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ABSTRACT

Cased boreholes along the Alaska Highway easement in the southern Yukon were acquired from TransCanada Pipelines Ltd. by the Geological Survey of Canada. Eight of the boreholes between KP1559 (near Haines Junction) and the Alaska border were instrumented for ground temperature measurement in July 2013 to provide improved information on current permafrost conditions in the highway corridor. The initial data acquired shortly after installation of thermistor cables, indicates that ground temperatures are generally higher than -1°C except at one site near the Alaska border where ground temperature is about -3°C. The instrumented sites will be maintained in collaboration with the Yukon Research Centre, Yukon Department of Highways and Public Works and the Yukon Geological Survey. Continuous data collection for at least one year will facilitate characterization of ground thermal conditions in this portion of the corridor and provide updated information to support infrastructure design and decisions regarding development projects in the region.

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INTRODUCTION

Permafrost presents a challenge to development in northern Canada. The Alaska Highway Corridor traverses the discontinuous permafrost zone of the southern Yukon from the Alaska border to northern British Columbia. The potential for natural gas pipeline development and the need to develop climate change adaptation options for infrastructure such as the highway have stimulated the need for up to date information on permafrost and terrain conditions within the corridor. Construction and operation of infrastructure associated with development projects can result in changes to the ground thermal regime resulting in thaw settlement, frost heave, drainage alteration and landscape instability which may affect infrastructure integrity and have consequences for terrestrial and aquatic ecosystems. Knowledge of current permafrost conditions in the corridor is essential to characterize terrain response to construction and operation of infrastructure and to ensure environmental impacts are minimized, maintaining the integrity of both the environment and the infrastructure. Changes in permafrost conditions over the last three to four decades have been documented along the Alaska Highway corridor between Whitehorse YT and Fort St. John BC (e.g. James et al., in press; James, 2010) and elsewhere in northern Canada (e.g. Smith et al., 2010). Therefore, improved knowledge regarding how permafrost conditions may change over time is also required to adequately ensure planning of development projects is done in an appropriate and responsible manner.

The Geological Survey of Canada (GSC) acquired, from TransCanada Pipeline Ltd., a suite of cased boreholes located on the Alaska Highway easement between the Alaska border and KP1559 near Haines Junction. Boreholes were instrumented for ground temperature measurement in July 2013 by GSC in collaboration with the Yukon Department of Highways and Public Works, Yukon Research Centre and Yukon Geological Survey. This report describes the fieldwork conducted in summer 2013, including information on field sites. A summary of the initial ground thermal data collected from the field sites is also provided.

STUDY SITES

The field sites are located on the highway easement between approximately KP1559 and KP1902 (Figure 1). The study area is located within the Western Cordillera and the highway corridor crosses the Teslin and Kluane Plateau over the Shakwak Trench and follows the Kluane Ranges (Mathews, 1986). Elevation in the region is variable reflecting the numerous mountains, valleys and plateaus. However the highway corridor itself is less variable in elevation than the surrounding area with elevation of the study sites ranging from approximately 600 to about 850 m a.s.l.

The study area was last glaciated 80ka to 10ka years ago during the Wisconsinan (Bond, 2004, Duk-Rodkin, 1999). The area traversed by the corridor from Whitehorse to Beaver Creek was covered by the Cordilleran Ice Sheet (Fulton, 1989). Deglaciation was characterised by multiple changes in ice flow, glacial re-advances, periods of dynamic equilibrium and glacial lake development which shaped the landscape (Bond, 2004; Jackson et al., 1991).

Fluctuations in the level and size of Kluane Lake during the Holocene have probably resulted in deposition of glaciolacustrine sediments in the surrounding area (Bostock, 1969;

Clague et al., 2006). The lake level rose most recently, to a level 12 m above present levels, in the 17th century during the Little Ice Age advance of Kaskawulsh Glacier (Clague et al., 2006; Brahney et al,. 2008, 2010). Glaciolacustrine deposits are found near Haines Junction and in the Alsek valley associated with Neoglacial Lake Alsek which resulted from surges of the Lowell Glacier and damming of the Alsek River over the past 3000 years (Lipovsky, 2011; Clague and Rampton, 1982). The glacial history in the northwestern portion of the study area near Beaver Creek is not clear but extensive moraines and till underlain by glaciofluvial deposits indicate a dynamic glacial history (Rampton, 1969, 1971). According to Rampton (1971), the Macauley Glaciation began in this area at about 40,000BP and lasted until 13,500BP. Portions of the area remained ice-free but were still exposed to extreme glacial influences.

Surficial materials in the study area vary from coarse-grained sands, gravels and tills, associated largely with moraine and outwash deposits, to fine-grained silts and clays associated with alluvial and lacustrine deposits (Fuller and Jackson, 2009; Clague, 1989). Peat, generally less than 5 m thick is found in large areas that are poorly drained (Clague, 1989; Foothills Pipe Lines, 1979). Sediment thickness generally exceeds 10 m in the section of the corridor where the boreholes are located (Foothills Pipe Lines, 1979). According to terrain analysis presented in the Environmental Impact Statement for the original pipeline application (Foothills Pipe Lines, 1979), peat was observed in about 35% of the terrain in the section of the corridor within about 370 km of the Alaska border.

The climate in the southern Yukon is subarctic continental, with cold winters and short mild summers (Jackson et al., 1991). Climate data for three Environment Canada weather stations between Whitehorse and the Alaska border (Whitehorse, Haines Junction, Burwash and Beaver Creek) are provided in Table 1 and can be used to characterize the climate in the Alaska Highway Corridor. Mean annual air temperature (based on 1981-2010 Normals) ranges from -0.07°C at Whitehorse to -4.87°C at Beaver Creek. January air temperature ranges from -15.5°C at Whitehorse to -25.21°C at Beaver Creek. July temperatures are lower at Haines Junction and Burwash (7.24 and 13.06°C respectively) compared to Whitehorse and Beaver Creek where they are about 14°C (Table 1). Total precipitation is greater in the western portion of the corridor, where it is greater than 400 mm, compared to that at Whitehorse which receives 262 mm. The proportion of total precipitation that fall as snow is 30-40%.

The corridor is located within the discontinuous permafrost zone (Figure 1, Heginbottom et al., 1995), largely within the sporadic discontinuous zone except for the portion that is within about 50 km of the Alaska border. Studies done in the 1970s for the Environmental Impact Statement for the proposed pipeline indicate that north of Kluane Lake, permafrost is nearly continuous with taliks present under major streams and lakes and isolated south facing slopes (Foothills Pipelines, 1979). South of Kluane Lake permafrost is less abundant, becoming patchy near Whitehorse where it is largely limited to organic terrain (James, 2010; Lewkowicz et al., 2011). Observations in the 1970s, indicate that permafrost is generally less than 20 m thick in the corridor and in many places it is less than 10 m thick (Burgess et al., 1982; Smith and Burgess, 2002) although Foothills Pipelines (1979) reported that permafrost thickness exceeds 45 m near the Alaska border. Recent surveys utilizing Electrical Resistivity Tomography in the corridor indicate that permafrost is thicker than 20 m in sections of the corridor between Destruction Bay and the Alaska Border (Duguay, 2013). Shallow temperature measurements made within the corridor between 1978 and 1981 indicate that mean annual ground temperatures are generally above -3°C (Burgess et al., 1982). More recent temperature information along the corridor (2011-12) as well as regional data (2008-09) for the southern Yukon, including that at higher elevations, also indicates that warm permafrost conditions exist with temperatures approaching 0°C for the section of the corridor between Whitehorse and the BC border (Blais-Stevens et al., 2013; Duguay, 2013; Duguay et al., 2012; Lewkowciz et al., 2011; Smith et al., 2010).

The location of the eight study sites is shown in Figure 1 and provided in Table 2 which also includes a brief site description. Boreholes are located on the highway easement and vary in distance from the existing highway from 10 m to greater than 30 m with many located in or near areas that were previously disturbed. Photos of sites taken in July 2013 are provided in Figures 2 to 9 and borehole location is also shown on air photos in Appendix A.

Boreholes were drilled by TransCanada Pipeline in 2011 and all are less than 10 m deep. Boreholes were preserved for temperature measurement through installation of a 25 mm plastic casing following completion of drilling. A metal box covers the section of the casing above ground level and protects the casing.

SUMMER 2013 FIELD INVESTIGATIONS

Borehole sites were visited July 5 to 8, 2013. Multi-sensor temperature cables were installed in six boreholes to depths of up to 9.9 m (Table 2). The accuracy of the thermistors utilized is better than ±0.1°C. The cables were connected to eight channel dataloggers manufactured by RBR Ltd. (resolution better than ±0.01°C) to record temperature measurements at eight hour intervals. After cables were installed, the borehole was filled with silicone oil to prevent air convection in the borehole and also provide better contact between the thermistors and the ground. Installation of instrumentation was similar to that done by the GSC at other field sites in northern Canada (e.g. Smith et al., 2009).

In two of the shallower boreholes (AH2013-T1, AH2013-T2), 4-channel HOBO Microstation loggers (manufactured by Onset Corp.) connected to HOBO 12-bit temperature sensors were installed to measure temperatures to a depth of 4.9 m. The accuracy and resolution of this system is better than ±0.2°C and ±0.03°C respectively. The loggers record temperatures at four hour intervals.

At two sites (AH2013-T4 and AH2013-T7), instrumentation was installed to measure snow depths (Table 2). This consisted of a series of nine Thermochron iButton temperature loggers (accuracy ±1°C) mounted on a wooden stake up to 1 m above the ground surface. The spacing of the iButtons increases with height above the ground from 5 to 20 cm. Snow depths are inferred through analysis of temperature patterns at each height as described by Lewkowicz (2008). Resolution of the system depends on the sensor spacing.

Sites were visited one to three days after cable installation to make initial manual temperature measurements. Temperatures within the silicone filled casing should have stabilized within a day of installation. Manual measurements of resistance at multi-sensor cables were made using a Fluke Multimeter and later converted to temperatures. Live readings of ground temperatures were also made at one of the HOBO Microstations. It was only possibly to take a live reading of temperature at the second Microstation (AH2013-T1) at the time of installation when there was insufficient time for the thermistors to equilibrate with the ground temperature.

INITIAL RESULTS

Initial ground temperature measurements were made July 7-8 2013 at all sites except AH2013-T1. Ground temperature profiles are provided in Figures 3 to 9 and ground thermal conditions at each site are summarized in Table 3. Although the data are not sufficient to determine the mean annual ground temperature, measurements made at the maximum depth at most sites (7 to 10 m) likely provide a good estimate of the ground temperature at the depth of zero annual amplitude.

Ground temperatures indicate that permafrost is present at all sites except AH2013-T2 and geotechnical borehole logs indicate that permafrost is likely absent at AH2013-T1 (Table 3, Figure 3). Ground temperature measurements made in 1978-1981 by Burgess et al. (1982) between Whitehorse and Kluane as well as more recent measurements reported in Duguay (2013) also indicate that unfrozen conditions may exist in the vicinity of AH2013-T1. Although ground temperature measurements (Burgess et al. 1982; Duguay, 2013) at other sites in the corridor adjacent to Kluane Lake in the vicinity of AH2013-T2 indicate permafrost is present, permafrost is sporadic in this region. Also, removal of vegetation along the easement may have resulted in warmer ground conditions.

At the other six sites permafrost is generally warm with ground temperatures above -1°C at depths of 7-10 m (Table 3, Figures 4 to 8). The one exception is the site to the northwest of Beaver Creek (AH2013-T8) where the temperature is about -3°C at a depth of 9.9 m (Figure 9). Although there is no apparent spatial pattern, the two coldest sites (AH2013-T7 and AH2013-T8) are located towards the northwest end of the corridor within 30 km of the Alaska border (Figure 10). Air temperatures are lower in the Beaver Creek area compared to Burwash (Table 1), particularly in the winter and this may be partially responsible for the colder ground conditions in the northwest portion of the corridor. An insulating organic layer and thick peat accumulation of several meters (Table 2) at AH2013-T8 would also be responsible for colder permafrost conditions.

There is very little variation in temperature with depth within the frozen ground particularly at the warmer permafrost sites. Conditions may therefore be isothermal at the warm permafrost sites with temperatures varying less than 0.2 or 0.3°C with depth as observed for example at AH2013-T4 and AH2013-T6 (Figures 5 and 7).

FUTURE PLANS

At least one full year of ground temperature data will be required to adequately characterize the ground thermal regime at the field sites. Data from the loggers will be acquired in summer 2014 and the continuous record will be utilized to determine the range in ground temperature at each measurement depth (and define the temperature envelope) and also to determine the maximum depth of summer thaw. Data collection is planned for several years to better characterize regional ground thermal conditions.

The iButtons installed at AH2013-T4 and AH2013-T7 will provide information on winter snow cover. The Yukon Research Center and Yukon Department of Highways and Public Works plan to install weather stations at AH2013-T6 and AH2013-T8. Information acquired from the iButtons and the weather stations will facilitate better characterization of microclimate conditions and help to explain the spatial variation in ground thermal conditions.

SUMMARY

Eight boreholes along the Alaska Highway easement in the southern Yukon were instrumented for ground temperature measurement in July 2013. Initial ground temperature measurements to depths of 9.9 m indicate the permafrost is generally warm with temperatures above -1°C. Colder ground conditions are however present to the northwest of Beaver Creek, near the Alaska border where ground temperatures are about -3°C.

Data collected to date, are not sufficient to adequately characterize the ground thermal regime. The continuous measurements over at least one year will be utilized to better describe the current ground thermal conditions along the corridor. These data complement information being acquired elsewhere in the corridor and will improve our knowledge of regional permafrost conditions and support decisions regarding development in the corridor.

ACKNOWLEDGEMENTS

The field investigations were supported by Natural Resources Canada and the Program for Energy Research and Development. Maintenance of the field sites and data collection is a collaborative effort with Yukon Research Centre, Yukon Department of Highways and Public Works and Yukon Geological Survey. The boreholes were drilled by TransCanada Pipelines Ltd. and we thank them for making the boreholes available to us. Assistance with graphic preparation by J. Chartrand is also appreciated.

REFERENCES

Blais-Stevens, A., Smith, S.L., Kremer, M., Bonnaventure, P., Lewkowicz, A.G., Lipovsky, P., Duguay, M., Ednie, M., and Koch, J. 2013. Geohazard information and permafrost characterization surveys along the Yukon Alaska Highway Corridor, Geological Survey of Canada Scientific Presentation 16.

Bond, J. 2004. Late Wisconsinan McConnell glaciation of the Whitehorse map area (105D), Yukon. In Yukon Exploration and Geology 2003. Yukon Geological Survey. pp. 73-88.

Bostock, H.S. 1969. Kluane Lake, Yukon Territory; its drainage and allied problems, Geological Survey of Canada, Paper 69-28.

Brahney, J., Clague, J.J., Edwards, T.W.D., and Menounos, B. 2010. Late Holocene paleohydrology of Kluane Lake, Yukon Territory, Canada. Journal of Paleoliminology, 44: 873-885.

Brahney, J., Clague, J.J., Menounos, B., and Edwards, T.W.D. 2008. Timing and cause of water level fluctuations in Kluane Lake, Yukon Territory, over the past 5000 years. Quaternary Research, 70: 213-227.

Burgess, M.M., Judge, A.S. and Taylor, A.E., 1982. Yukon ground temperature data collection - 1966 to August 1981, Earth Physics Branch Open File 82-1, E.M.R., Ottawa.

Clague, J.J. (compiler), 1989. Quaternary geology of the Canadian Cordillera. In Chapter 1, Quaternary Geology of Canada and Greenland. Geological Survey of Canada, Geology of Canada, no. 1. pp. 17-95.

Clague, J.J., Luckman, B.H., Van Dorp, R.D., Gilbert, R., Froese, D., Jensen, B.J.L., and Reyes, A.V. 2006. Rapid changes in the level of Kluane Lake in Yukon Territory over the last millennium. Quaternary Research, 66: 342-355.

Clague, J.J., and Rampton, V.N. 1982. Neoglacial Lake Alsek. Canadian Journal of Earth Sciences, 19: 94-117.

Duguay, M.A. 2013. Permafrost changes along the Alaska Highway Corridor, southern Yukon, from ground temperature measurements and DC electrical resistivity tomography. M.Sc. Thesis, University of Ottawa, Ottawa.

Duguay, M., Smith, S.L. and Lewkowicz, A.G., 2012. Validation of current ground thermal conditions, Alaska Highway corridor, Yukon Canada. In: D.S. Drozdov (Editor), Extended abstracts of the Tenth International Conference on Permafrost The Fort Dialog-Iset Publisher, Tyumen, Ekaterinburg, Salekhard, Russia, pp. 129-130.

Duk-Rodkin, A. 1999. Glacial limits map of Yukon Territory. Geological Survey of Canada Open file 3694, Indian and Northern Affairs Canada Geoscience Map 1999-2.

Foothills Pipe Lines (South Yukon) Ltd. 1979. Environmental Impact Statement for the Alaska Highway Gas Pipeline.

Fuller, T. and Jackson, L. 2009. Quaternary Geology of the Yukon Territory, Yukon Geological Survey.

Fulton, R.J. 1989. Quaternary Geology of Canada and Greenland. In Geology of Canada. Geological Survey of Canada, p. 839.

Heginbottom, J.A., Dubreuil, M.-A., and Harker, P.A. 1995. Canada -- Permafrost; National Atlas of Canada, 5th Edition Ottawa: Geomatics Canada, National Atlas Information Service, and Geological Survey of Canada, Plate 2.1 (MCR 4177).

Jackson, L.L., Ward, B., Duk-Rodkin, A., and Hughes, O.L. 1991. The last Cordilleran ice sheet in southern Yukon Territory. Géographie physique et Quaternaire, 45: 341-354.

James, M. 2010. Historic change in permafrost distribution in northern British Columbia and southern Yukon Territory, Canada, M.Sc. Thesis, University of Ottawa, Ottawa.

James, M., Lewkowicz, A.G., Smith, S.L., and Miceli, C.M. in press. Multi-decadal degradation and persistence of permafrost in the Alaska Highway corridor, northwest Canada. Environmental Research Letters.

Lewkowicz, A.G. 2008. Evaluation of miniature temperature-loggers to monitor snowpack evolution at mountain permafrost sites, northwestern Canada. Permafrost and Periglacial Processes, 19: 323-331.

Lewkowicz, A.G., Etzelmuller, B. and Smith, S.L., 2011. Characteristics of discontinuous permafrost from ground temperature measurements and electrical resistivity tomography, southern Yukon, Canada. Permafrost and Periglacial Processes, 22: 320-342.

Lipovsky, P. 2011. Long-term monitoring of glacial dynamics, Lowell Glacier, Yukon. Annual Progress Report, Yukon Geological Survey.

Mathews, W.H. 1986. Physiographic Map of the Canadian Cordillera. Geological Survey of Canada Map 1701A.

Rampton, V.N. 1969. Pleistocence geology of the Snag-Klutlan area, southwestern Yukon Territory, Canada, Ph.D. Thesis, University of Minnesota.

Rampton, V.N. 1971. Late Pleistocene glaciations of the Snag-Klutlan area, Yukon Territory. Geological Society of America Bulletin, 82: 959-978.

Smith, S.L. and Burgess, M.M., 2002. A digital database of permafrost thickness in Canada, Geological Survey of Canada Open File 4173.

Smith, S.L., Chartrand, J., Nguyen, T.N., Riseborough, D.W., Ednie, M., and Ye, S. 2009. Geotechnical database and descriptions of permafrost monitoring sites established 2006-07 in the central and southern Mackenzie Corridor, Geological Survey of Canada Open File 6041.

Smith, S.L., Romanovsky, V.E., Lewkowicz, A.G., Burn, C.R., Allard, M., Clow, G.D., Yoshikawa, K., and Throop, J. 2010. Thermal state of permafrost in North America - A contribution to the International Polar Year. Permafrost and Periglacial Processes, 21: 117-135.

Table 1. Climate data for Environment Canada weather stations along the Alaska Highway corridor based on 1981-2010 normals.

	Whitehorse 60.7°N 135.07°W	Haines Junction 60.75°'N 137.5°W	Burwash 61.37°N 139.13°W	Beaver Creek 62.4°'N 140.87°W
Mean Annual Temperature	-0.07°C	-4.22°C	-3.23°C	-4.87°C
Jan. Temperature	-15.5°C	-20.62°C	-20.51°C	-25.21°C
July Temperature	14.34°C	7.24°C	13.06°C	14.08°C
Total Annual Precipitation	262.32 mm	353.2 mm	274.73 mm	417.26 mm
Total Annual Rainfall	160.89 mm	189.3 mm	195.15 mm	298.62 mm
Total Annual Snowfall	141.76 cm	163.87 cm	105.54 cm	117.92 cm

Table 2. Description of sites instrumented for ground temperature measurement.

Site	Latitude (°N)	Longitude (°W)	Site Description	Soil description	Instrumentation
AH2013-T1	60.840	137.278	Disturbed area between highway and old road	Silt (<1m) underlain by sand	HOBO logger with sensors installed to 4.95 m
AH2013-T2	61.232	138.762	Open area with shrubs on edge of conifer forest	Organic silt (~1 m) over sandy till	RBR logger and Multi-thermistor cable installed to 9.67 m
AH2013-T3	61.273	138.847	10-15 m from embankment, open area with shrubs, ground cover, hummocky, edge of conifer (black spruce) forest	Organic silt (~1 m) underlain by silt	RBR logger and Multi-thermistor cable installed to 7.43 m
AH2013-T4	61.595	139.468	Shrub and grass covered area adjacent to open forest	Sand (some gravel) underlain by ice rich silt at 8.5 m depth	RBR logger and Multi-thermistor cable installed to 8.36 m. Snow depth instrumentation
AH2013-T5	61.598	139.477	Shrub and grass covered area on edge of wooded area	Organic silt (~1 m) underlain by sand	HOBO logger with sensors installed to 4.85 m
AH2013-T6	61.970	140.452	Open area with small conifers, shrubs (re-grown	Surface organic (vegetation) layer 0.1m Ice-rich silt underlain by sand at 4m depth	RBR logger and Multi-thermistor cable installed to 8.82 m
AH2013-T7	62.340	140.833	Open mixed forest	Surface organic (vegetation) layer 5 cm Organic silt to ~1 m Ice-rich silt underlain by till at 6 m	RBR logger and Multi-thermistor cable installed to 9 m. Snow depth instrumentation
AH2013-T8	62.554	140.974	Hummocky with small spruce, shrub, willow	Organic (vegetation) layer 0.1 m Peat and ice-rich silt extends to borehole bottom	RBR logger and Multi-thermistor cable installed to 9.94m

Table 3. Ground temperature measured at deepest sensor in July 2013.

Site	Temperature	Measurement Depth	Permafrost Y(es) or N(o)
AH2013-T1	NA		N (based on geotechnical log)
AH2013-T2	0.93°C	9.67 m	N
AH2013-T3	-0.56°C	7.43 m	Y
AH2013-T4	-0.38°C	8.36 m	Y
AH2013-T5	-0.48°C	4.85 m	Y
AH2013-T6	-0.42°C	8.82 m	Y
AH2013-T7	-0.71°C	9.0 m	Y
AH2013-T8	-3.07°C	9.94	Y

Figure 1. Location of boreholes along the Alaska Highway easement instrumented for ground temperature measurement in summer 2013. Permafrost zones (from Heginbottom et al. 1995) are also shown.

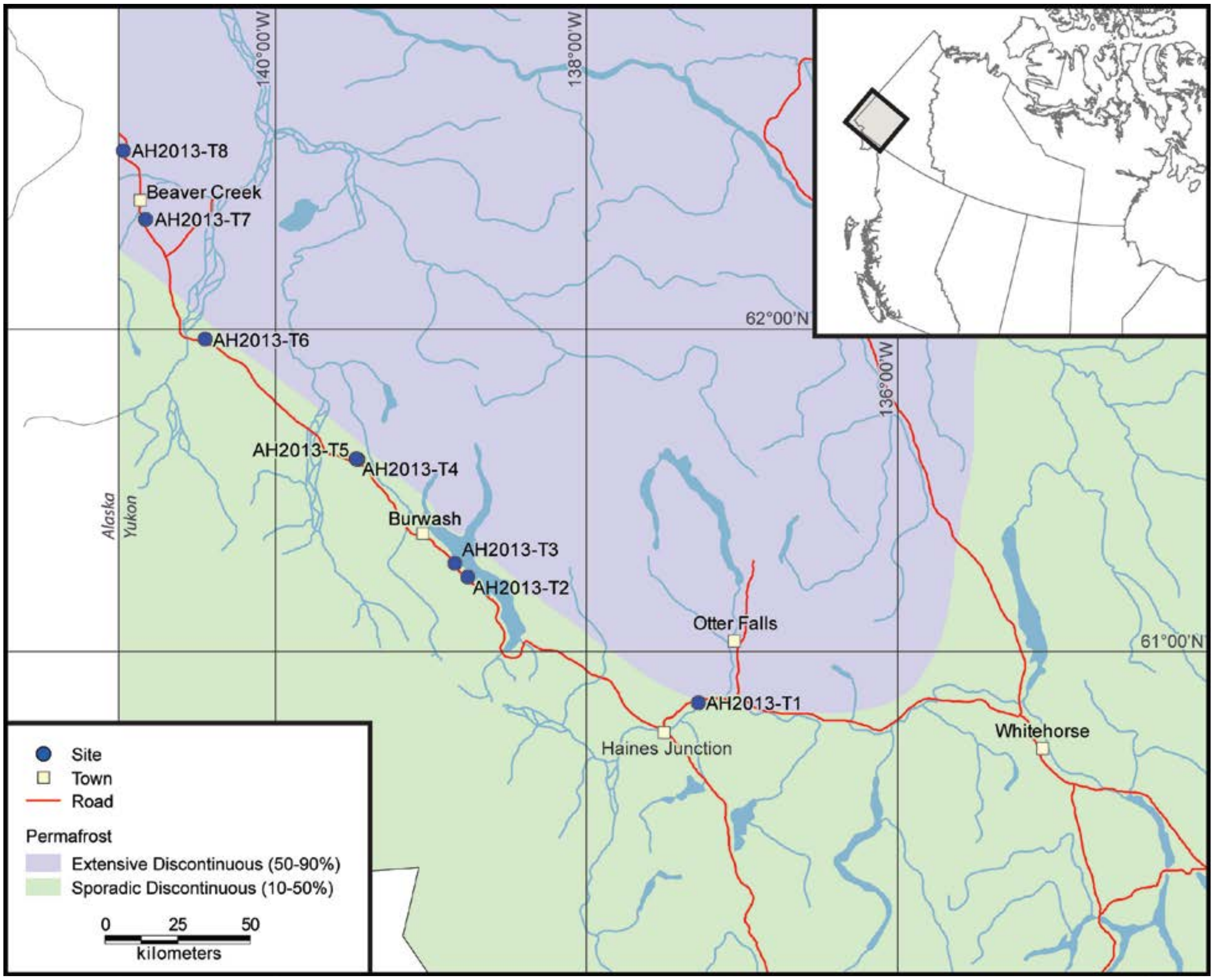


Figure 2. Photo of AH2013-T1 (July 5 2013).

Figure 3. Photo (A) and July ground thermal profile (B) for AH2013-T2.

A

B

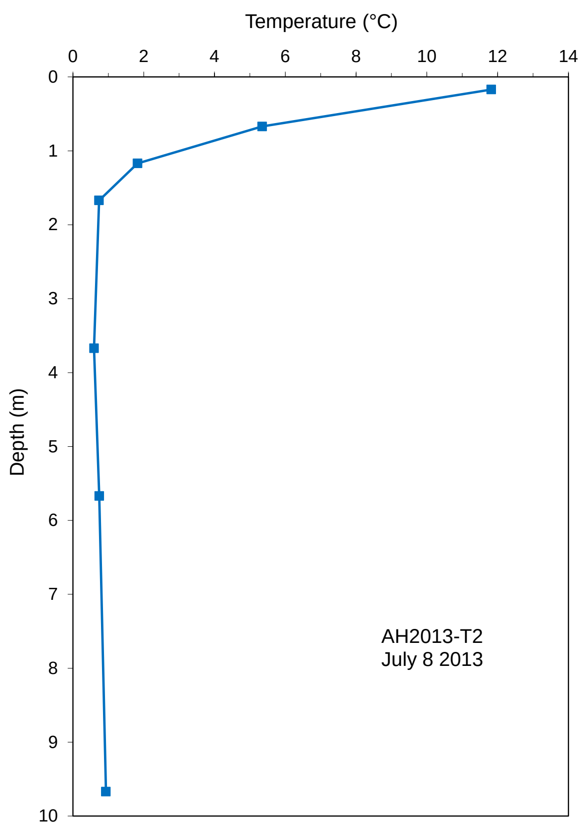


Figure 4. Photo (A) and July ground thermal profile (B) for AH2013-T3.

A

B

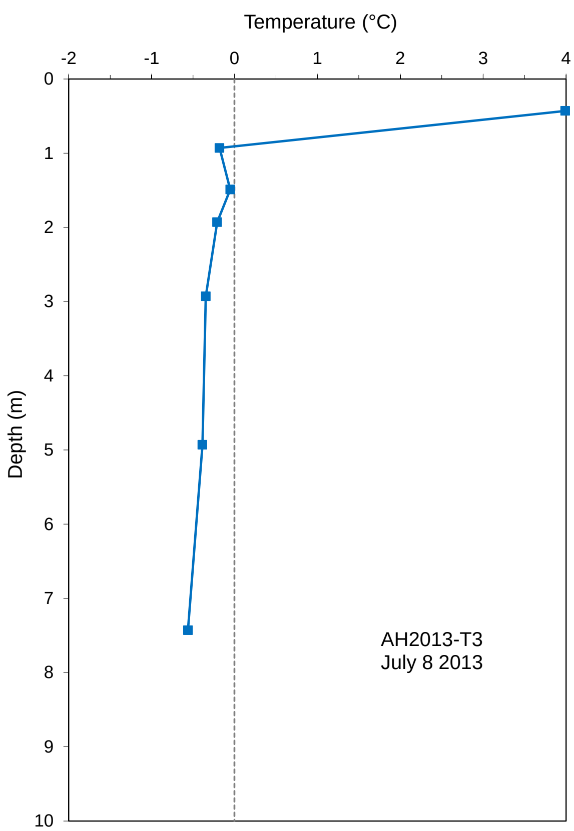


Figure 5. Photo (A) and July ground thermal profile (B) for AH2013-T4.

A

B

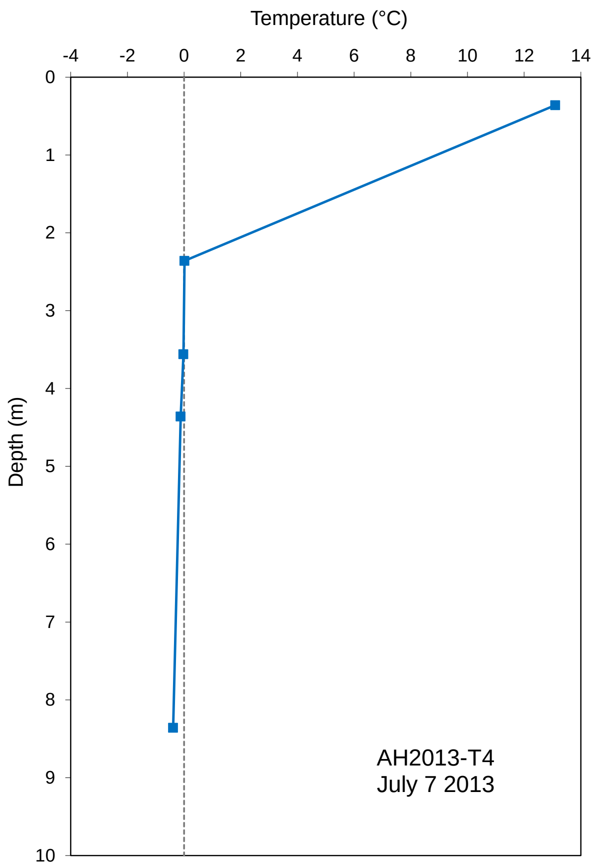


Figure 6. Photo (A) and July ground thermal profile (B) for AH2013-T5.

A

B

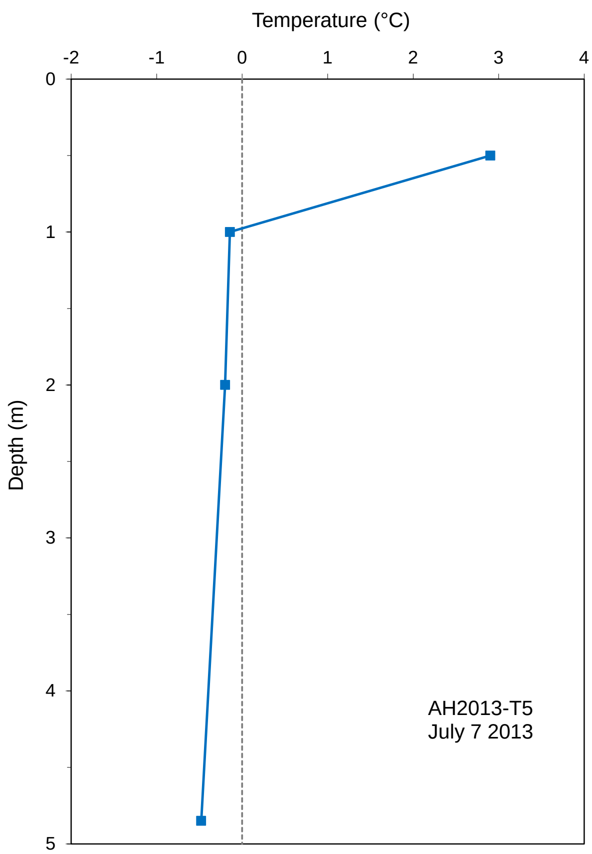


Figure 7. Photo (A) and July ground thermal profile (B) for AH2013-T6.

A

B

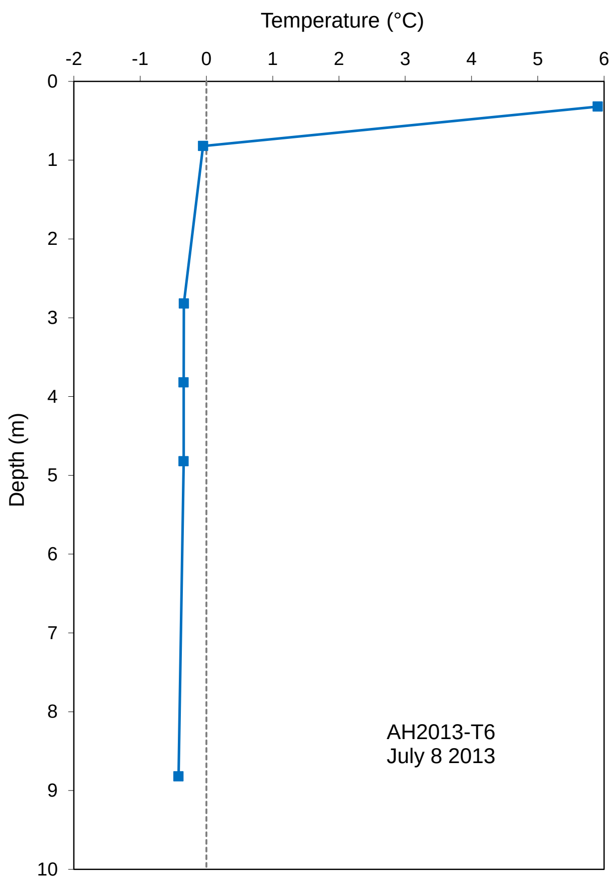


Figure 8. Photo (A) and July ground thermal profile (B) for AH2013-T7.

A

B

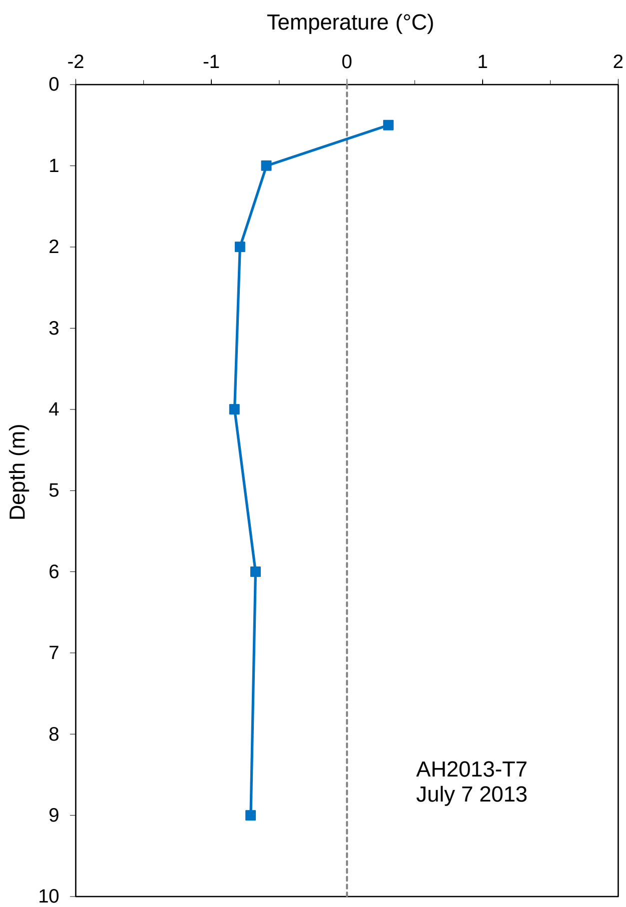


Figure 9. Photo (A) and July ground thermal profile (B) for AH2013-T8.

A

B

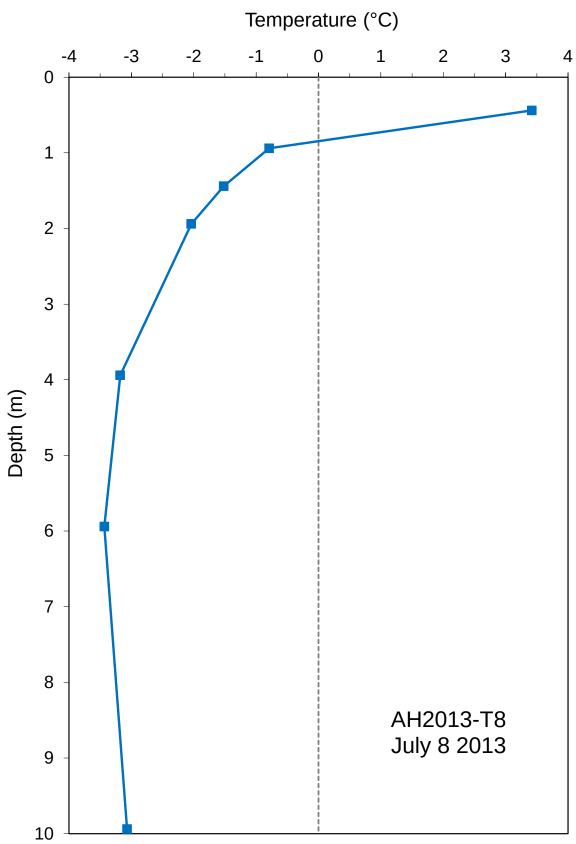
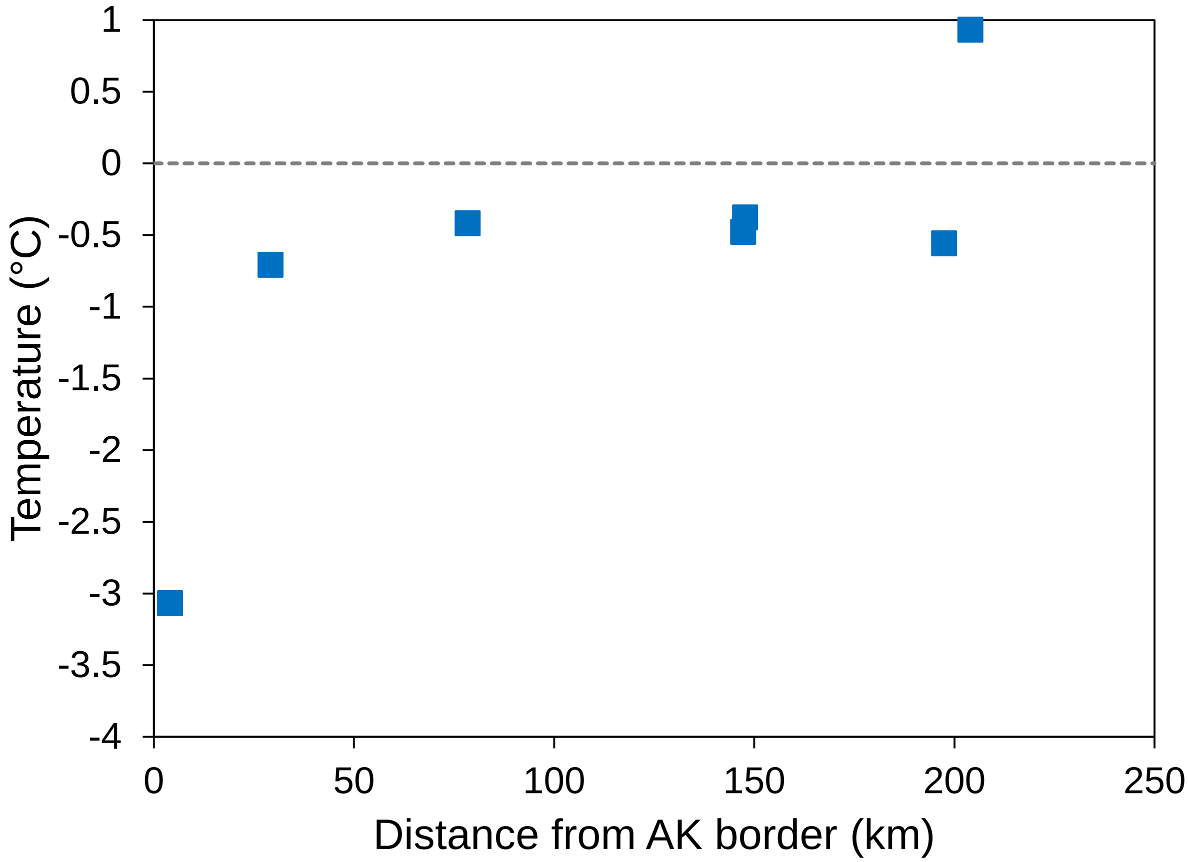


Figure 10. Variation in ground temperature (measured at deepest sensor) with distance along the corridor from the Alaska border.

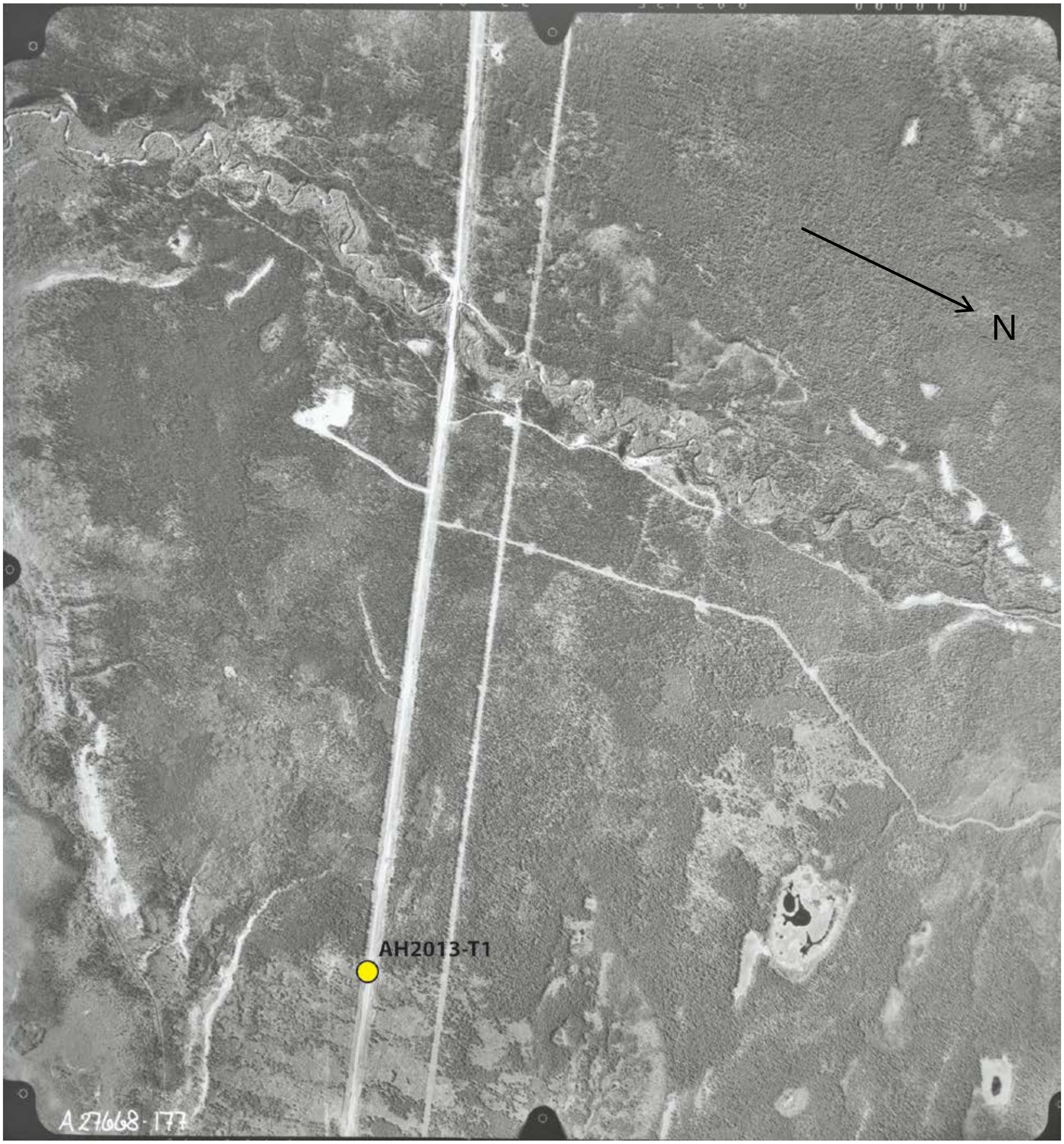


APPENDIX

AIR PHOTOS OF BOREHOLE SITES

Note: Dates of air photos range from 1964 to 1993. Road alignments for some sites have changed since the air photo was taken.

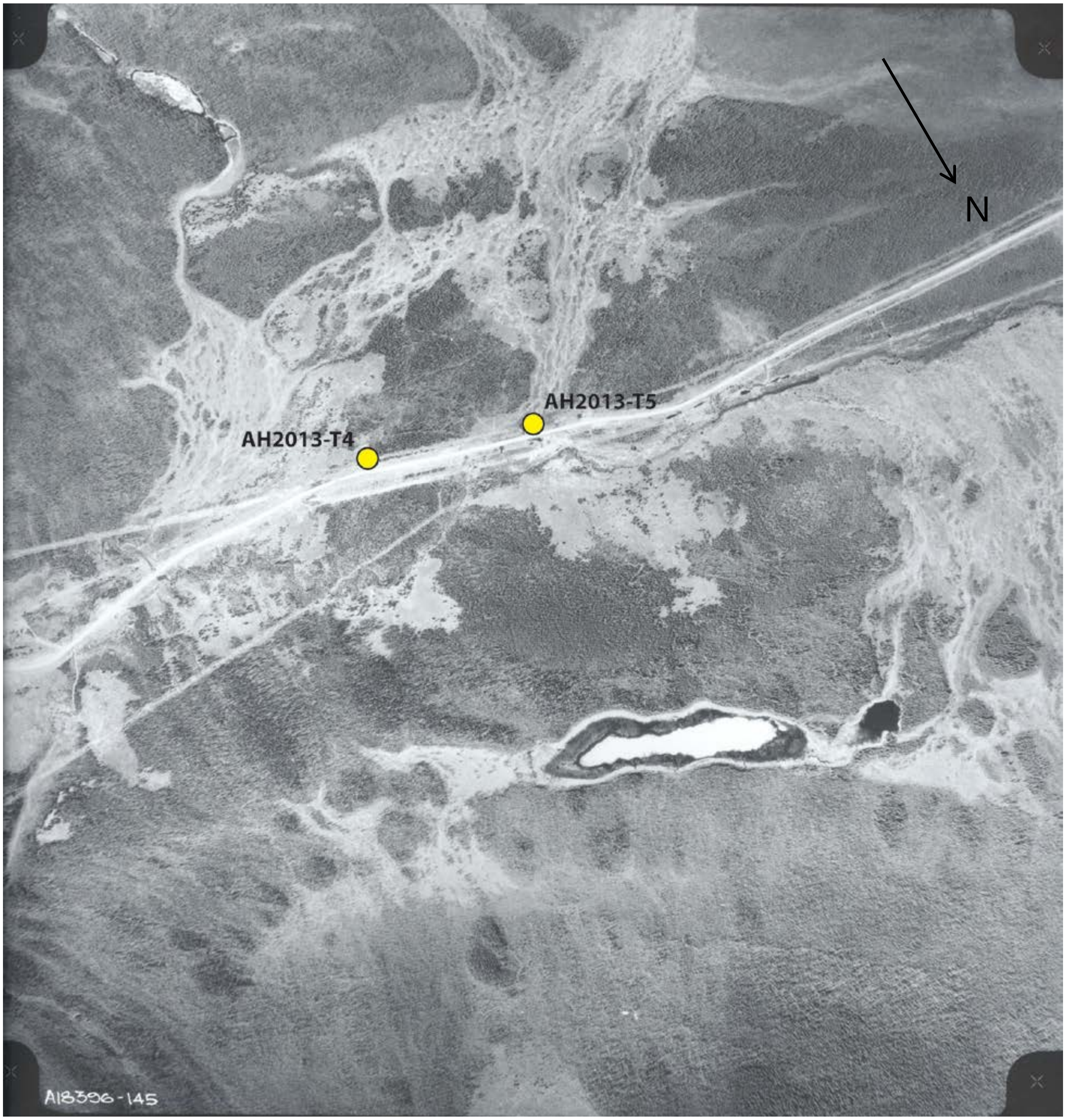
AH2013-T1 (air photo August 1990)



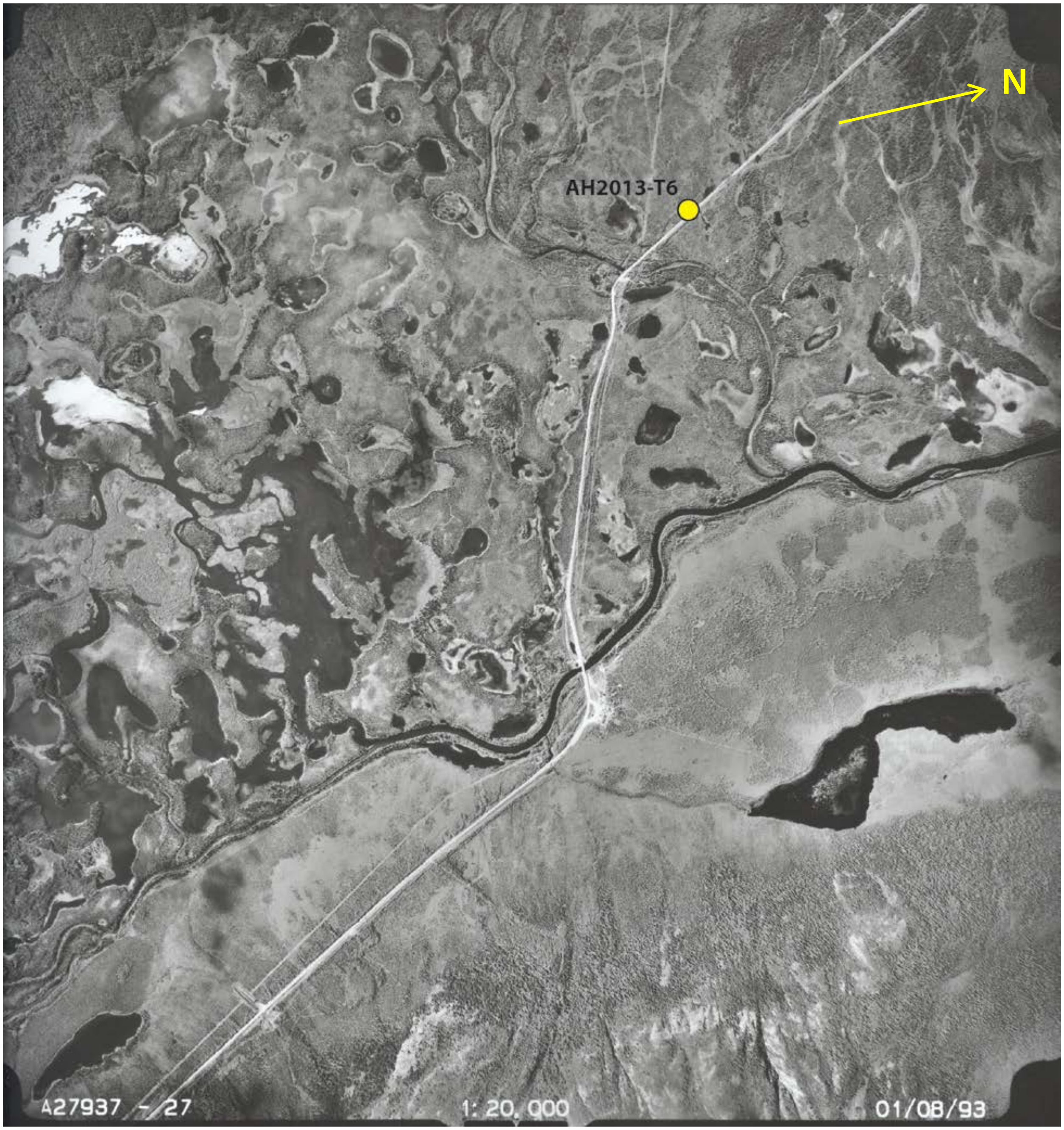
AH2013-T2 (air photo August 1975)

AH2013-T3 (air photo August 1975)

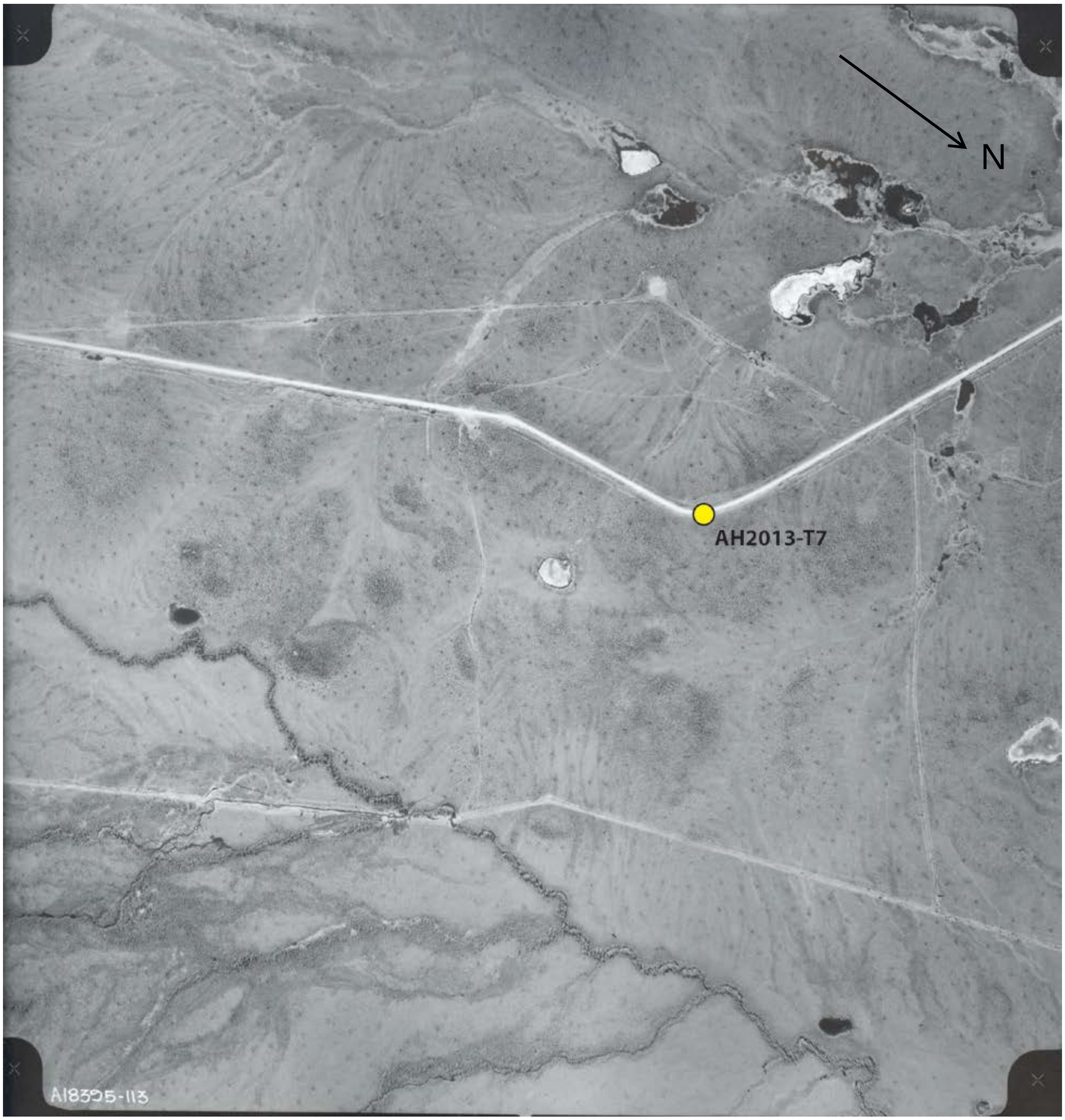
AH2013-T4 and AH2013-T5 (air photo May 1964)



AH2013-T6 (air photo August 1993)



AH2013-T7 (air photo May 1964)



AH2013-T8 (air photo May 1964)