole MZ-10-01 indicated artesian conditions at the borehole collar. The static hydraulic head was estimated at 17.6 m above the borehole collar. Flowing boreholes indicating hydraulic heads that are above the ground surface elevation were anecdotally documented in boreholes during previous field investigations. Similarly artesian flow occurred at exploration holes in the Bong area, approximately 4 km South-East of Kiggavik Main Zone.

Hydraulic head data collected in three vibrating wire piezometers during the 2009 field season indicate that hydraulic heads in the deep groundwater flow regime are generally consistent with the elevations of lakes interpreted to have open taliks near the proposed mines (Table 8.1-1). The hydraulic head measured in one piezometer located in the area of the Main Zone deposit was approximately 215.5 masl which is consistent with the elevations of nearby Ridge Lake (230.7 metres above sea level [masl]), and Felsenmeer Lake (222.8 masl). The hydraulic head in a piezometer in the area of the End Grid deposit was 175.5 masl, which is consistent to the hydraulic head in nearby Mushroom Lake (about 173.2 masl). This result may indicate a good hydraulic connection between Mushroom Lake and the vibrating-wire piezometer location.

Table 8.1-1 Hydraulic Heads at Piezometer Locations

Borehole	Collar Elevation (masl)	Depth below Ground Surface (m)	Hydraulic Head (masl)	Date	Field Program
AND09-03	166.2	281.3	169.7	08/22/09	Golder, 2009
END09-01	166.2	271.1	175.5	08/22/09	Golder, 2009
MZ09-04	190.4	246.4	215.5	08/24/09	Golder, 2009
MZ10-01	186.7	247.9	204.3	08/20/10	Golder, 2010
NOTES: masl = metres above sea level; m = metres					

8.2 Groundwater Flow

Taliks beneath larger lakes extend down to the deep groundwater regime. The elevations of these lakes provide the principal driving force for deep groundwater flow. Generally, groundwater will flow from higher elevation lakes to lower elevation lakes.

Figure 2.3-1 and Table 2.3-1 identify lakes near the Project site that satisfy both the minimum dimensional requirements and depth requirements to support a talik extending to the deep groundwater flow system. Flow directions in the deep groundwater flow regime were inferred from the elevations of these lakes and are presented on Figures 8.2-1 and 8.2.2. These results indicate that the predominant groundwater flow in area of the Main Zone, Centre Zone, and East Zone deposits is south towards Fox Lake, Pointer Lake, Jaeger Lake, and Judge Sissons Lake. Groundwater in this area may also discharge to Sleek Lake, located to the southwest, and Scotch Lake, located to the southeast. In the area of the Andrew Lake and End Grid deposits, the predominant groundwater flow direction is inferred to be southeast towards Boulder Lake, and Judge Sissons Lake. These groundwater flow directions have been inferred assuming that open taliks exist beneath lakes identified on Figure 2.3-1 as large enough to support an open talik, but for which no bathymetric data is available. It is also assumed that on the regional scale, the hydraulic conductivity of the bedrock beneath the permafrost is relatively homogeneous and isotropic.

9 Summary

The shallow groundwater flow regime at the Project site has little to no hydraulic connection with the groundwater regime located below deep permafrost. Permafrost depth ranges from about 210 m depth in the area of the Main Zone, Centre Zone, and East Zone deposits to about 250 m depth in the area of the Andrew Lake deposit and End Grid deposit.

The groundwater in the Project area is currently not used as a water source due to the presence of permafrost and the availability of good quality water from surface water sources.

Hydraulic tests indicate that the hydraulic conductivity (K) of the rock at the Project site might be partially related to the rock type, with syenitic gneiss and granitic rock generally having a higher K than the metasediments. Although the majority of testing at the site has yielded low hydraulic conductivity values on the order of 1×10^{-9} m/s, hydraulic conductivities of up to 10^{-6} m/s have been measured in some boreholes.

The major element chemistry of the groundwater sample collected in 2009 has a distinct chemical signature, indicated from the presence of major ions (i.e., calcium, chloride and sodium), compared to the lake samples, and historic drill return samples, which all have very low major element concentrations. The groundwater sample has over an order of magnitude greater TDS than the historic drill return and lake water samples. The measured TDS of the groundwater sample, which was collected at about 250 m below ground surface, is about 3,500 mg/L. This TDS is consistent with the composition of deep groundwater in the Canadian Shield (Frape and Fritz, 1987) at the depth that the sample was collected.

Deep groundwater flow in the area of the Project site is dependent on the elevations of large lakes with open taliks. Groundwater flow in the area of the Main Zone, Centre Zone and East Zone deposits is inferred to be south towards Fox Lake, Pointer Lake, Jaeger Lake, and Judge Sissons Lake. Groundwater in this area may also discharge to Sleek Lake, located to the southwest, and Scotch Lake, located to the southeast. In the area of the Andrew Lake, and End Grid deposits, the predominant groundwater flow direction is inferred to be southeast towards Boulder Lake, and Judge Sissons Lake. These groundwater flow directions have been inferred assuming that open taliks exist beneath lakes identified as large enough to support an open talik, and that on the regional scale the hydraulic conductivity of the bedrock beneath the permafrost is relatively homogeneous and isotropic.

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11 Figures

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

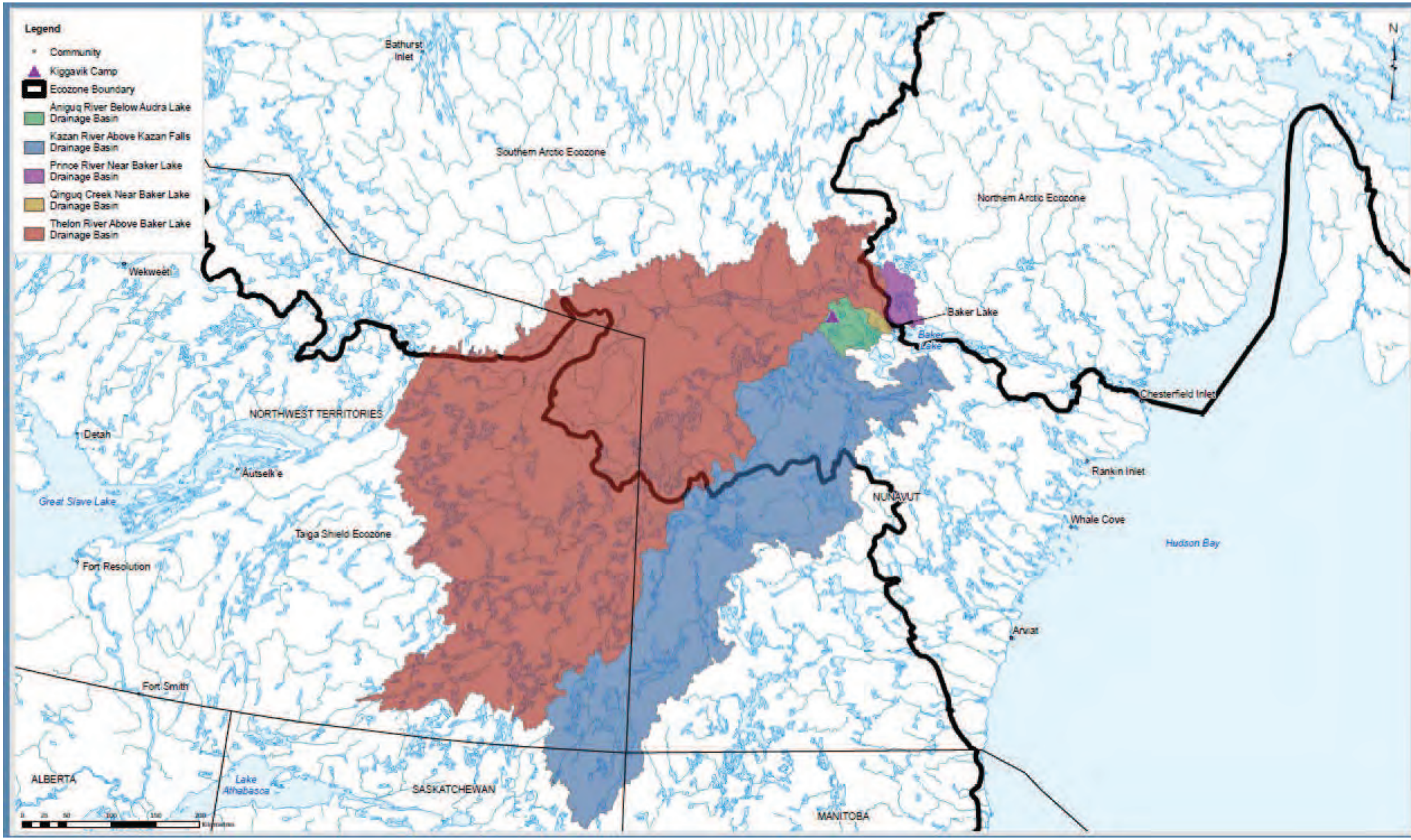
FIGURE 1.1-1
GENERAL LOCATION OF PROPOSED KIGGAVIK PROJECT IN CANADA

GEOLOGY AND HYDROGEOLOGY BASELINE

Kiggavik Project

AREVA

AREVA Resources Canada Inc - P.O. Box 9204 - 817 - 45th Street West - Saskatoon, SK - S7K 3X5



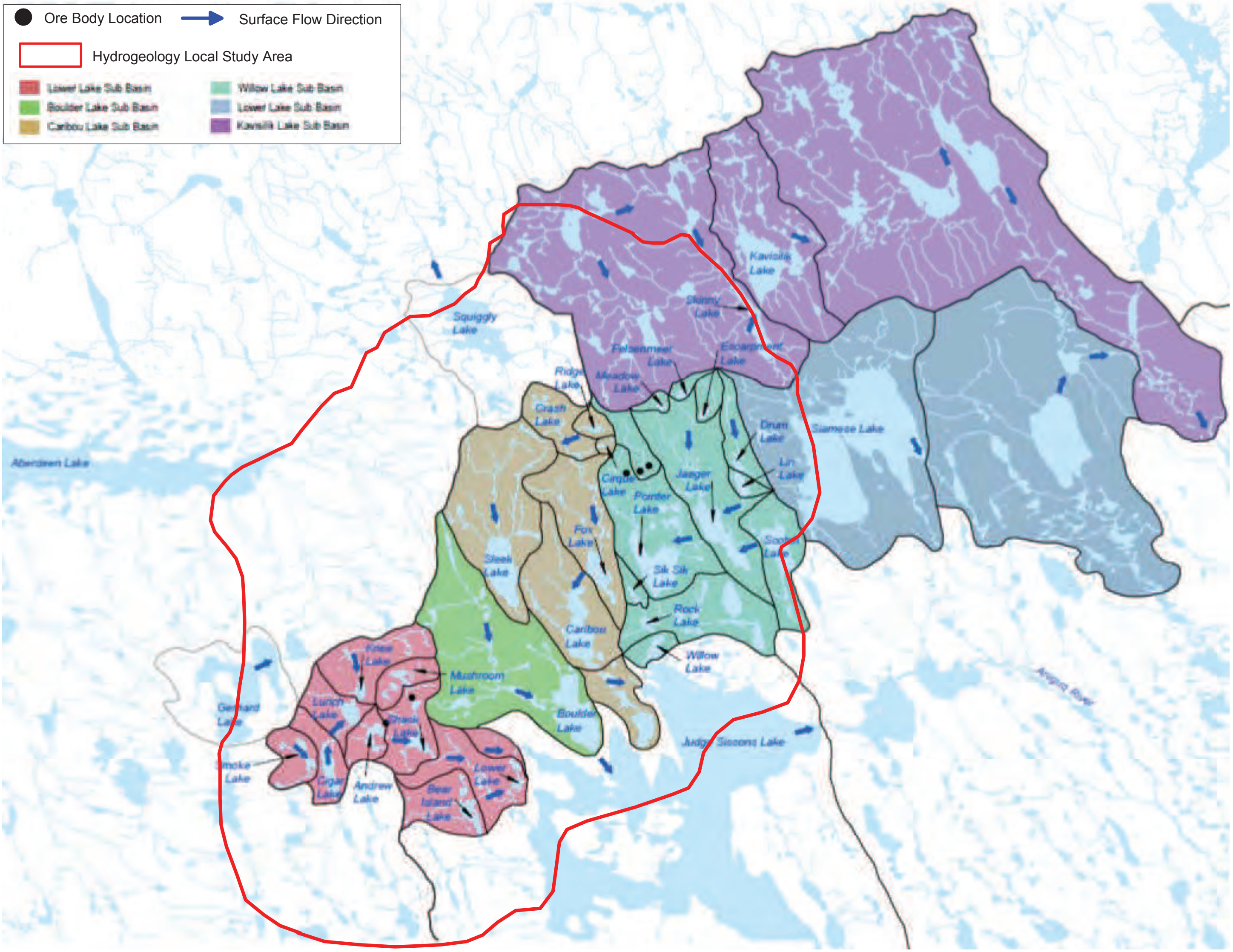
Technical Appendix 5B
Geology and Hydrogeology Baseline
December 2011

Figure 2.1-1
Hydrogeology Regional Study Area

Kiggavik Project

AREVA

Areva Resources Canada Inc.- P.O Box 9204 – 817 – 45th Street W – Saskatoon – S7K 3X5



Technical Appendix 5B
Geology and Hydrogeology Baseline
December 2011

Figure 2.1-2
Hydrogeology Local Study Area

Kiggavik Project

AREVA

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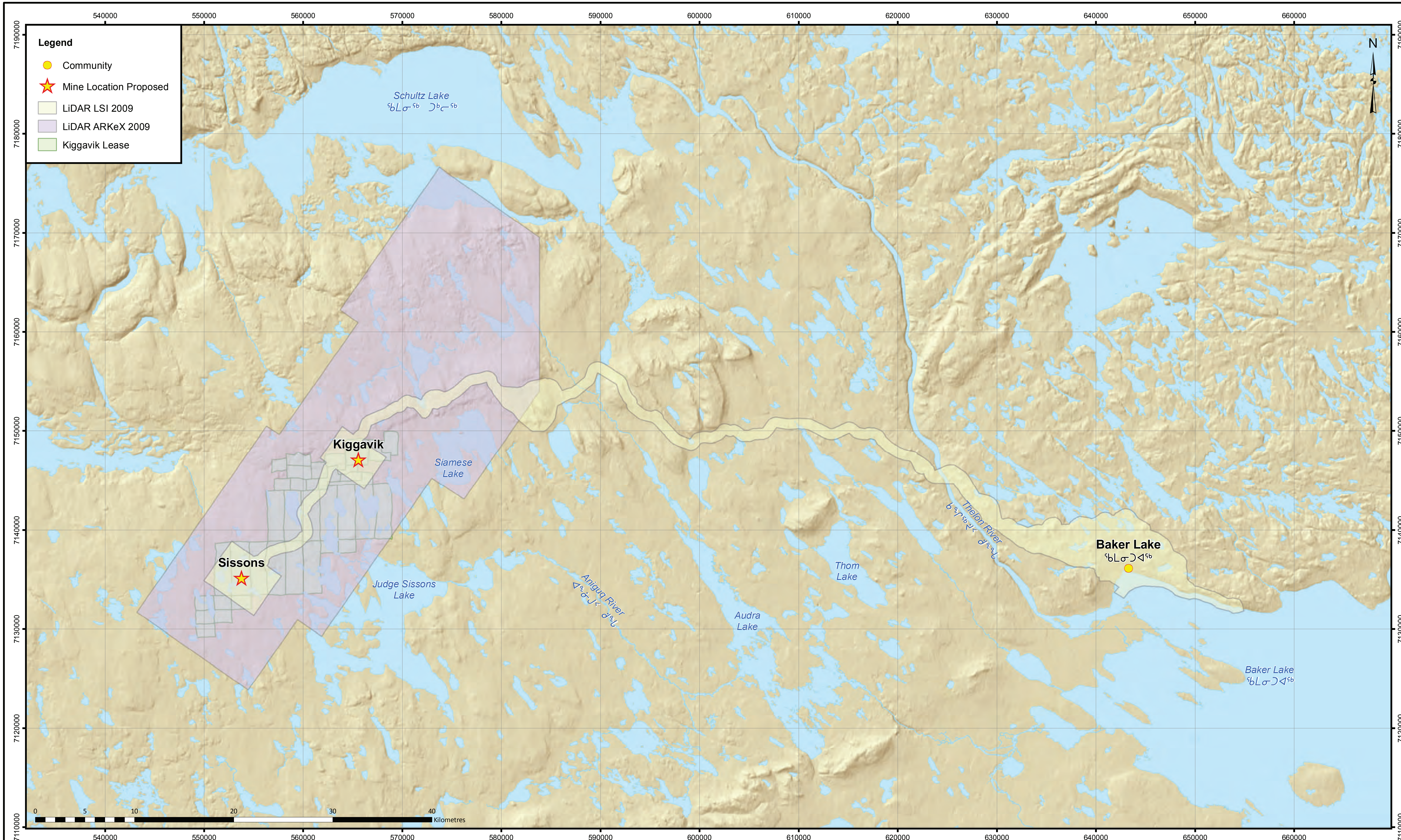

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Data Sources: *Natural Resources Canada, Geobase®, Nation Topographic Database, AREVA Resources Canada Inc.*

FIGURE 2.2-1
LiDAR COVERAGE

GEOLOGY AND HYDROGEOLOGY BASELINE

Kiggavik Project

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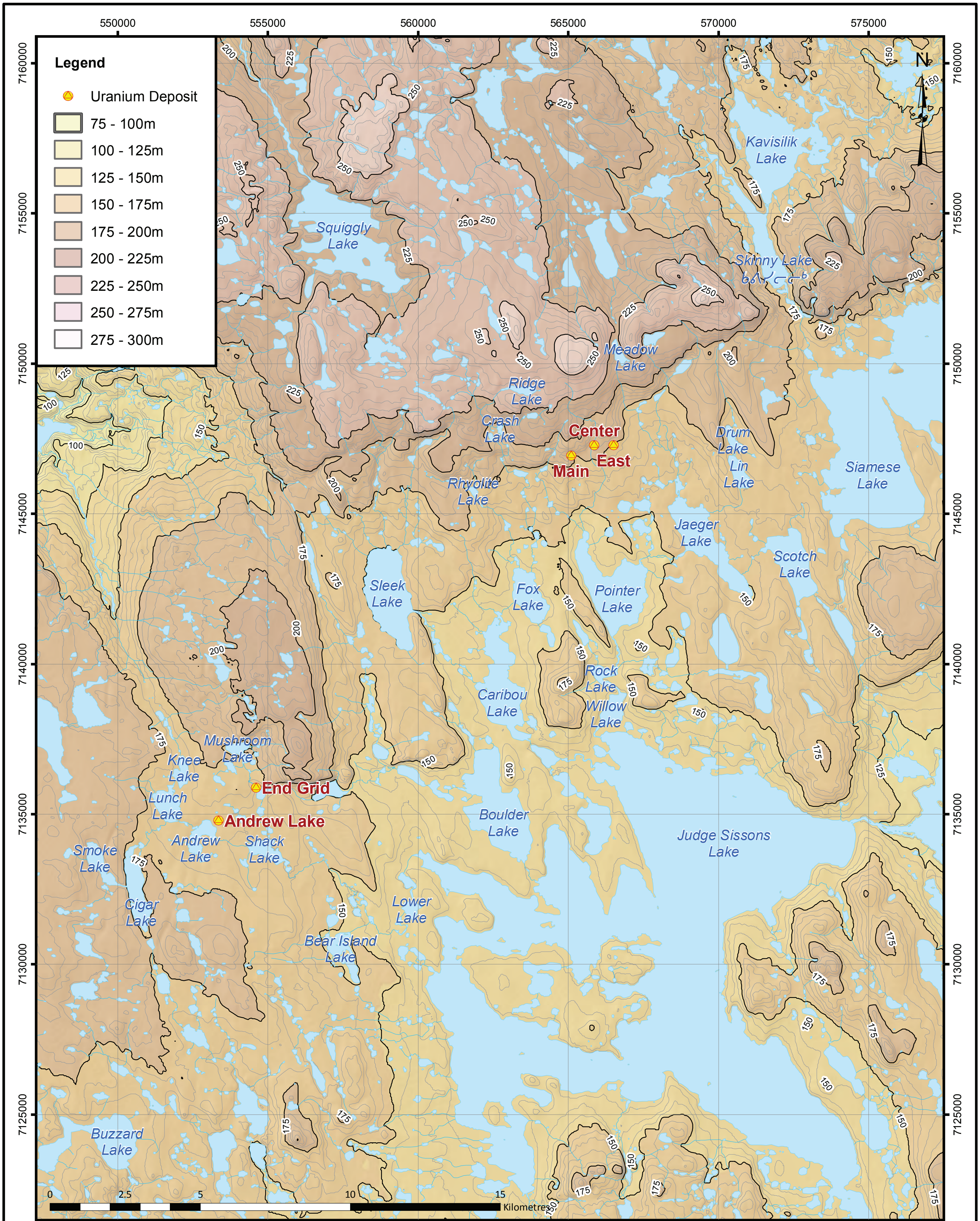

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FIGURE 2.2-2
TOPOGRAPHY OF PROJECT AREA

GEOLOGY AND HYDROGEOLOGY BASELINE

Kiggavik Project

AREVA

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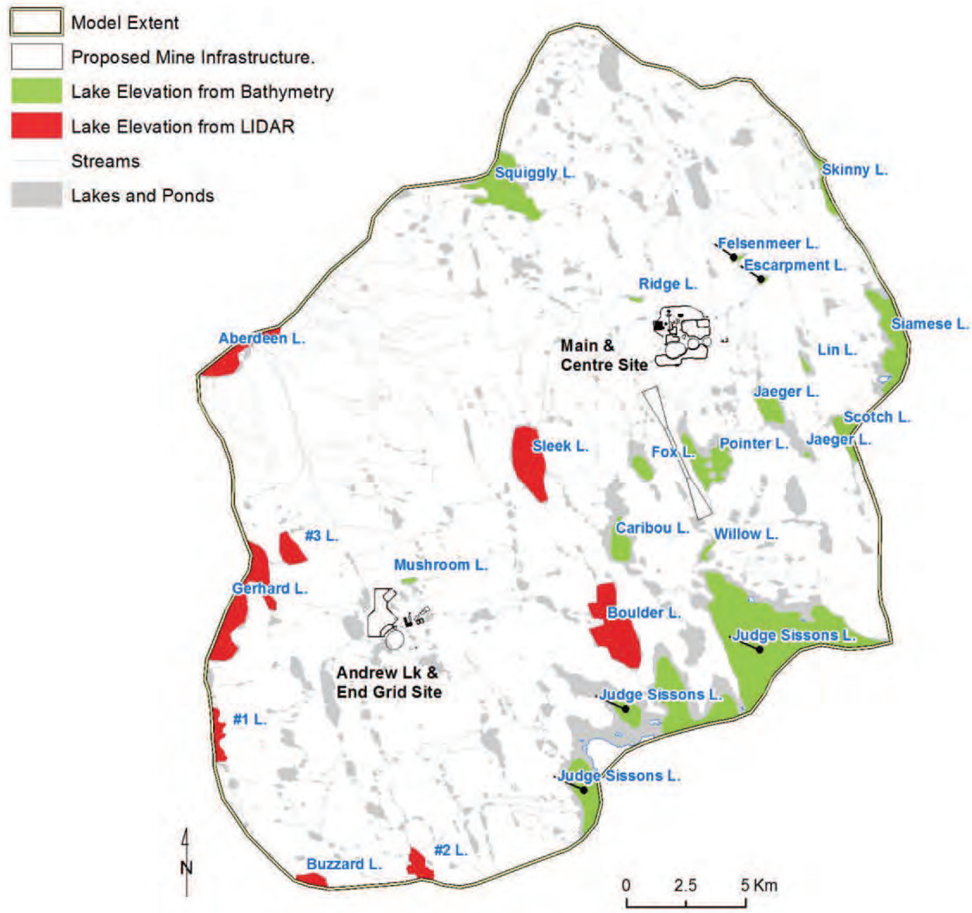

Figure 2.3-1
Location of lakes supporting taliks within numerical flow model domain