Preliminary data from the establishment of long-term ground temperature reference sites in five Yukon communities

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Abstract

A drilling program was conducted in fall 2023 to install deep (up to 35 m) ground temperature monitoring boreholes in communities at risk from permafrost thaw. These boreholes will serve as long-term reference sites in both undisturbed and developed locations within or adjacent to communities. These boreholes also filled knowledge gaps that included the thickness of permafrost, and temperature data at the bottom of permafrost. Prior to this program, only 3 of the 34 permafrost-monitoring boreholes managed by the Yukon Geological Survey recorded temperatures through to the bottom of permafrost; furthermore, none of these boreholes are in the extensive discontinuous or continuous permafrost zones. Fifteen boreholes were drilled in five different communities across the Yukon: Dawson City, Mayo, Ross River, Beaver Creek and Haines Junction. Permafrost was encountered in 10 of the 15 boreholes, and the bottom of permafrost, or bedrock, was reached in at least one borehole in each community.

Introduction

In October 2023, the Yukon Geological Survey (YGS) drilled 15 boreholes in 5 Yukon communities. Boreholes were drilled in Dawson City, Mayo, Ross River, Beaver Creek and Haines Junction (Fig. 1). The primary purpose of these boreholes is to establish deep, long-term ground temperature monitoring stations to provide insight into how permafrost conditions (i.e., temperature and thickness) are changing in and adjacent to these communities. Geotechnical analysis of cores extracted from the boreholes also help characterize local permafrost properties such as ice content, sediment texture and genetic material. Prior to the installation of these sites, YGS was managing 34 permafrost-monitoring stations, primarily in communities or along major transportation corridors. Only 4 of the existing sites are deeper than 10 m, and none are more than 20 m deep.

The Yukon has a sub-arctic continental climate, and has regional variation depending on latitude, topography and continentality (Smith et *al*., 2004). Large mountain ranges acting as orographic barriers play a major role in variability of precipitation. Annual precipitation ranges from 3500 mm on the coastal Alaska side of the St. Elias Mountains, to as little as 200 mm in the North Slope region (Smith et *al*., 2004). Annual mean temperatures

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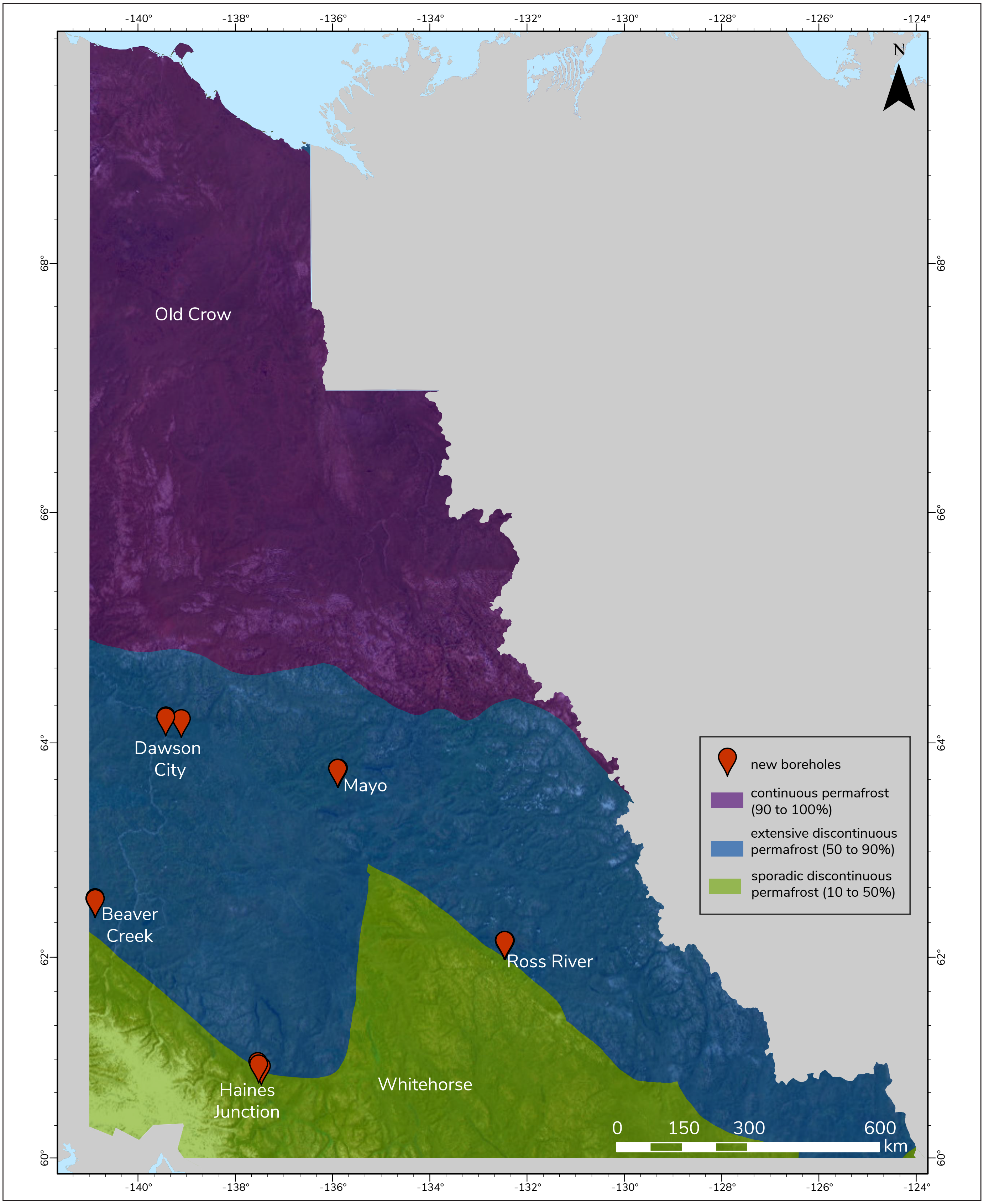

Figure 1. *Map illustrating new borehole locations and permafrost distribution in the Yukon.*

vary from approximately –2°C in the south to –10°C along the North Slope (Smith *et al.*, 2004). Although there is spatial and temporal variation, there has been an overall increasing trend of precipitation and air temperature. The annual average temperature over northern Canada increased by 2.3°C between 1948 and 2016, and is expected to continue rising (Bush and Lemmen, 2019).

Permafrost in the territory ranges from continuous to sporadic discontinuous, depending largely on latitude and elevation (Fig. 1; Heginbottom *et al.*, 1995). Smaller-scale controls include vegetation, slope angle, aspect, site moisture, surficial geology, precipitation and disturbance. Permafrost is warming and thawing across the Arctic, primarily due to rising air temperatures driven by climate change (Smith *et al.*, 2022). The YGS' new monitoring sites will track changes in ground temperature across the territory as air temperatures continue to rise.

Methodology

The approach for this project was modelled, where possible, on best practices for ground temperature monitoring as proposed by Noetzi *et al.* (2021), including recommendations for site selection, strategy for temperature sampling, and drilling procedures.

The five communities were selected to provide geographical distribution across the territory, while prioritizing areas having potentially thick permafrost (i.e., >10 m), and ease of access for future site visits. Sites within each community were selected based on the assumed presence of permafrost. Access for the drill rig and areas sited for future development were also considered. It was important that each site is broadly representative of the permafrost conditions of the region.

The boreholes were drilled with a sonic drill by Northern Sonic Drilling and Consulting (Northern Sonic) between October 6 and 16, 2023 (Fig. 2). The sonic drill used low-pressure tracks and an elevated working platform to minimize site disturbance during the drilling process. Each borehole was drilled with a four-inch diameter bit, cased with one-inch schedule 80 PVC pipe. The boreholes were backfilled primarily with bentonite chips, except for the top two feet, which was backfilled with sand. The casings at the surface are housed in lockable aluminum covers, which protrude approximately one metre from the ground surface (Fig. 3). Boreholes were drilled without the use of water, whenever possible, to minimize the thermal disturbance to permafrost; however, the vibration of the sonic drill generated excess heat during drilling, particularly in coarse materials. This disturbance means ground temperatures will take time to recover from the thermal effect of drilling, especially where permafrost temperatures are near 0°C. Estimates of ground thermal conditions presented in this paper are preliminary, and may not have completely recovered from the initial drilling.

Nearly continuous intact cores were recovered during drilling. Preliminary core logging was completed on site to document material thickness, texture, colour, thermal state, ice content, cryostructures and moisture. Drill cores displaying complex stratigraphy were taken to the YGS Core Library for detailed logging and photography. Samples were collected from representative intervals to analyze ice content. Metadata collected at each site included location, elevation, slope, aspect, site drainage, vegetation, disturbance and surface morphology. Samples of buried organic carbon were collected for radiocarbon dating where the results would yield useful information about site chronology. Radiocarbon ages were not available in time for publication of this report. Temporary data loggers and thermistor strings were installed in most boreholes with the intention of recording preliminary ground temperature data to inform the configuration of custom, site-specific, thermistor strings for long-term deployment. A list of monitoring sites, including the location, elevation and depth of borehole, is found in Table 1.

Site descriptions and preliminary results

Dawson City

Dawson City is the most northern community in the Yukon that is accessible by road year-round and is the most populated community in the Yukon after Whitehorse (Yukon Bureau of Statistics, 2023). The town is located at the confluence of the Yukon and Klondike rivers and is within an unglaciated region of the territory. Mean annual air temperature in Dawson City is –3.8°C, based on data from the Dawson City meteorological station between 1991 and 2020

Figure 2. Northern Sonic Drilling and Consulting's sonic drill at site YGS_BeaverCreek_BH4 in Beaver Creek.

Figure 3. Completed site at YGS_BeaverCreek_BH4 in Beaver Creek.

Table 1. *List of monitoring sites, including location, elevation and depth of borehole.*

Site	Location	Elevation (m)	Depth (m)
YGS_Moosehide	64.07088, –139.42291	352	28.0
YGS_DawsonRec	64.06197, –139.42914	321	10.9
YGS_YDA	64.04677, –139.10792	352	14.9
YGS_Mayo_School	63.59790, –135.89438	513	35.0
YGS_Mayo_GroupHome	63.59740, –135.87889	519	15.5
Mayo_WRB_Admin	63.59592, –135.89528	519	14.0
YGS_RR_Lagoon	61.97849, –132.46902	683	26.5
YGS_RR_LagoonRd	61.97901, –132.46124	663	17.3
YGS_RR_Hwys	61.97732, –132.44720	653	11.2
YGS_BC_Ptarmigan	62.38028, –140.88485	669	21.2
YGS_BC_Brown	62.38855, –140.88160	659	16.0
YGS_BC_Hwys	62.37973, –140.87811	667	12.1
YGS_HainesRd	60.74084, –137.46242	634	16.3
YGS_HJ_AirportRdDeep	60.78581, –137.53599	638	26.8
HJ_WRB_CO	60.76194, –137.51859	617	26.2

(Environment Canada, 2023). Dawson is located in the extensive discontinuous permafrost zone, that is, 50–90% of the area is underlain by permafrost (Heginbottom et *al*., 1995). Ice-rich permafrost is common in the Dawson City region and is susceptible to degradation, which has caused extensive damage to many buildings in the area.

YGS_Moosehide

Borehole YGS_Moosehide is located at the north end of town on the prehistoric Moosehide landslide deposit (Fig. 4a). The lower portion of the landslide deposit, where the borehole is located, consists of frozen, rubbly colluvium, which is creeping downslope (Brideau et *al*., 2007). The borehole is approximately 120 m east of, and 40 m higher in elevation than the Yukon River. The organic mat at this site is thin and discontinuous. Site vegetation includes white spruce (*Picea glauca*), soapberry (*Shepherdia canadensis*) and various grasses. The YGS_Moosehide borehole is 28 m deep. Drilling did not penetrate through the bottom of the landslide deposit, and materials in the borehole range from fine grained to rubbly colluvium (Fig. 5a; Appendix A1). The top one metre of diamict is enriched in organic content, likely in part from ongoing slope deformation. At approximately 20 m depth, the estimated ice content averaged 40% in ice lenses thicker than 1 cm and ice coatings on grains throughout the bottom 8 m of the core. Preliminary temperature data collected a month after installation indicates that the top of permafrost is at 7 m depth. Although the temporary thermistor string only extends to 21 m, extracted core was frozen to the bottom of the borehole, indicating that permafrost is at least 21 m thick.

YGS_DawsonRec

Borehole YGS_DawsonRec is located in the parking lot of the Art and Margaret Fry Recreation Centre on a Yukon River fluvial terrace (Fig. 4a). This borehole was drilled in collaboration with Yukon Water Resources Branch (WRB) to expand on their Yukon Observation Well Network (YOWN). The borehole is approximately 30 m north of the building and 5 m from the fence of a neighbouring residential property. The site is clear of vegetation and has been covered with gravel fill. Plans are in place to build a new recreation facility because thawing permafrost has limited the use of the current recreation centre. The borehole contains a two-inch PVC pipe that houses WRB's instrumentation and an adjacent one-inch PVC pipe that houses YGS' permafrost monitoring instrumentation. The YGS_DawsonRec borehole is 10.9 m deep and surficial sediments are predominantly composed of gravel (Fig. 5b; Appendix A2). No visible ice was found in the core, but ground temperature data indicates the top of permafrost is at approximately 5 m depth.

YGS_YDA

Borehole YGS_YDA is located on a Klondike River fluvial terrace, approximately 180 m east of the north end of the Dawson City Airport (Fig. 4b). Evidence of permafrost degradation at this site includes thermokarst ponds and leaning trees. Vegetation at the site includes black spruce (*P. mariana*), dwarf birch (*Betula nana*), Labrador tea (*Rhododendron groenlandicum*) and a mossy organic mat. A cross-slope drainage ditch, installed to redirect snowmelt away from the airport, is located 65 m upslope of the site. Plans to construct helicopter pads approximately 100 m west of the drill site will include clearing of trees and ground compaction, which may have minor thermal impacts on the site in the future. The YGS_YDA borehole is 15 m deep and is instrumented with a thermistor string to 14.9 m depth. This borehole intersected bedrock at 14.5 m. The predominant surficial material at this site is gravel (Fig. 5c; Appendix A3). Drill core contained up to 20% visible ice over an interval of 1 m including ice lenses up to 5 cm thick. Ground temperature data retrieved approximately one month after installation indicated that permafrost is present from 1 m depth to the bottom of the borehole, confirming that permafrost is at least 14 m thick at this site.

Mayo

The Village of Mayo is located at the confluence of the Mayo and Stewart rivers and is within the limit of the McConnell glaciation, the most recent glaciation in the territory. Mean annual air temperature in Mayo is –2.4°C, based on data from the Mayo A meteorological station between 1981 and 2010 (Environment Canada, 2023). Mayo is situated within the extensive discontinuous permafrost zone. Those areas within the Village of Mayo that are underlain by fine-grained glaciolacustrine sediments are commonly ice rich (Northern Climate Exchange, 2011), and infrastructure in these areas has experienced damage due to permafrost thaw-induced subsidence, particularly in the Lower East End Subdivision.

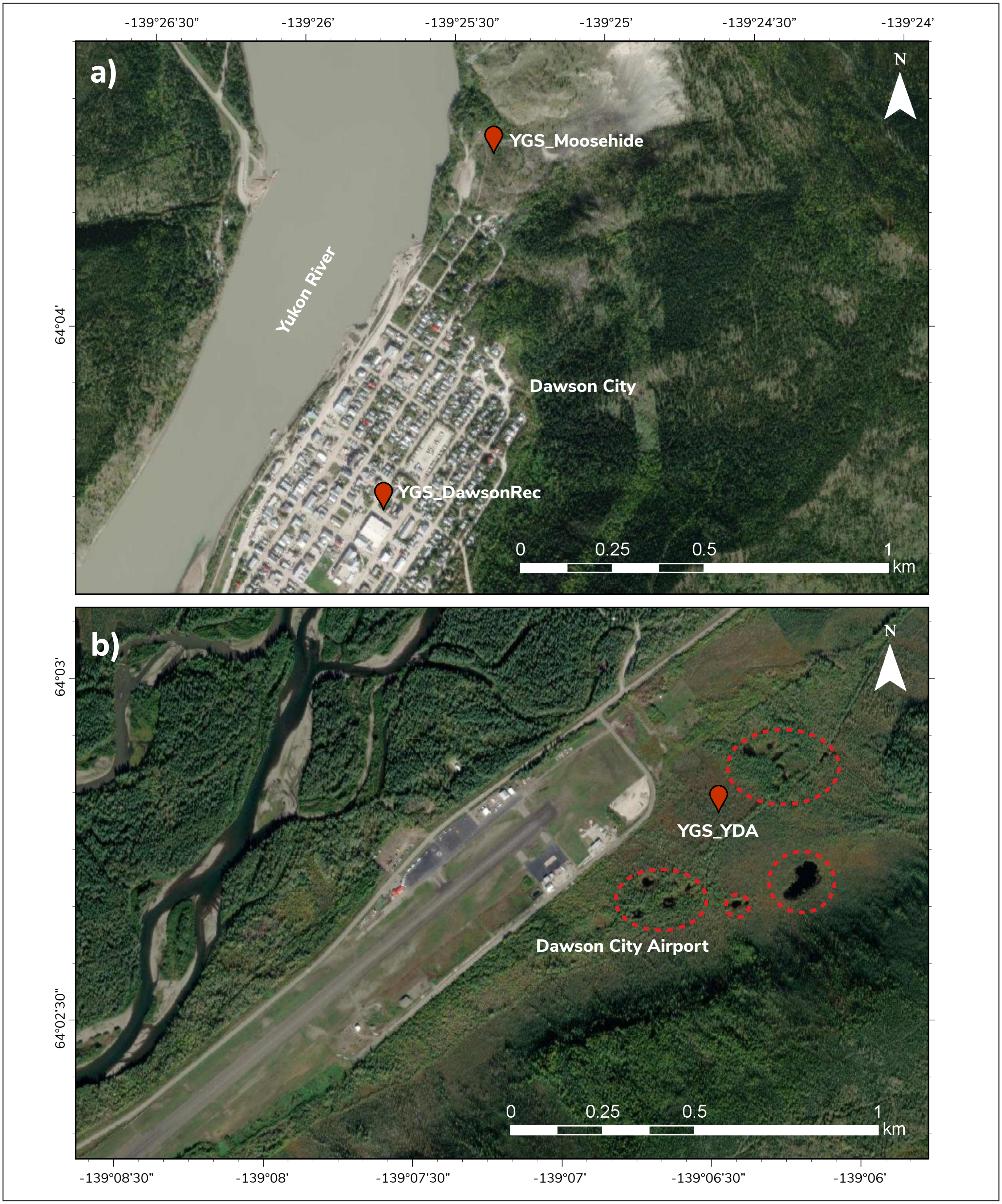

Figure 4. *Dawson region monitoring site locations:* ***a)*** *Dawson City (YGS_Moosehide and YGS_DawsonRec); and* ***b)*** *Dawson City Airport (YGS_YDA); thermokarst ponds delineated by red dashed lines.*

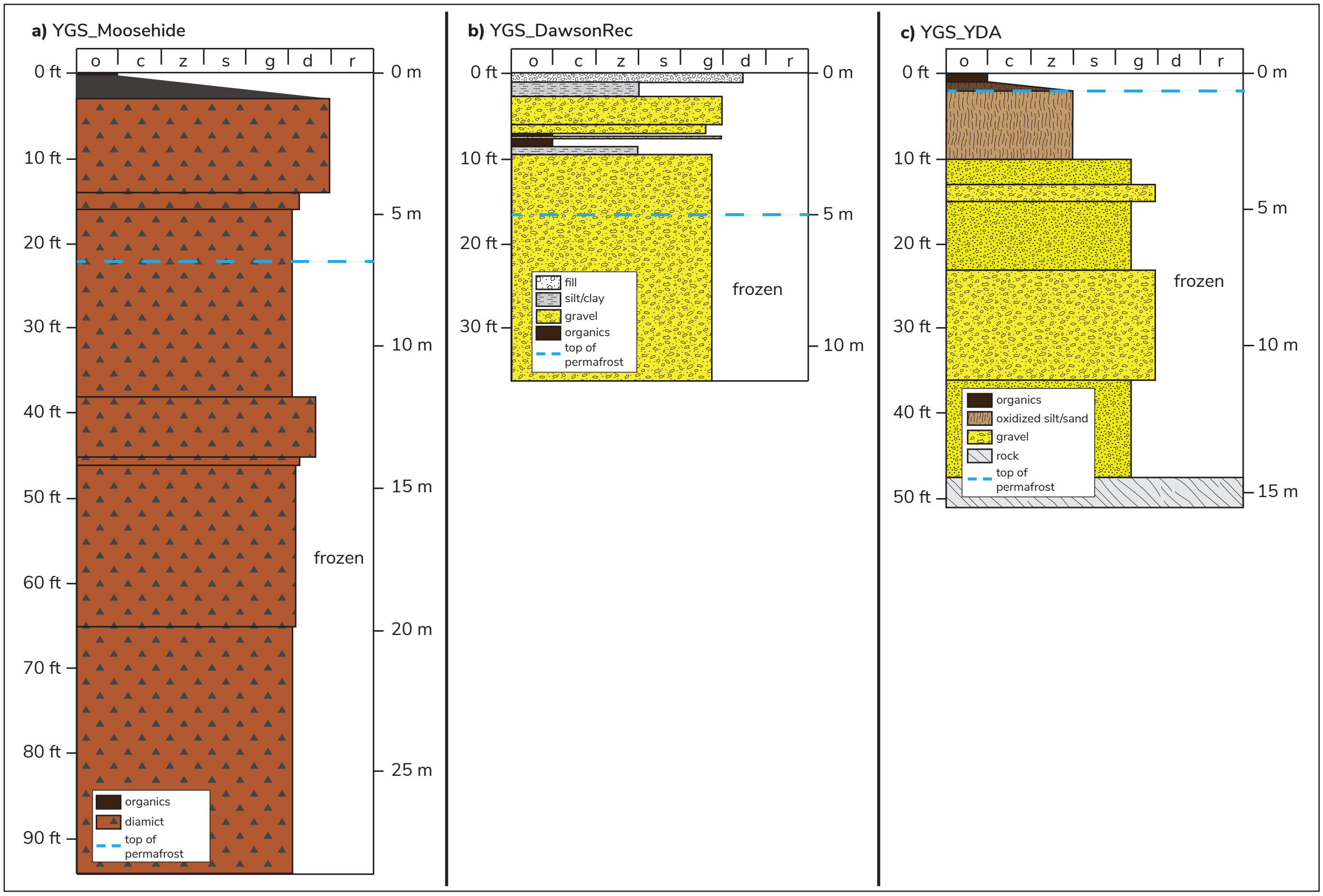

Figure 5. *Borehole logs for Dawson region:* ***a)*** *YGS_Moosehide;* ***b)*** *YGS_DawsonRec; and* ***c)*** *YGS_YDA.*
o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble.

YGS_Mayo_School

Borehole YGS_Mayo_School is located adjacent to a cutline approximately 100 m northeast of the school (Fig. 6). This site was selected because it is located in a relatively undisturbed forest close to the Village of Mayo, and likely represents typical permafrost conditions for the community. Additionally, an electrical resistivity tomography (ERT) survey completed in 2011 (Northern Climate Exchange, 2011) showed a deep zone of high-resistivity material at this site, which was interpreted as thick permafrost. The vegetation at this site is predominantly white spruce and black spruce, willow shrubs, Labrador tea and a mossy organic mat. Borehole YGS_Mayo_School is 35 m deep, and is the deepest borehole drilled during this project. The surficial materials at this site are primarily glaciolacustrine sediments of silty clay to fine sand, overlain by a few metres of sandy gravel near the surface (Fig. 7a; Appendix A4). Preliminary temperature data and drilling observations indicate that permafrost is 20.5 m thick and extends from 8.5 to 29 m depth. Ice lenses ranging from 1 to 5 cm thick were present in the core between 14 and 20 m.

YGS_Mayo_GroupHome

Borehole YGS_Mayo_GroupHome is located on the north side of the Group Home Road approximately 450 m east of the intersection with the Mayo Elsa Road (Fig. 6). Permafrost thaw has occurred in the area as is evidenced by the development of tension cracks from ground subsidence and abundant thermokarst ponds. Vegetation at this site includes birch (*Betula* sp.), black and white spruce and moss. Borehole YGS_Mayo_GroupHome is 15.5 m deep and is instrumented to 15 m. Surficial deposits at this site are primarily glaciolacustrine clay (Fig. 7b; Appendix A5). Preliminary data suggest the top of permafrost is at 6 m depth and the bottom of permafrost is at 12.5 m. Ice lenses up to

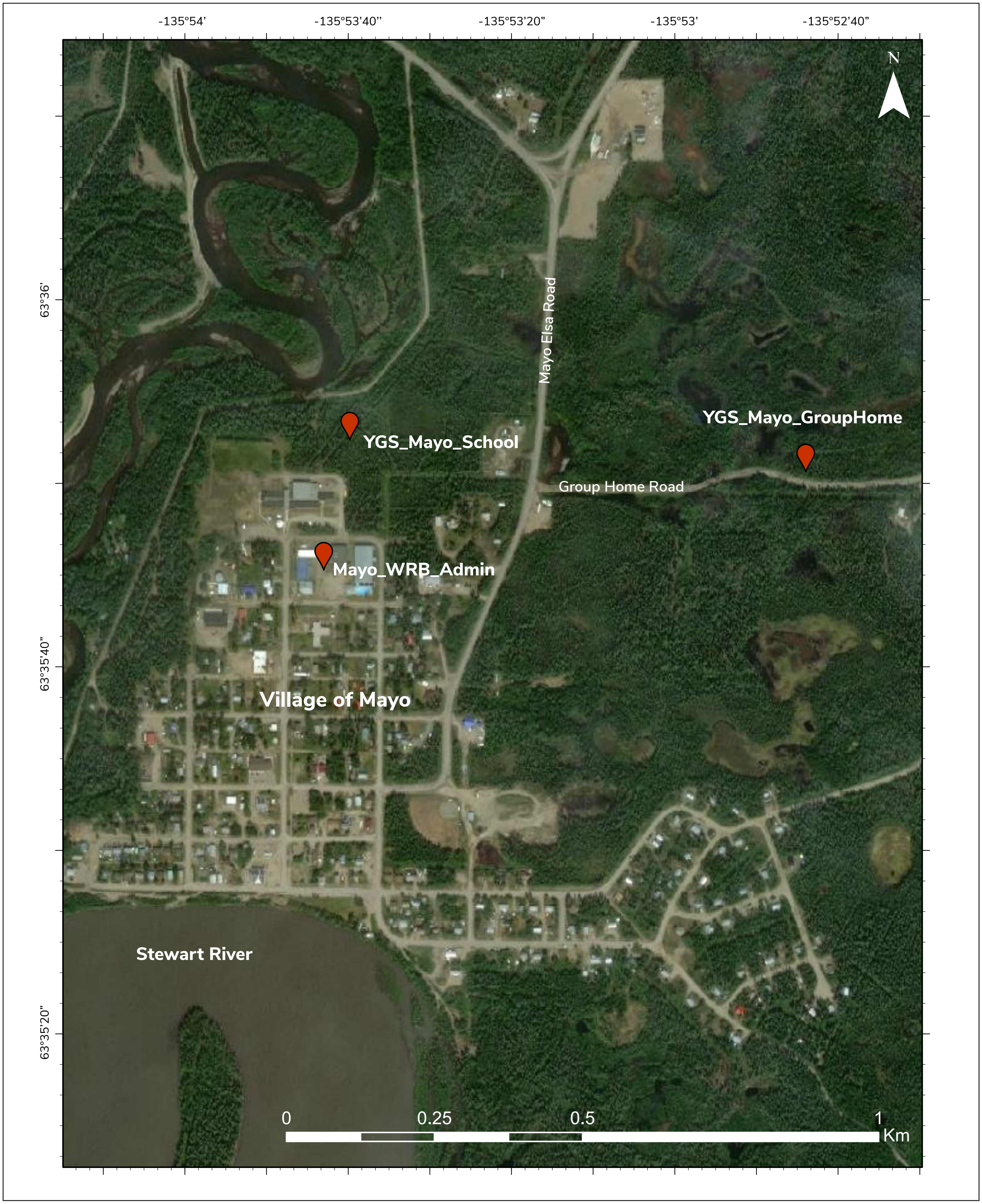

Figure 6. *Mayo monitoring site locations.*

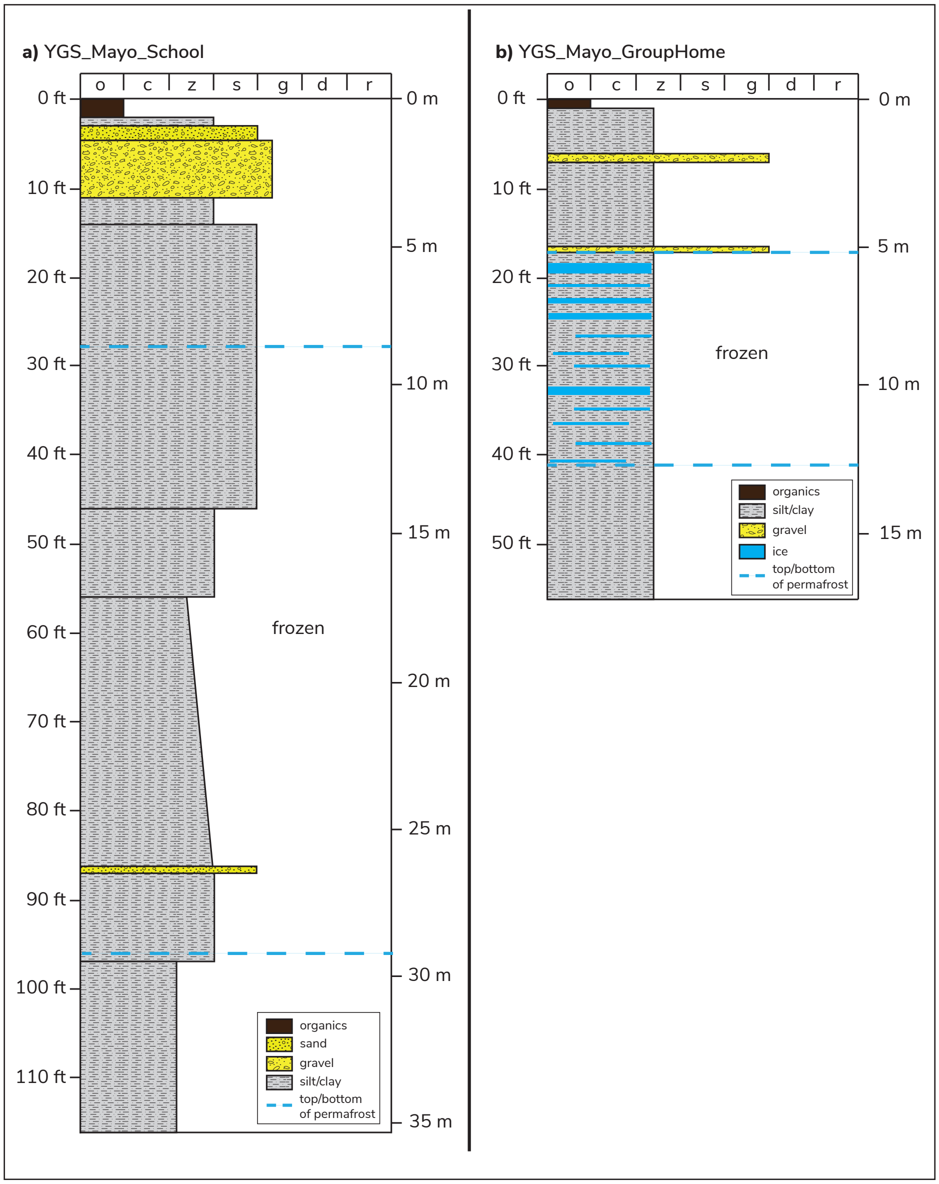

Figure 7. *Borehole logs for Mayo:* **a)** *YGS_Mayo_School; and* **b)** *YGS_Mayo_GroupHome. o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble.*

20 cm thick were observed between 5 and 12.5 m, and ice content reached a maximum of 80% from 5 to 8 m.

Mayo_WRB_Admin

Borehole Mayo_WRB_Admin is located in the parking lot behind the Village of Mayo's main administrative building and was drilled by WRB as a YOWN site for long-term groundwater monitoring in the community (Fig. 6). There are several buildings at this site, some as close as 10 m from the borehole. The borehole is 14 m deep and surficial materials consist of 5.5 m of gravel overlying a silty clay unit. The deposits are interpreted as fluvial gravel overlying glaciolacustrine sediment. No permafrost was encountered during drilling, and the borehole was not cased or instrumented for ground temperature monitoring.

Ross River

Ross River is located along the Canol Road, on a fluvial terrace above the Pelly River. The terrace is composed of fluvial sediments underlain by a thick unit of fine-grained glaciolacustrine material, which was deposited by a glacial lake that was present at the end of the McConnell Glaciation approximately 12 000 ka ago (Jackson, 1994; Bond, 1999). Mean annual air temperature in Ross River is –4.5°C, based on historical data between 1976 and 2005 (Prairie Climate Centre, 2019). Ross River is on the border between the extensive discontinuous permafrost zone (50–90% underlain by permafrost) and the sporadic discontinuous permafrost zone (10–50% underlain by permafrost) (Heginbottom et al., 1995). Widespread infrastructure damage has occurred in the community due to permafrost thaw (e.g., the damage at Ross River School), suggesting that ice-rich permafrost is likely pervasive in the area (Calmels et al., 2016).

YGS_RR_Lagoon

Borehole YGS_RR_Lagoon is located approximately 110 m south of the southern corner of the Ross River wastewater treatment facility (Fig. 8). The site is approximately 10 m from a small road and 50 m from a

Figure 8. *Ross River monitoring site locations. Drained thermokarst pond delineated by red dashed line.*

drained thermokarst pond (Fig. 8). Vegetation consists predominantly of black and white spruce and moss. The borehole is 26.5 m deep and is instrumented to 20 m. Surficial materials at this site consist predominantly of clay overlain by unfrozen gravel (Fig. 9a; Appendix A6). These deposits are interpreted as fluvial gravel overlying glaciolacustrine sediment. Drill core suggests that permafrost is 18.4 m thick and permafrost extends from 3.5 m to 21.9 m depth. Core from this site contained up to 90% ice over some 3 m intervals (e.g., from 11 m to 14 m depth; Fig. 9a).

YGS_RR_LagoonRd

Borehole YGS_RR_LagoonRd is located in a forested area on the south side of the road leading into the wastewater treatment facility (Fig. 8). Vegetation includes black and white spruce, aspen (*Populus* sp.), willow shrubs (*Salix* sp.) and moss. The borehole is 17.3 m deep. The surficial materials at this site consist of 5.8 m of sandy gravel underlain by clay to the bottom of the borehole (Fig. 9b; Appendix A7). These deposits are interpreted as fluvial gravel overlying glaciolacustrine sediment. Less ground ice was observed in the core from this borehole compared with YGS_RR_Lagoon. Rare ice lenses up to 3 cm thick were present from 5.7 to 10.9 m. The top of permafrost was encountered at 3.3 m depth; it is at least 14 m thick and extends beyond the bottom of the borehole.

YGS_RR_Hwys

Borehole YGS_RR_Hwys is located in the Yukon Highways and Public Works compound adjacent to a YOWN groundwater monitoring well, which intersected permafrost (Fig. 8). The site is located in the southeast corner of the compound, approximately 10 m from the perimeter fence, and 80 m from the closest building structure. The site was clear of vegetation. The borehole was cased and drilled to a depth of 11.2 m. The top of permafrost was encountered at 8.2 m. The upper half of the borehole was predominantly gravel,

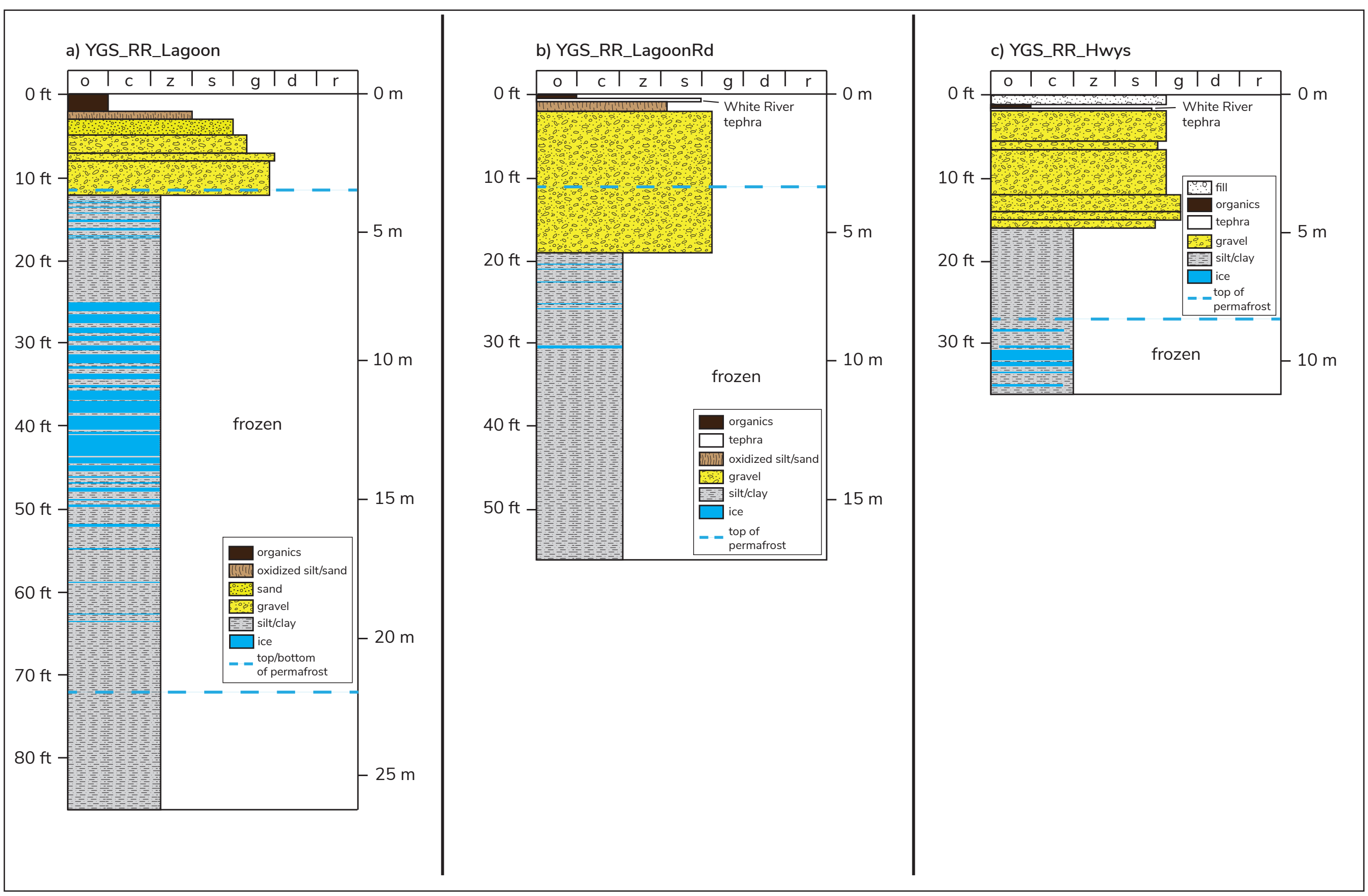

Figure 9. *Borehole logs for Ross River:* ***a)*** *YGS_RR_Lagoon;* ***b)*** *YGS_RR_LagoonRd; and* ***c)*** *YGS_RR_Hwys. o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble.*

which was underlain by clay to the bottom of the hole. (Fig. 9c; Appendix A8). These sediments are interpreted as fluvial gravel overlying glaciolacustrine sediment. Ice lenses of variable thicknesses were observed from 8.2 m depth to the bottom of the borehole. This site is not currently instrumented.

Beaver Creek

Beaver Creek is located on the Alaska Highway, approximately 30 km south of the Alaska border. Beaver Creek was glaciated during the Reid and Gladstone glaciations, but is approximately 15 km beyond the limit of the McConnell glaciation (Duk-Rodkin, 1999). The town site is located on a McConnell-aged glacial outwash plain. Mean annual air temperature in Beaver Creek is –4.9°C, based on data from the Beaver Creek A meteorological station between 1981 and 2010 (Environment Canada, 2023). Beaver Creek is located in the extensive discontinuous permafrost zone (Heginbottom *et al*., 1995). Although permafrost is expected to be present under most of the community, the coarse-grained surficial materials underlying most of the town are generally ice-poor and thaw stable.

YGS_BC_Ptarmigan

Borehole YGS_BC_Ptarmigan is located on the north side of Ptarmigan Road (Fig. 10). Vegetation at the site consists of black and white spruce trees averaging 10 m high. Most of the forest in Beaver Creek has been thinned for wildfire management, but there is extensive regrowth of black and white spruce approximately one metre tall. The presence of widespread leaning trees suggests some permafrost degradation is occurring in the area. The borehole is 21.2 m deep and is instrumented to 20 m. The predominant sediment observed in core is gravel, and compact diamict below 17 m depth (Fig. 11a; Appendix A9). Surficial sediments at this site are interpreted as Gladstone and McConnell-aged glaciofluvial outwash overlying Gladstone-aged till. Because the surficial sediments at this site are predominantly coarse and dry, most of the core came out hot from drilling. For this reason, none of the retrieved core was frozen, but extrapolated preliminary temperature data downloaded from the data logger suggest that permafrost is 6 m thick, and extends from 3 m to 9 m depth.

YGS_BC_Brown

Borehole YGS_BC_Brown is located 40 m west of the cul-de-sac at the end of Brown Street (Fig. 10). Black and white spruce at the site are approximately 20 m tall, and have been thinned for fuel abatement purposes. The understory consists of willow, dwarf birch and Labrador tea, and the moss mat is approximately 30 cm thick. The site is located in a 30 by 30 m depression up to 2 m deep. Borehole YGS_BC_Brown was drilled to a depth of 17 m, but was only cased and instrumented to 16 m. The surficial geology at this site is similar to the Ptarmigan Road site; most of the core comprises gravel and diamict below 15.8 m (Fig. 11b; Appendix A10). Surficial deposits at this site are interpreted as Gladstone and McConnell-aged glaciofluvial outwash overlying Gladstone-aged till. Both the core and the initial temperature profiles indicate that there is no permafrost at this site.

YGS_BC_Hwys

Borehole YGS_BC_Hwys was drilled as a YOWN groundwater monitoring well, located along the fence in the Yukon Highways and Public Works compound, approximately 70 m from the main building (Fig. 10). A ground temperature monitoring casing (one-inch PVC pipe) was installed adjacent to the groundwater monitoring casing (two-inch PVC pipe) in the same borehole; however, permafrost-monitoring instrumentation was not installed at the time of drilling. This site has been cleared of vegetation. The borehole is 12.1 m deep and the surficial sediments are almost entirely gravel, except for a thin layer of diamict at a depth between 5.8 and 6.4 m (Figure 11c; Appendix A11). Surficial deposits at this site are interpreted as Gladstone-aged advance and retreat glaciofluvial outwash bracketing Gladstone-aged till. This package is overlain by McConnell-aged glaciofluvial outwash. There was no evidence of permafrost observed during drilling, but the site will be instrumented in the future to confirm the presence or absence of permafrost.

Haines Junction

Haines Junction is the most southern community in Yukon chosen for this monitoring program. The area was inundated at least once by Glacial Lake Champagne at the end of the McConnell glaciation. During the Little Ice Age, which occurred between the 16^{th} and 19^{th} centuries, Neoglacial Lake Alsek repeatedly flooded

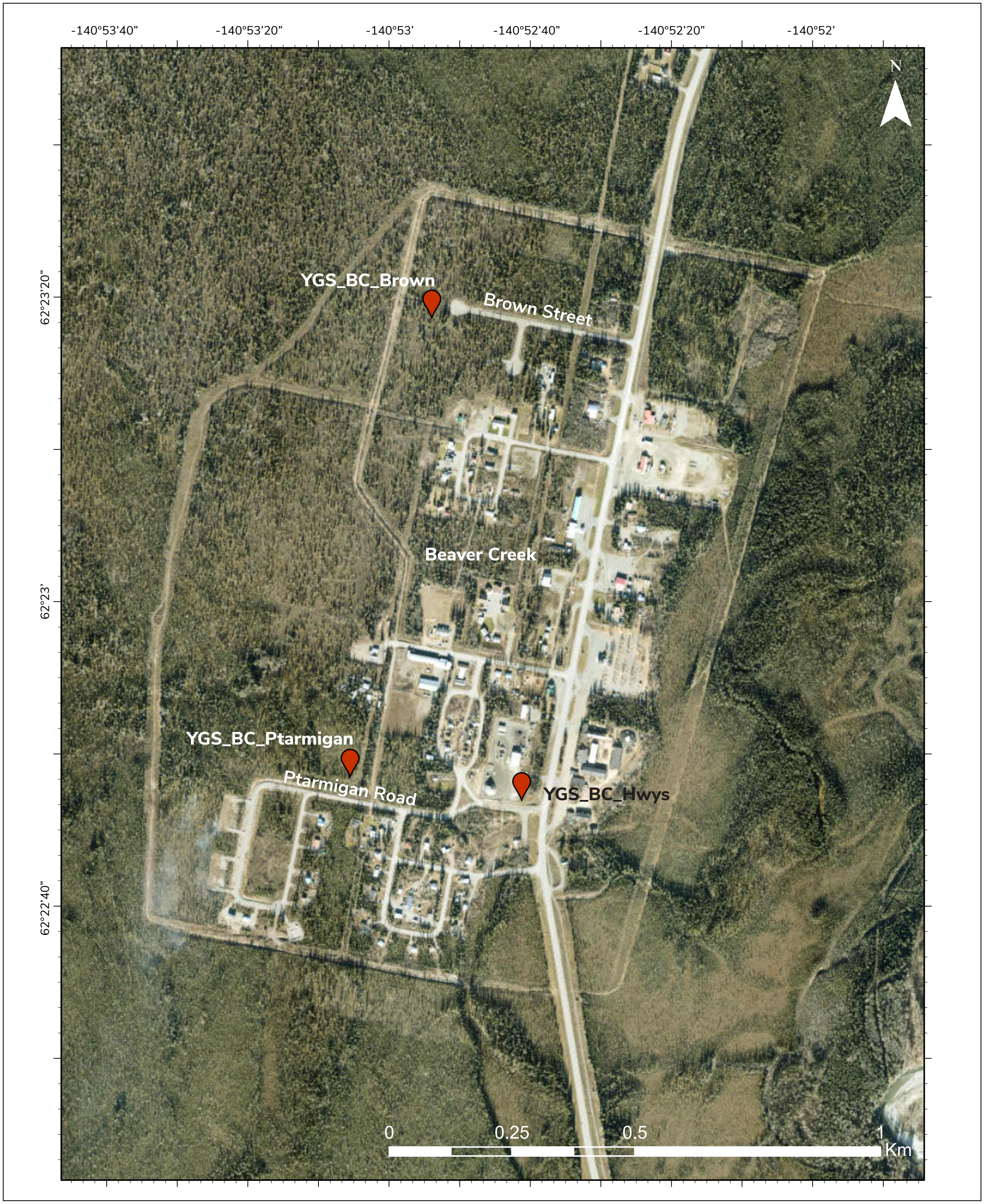

Figure 10. *Beaver Creek monitoring site locations.*

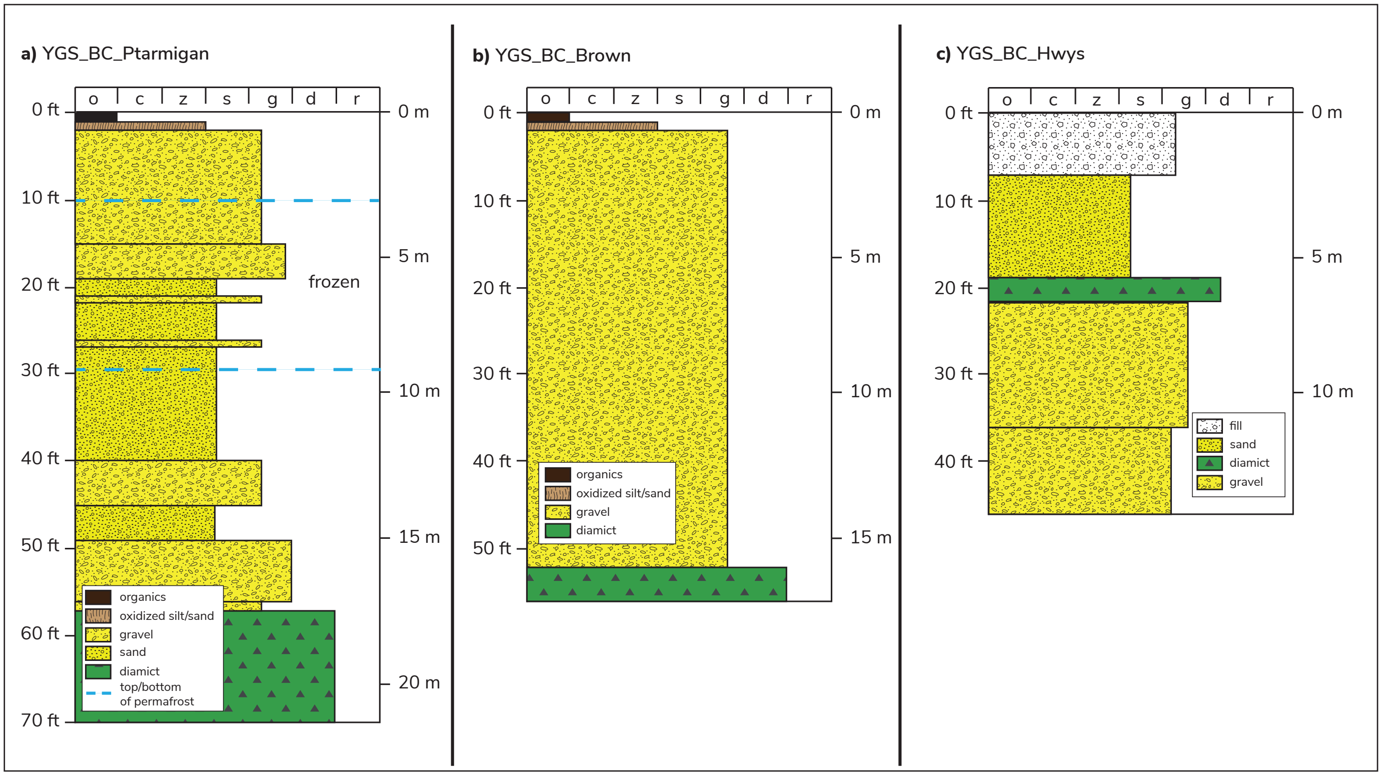

Figure 11. *Borehole logs for Beaver Creek:* ***a)*** *YGS_BC_Ptarmigan;* ***b)*** *YGS_BC_Brown; and* ***c)*** *YGS_BC_Hwys. o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble.*

the area (Clague and Rampton, 1982). Surficial deposits in the region consist of complex sequences of glaciolacustrine, till, fluvial and glaciofluvial sediments (Rampton and Paradis, 1979), which are currently being mapped in detail by YGS. Mean annual air temperature in Haines Junction is –2.1°C, based on historical data between 1976 and 2005 (Prairie Climate Centre, 2019). Haines Junction is within the sporadic discontinuous permafrost zone, meaning 10–50% of the area is expected to be underlain by permafrost (Heginbottom et al., 1995). In this region, permafrost is found primarily in low-lying areas and on north-facing slopes.

YGS_HainesRd

Borehole YGS_HainesRd is located near a forestry cut block approximately 3 km southeast of Haines Junction along the Haines Road (Fig. 12). This site shows widespread evidence of permafrost degradation including small thaw ponds and a drunken black spruce forest. Yukon University's YukonU Research Centre Permafrost and Geoscience group completed an ERT survey at this site prior to drilling. The survey line ran roughly southwest and was 160 m long. The ERT profile suggested that the area most likely to be frozen occurred at 110 m along the survey line. The borehole was drilled approximately 40 m along the ERT line due to access constraints. The YGS_HainesRd borehole is 16.3 m deep and is instrumented to 16 m. Surficial sediments at this site consist of alternating layers of diamict and gravel (Fig. 13a; Appendix A12). These deposits are interpreted as a complex sequence of till interstratified with glaciofluvial outwash gravel. Although surface features and vegetation were typical of permafrost environments, there was no permafrost observed during drilling and core inspection. This was confirmed by ground temperatures downloaded approximately three weeks after the borehole was drilled, suggesting that permafrost at this site has completely degraded.

YGS_HJ_AirportRdDeep

Borehole YGS_HJ_AirportRdDeep is located 400 m south of the Haines Junction Airport (Fig. 12). A 10 m deep ground temperature monitoring borehole (YGS_HJ_BH6) drilled in early 2023 is located approximately

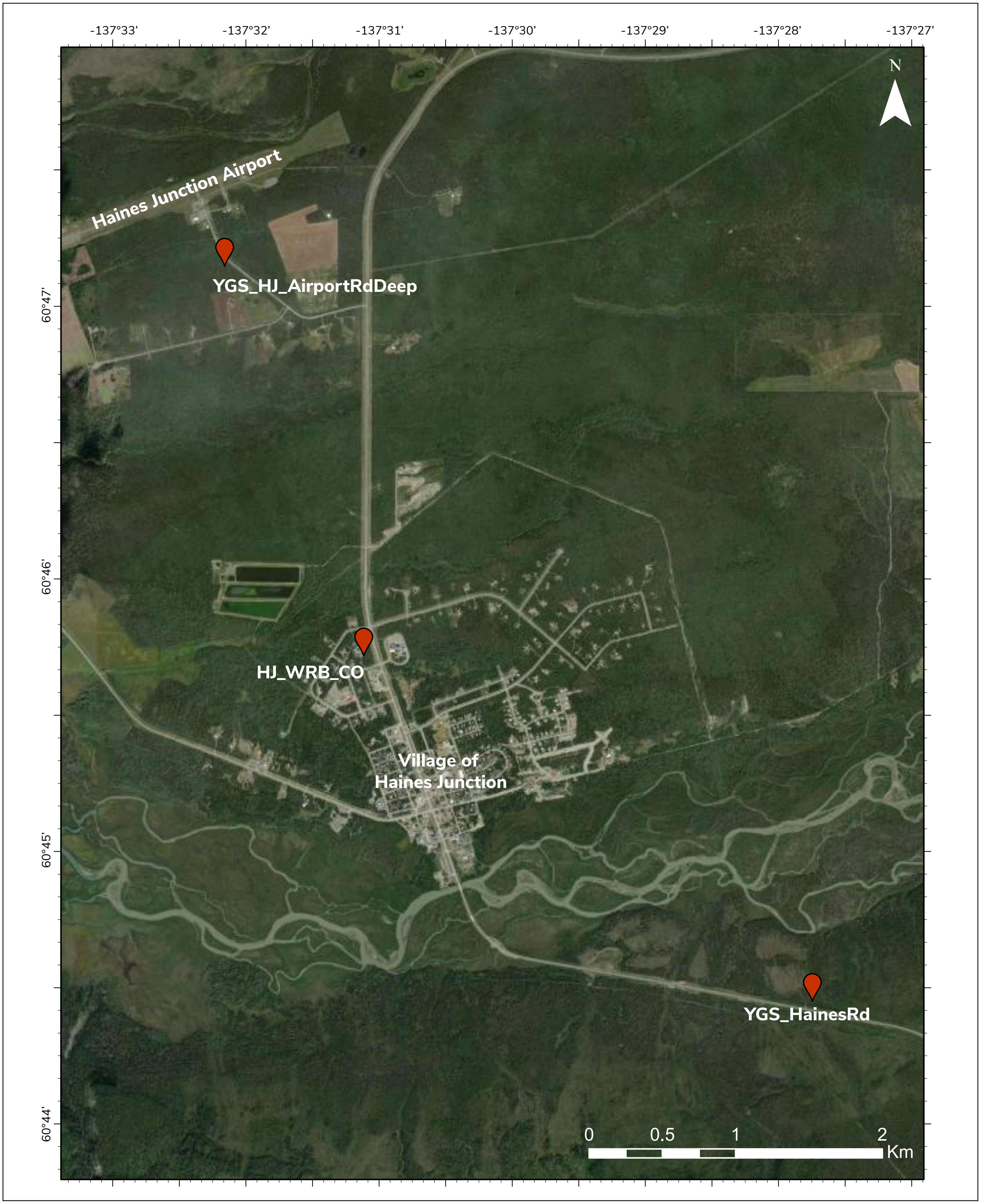

Figure 12. *Haines Junction monitoring site locations.*

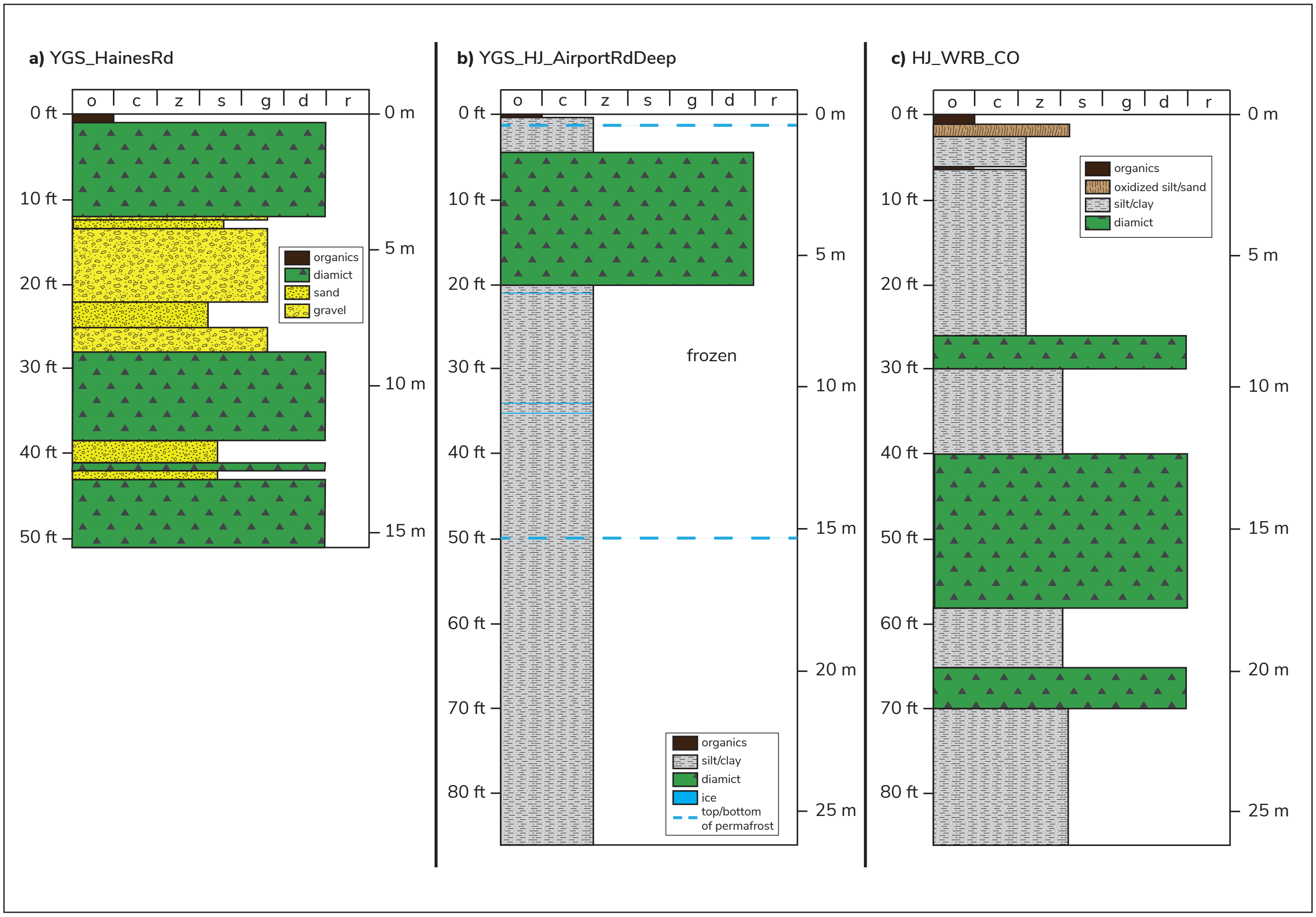

Figure 13. *Borehole logs for Haines Junction:* ***a)*** *YGS_HainesRd;* ***b)*** *YGS_HJ_AirportRdDeep; and* ***c)*** *HJ_WRB_CO. o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble.*

100 m north of borehole YGS_HJ_AirportRdDeep, and ground temperatures measured in this hole indicated that the bottom of permafrost exceeds 10 m depth. The YGS_HJ_AirportRdDeep site was selected to expand our understanding of permafrost in this area, and to determine the true thickness of the permafrost. Permafrost is inferred at the site based on the presence of a drunken black spruce forest in the surrounding area. Understory vegetation includes willow and soapberry, and the ground surface is covered with moss. The borehole is 26.8 m deep and is instrumented to 20 m. The surficial sediments at this site are predominantly silty clay containing a layer of diamict from 1.4 to 5.9 m depth (Fig. 13b; Appendix A13). The stratigraphy is interpreted as Glacial Lake Champagne glaciolacustrine sediments overlain by a McConnell-aged re-advance till, capped by Neoglacial Lake Alsek sediments. The top of permafrost was encountered at 1 m depth, and the bottom is located between 15 m and 20 m depth based on ground temperature data (estimated at <17 m in the drill logs). Intact ice lenses up to 1.5 cm thick were observed between 6 m and 10 m depth. The core was frozen from 10 to 17 m depth, but there was no visible ice.

HJ_WRB_CO

Borehole HJ_WRB_CO is a YOWN groundwater monitoring well located at the southeast edge of the Haines Junction Conservation Officer's compound, approximately 15 m from the perimeter fence and 25 m from the main building (Fig. 12). The site is cleared of vegetation. The HJ_WRB_CO borehole is 26.2 m deep. The surficial sediments encountered at this site are primarily alternating silty clay and diamict (Figure 13c; Appendix A14). The series of diamict layers are interpreted to represent till deposited at a fluctuating ice front. These till units are interstratified with lacustrine sediments from Glacial Lake Champagne. The till-lacustrine package is overlain by what is interpreted to be a sequence of Neoglacial Lake Alsek sediments interbedded with organics. A thin veneer of eolian loess caps the entire package. Permafrost was not encountered at this site during drilling, and permafrost-monitoring instrumentation was not installed in the borehole.

Future work

In spring 2024, customized instrumentation will be installed at selected borehole locations to match the depth of key permafrost horizons. At this time, ground-surface temperature loggers will be installed at the sites outside and adjacent to the borehole. An additional shallow borehole will also be drilled at each site to determine how much of a thermal effect the drill disturbance and borehole housing has on near-surface ground temperatures.

Data and interpretations from each site will inform future development in the area and each site will serve as a reference of how ground temperatures respond to changes in air temperature and precipitation in different regions of the Yukon. Geotechnical data, including volumetric and gravimetric ice-content measurements, will provide more information on extent of ground subsidence expected as permafrost thaws and what the implications might be for existing and future development.

Conclusions

Fifteen boreholes were drilled in five communities in October 2023. Borehole depths ranged from 10.9 m to 35.0 m. Permafrost was encountered in 10 boreholes and 5 boreholes penetrated the bottom of permafrost. Drilling observations and ground temperature data collected to date provide preliminary estimates of local permafrost and active layer thicknesses. In Dawson City, permafrost is at least 21 m thick on the lower portion of Moosehide Slide and at least 14 m thick near the airport, and the top of permafrost is quite deep (5–7 m) at the disturbed sites (e.g., Moosehide and the recreation centre), and shallow (1 m) at the undisturbed site near the airport. In the two Mayo boreholes, permafrost was 6.5 m and 20.5 m thick, and the top of permafrost was estimated from drill core to be at 5 m and 8.5 m depth, respectively. In Ross River, permafrost was greater than 14 m and 18.4 m thick at the two undisturbed sites; active layers are approximately 3.5 m thick. In one of three Beaver Creek boreholes, permafrost is 6 m thick and has a 3 m thick active layer. Near Haines Junction airport, permafrost is approximately 16 m thick and has a 1 m thick active layer.

Long-term ground temperature monitoring is planned to begin in 2024 and will document permafrost change at both relatively undisturbed and developed sites in these communities. These monitoring sites fill critical gaps in the existing ground temperature monitoring network. Additional site information and monitoring data will be available in the Yukon Permafrost Database (https://service.yukon.ca/permafrost/) in 2024.

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Appendix A

Appendix A1. *Detailed borehole log for YGS_Moosehide.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.2	o	organics	no	n/a
0.2	0.9	od	organic-enriched coarse diamict	no	n/a
0.9	1.8	d	diamict; grey	no	n/a
1.8	2.3	d	diamict; boulder at 2.0 m	no	n/a
2.3	3.5	d	diamcit; boulder from 2.3 to 3.4 m	no	n/a
3.5	4.3	d	no return	no	n/a
4.3	4.9	d	sandy rubble	no	n/a
4.9	7.0	d	sandy rubble; grey	no	n/a
7.0	7.9	d	sandy rubble; grey	yes	n/a
7.9	11.6	d	diamict; more fines than previous interval; grey	yes	n/a
11.6	13.7	d	clay-rich diamict; light grey to buff	yes	n/a
13.7	16.5	d	clay-rich diamict; grey to buff; dark grey from 13.7 to 14.0 m	yes	n/a
16.5	20.1	d	rubbly diamict; rare boulders; moist to wet; mottled light grey and buff; oxidized from 19.5 to 19.8 m	yes	n/a
20.1	23.2	d	muddy to sandy rubbly diamict; medium grey; highly oxidized from 23.6 to 24.4 m	yes	ice is bonding core,~40% ice in distinct lenses >1 cm, ice coating grains
23.2	28.7	d	sandy diamict; abrupt colour changes: dark grey to black from 25.0 to 26.2 m; brown from 26.2 to 27.4 m; green/grey from 27.4 to 28.7 m	yes	visible ice coating grains

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A2. *Detailed borehole log for YGS_DawsonRec.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.3	sg	backfill gravel; buff colour	no	n/a
0.3	0.8	ozcg	organic-enriched, silty to clay-rich gravel; ~30% clasts; grading from lighter to darker brown	no	n/a
0.8	1.8	szg	gravel; sandy-silt matrix; pebbles and cobbles; light brown	no	n/a
1.8	2.1	czsg	clay-rich, silty to sandy gravel; grey	no	n/a
2.1	2.2	o	organics	no	n/a
2.2	2.3	sg	sandy gravel; grey	no	n/a
2.3	2.6	o	fibric organics	no	n/a
2.6	2.9	cz	clay-rich silt; no clasts; grey	no	n/a
2.9	3.4	zsg	sandy to silty gravel; pebbles and cobbles; grey	no	n/a
3.4	5.0	zsg	coarse sand and gravel, some silt; cobbles up to 20 cm; grey	no	n/a
5.0	5.8	zsg	coarse sand and gravel, some silt; cobbles up to 20 cm; grey	yes	no visible ice
5.8	6.1	zsg	sandy to silty gravel; mostly pebbles; grey	yes	no visible ice
6.1	7.9	zsg	silty to sandy gravel; mostly pebbles; wet and dry alternating layers; grey and buff	yes	no visible ice
7.9	11.0	zsg	variable gravel, mainly pebbles, a few cobbles up to 12 cm, grey; pebble lens at ~10.7 m; light brown	yes	no visible ice

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A3. *Detailed borehole log for YGS_YDA.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.3	oz	fibric organics	no	n/a
0.3	0.6	oz	humic organics grading to organic-rich silt	no	n/a
0.6	3.0	oz	organic-rich silt	yes	ice lenses 2–5 cm thick, ~15% visible ice
3.0	4.0	zg	silty, pebble gravel	yes	20% visible ice, coating particles
4.0	4.6	sg	sandy gravel, dry	yes	no ice visible
4.6	7.0	g	gravel	yes	ice coating particles
7.0	11.0	g	gravel	yes	n/a
11.0	14.5	czg	muddy gravel, brown/grey; dry silt lenses	yes	n/a
14.5	15.5	r	weathered schist	yes	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A4. *Detailed borehole log for YGS_Mayo_School.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.6	o	fibric to mesic organics	no	n/a
0.6	0.9	z	silt; grey	no	n/a
0.9	1.4	zs	silty sand; grey/buff	no	n/a
1.4	1.8	sg	poorly sorted, sandy pebble gravel; fining upward	no	n/a
1.8	3.4	sg	sandy gravel; coarse sand and pebbles; water at the top of the interval	no	n/a
3.4	4.3	zc	sticky clay; dense; wet; grey	no	n/a
4.3	4.9	zs	silty fine sand	no	n/a
4.9	7.9	zs	silty fine sand	no	n/a
7.9	8.5	zs	silty fine sand; grey	no	n/a
8.5	11.0	zs	silty fine sand; grey	yes	no visible ice
11.0	14.0	zs	silty fine sand; more fines and wetter from 11.3 to 11.6 m	yes	no visible ice
14.0	17.1	z	silt; dry; grey	yes	ice lens at 15.2 m, ~1 cm thick
17.1	20.1	zsc	rhythmite – alternating lenses of clay and silty fine sand; each about 1 cm thick	yes	clay lenses often not frozen; ice lens at 19.5 m, ~2 cm thick; chunks of ice up to 5 cm thick
20.1	23.2	cz	rhythmite – silt lenses getting thicker	yes	relatively ice poor
23.2	26.2	cz	fining upward; becomes more massive; silts at the bottom of the interval	yes	no visible ice
26.2	29.0	z	silt; 5 cm well-sorted sand lens at 26.2 m	yes	n/a
29.0	29.3	z	silt	no	n/a
29.3	36.0	cz	clay-rich silt; soft and sticky; pebble at 35.4 m	no	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A5. *Detailed borehole log for YGS_Mayo_GroupHome.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.3	o	fibric organics	no	n/a
0.3	0.6	cz	clay-rich silt; dense; wet; grey/brown	no	n/a
0.6	1.2	z	silt; dry; very powdery	no	n/a
1.2	1.8	scz	clay-rich silt; dense; wet; coarse sand lenses up to 3 cm thick	no	n/a
1.8	2.1	g	cobble gravel; clasts up to 10 cm; saturated	no	n/a
2.1	5.0	zc	mostly clay, some silt; dense, stiff, dry	no	n/a
5.0	5.2	g	thin gravel lens	no	n/a
5.2	5.8	zc	silty clay; some gravel at the bottom of the interval	yes	ice lenses
5.8	7.9	zc	silty clay; clay layers are unfrozen	yes	ice lenses from 5.2 to 7.9 m; occasional ice lenses up to 20 cm thick containing suspended sediment
7.9	11.0	zc	silty clay with ice lenses	yes	ice lenses, up to 20 cm thick; unfrozen between lenses
11.0	12.5	zc	silty clay with ice lenses; clay lenses are thawed	yes	ice lenses
12.5	14.0	cz	stiff clay	no	n/a
14.0	17.1	szc	stiff clay and silt; some fine sand lenses	no	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A6. *Detailed borehole log for YGS_RR_Lagoon.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.6	o	fibric organics; White River ash ~3 cm thick at 0.6 m	no	n/a
0.6	0.9	z	silt; some oxidation; loose, buff colour	no	n/a
0.9	1.5	zs	silty sand; fining upwards; grey/ brown at the top, colour change to dark grey at the bottom	no	n/a
1.5	2.1	zsg	sandy pebble gravel, some silt; first 0.2 m wetter, bottom 0.2 m dry and loose; grey	no	n/a
2.1	2.4	sg	open-work cobble gravel	no	n/a
2.4	3.4	zsg	poorly sorted gravel; pebbles and cobbles	no	n/a
3.4	3.7	msg	muddy, coarse sand and gravel	yes	top of permafrost in gravel ~3.5 m
3.7	4.9	zc	silty clay; sticky; stiff; dark grey	yes	ice lenses ~1 cm starting at 3.8 m; ice lenses up to 8 cm thick
4.9	7.3	zc	silty clay; dark grey; pebbles and coarse sand from 7.0 to 7.3 m	yes	ice lenses variable thickness; ~15 cm ice lens near bottom of interval
7.3	11.0	zc	mostly ice with lenses of stiff frozen silty clay; dark grey	yes	high ice content; large sections pure ice starting at ~7.6 m
11.0	14.0	zc	mostly ice; lenses of silty clay up to 20 cm thick	yes	~90% ice
14.0	17.1	zc	alternating lenses of pure ice and silty clay; ice thickness ranging from 20 to 50 cm; more clay lenses than previous unit	yes	~50–60% ice over whole section
17.1	20.1	zc	stiff clay; trace silt; dry, dark grey; more clay than ice in this unit	yes	~10% ice; small ice lenses ~0.5 cm thick; ice lens at 17.4 m ~20 cm thick
20.1	23.2	zc	stiff, silty clay; more moisture below ~21.3 m where thawed	yes	thawed at 21.9 m; very little visible ice in frozen section
23.2	26.2	zc	clay, trace silts; well-bonded; dark grey	no	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A7. *Detailed borehole log for YGS_RR_LagoonRd.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.2	o	fibric organics	no	n/a
0.2	0.2	-	White River ash	no	n/a
0.2	0.6	sz	sandy silt; oxidized; darker orange at the top fading to light brown at the bottom	no	n/a
0.6	1.8	zsg	silty to sandy gravel; pebbles and cobbles up to 10 cm; loose and dry; mottled light grey and brown colour	no	n/a
1.8	3.4	zsg	silty to sandy gravel; 80% pebbles, 20% smaller cobbles (~7 cm); saturated; light grey	no	n/a
3.4	4.9	zsg	silty to sandy gravel; 80% pebbles, 20% smaller cobbles (~7 cm); saturated; light grey	yes	n/a
4.9	5.8	zsg	silty to sandy gravel; pebbles and cobbles; wet; grey	yes	ice likely melted from drilling
5.8	7.9	zc	silty clay; stiff; dark grey	yes	small (<0.5 cm) ice lenses; at 7.3 and 7.6 m ice lenses ~2 cm each; a lot of core has no visible ice
7.9	11.0	zc	silty clay	yes	bottom 1.5 m has no visible ice; 1 cm ice lens at 8.2 m; 3 cm ice lens at 9.4 m; 90% of core has no visible ice
11.0	17.1	zc	silty clay; rare sand lenses	yes	no visible ice

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A8. *Detailed borehole log for YGS_RR_Highways.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.3	g	backfill gravel	no	n/a
0.3	0.5	zso	silty to sandy organics; some pebbles; dry; brown	no	n/a
0.5	0.5	-	White River ash	no	n/a
0.5	1.7	zsg	silty to sandy pebble gravel; loose and dry; grading from light brown at the top to light grey at the bottom	no	n/a
1.7	2.0	czsg	clay-rich silty to sandy pebble gravel; powdery; light grey	no	n/a
2.0	3.7	sgF	coarse, sandy gravel; mostly pebbles; some moisture	no	n/a
3.7	4.3	g	gravel	no	n/a
4.3	4.6	czg	clay-rich, silty pebble gravel; dark grey	no	n/a
4.6	7.9	zc	clay; trace silt; stiff; dark grey	no	n/a
7.9	11.0	c	clay; stiff; dark grey	yes	frozen starting at 8.2 m; ice lenses of varying thickness (0.5–5 cm) all the way to 11.0 m; top of permafrost is ice rich, up to 90% ice

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A9. *Detailed borehole log for YGS_BC_Ptarmigan.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.3	o	fibric organics; 25 cm moss mat	no	n/a
0.3	0.6	szg	fine sand to silty gravel; 40% rounded pebbles; dark brown; saturated	no	n/a
0.6	2.1	zsg	silty-sandy gravel; rounded pebbles; loose and dry; light grey	no	n/a
2.1	4.6	zsg	silty-sandy gravel; poorly sorted; rounded pebbles; coarser sand from 4.0 to 4.6 m; saturated from 4.3 to 4.6 m	undetermined	n/a
4.6	4.9	zsg	silty-sandy gravel; dry	undetermined	n/a
4.9	5.8	zsg	silty-sandy gravel; matrix fining downwards; saturated first 0.5 m, then damp to 5.5 m; 5.5–5.8 m dry and loose	undetermined	n/a
5.8	12.2	gzs	fine sand and silt, massive; dense, dry, well-bonded; layer of rounded pebbly gravel from 6.4 to 6.7 m; silty fine sand with rounded pebbles and some coarse sand from 7.9 to 8.2 m	undetermined	n/a
12.2	13.7	sg	well-sorted pebble gravel and coarse sand	no	n/a
13.7	14.9	zs	silty fine sand; massive with a few pebbles; saturated at 14.6 m	no	n/a
14.9	17.1	zsg	poorly sorted, silty, sandy gravel; loose; large cobble at 16.5 m; silty, fine sand lens at 15.8 m; wet and sticky below 16.5 m	no	n/a
17.1	19.2	d	matrix-supported diamict; saturated; sticky; brown	no	n/a
19.2	20.7	d	matrix-supported diamict; silty sand matrix; 60% pebbles ranging from rounded to sub-angular; moderately dense; dark grey	no	n/a
20.7	21.3	d	matrix-supported diamict; silty sand matrix; pebbles to cobbles; very dense	no	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A10. *Detailed borehole log for YGS_BC_Brown.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.3	o	fibric organics	no	n/a
0.3	0.6	sz	dense, sandy silt; oxidized; pebbles at the bottom of unit	no	n/a
0.6	2.1	zsg	silty-sandy gravel; 40% clasts: 70% pebbles, 30% cobbles; clasts are subangular to subround; dry and loose; light grey	no	n/a
2.1	3.7	sg	sandy pebble gravel; medium-grained sand; 80% pebbles	no	n/a
3.7	15.2	zsg	silty-sandy gravel; 70% pebbles, 30% cobbles; grey, dry, powdery; lenses of fines and damp gravel from 5.2 to 5.8 m; muddy layer at 5.5 m	no	n/a
15.2	15.8	zsg	silty-sandy gravel; loose and damp; 70% clasts: 40% granules, 40% pebbles, 20% cobbles; clasts are rounded to subrounded	no	n/a
15.8	17.1	d	matrix-supported diamict; silty-sand matrix; 60% clasts: 40% granules, 60% pebbles; clasts are rounded to subangular; crumbly, damp, moderately compact	no	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A11. *Detailed borehole log for YGS_BC_Hwys.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	2.1	g	backfill gravel	no	n/a
2.1	5.8	szg	silty-sandy gravel; mostly pebbles, some cobbles; clasts are subround; brown near top to light grey near bottom	no	n/a
5.8	6.4	d	matrix-supported diamict; sandy silt matrix; cohesive but not dense; 50% clasts: 70% pebbles, 30% cobbles, rounded to subrounded; damp; brown	no	n/a
6.4	11.0	zsg	silty-sandy gravel; 60% clasts: 70% pebbles, 30% cobbles; fewer clasts below 9.4 m, water table at ~10.7 m	no	n/a
11.0	14.0	sg	sandy pebble gravel; saturated	no	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A12. Detailed borehole log for YGS_HainesRd.

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.3	ozs	0–0.2 m fibric organics; 0.2–0.3 m mesic organics	no	n/a
0.3	3.7	d	matrix-supported diamict; sandy, silt matrix; 0.3–0.9 m looser, mixed with organics; 0.9–3.7 m grey and sticky; increased moisture toward bottom of unit	no	n/a
3.7	8.5	zsg	silty to sandy pebble gravel; finer layer at 3.8–4.0 m; well-sorted medium sand; 6.0–6.7 m fine to coarse sand, coarsening upward, a few small pebbles at the top; 6.7-7.6 m silty fine sand, no cobbles, well-sorted; pebble-cobble gravel from 7.9-8.5 m	no	n/a
8.5	11.0	d	matrix-supported diamict; silty, fine sand matrix; 15% clasts; pebbles and cobbles; moderately dense	no	n/a
11.0	11.7	d	matrix-supported diamict; fine sand and silt matrix; ~10% clasts, granules and pebbles; dry and dense	no	n/a
11.7	12.5	s	well-sorted, fine to medium-grained sand; fining downward; occasional pebble; damp, grey	no	n/a
12.5	15.5	d	diamict; ~10% clasts at top, increasing to 40% at the bottom of the unit	no	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A13. *Detailed borehole log for YGS_HJ_AirportRdDeep.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	1.4	zc	silty clay; some laminations; very sticky; damp; tan colour	yes	n/a
1.4	6.1	d	matrix-supported diamict; silty to fine-sand matrix; at 4.9 m coarser sand lens ~10 cm thick; 5.0–6.1 m crumbly brown silt and clay matrix with angular pebbles and granules	yes	n/a
6.1	26.2	cz	silty clay; massive, no laminations; 6.1–7.5 m: very few clasts <5%, very dense; 7.5–7.9 m: dry, very dense, pebbles and granules ~5%; colour change at 6.1 m from brown to grey; fines upward	yes	ice lens ~1.5 cm at 10.4 m; ice lens ~1 cm at 10.8 m

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble

Appendix A14. *Detailed borehole log for HJ_WRB_CO.*

Start (m)	End (m)	Grain size*	Description	Permafrost	Ice description
0.0	0.3	o	organics	no	n/a
0.3	0.8	sz	fine to sandy silt; oxidized in bottom half	no	n/a
0.8	1.8	cz	silt and clay; no clasts; first 0.3 m crumbly then compact	no	n/a
1.8	7.9	cz	same as above, stickier; organics at ~1.9 m; occasional clasts, pebbles starting at 7.0 m, <5%; some laminations visible at 3.0 m, and from 7.3 to 7.9 m	no	n/a
7.9	9.1	czd	matrix-supported diamict; 40% clasts: 20% granules, 70% pebbles, 10% cobbles; no cobbles in bottom 0.6 m; clasts are subangular to subround	no	n/a
9.1	12.2	czd	matrix-supported diamict; 5–10% pebbles; brown	no	n/a
12.2	17.7	d	matrix-supported diamict; clay-rich, silty to fine sand matrix; 25–30% clasts: 90% pebbles, 10% cobbles; no obvious structure; grey, very compact	no	n/a
17.7	19.8	sz	fine, sandy-silt with very few clasts, <5% pebbles	no	n/a
19.8	21.3	d	matrix-supported diamict; clay-rich, silty fine sand matrix; 15–20% clasts	no	n/a
21.3	26.2	zs	silty fine sand; some fine laminations at 22.7 m, thixotrophic; wet at 22.9 m and 24.1 m	no	n/a

* o: organic; c: clay; z: silt; s: sand; g: gravel; d: mixed fragments; r: rubble