GEOLOGICAL SURVEY OF CANADA
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A Map and Summary Database of Permafrost Temperatures in Nunavut, Canada

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Publications in this series have not been edited; they are released as submitted by the author.

ABSTRACT

A summary database and map of recent permafrost temperatures is provided for Nunavut Canada. The database includes publicly available information from over 100 boreholes. About 20% of these boreholes are active permafrost thermal monitoring sites maintained by the Geological Survey of Canada and various partners (academic, community, government). Almost 80% of the boreholes were drilled as part of geotechnical investigation programs to support mineral resource development. Most of the ground temperature data provided are based on measurements made since 2000. The map and database provide regional information on permafrost thermal state that can be incorporated into territorial state of knowledge reports and support engineering design and environmental assessment for resource development projects in Nunavut.

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INTRODUCTION

Permafrost is a key component of the northern landscape that underlies most of the landmass of Nunavut and is an important influence on ecosystems and hydrological systems. Permafrost and the ground ice it contains present important challenges to resource development and engineering design in Nunavut. Climate change presents an additional challenge as the thermal state of permafrost may change through time and this may have implications for the integrity of infrastructure and ecosystems. Information on permafrost conditions is essential to ensure that infrastructure is appropriately designed and to ensure its integrity over the long-term.

Several mining projects are proposed for Nunavut, with the potential for more development in future. Design, environmental assessment and planning decisions associated with these developments require adequate baseline information including information on permafrost, a valued ecosystem component under the Nunavut General Monitoring Plan and in guidelines for environmental assessment. This report provides a map of recent permafrost temperatures in Nunavut acquired from permafrost monitoring sites maintained by the Geological Survey of Canada and from other publicly available sources. A summary database of available information on permafrost thermal state is also provided. This report provides more up to date information on ground thermal conditions than the earlier historical ground temperature database of Smith and Burgess (2000).

DATA SOURCES AND PRESENTATION

Data Sources

The data compiled in this report are derived from a number of sources. The Geological Survey of Canada (GSC) collaboratively maintains several permafrost monitoring sites in Nunavut. This regional network consists of a suite of boreholes, the majority of which are less than 20 m deep, instrumented with a multi-thermistor cable. At most of these sites data loggers are connected to the cable to provide a continuous record of ground temperatures. Details of the instrumentation are provided elsewhere (e.g. Smith et al., 2010) but the measurement system provides for an accuracy and resolution better than 0.1°C. Most of these boreholes have been established in the last 5 years but some have been in operation more than 10 years.

The five boreholes at Canadian Forces Station (CFS) Alert are the most northerly sites and have been in operation since 1978 (e.g. Smith et al., 2003). The boreholes are 15 to 60 m deep and are located along a topographic transect.

Permafrost monitoring sites were established in communities in Nunavut in 2008 and 2009 as a contribution to an International Polar Year (IPY) project and to support development of community climate change adaptation plans (Ednie and Smith, 2010, 2011). These sites were established in collaboration with the individual communities and with the Nunavut Government Departments of Community and Government Services and Environment. Six boreholes were established in 2008 in the Baffin region and four were established in 2009 in the Kivalliq and Kitikmeot regions. Temperature cables connected to data loggers were installed in boreholes that were 15 m deep. Data for at least two years are available from eight of the boreholes. Boreholes were also instrumented in Iqaluit and Pangnirtung in 2009 and 2010 respectively as part of a collaborative project with Université Laval to characterize permafrost conditions (e.g. Leblanc et al. 2010, 2013).

As part of a collaborative IPY project with University of Ottawa, five shallow boreholes (5-10 m deep) were instrumented in 2009 on Ellesmere Island at Eureka. These boreholes were established along a topographic transect as part of a study to investigate the role of atmospheric temperature inversions on the ground thermal regime. Data for three of the boreholes, based on a three year record, are provided in this report.

A shallow (3 m) borehole was established by GSC and Environment Canada in 1997 in Baker Lake (e.g. Smith et al. 2001; Throop et al., 2008, 2010). Data collection was suspended in 2007 and the most recent data from the site is reported here. Environment Canada operates a monitoring site in Iqaluit consisting of two boreholes 5 m in depth (e.g. Smith et al., 2005; Throop et al., 2010). Data are not available after 2005 but the most recent information available is included in this report. Three shallow boreholes are maintained by Université Laval on Bylot Island and data collected during the IPY period, 2007-08 (Smith et al., 2010), are included here.

Information on the ground thermal regime is gathered as part of the baseline and geotechnical investigations conducted at potential resource development sites. Information on these studies is included in the documentation submitted as part of the environmental assessment and regulatory processes and is available on the public registry of the Nunavut Impact Review Board. Relevant data on the ground thermal regime was extracted from reports associated with the Jericho, High Lake, Doris, Meadowbank and Mary River projects. For some sites, only a single ground temperature measurement was made at various depths in the borehole. At other sites, periodic measurements at various time intervals have been made. Most of these data have been collected since 2000. The mine site boreholes account for almost 80% of the boreholes included in the database.

Data Accuracy and Limitations

The goal in this report is to provide the mean annual ground temperature (MAGT) at the depth of zero annual amplitude (ZAA). This is considered to be the depth at which the seasonal variation in temperature is 0.1°C or less. For sites at which data are collected continuously or several times throughout the year at sufficient depth, MAGT at ZAA (or depth closest to it) can be easily calculated. For some sites however, seasonal variation may be greater than 0.1°C at the deepest measurement point and in this case the MAGT for the deepest measurement is determined and included in the compilation. For some sites, measurements were only made periodically and data are not sufficient to determine the annual range in temperature. For these sites, the mean value of measurements at the depth closest to 20 m was determined and compiled.

Although ground temperatures have generally been measured with accuracy and precision better than 0.1°C, the precision of the values presented in the database is variable. For data obtained from GSC monitoring sites, the precision is greater than 0.1°C. For mining projects, temperature data for many sites were extracted from graphic presentations of ground temperature profiles and precision therefore varies between 0.1 and 0.5°C. The data however are still sufficient to provide information on the range in ground temperature that may be found in a given region.

DESCRIPTION OF DATABASE AND MAPS

Data on ground temperature has been compiled into an MS Excel Spreadsheet (NUGT.xls). The fields in the database are outlined below.

Borehole – Name given to borehole by original investigator.
Date – Period over which data were collected to determine the MAGT presented in the database.
Elevation (m) – Borehole elevation in metres above mean sea level (if available).
Depth (m) – Depth of ground temperature measurement.
Temp (°C) - Mean annual ground temperature at level of zero annual amplitude or depth closest to it.
Lat – Latitude (°N) for the borehole location.
Long – Longitude (°W) for the borehole location.
Local Name/Description – Additional information is provided regarding the borehole location
Original DB – Project for which the data were collected or location of database.
Comments – Other information regarding the MAGT value including whether it is measured at depth of zero annual amplitude.
Reference – Reference to relevant reports and source of data (complete citation provided in Data Source list)

A summary of the information in the database is provided in Table 1. Figure 1 provides a map of recent ground temperatures in Nunavut. This provides more detailed information on permafrost thermal state than the map of Smith et al. (2010) that presented data collected during the IPY period (2007-08). Although some of the data presented in Figure 1 were collected a decade ago or more (e.g. measurements in some boreholes at Jericho mine site), the map still provides an updated summary of ground thermal conditions in Nunavut compared to the earlier map of Smith and Burgess (2000). Five larger scale maps are provided (Figures 2, 3, 4, 5, 6) for the area around proposed and existing mine sites, where measurements were made in several boreholes located within a few tens of metres to a few kilometres of each other.

GROUND TEMPERATURE CONDITIONS IN NUNAVUT

Ground temperatures in Nunavut range from colder than -15°C to warmer than -2°C (Figures 1 and 7). However, permafrost at temperatures greater than -2°C are only observed at two borehole sites; permafrost temperatures are below -5°C at more than 75% of the total 111 borehole sites (Figure 7) with a median ground temperature of -7.5°C. It should however be noted that the measurements at about 30 (27%) of the boreholes are above the depth of ZAA (Figure 7) and therefore only approximate MAGT at the depth of ZAA. Warmer permafrost conditions generally occur near water bodies (e.g. Figures 2 to 5) and for the mine sites these would include boreholes drilled at proposed dam alignments or water crossings.

Permafrost temperatures generally decrease northward (Figure 8) as climate becomes colder. However, there is a great deal of local and regional variation as shown in the larger scale maps in Figures 2 to 6. Over areas of a few square kilometres, the range in mean annual ground temperature can be more than 5°C. In the Hope Bay area, at the proposed Doris Mine site, for example, ground temperatures measured in 25 boreholes over an approximately 40 km^2 area, range from -3.6 to -9.5°C (Figure 2, Table 1). This high spatial variability is due to a number of factors including proximity to the coast and other water bodies, topography, vegetation cover and snow cover (e.g. Smith et al., 2010).

SUMMARY

Recent information on permafrost thermal state has been compiled in a database and map. This information facilitates characterization of regional permafrost conditions and a valued ecosystem component, and can be incorporated into state of knowledge reports for Nunavut. Essential information is provided which may be utilized for engineering design and to support environmental assessment and decisions associated with northern resource development projects. It is hoped that periodic updates of this map can be provided as information from additional sites becomes available and as more data become available from existing long-term monitoring sites.

ACKNOWLEDGEMENTS

Support for this data compilation is provided by the Geological Survey of Canada, Natural Resources Canada. Establishment of GSC monitoring sites and subsequent data collection has been supported by various funding sources over the past several years, most recently by the Canadian government's International Polar Year Program and Aboriginal Affairs and Northern Development Canada. The assistance of Environment Canada, Department of National Defence (CFS Alert) and communities for site maintenance and data collection at GSC sites is much appreciated. A.-M. Leblanc (GSC) kindly reviewed the manuscript and provided information on Iqaluit and Pangnirtung boreholes.

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Table 1. Summary of ground thermal information provided in the database. MAGT refers to the mean annual ground temperature at the depth of zero annual amplitude (or measurement depth closest to it). For sites with more than one borehole (BH), a range in MAGT is provided.

Site	Lat (°N)	Long (°W)	MAGT (°C)	Number of BHs	Period	Reference
Alert	82.5	62.4	-11.1 to -14.4	5	2007-2011	Updated from Smith et al. (2010, 2012)
Eureka	79.9	85.9	-14.8 to -15.8	3	2009-12	GSC database
Gemini	79.9	84.1	-15.5	1	2004-05	Updated from Taylor et al. (2006)
Pat Bay	77.3	105.4	-15.6	1	1994-95	Taylor et al. (2006)
Arctic Bay	73.0	85.1	-10.3	1	2008 -12	Updated from Ednie and Smith (2010, 2011)
Igloolik	69.4	81.8	-8.4	1	2008 -11	Updated from Ednie and Smith (2010, 2011)
Clyde River	70.5	68.5	-6.9	1	2008 -12	Updated from Ednie and Smith (2010, 20110
Taloyoak	69.5	93.6	-9.7	1	2009–12	Updated from Ednie and Smith (2010)
Resolute Bay	74.7	94.9	-11.9	1	2008–12	Updated from Ednie and Smith (2010, 2011)
Pond Inlet	72.7	77.9	-8.3	1	2008–12	Updated from Ednie and Smith (2010, 2011)
Pangnirtung	66.1	65.7	-2.9 to -7	3	2008–10	Updated from Ednie and Smith (2010, 2011); Leblanc et al. (2010, 2011)
Kugaaruk	68.5	89.8	-8.2	1	2009 -11	Updated from Ednie and Smith (2010)
Iqaluit	63.7	68.5	-5.6 to -7.1	3	2003-04 & 2011-12	Throop et al. (2010, 2012); Leblanc et al. (2013)
Bylot Island	73.1	79.9	-10.8	1	2007-08	Smith et al. (2010)
Baker Lake	64.2	95.5	-7.9	1	2006-07	Smith et al. (2010), Throop et al. (2012)
Hope Bay (Doris Mine site)	68.1	106.5	-3.6 to -9.5	25	2003 &2004	SRK (2005)
High Lake Mine area	67.4	110.8	-2.3 to -6	14	2002	BGC (2006)
Jericho Mine area	66.0	111.5	-1.5 to -7.5	11	1996 & 2003	SRK (2003)
Meadowbank Mine area	65.0	96.0	-1.1 to -9.8	22	2002 - 2005	Cumberland Resources (2005)
Mary River Mine and transportation corridor	71.0	79.0	-6.6 to -10.5	14	2008	Knight Piésold Ltd. (2010a,b)

Figure 1. Map of mean annual ground temperature for Nunavut. Mean annual ground temperature is determined for the level of zero annual amplitude or closest measurement depth to it. The range in temperature (°C) is provided for areas with a cluster of measurements and larger scale maps for these areas are provided in figures 2, 3, 4, 5, 6. See Table 1 and the database for information on date and depth of measurement.

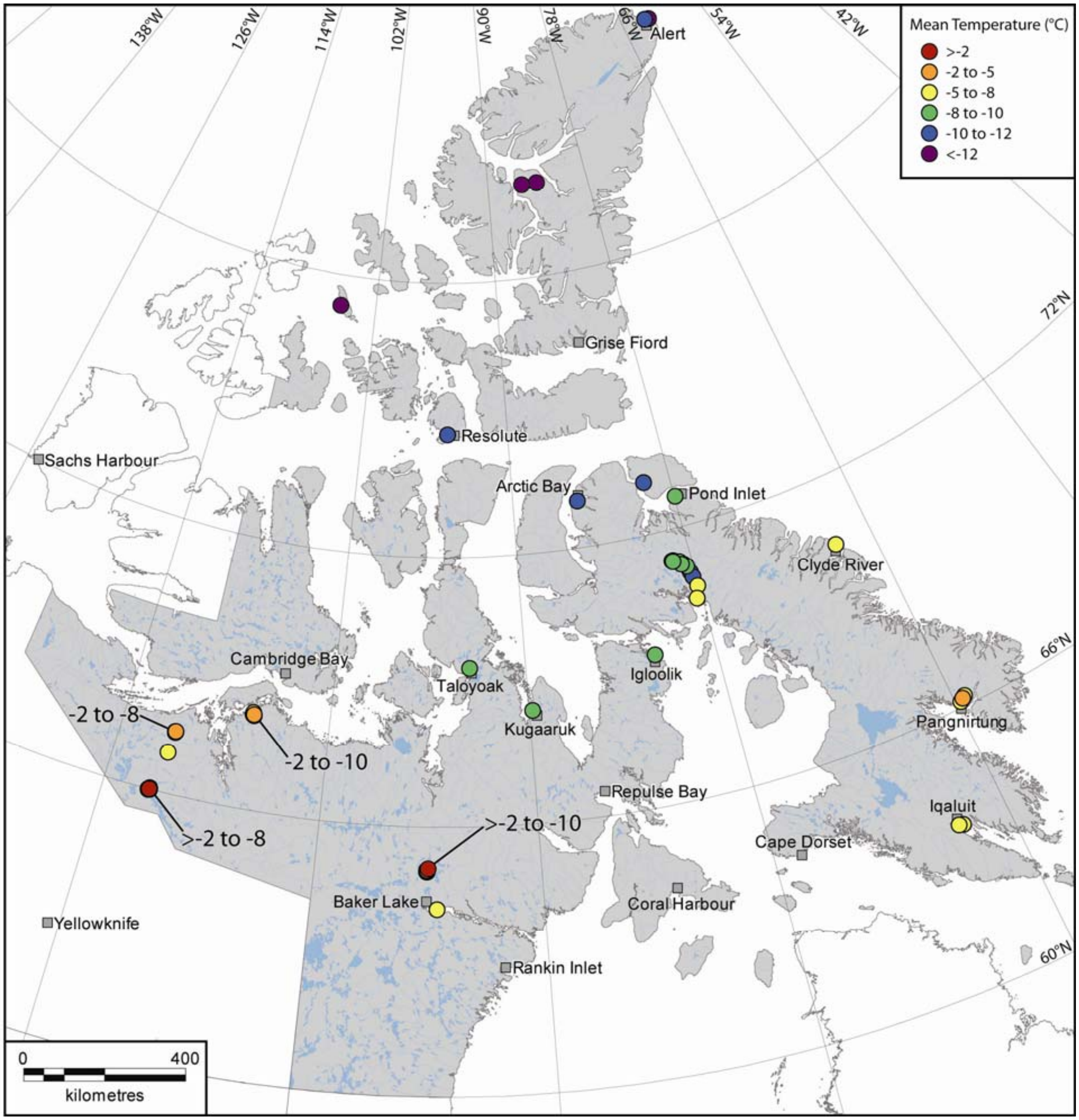

Figure 2. Mean annual ground temperature for the Hope Bay area. Mean annual ground temperature is determined for the level of zero annual amplitude or closest measurement depth to it. See Table 1 and the database for information on date and depth of measurement.

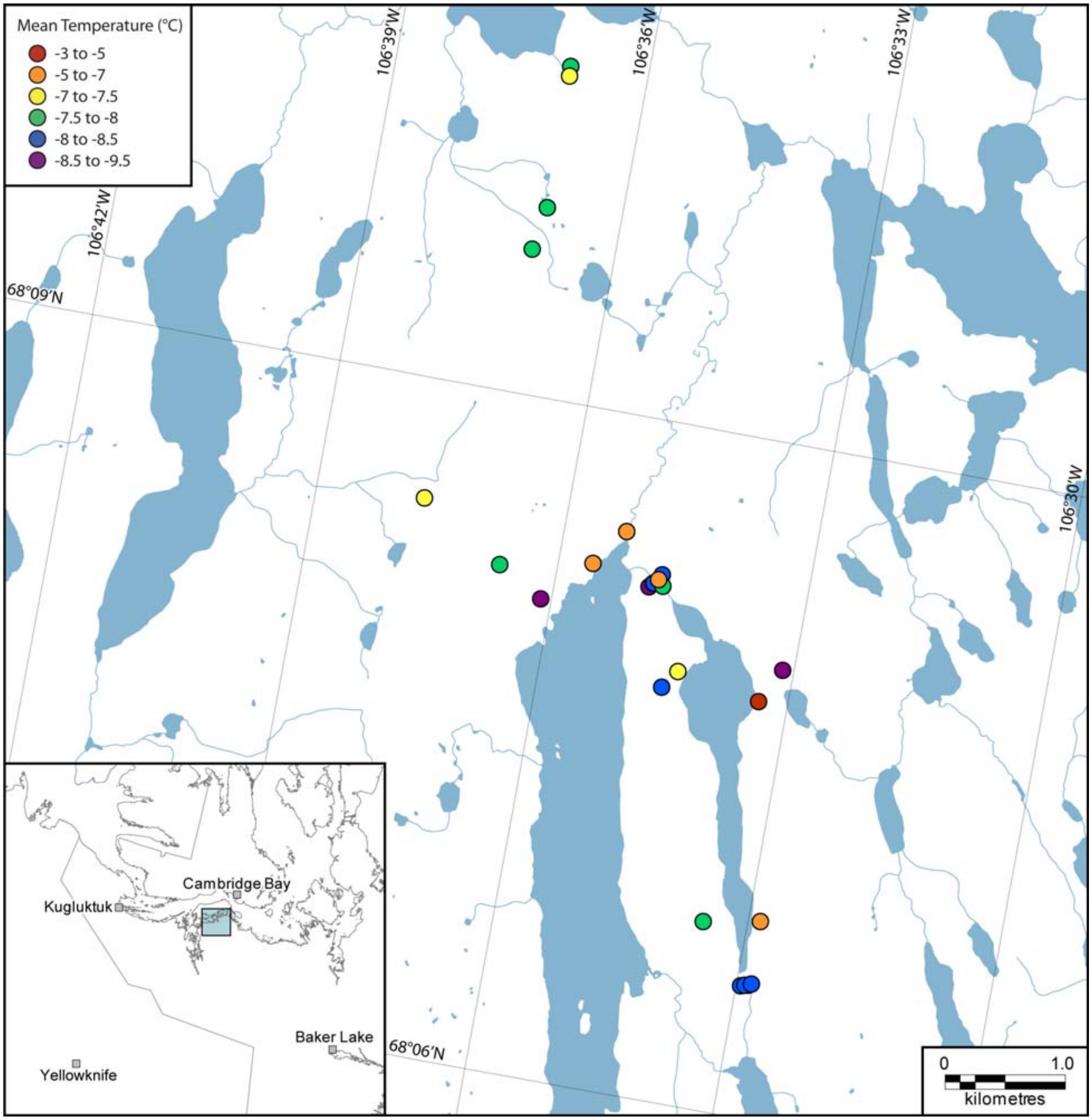

Figure 3. Mean annual ground temperature for the High Lake Mine area. Mean annual ground temperature is determined for the level of zero annual amplitude or closest measurement depth to it. See Table 1 and the database for information on date and depth of measurement.

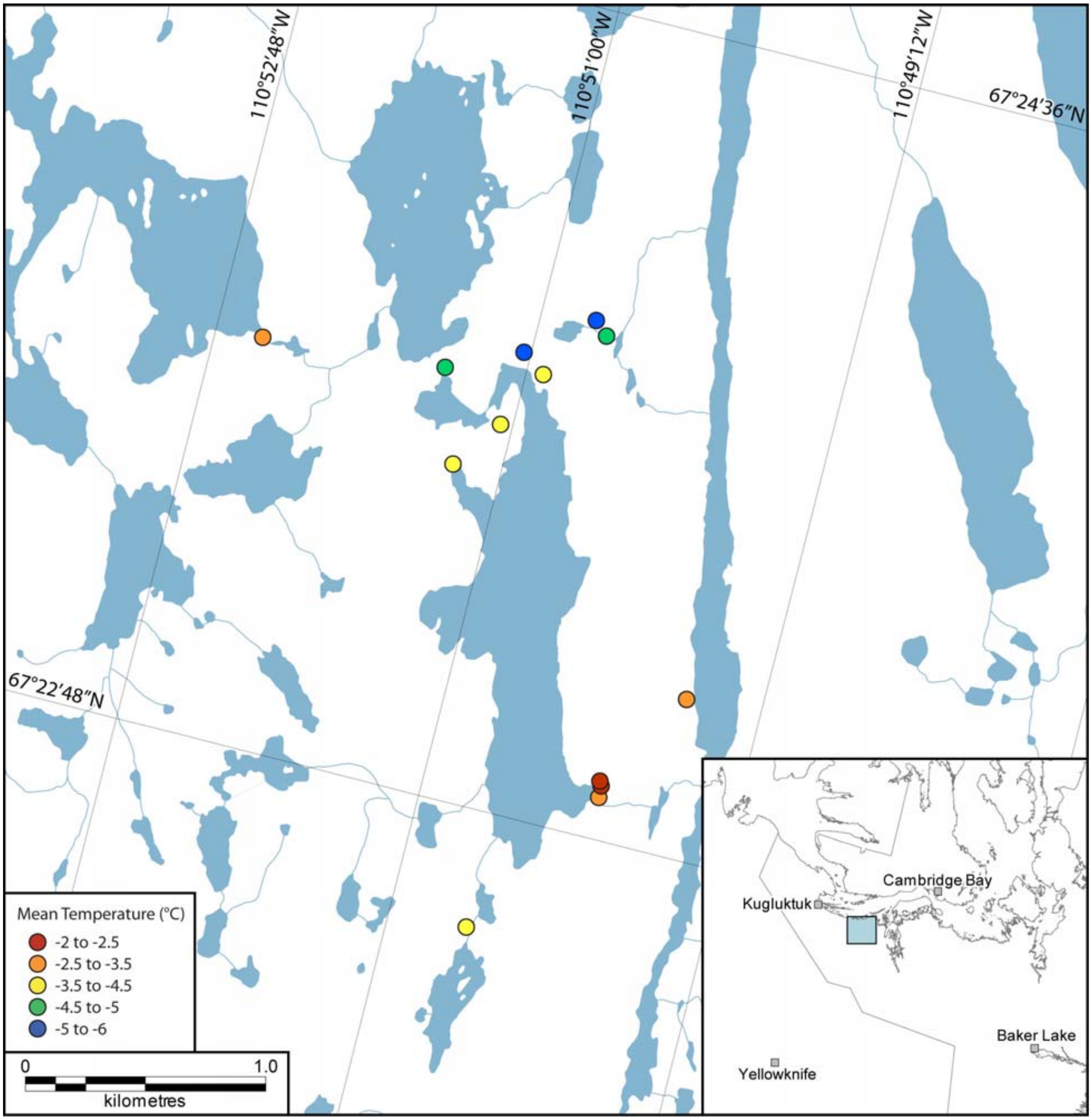

Figure 4. Mean annual ground temperature for the Jericho Mine area. Mean annual ground temperature is determined for the level of zero annual amplitude or closest measurement depth to it. See Table 1 and the database for information on date and depth of measurement.

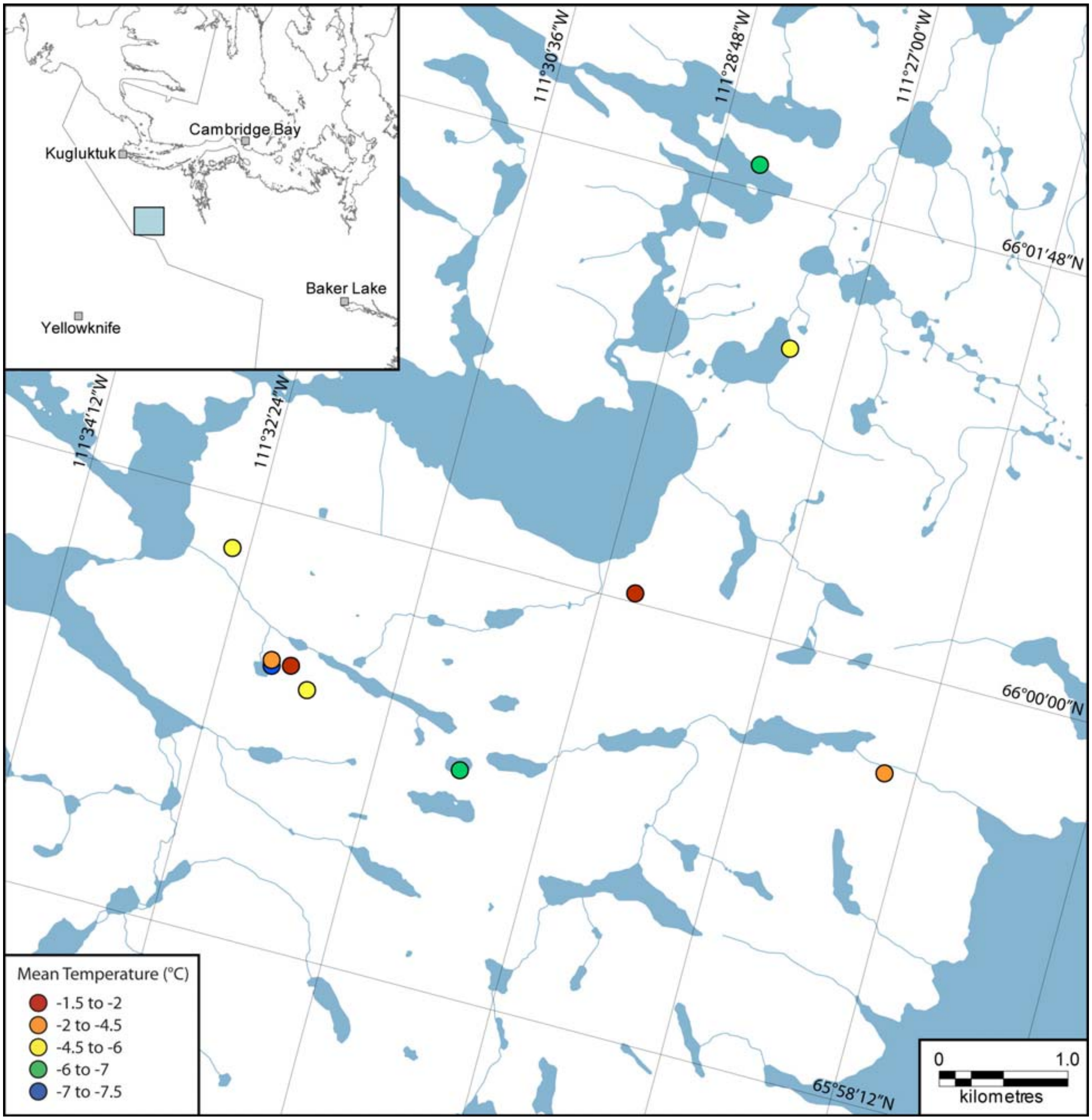

Figure 5. Mean annual ground temperature for the Meadowbank Mine area. Mean annual ground temperature is determined for the level of zero annual amplitude or closest measurement depth to it. See Table 1 and the database for information on date and depth of measurement.

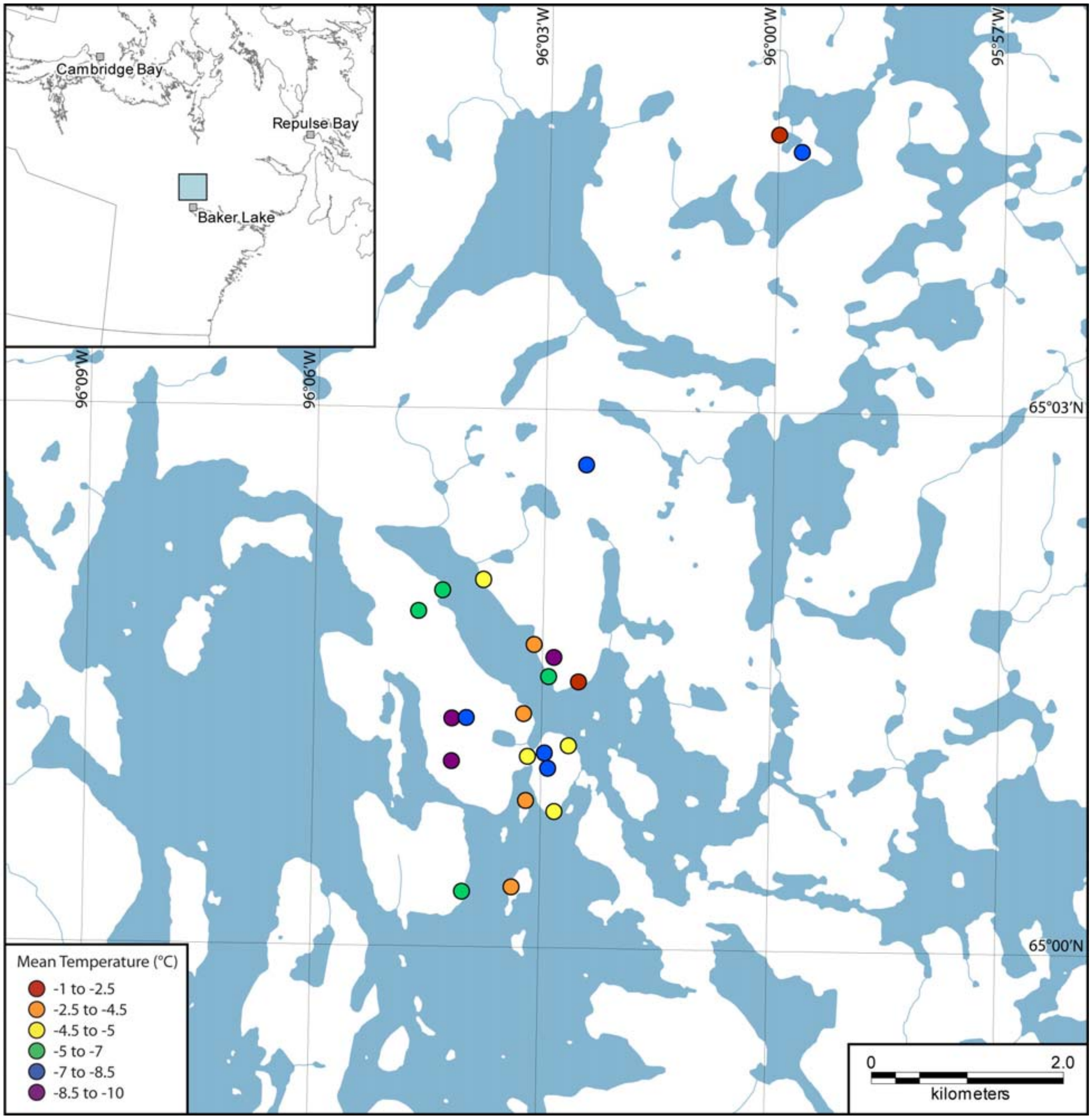

Figure 6. Mean annual ground temperature for northern Baffin Island for the Mary River Mine area. Mean annual ground temperature is determined for the level of zero annual amplitude or closest measurement depth to it. See Table 1 and the database for information on date and depth of measurement.

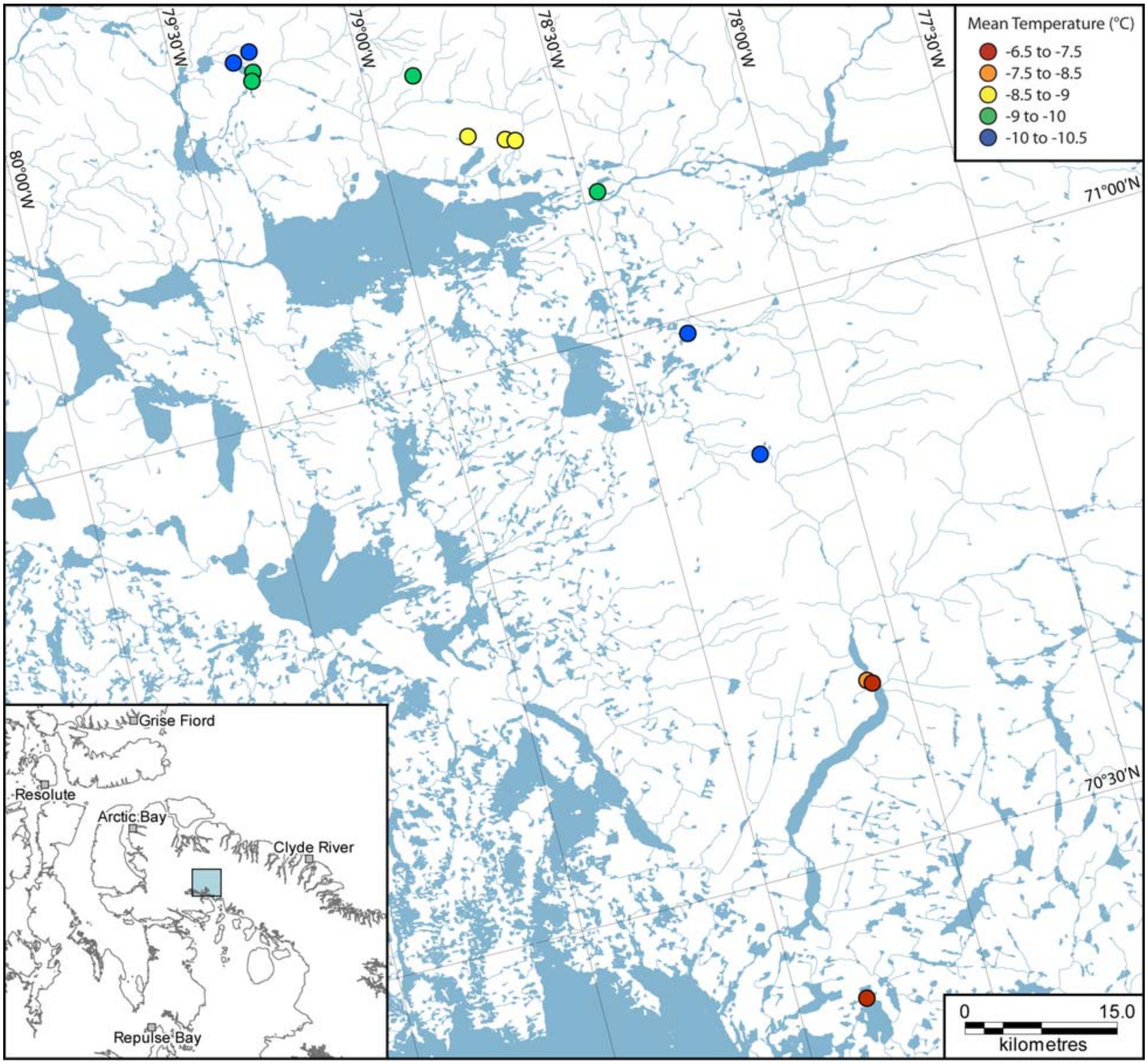

Figure 7. Frequency distribution for mean annual ground temperature (MAGT). Note the label on the x-axis is the upper boundary of the interval. The depth of temperature measurement relative to the depth of ZAA (near or above ZAA) is also indicated.

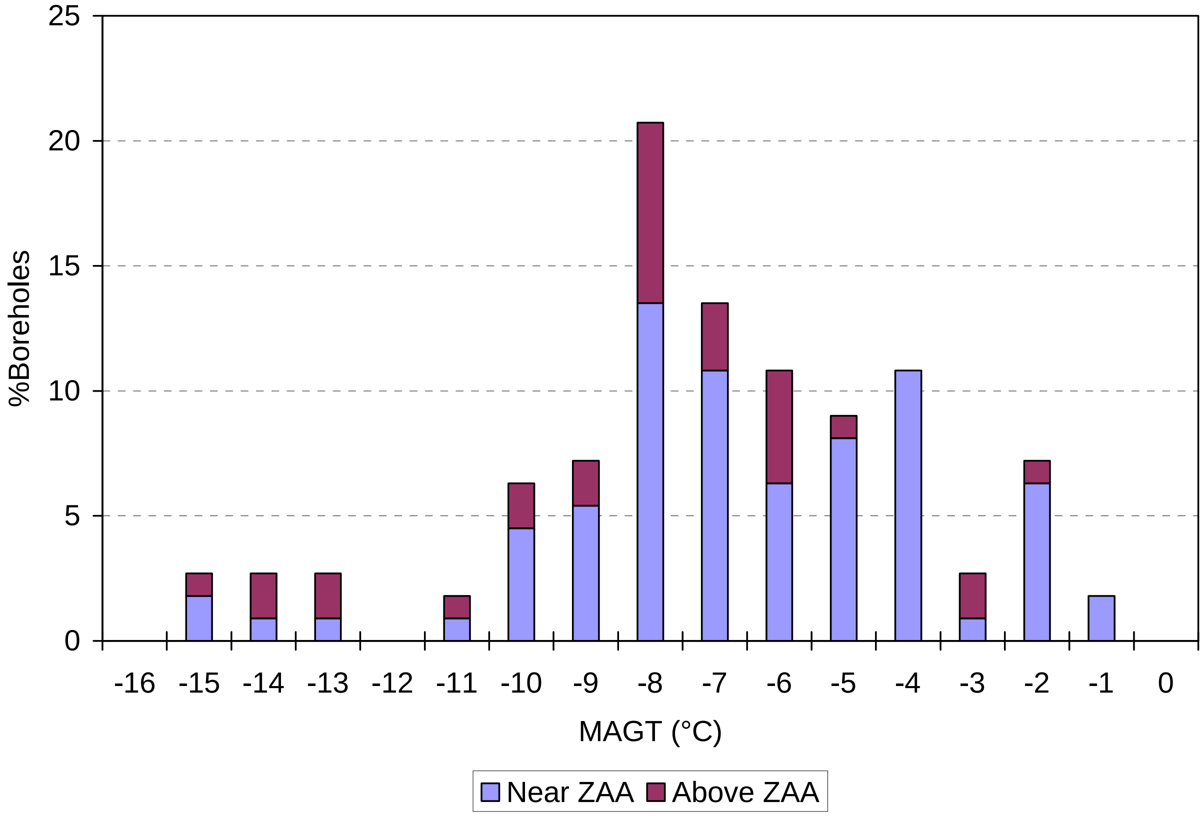

Figure 8. Relationship between mean annual ground temperature (MAGT) and latitude for Nunavut. The depth of temperature measurement relative to the depth of ZAA (near or above ZAA) is also indicated. The regression equation and R^2 value were determined utilizing all MAGT values in the database (used data from all 111 boreholes).