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A history of water and ice: a field guide to permafrost and environmental change in the Yellowknife area, Northwest Territories

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ABSTRACT

Permafrost is a fundamental component of northern landscapes and is inextricably linked to climate. The changing state of permafrost due to global warming has heightened its environmental and societal relevance. Permafrost refers to soils and rock that remains below 0°C, or commonly considered “frozen”, year-over-year, and it affects most of the terrain in the northern half of Canada. For thousands of years, permafrost has affected the landscape around Yellowknife. The occurrence and characteristics of permafrost in this region intimately relate to the history of glacial ice sheets and glacial lakes, which have had a dominant influence on the evolution of this landscape. Knowledge of the connections between permafrost conditions, climate, and geological history highlights why northern landscapes are now amongst the most dynamic on earth.

The purpose of this guidebook is to describe the influence of permafrost on landscape of the Yellowknife region, and to illustrate how our geological legacy has shaped the land that we live on today. It is increasingly evident that permafrost, which provides a foundation for northern ecosystems and communities, is not permanent. In many areas, permafrost is thawing in response to natural environmental disturbances, due to human activity through the development of infrastructure, and by climate warming. Understanding how these changes impact the environment and infrastructure are critical to the resilience of northern society.

This guidebook provides an overview of the environmental and permafrost conditions in the Yellowknife area. Part I describes the characteristics of permafrost and its influence on the environment and on northerners. Part II describes the landscape around Yellowknife, highlighting the legacy of Glacial Lake McConnell and its imprint on the present day geography and permafrost conditions of the Great Slave Lowland region. Part III presents a tour of Yellowknife and the surrounding region, describing field stops that illustrate landscape history, local permafrost conditions, and the consequences of permafrost thaw.

Part 1: Permafrost

What is permafrost?

Permafrost is the frozen ground that underlies terrain throughout sub-Arctic, Arctic and mountainous regions of Canada. It is the cement that holds landscapes together, providing the foundation for northern ecosystems, communities and roads. The extent of permafrost increases northward with a decrease in mean annual air temperatures. Northwest Territories fall within the zones of continuous, discontinuous, and sporadic permafrost (Figure 1). In Arctic tundra regions, permafrost underlies almost all of the land area. The Yellowknife region is within the extensive discontinuous permafrost zone, where 50 to 90% of the land is underlain by frozen ground. In contrast, Hay River on the southern side of Great Slave Lake is in the sporadic permafrost zone where only 10 to 50% of the land is underlain by permafrost. Further south, permafrost persists in patches of organic soils to comprise less than 10% of the land area.

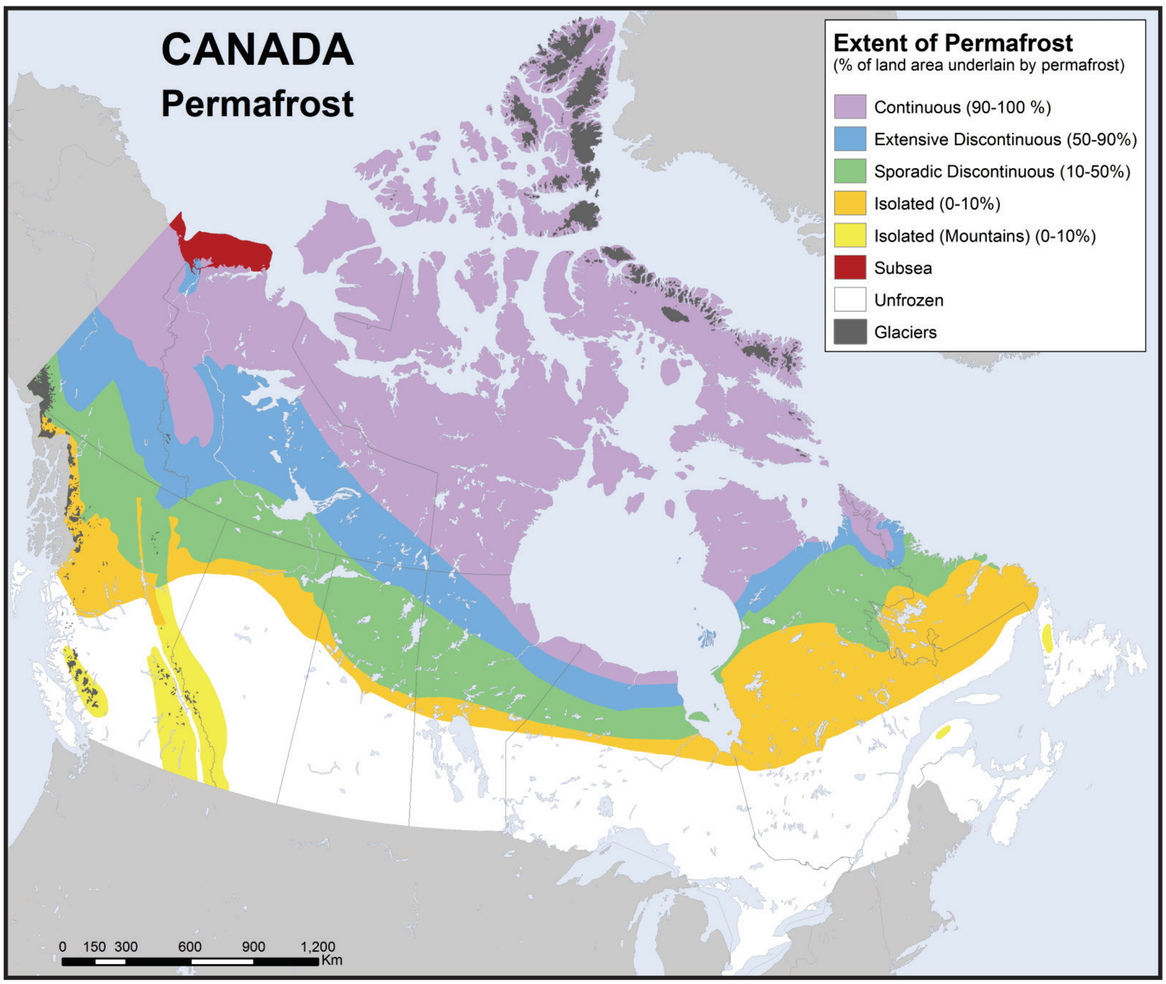


Figure 1. Permafrost map of Canada (Heginbottom JA, Dubreuil MA, Harker PA. 1995. Canada — permafrost, National Atlas of Canada, 5th edition. National Atlas Information Service, Natural Resources Canada, Ottawa. MCR 4177)

Characteristics of permafrost

Geographical variation of permafrost thickness and temperatures

Permafrost thickness relates primarily to air temperature, thermal properties of earth materials and the geothermal gradient. The age of the terrain surface, proximity to water bodies, surface drainage, vegetation and snow cover are also factors that contribute to local variation in permafrost conditions. On the barren lands north of the Yellowknife region, continuous permafrost is about 400 m thick. Permafrost thickness decreases southward with increasing mean annual air temperatures (Figure 2), and when encountered in the Yellowknife area it is typically less than 50 m thick. Within the southern zone of discontinuous permafrost, isolated patches may be only a few metres thick. In permafrost areas, the lakes and rivers that exceed the depth of maximum winter ice thickness are underlain by unfrozen ground called a talik.

Permafrost is the result of cold climate conditions, so there are direct associations between air and permafrost temperatures. Generally, the permafrost temperatures get colder northward, but local variation occurs due to differences in soil properties, vegetation, snow cover and proximity to water bodies. The mean annual ground temperature provides one index of permafrost thermal conditions that can be compared between sites and regions. In the High Arctic, mean ground temperature may be as low as -15 °C. In the Slave Geological Province north of Yellowknife, the lowest permafrost temperatures are about -5 °C but in the discontinuous permafrost around Yellowknife, the permafrost temperatures are typically above -2 °C.

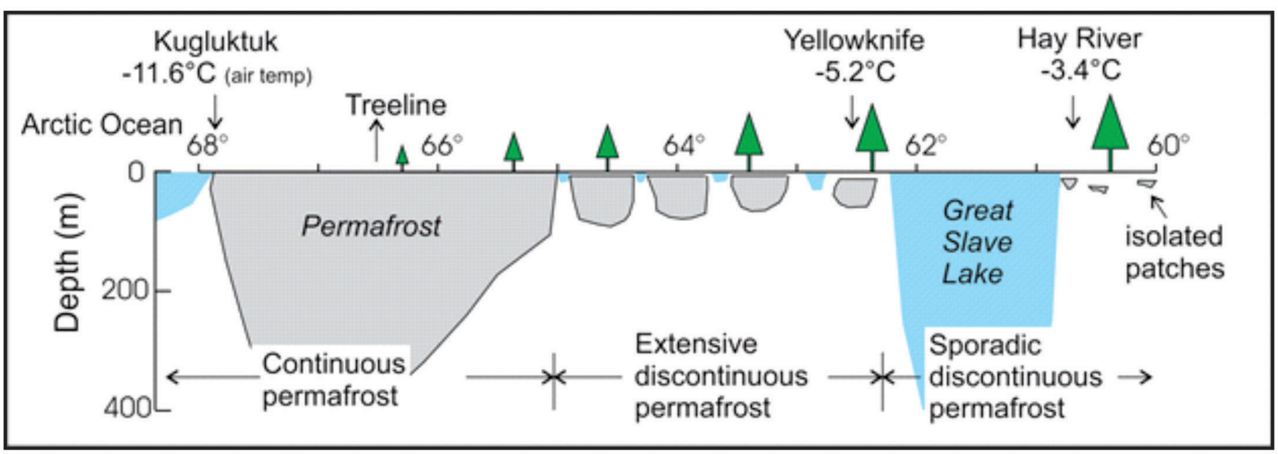


Figure 2. Permafrost thicknesses and mean annual air temperatures along a north to south transect from Kugluktuk, Nunavut to Hay River, NWT (Adapted from Brown RJE. 1970. Permafrost in Canada. University of Toronto Press, 234 p).

Ground temperature profiles

The ground thermal regime is described by an annual ground temperature envelope (Figure 3). The near surface layer that thaws in summer and freezes in winter is called the active layer. Seasonal temperature variations decrease to the depth of zero annual amplitude, where temperature remains constant throughout the year. Variation in air temperatures and the nature of the underlying earth materials influence the depth of zero annual amplitude. In warm permafrost comprised of icy, fine-grained soils, the depth of zero annual amplitude can be close to the ground surface because energy is consumed as water in soil pores thaws or freezes. In cold, continuous permafrost or in bedrock, ground temperatures may vary seasonally to depths exceeding 15 m. Under equilibrium conditions, ground temperatures increase below the depth of zero annual amplitude to the base of permafrost due to the geothermal heat flux.

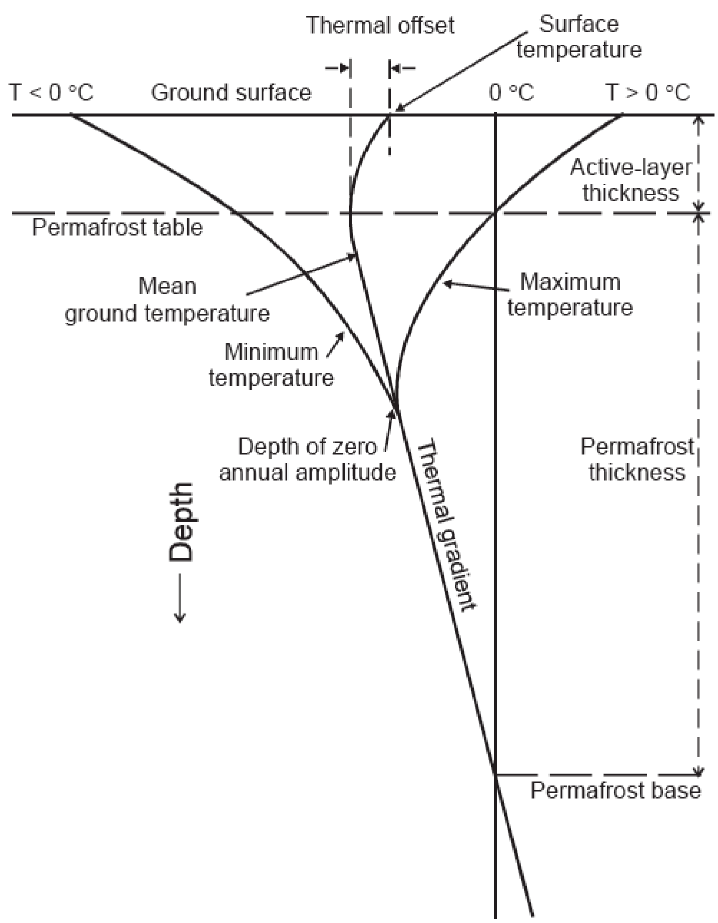


Figure 3. Typical ground temperature profile in a permafrost area (Burn CR. 2004). The thermal regime of cryosols. (In Cryosols: Permafrost-affected Soils, Kimble JM (ed.). Springer-Verlag: Berlin, Germany; 391-413.)

Disturbance at the ground surface or climate change can increase permafrost temperatures. As permafrost temperatures approach 0 °C they may respond more slowly to the effects of warming due to the absorption of latent heat as pore ice is thawed. In contrast, cold permafrost does not approach the phase change temperature of water, so that ground surface warming can more rapidly increase the temperatures of colder permafrost. As a result, permafrost near 0 °C may not appear to be warming, but its geotechnical properties may alter as pore ice converts to water at temperatures near 0 °C. This is typically observed with thawing permafrost in fine-grained materials.

Active layer

The active layer freezes and thaws annually (Figure 3). The main factors that influence the thickness of the active layer are summer air temperature, soil conditions, vegetation cover, and slope aspect. In continuous permafrost active-layer thicknesses range from about 0.3 m in organic soils to more than 1.0 m in dry sandy soils. The active layer in bedrock may be several metres thick. Figure 4 indicates the depth of the active layer and top of permafrost beneath forests in the Yellowknife area.

In permafrost terrain there is a general southward increase in active-layer thicknesses, mainly due to increases in summer air temperatures. However, differences in soil, vegetation and drainage conditions cause significant local variation. Sub-Arctic spruce forests with thick organic soils may have maximum active layers less than 0.6 m thick, but barren tundra can thaw to depths of 2.0 m in coarse-grained soils or shallow bedrock areas with a southern exposure.

Disturbance or removal of the surface organic layer can cause active-layer thickness to increase and near-surface permafrost to thaw. This can have a major effect on the ground stability in ice-rich terrain.

There is a zone at the top of the permafrost, which can become part of the active layer during periods of climate warming or following disturbance such as fire, and then revert back to permafrost as the active layer thins after vegetation recovery or climate cooling. This is called the transient or intermediate layer (Figure 4) and it is a common feature of permafrost throughout the subarctic boreal region.

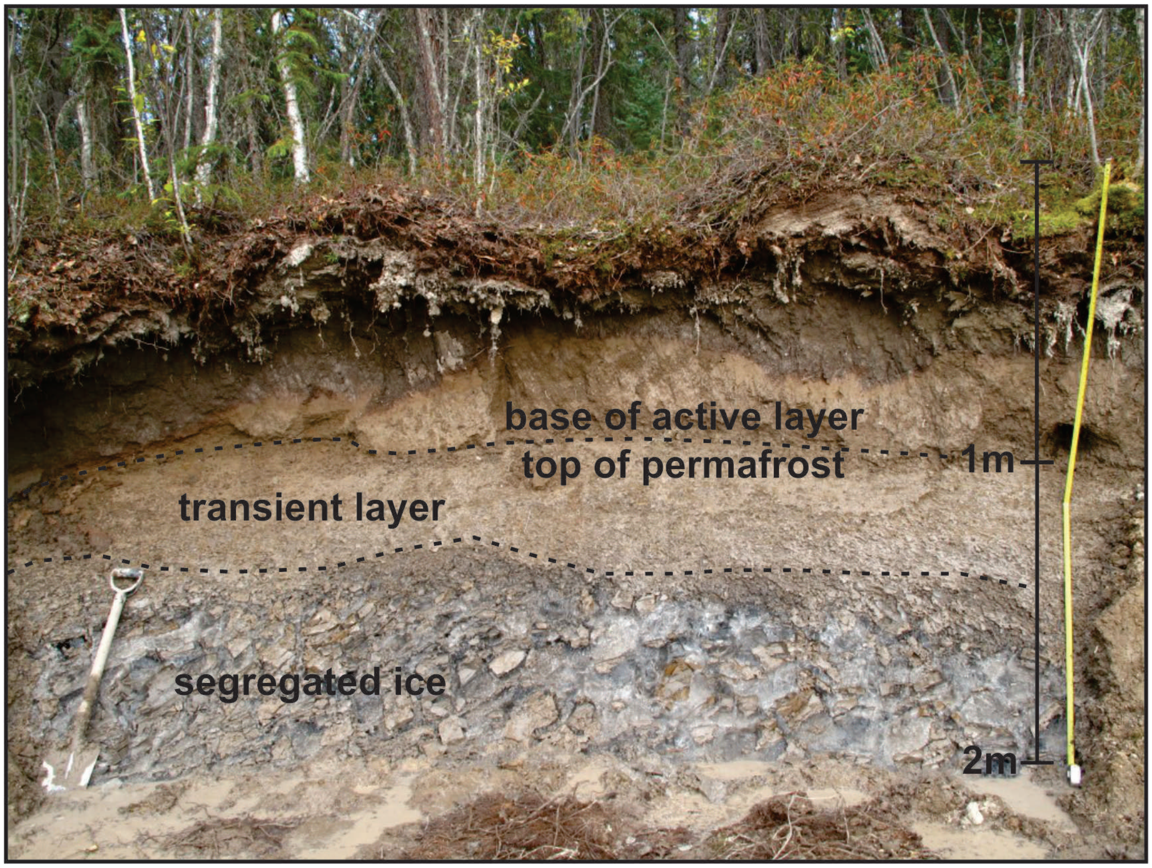


Figure 4. Exposure of permafrost soils in the Yellowknife area. The active layer is about 0.9 to 1.2 m thick beneath the forest cover. The ice content increases significantly with depth and thick segregated ice lenses occur below 1.5 m depth. This ice developed when permafrost aggraded into emergent lacustrine sediments along the receding shoreline of Great Slave Lake.

Ground ice

Permafrost derives its environmental and geotechnical significance from the occurrence and characteristics of ground ice within it. In some environments, near-surface permafrost is comprised mostly of ice. Thawing of permafrost and melting of ground ice causes the terrain to subside and reduces slope stability. The consequences of permafrost thaw greatly depend on the nature and distribution of ground ice, soil conditions and characteristics of the landscape.

Excess ice is the volume of ice in the ground that exceeds the total pore volume of the soil under natural unfrozen conditions. Thermokarst refers to the suite of processes that produce characteristic landforms that result from the thawing of ice-rich permafrost or melting of excess ground ice. Thermokarst landforms include thaw slumps, pits, ponds, and thaw/thermokarst lakes. In forested areas, thawing permafrost is often associated with leaning spruce trees that begin to topple as the underlying ice-rich permafrost thaws. This “drunken forest” can be a good indicator of underlying ice-rich permafrost.

Ground ice can be classified by its appearance or structure. Pore ice occurs within interstices of soil and rock and acts to bond earth materials. Larger horizontal or vertical bodies of mostly pure ice can range from segregated ice lenses that are only millimetres thick, to massive ice layers several metres thick. Segregated ice can form with the initial development of permafrost due to temperature-induced suction gradients that draw water from saturated sediments into the freezing ground. This ice can be encountered at depths several metres below the terrain surface. Permafrost at the base of the active layer can also contain segregated ice lenses because thermal gradients in late summer can draw water into the top of permafrost. Figure 5 illustrates a frozen sediment core containing segregated ice lenses.

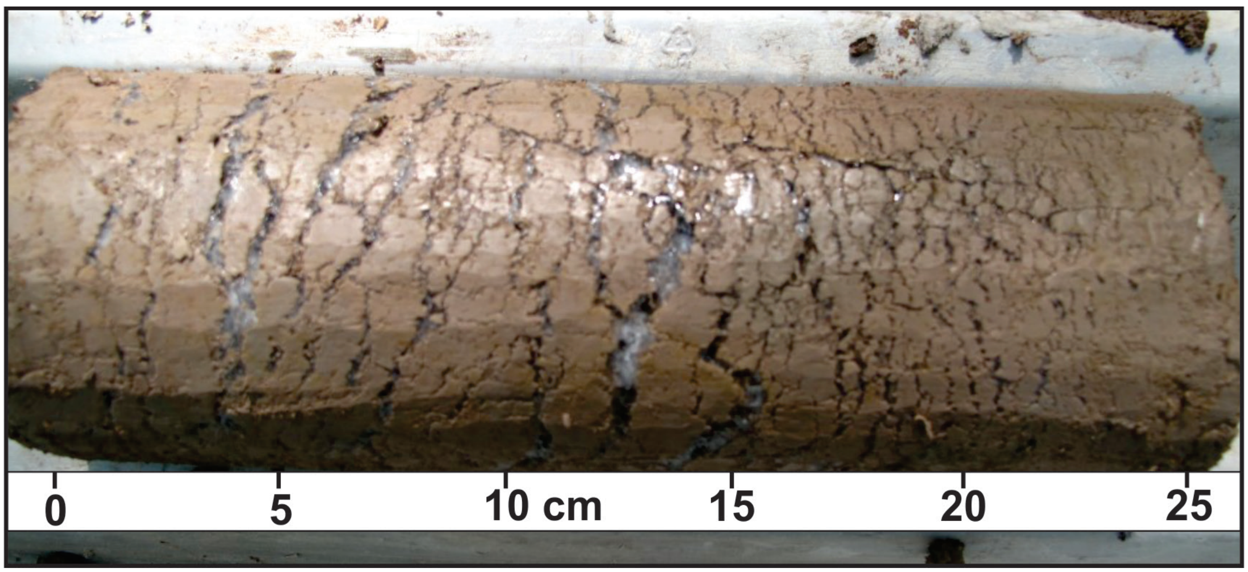


Figure 5. Permafrost core of silty clay with abundant segregated ice lenses from the Yellowknife area.

Climate change and permafrost

Circumpolar permafrost temperatures have been increasing due to recent climate warming. Field evidence indicates that rapidly rising air temperatures since the 1970s have caused permafrost in the sub-Arctic boreal forest regions of the Northwest Territories to warm by about 2 °C. The rate of temperature increase has been lower in discontinuous permafrost due to the latent heat effects associated with melting ground ice just below 0 °C. However, in this region there is growing evidence of increasing thermokarst and eradication of thin permafrost.

Climate warming will cause ground temperatures to continue increasing; thin permafrost in isolated patches and the sporadic discontinuous zone will eventually disappear. Thawing of near-surface ground ice will cause terrain subsidence leading to a cascade of ecosystem and hydrological affects. Thaw-driven settlement of terrain will damage roads and may compromise building foundations. An increase in active-layer thicknesses may also promote greater seasonal frost heave effects at sites with frost-susceptible soils.

Measuring ground temperatures in a variety of different terrains provides baseline information for planning infrastructure, monitoring effects of climate warming and calibrating and validating predictive models. Mapping thermokarst terrain can provide valuable information on the distribution of sensitive landscapes as well as characterizing the environmental consequences of permafrost thaw.

General circulation models (GCMs) are tools that allow scientists to explore how global climate may change with future increases in atmospheric greenhouse gases. Most current GCMs project global average air temperatures to warm by 0.6-0.7 °C by 2030 relative to the 1980-1999 period. The models indicate that most of this projected increase in air temperature is due to the emission of greenhouse gases into the atmosphere.

All GCMs indicate that climate change will be greater in the Arctic than in other regions of Canada, and that warming will become more pronounced over time. Given moderate emissions scenarios, mean annual air temperatures in the Arctic are expected to increase by an average of 5 °C in the next 100 years. Winter air temperatures will likely be affected the most, while summer temperature increases are anticipated to be more modest.

Glossary

Permafrost: Ground (soil or rock) that remains at or below 0 °C for at least two years.

Active layer: The top layer of ground subject to annual thawing and freezing in areas underlain by permafrost.

Ice-rich permafrost: Permafrost containing excess ice, defined as the volume of ice in the ground which exceeds the total pore space that the ground would have under natural unfrozen conditions.

Thaw slump: A slope failure feature caused by the melting of ground ice and downslope sliding and flow of the resulting debris.

Thermokarst: The process by which characteristic landforms result from thawing of ice-rich permafrost. Thermokarst processes may cause lakes to enlarge, peatlands to collapse and landslides or thaw slumps to develop.

Talik: A layer or body of unfrozen ground in a permafrost area.

Part 2: Great Slave Lowland

Introduction

Glaciation and landscape evolution following retreat of the Laurentide Ice Sheet some ten thousand years ago have shaped the permafrost environments around Yellowknife. Throughout western Canada, lakes of varying size formed along the retreating margins of the continental ice sheet. Glacial meltwaters accumulated to form lakes because the weight of the ice sheet depressed the Earth's crust. Glacial Lake McConnell covered nearly 15% of present-day Northwest Territories, occupying the combined basins of Great Bear, Great Slave, and Athabasca lakes. Gradual rebound of the Earth's crust has caused these proglacial lakes to shrink. The fine-grained sediments that were deposited on the lake bottoms now comprise the most sensitive permafrost terrain in the Great Slave Lowland along the north shore of Great Slave Lake. Since the North Slave region hosts the highest human population and infrastructure density in the Northwest Territories, permafrost thaw can have significant societal and environmental implications.

Geographic Setting

The Great Slave Lowland is an 11 000 km^2 physiographic region that characterizes the northwestern shore of Great Slave Lake, Northwest Territories (Figure 6). The landscape is a low-relief Precambrian bedrock surface with silty-clay lacustrine deposits filling low-lying areas. It is bordered to the southwest by Great Slave Lake and the Taiga Plains, and to the north by the Great Slave Upland with higher relief and more bedrock exposure.

The region has a continental climate. The mean annual air temperature is -4.1 °C and precipitation averages 291 mm annually, with 41% falling as snow. The landscape is poorly-drained with numerous water bodies dissecting a mosaic of terrestrial environments (Figure 7). The wetter soil conditions lead to a lower frequency of forest fires than in the surrounding well-drained rocky uplands. The predominant vegetation communities are black-spruce (*Picea mariana*) forest with a heath understory on hummocky ground, barren bedrock outcrops with sparse Jack pine (*Pinus banksiana*), and mixed black spruce-deciduous forest. White birch (*Betula papyrifera*) forests with herbaceous understory, and open peatlands constitute a small proportion of the land cover. The remaining land area consists of fens and bogs. The regional streamflow is from the north towards Great Slave Lake, but a low topographic gradient and rectilinear bedrock fault-controlled drainage patterns contribute to an abundance of lakes and wetlands (Figure 7).

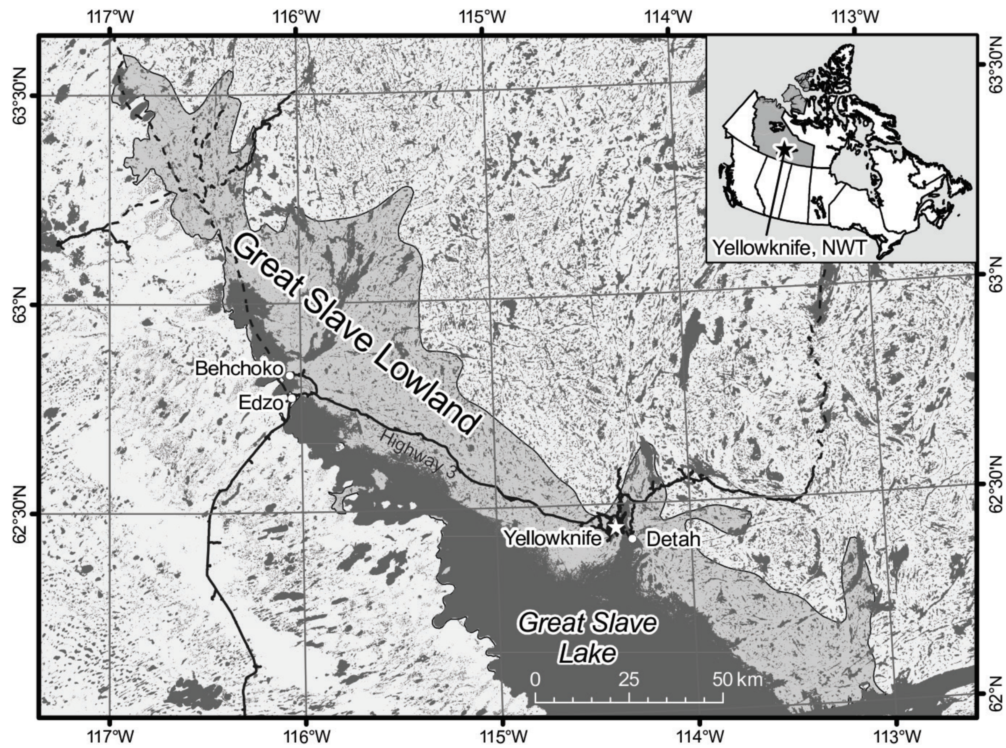


Figure 6. Great Slave Lowland and surrounding area (Wolfe SA, Morse PD, Kokelj SV, Gaanderse AJ. 2017. Great Slave Lowland: The Legacy of Glacial Lake McConnell. In: O. Slaymaker (Ed) Landscapes and Landforms of Western Canada. 87-96 pp).

Figure 7. Great Slave Lowland along the north shore of Great Slave Lake. Wetlands are forming along emerging shorelines and within shallow bays as water levels decline. Exposed bedrock, coniferous forest, and deciduous forest comprise terrain in foreground.

The Legacy of Glacial Lake McConnell

About 13 000 years ago, glacial Lake McConnell inundated the Great Slave Lowland behind the retreating Laurentide Ice Sheet. This immense pro-glacial lake persisted along the retreating glacial margin between about 13 000 and 9500 years ago. Larger than any freshwater lake in existence today, it was named after R.G. McConnell who first recognized the paleo-shorelines that indicated previously higher water levels in Great Slave Basin. At its maximum extent around 10 700 years ago, the lake covered the basins of Great Bear Lake, Great Slave Lake, and Lake Athabasca (Figure 8).

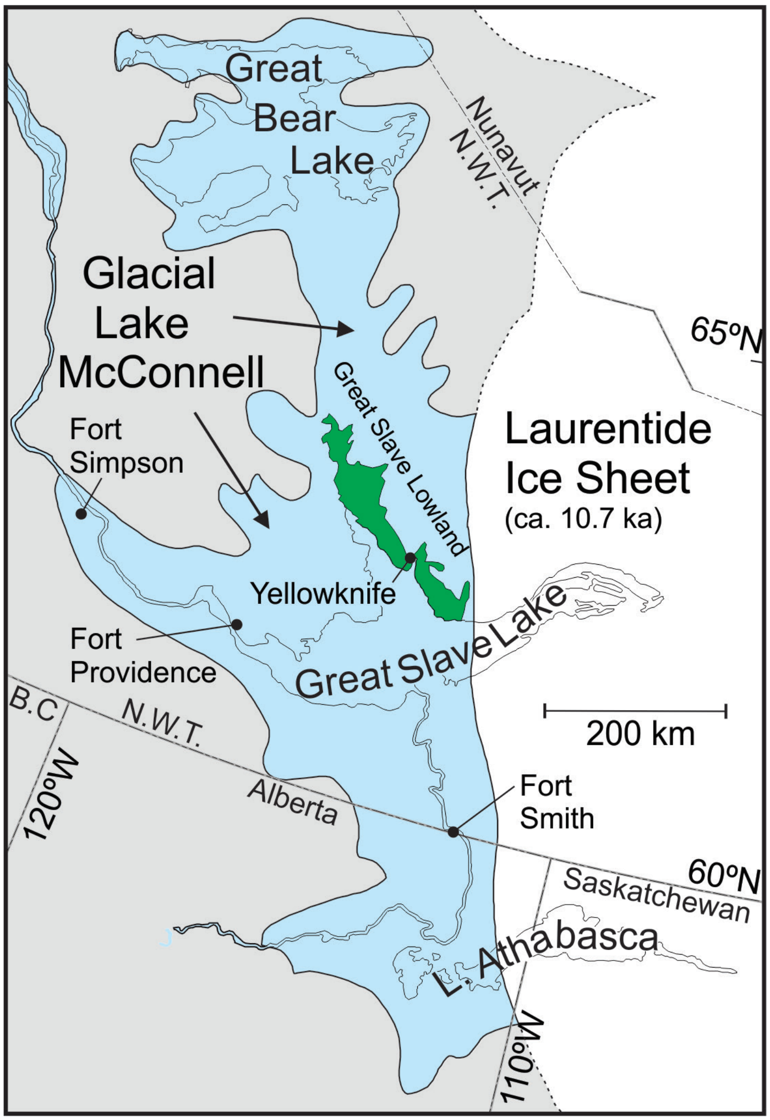


Figure 8. Glacial Lake McConnell at its maximum extent approximately 10 700 years ago as defined by Smith DG. 1994. Glacial Lake McConnell paleogeography, age, duration, and associated river deltas, Mackenzie River Basin, western Canada. Quaternary Science Reviews 13, 829–843.

Lake McConnell developed as the result of glacio-isostatic loading caused by regional differences in glacial ice thickness. Evidence of the lake exists today as raised beaches and wave-washed glacial features. In the Great Slave basin, the maximum McConnell lake elevation was about 320 m above sea level (asl) along northeastern Great Slave Lake, compared to only about 180 m asl at Fort Smith. This contrast in elevation is due to differential rates of uplift that followed the retreat of glacial ice, which has caused a gradual tilting of the basin towards the Fort Province drainage outlet now occupied by the Mackenzie River.

Great Slave Lowland was inundated to an elevation of what is now about 280 m asl and more than 100 m above the present-day lake level. As the terrain was uplifted, Lake McConnell disconnected from the Great Bear Basin, and then around 9500 years ago water level declines separated the Great Slave and Athabasca basins. Ancestral Great Slave Lake continued to recede with post-glacial uplift to its present elevation of 156 m asl. The present-day uplift in the Yellowknife area is about 5 mm per year. The recession of Great Slave Lake is constrained by the Mackenzie River outlet at Fort Providence, with uplift along the southern shore of the lake occurring at a rate of about 2 mm per year. Therefore, the lake level at Yellowknife is falling at about 3 mm per year due to differential isostatic uplift.

Glacial Lake McConnell and the continued recession of Great Slave Lake has left behind silt and clay deposits that cover nearly 70% of Great Slave Lowland. Glaciolacustrine sediments settled within deep-water basins, and as water levels receded, materials continued to accumulate in topographic lows as wave action washed sediments from emerging rocky outcrops. These extensive areas of fine-grained deposits, restricted to localized pockets at higher elevations, influence the regional distribution of ice-rich permafrost terrain.

The age of permafrost in the region correlates to terrain elevation above the present level of Great Slave Lake with the youngest permafrost situated just above present day lake levels. For example, emergent terrain such as islands and nearshore environments along the North Arm represent conditions for permafrost growth today (Figure 7). In contrast, permafrost aggraded into upland terrain farther from Great Slave Lake when it emerged from the lake thousands of years ago.

Permafrost distribution and ground temperatures

Great Slave Lowland is within the extensive discontinuous permafrost zone, and permafrost ground temperatures range between 0 °C and about -3.0 °C. Permafrost underlies terrain with black spruce forest, mixed deciduous and coniferous forests with stands of white birch, and peatlands. These forests typically colonize unconsolidated fine-grained sediments but the mixed white spruce/white birch stands favour well-drained environments. Permafrost is absent beneath bedrock outcrops or in coarser-grained deposits where the organic cover is thin or absent, such as sandy outwash deposits with jack pine forest. The majority of deposits hosting permafrost are black spruce forests, or mixed deciduous and coniferous forests with white birch, and frozen-ground thicknesses typically exceed 10 m.

Shallow ground temperature measurements indicate that permafrost can exist in all forest types underlain by fine-grained glaciolacustrine sediments (Figure 9). Mean annual ground temperatures in permafrost range from -1.4 °C in black spruce forest to as warm as -0.02 °C in open peatland. Mean annual ground temperatures at sites with visible signs of permafrost degradation are generally greater than -0.2 °C. Ground temperatures are increasing at several monitoring sites due to rising air temperatures.

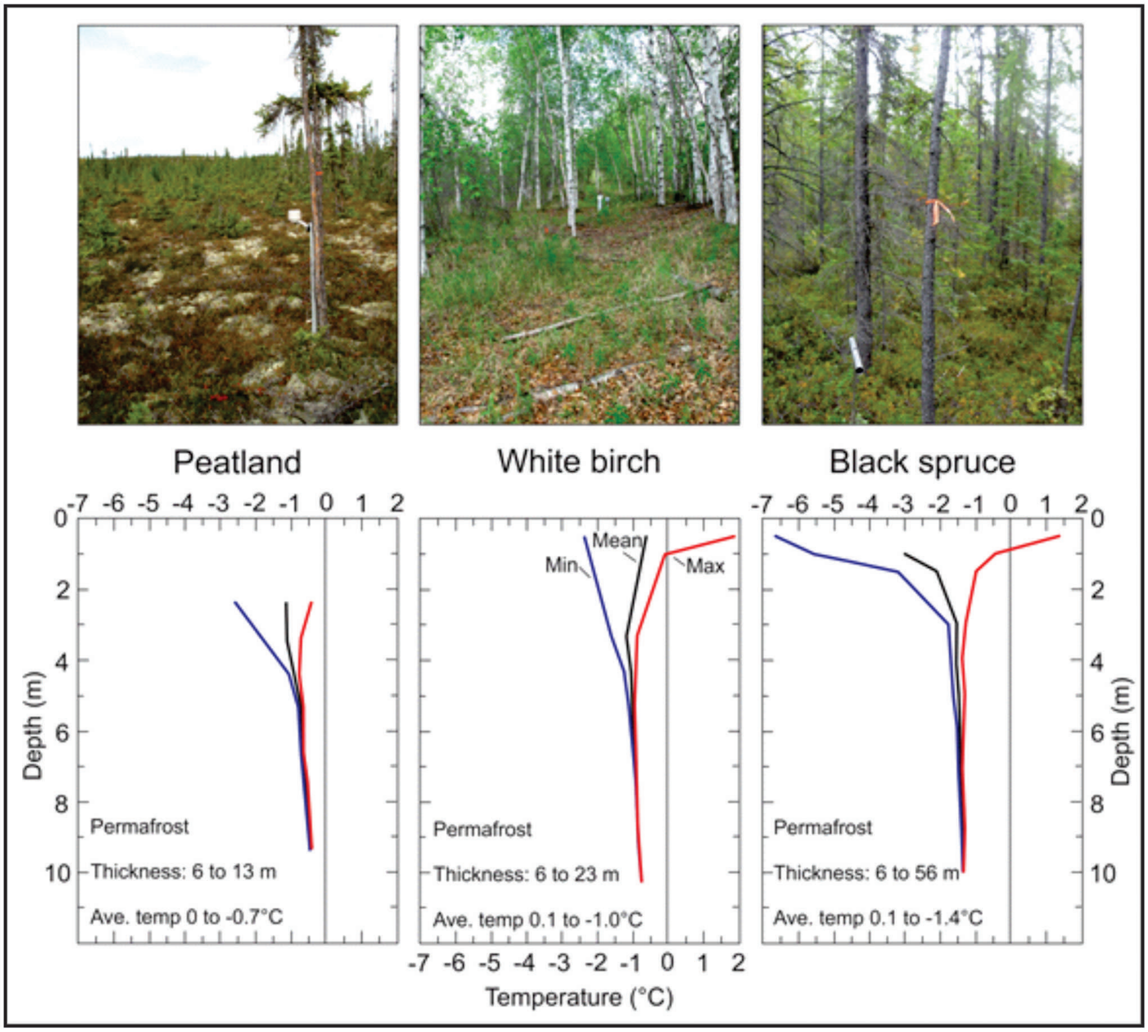


Figure 9. Vegetation cover and ground temperatures envelopes in peatlands, black spruce, and birch forests. The annual mean, maximum, and minimum temperatures plotted with depth show the seasonal range of ground temperatures at the 3 monitoring locations. Permafrost thickness and temperatures ranges for all monitoring sites from the 3 site types are from Morse et al. (Morse PD, Wolfe SA, Kokelj SV, Gaanderse AJR. 2015. Permafrost occurrence in subarctic forests of the Great Slave region, Northwest Territories, Canada. In: Proceeding of the 7th Canadian Permafrost Conference, 20-23 September, 2015, Quebec City, Quebec).

Hills of icy permafrost - lithalsas in the Great Slave Lowland

Permafrost landforms are commonly good indicators of ice-rich, thaw sensitive terrain. Lithalsas are mounds or small, elongated hills that form due to segregated ice lens development when permafrost aggrades into fine-grained, saturated soils characteristic of emergent shoreline environments in the Great Slave Lowland (Figure 10a). Ice lenses develop as moisture migrates towards the aggrading permafrost causing the surface to heave and the lithalsa to form (Figure 11). Since lithalsas are comprised of ice-rich permafrost these landforms are good indicators of sensitive permafrost terrain.

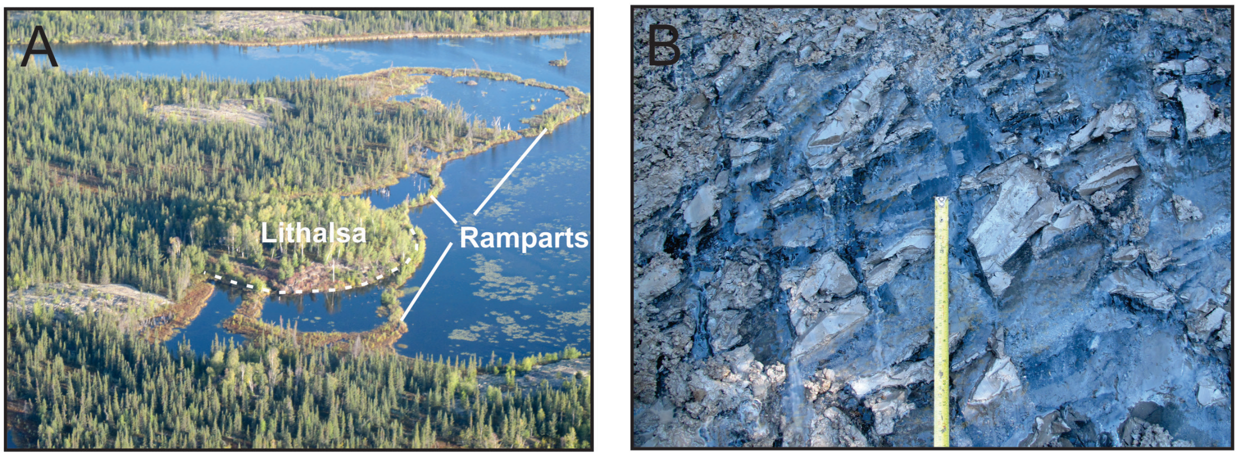


Figure 10. Lithalsa terrain and associated ground ice in the Great Slave Lowland; a) lithalsa with white birch forest adjacent to a pond contrasts with the surrounding bedrock and black spruce forest. Ramparts indicate margins of collapsed lithalsas; b) segregated ground ice in lacustrine clay exposed by the headwall of an active thaw slump developed in a lithalsa. (Wolfe SA, Morse PD, Kokelj SV, Gaanderse AJR. 2017. Great Slave Lowland: The Legacy of Glacial Lake McConnell. In: O. Slaymaker (Ed.) Landscapes and Landforms of Western Canada. 87-96 pp).

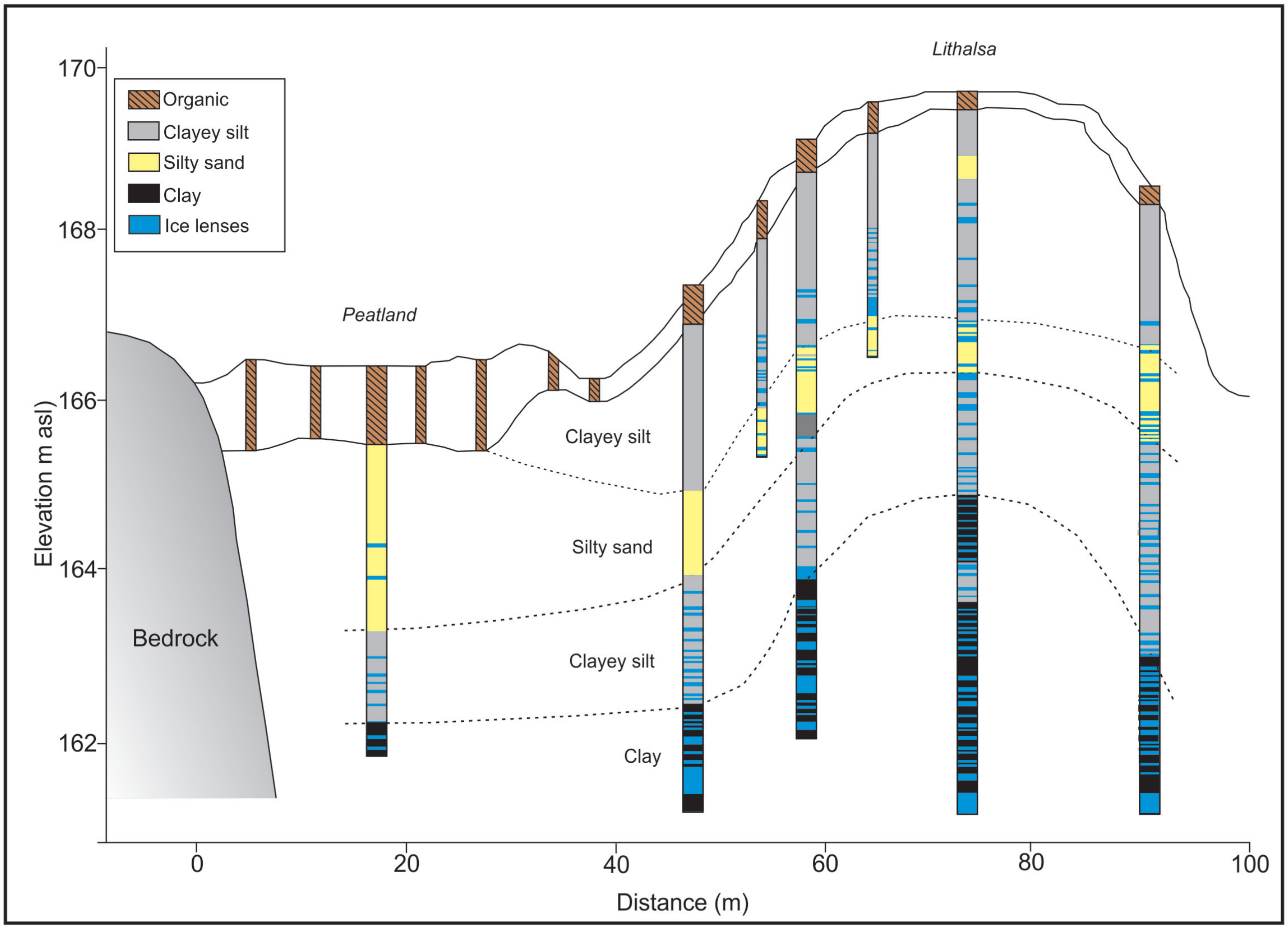


Figure 11. Borehole logs from a lithalsa west of Yellowknife showing sediment layers, and increasing ice content with depth. (Adapted from Gaanderse, AJR. 2105. Geomorphic origin of a lithalsa in the Great Slave Lowlands, Northwest Territories , Canada. MSc Thesis, Carleton University, Ottawa, pp. 157).

Lake recession and emergence of the Great Slave Lowland over the last several thousand years has been conducive to lithalsa development so these landforms are widespread throughout this region (Figure 12). Their development is an important component of permafrost landscape evolution that has influenced the ecology and terrain sensitivity of the Lowland area. Lithalsas are most common at elevations just above the present level of Great Slave Lake, indicating that many formed in the late Holocene, and some are less than 1000 years old. These well-drained hills or mounds are typically associated with white spruce and deciduous white birch forests with a thin organic cover. Today the mean annual ground temperatures are between -0.1 to -1.5 °C. Lithalsas contain significant amounts of ground ice at depth (Figure 10b) and since they typically occur adjacent to water bodies, their degradation and collapse can lead to the expansion of thermokarst ponds and wetland development common throughout the region.

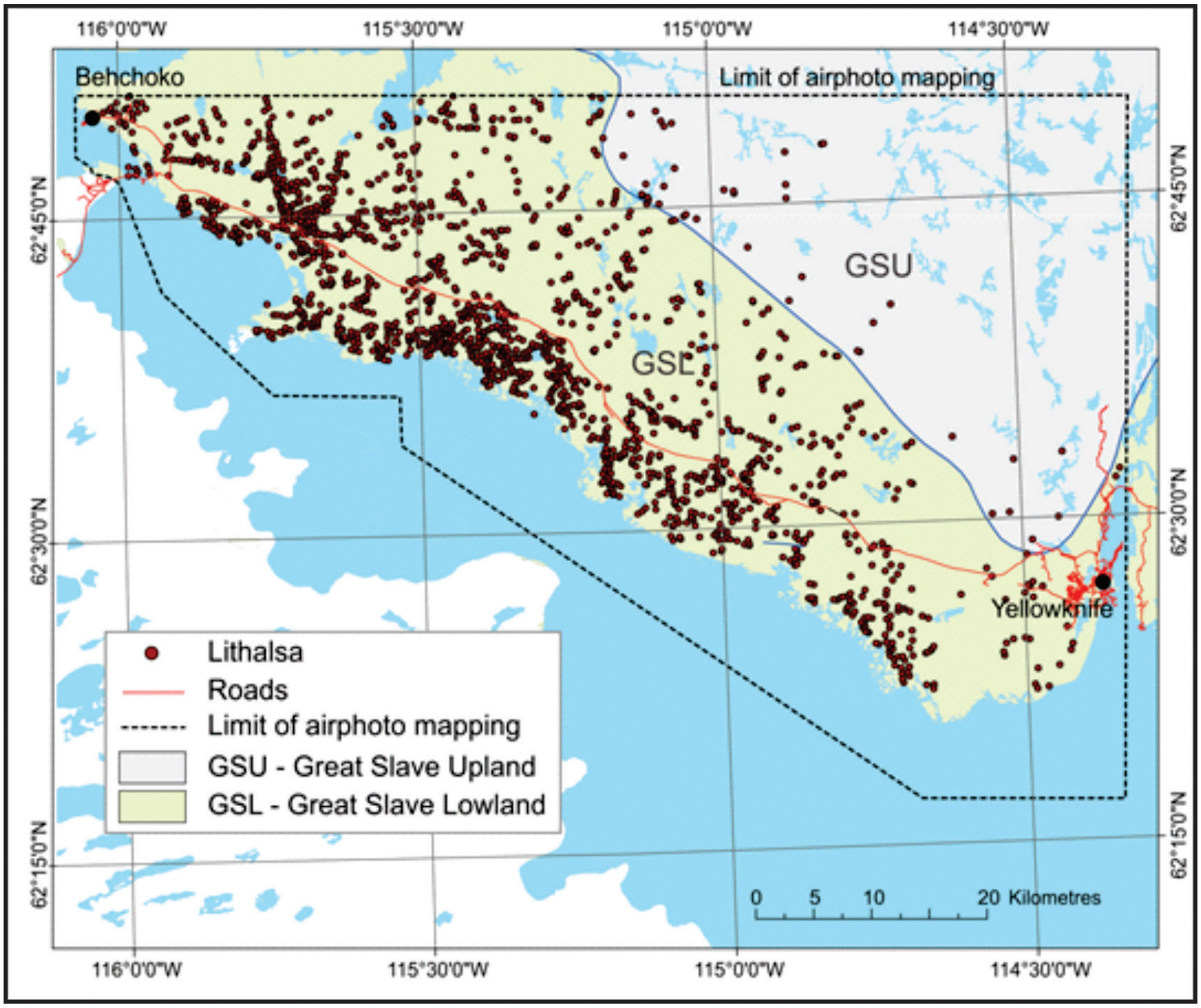


Figure 12. Distribution of 1777 lithalsas identified based on aerial photograph interpretation within the Great Slave Upland (GSU) and Great Slave Lowland (GSL) (Wolfe SA, Stevens CW, Gaanderse AJ, Oldenborger, GA. 2014. Lithalsa distribution, morphology and landscape associations in the Great Slave Lowland, Northwest Territories, Canada. Geomorphology 204: 302-313).

Landscape and permafrost evolution

Figure 13 shows landscape and permafrost evolution in the Great Slave Lowland. Clays deposited in the deep-water basin of Glacial Lake McConnell up to 10 000 years ago (Figure 13a) were overlain by silts and clays transported by streams or reworked along receding shorelines by wave action and deposited in nearshore environments (Figure 13b). As the lake level continued to drop, outcrops were exposed and numerous ponds, shallow wetlands, and streams formed in sediment-filled low-lying areas (Figure 13c). Permafrost formed as the emergent nearshore deposits were subjected to the subarctic climate (Figure 13d). Permafrost aggradation into saturated, fine-grained deposits has been conducive to ice-segregation, surface heave and lithalsa growth (Figures 13d and e). Surface disturbance from wildfires, hydrological changes, or climate warming can cause permafrost thaw and the collapse of lithalsas leaving behind ponds and ramparts as remnants of their existence (Figures 13f and 10a).

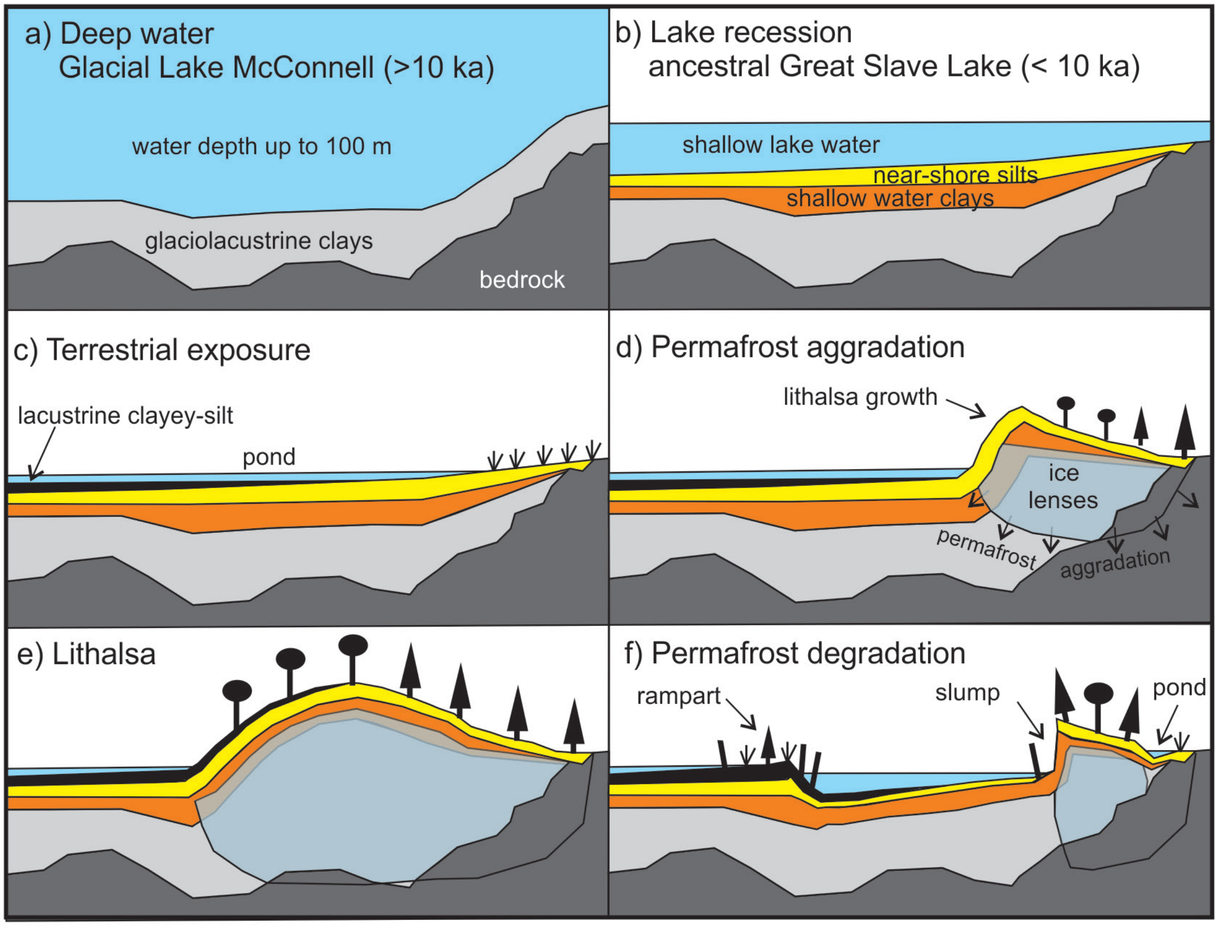


Figure 13. Conceptual diagram of lake level history, terrestrial exposure, permafrost aggradation and lithalsa formation and decay in Great Slave Lowland. (Wolfe SA, Morse PD, Kokelj SV, Gaanderse AJ. 2017. Great Slave Lowland: The Legacy of Glacial Lake McConnell. In: O. Slaymaker (Ed.) Landscapes and Landforms of Western Canada. 87-96 pp).

Communities and infrastructure in a changing climate

Over half of the Northwest Territories' population resides in the capital city of Yellowknife and surrounding smaller communities of Detah, N'dilo and Behchoko. Highway 3 passes through the Great Slave Lowland from Behchoko to Yellowknife and provides the only all-season road access to southern Canada. The Ingraham Trail (Highway 4) extends eastward from Yellowknife for about 70 km and a spur road connects Yellowknife and the community of Detah. The warm, ice-rich permafrost and the relatively high density of infrastructure and human use raises the importance of understanding the disturbance and climate change consequences of permafrost thaw in the Great Slave Lowland.

Climate warming is affecting the Great Slave Lowland. Annual mean air temperatures have increased by about 0.3 °C per decade since the 1940s, and by about 0.6 °C per decade since 1970 (Figure 14a). Rising air temperatures make the warm, ice-rich permafrost vulnerable to thawing and terrain subsidence, with impacts on ecology, hydrology, infrastructure and human use. Field studies provide evidence of permafrost warming, increasing active-layer thicknesses, and development of thermokarst terrain throughout the Lowland region. Profiles of mean annual ground temperatures commonly exhibit values in the top metre that are well above 0 °C, indicating that ground surface conditions can no longer sustain permafrost and that underlying frozen ground is in the process of thawing (Figure 9). These inverted temperature profiles with warmer temperatures at the surface than at depth are often the result of surface disturbance, including destruction of surface organic cover or poor drainage and water ponding. Thaw of ice-rich permafrost on sloping terrain can lead to slumping and the exposure of ground ice (Figure 10b), which may cause lithalsa decay, collapse of forested terrain into adjacent ponds, and wetland expansion (Figures 13e and f). Permafrost thaw in this environment can have a significant impact on terrestrial and aquatic ecosystems. Projected climate warming during the 21st Century indicates that permafrost degradation will affect terrain and infrastructure in the Yellowknife region through the coming decades (Figure 14b).

Permafrost thaw can have a significant impact on local infrastructure. In particular, maintaining safe roads and highways under conditions of warming and thawing permafrost will be an ongoing challenge. Based on ground-temperature trends, permafrost beneath highways constructed with blast rock is likely to degrade in the coming decades, in particular where the embankment inhibits drainage and causes ponding. In ice-rich areas, ground settlement beneath highway embankments is inevitable and ongoing maintenance will be required. However, snow management, improvement of drainage, and air convection through embankments can all reduce the rates of permafrost degradation through problem sections of the road. There are several sections of Highways 3 and 4 requiring maintenance and mitigation to compensate for ongoing settlement. The road sections affected by thaw-settlement are apparent by the undulating road surface and the required speed reduction for safe travel.

Permafrost thaw also has a significant impact on communities in the Great Slave Lowland. Streets, sidewalks, buildings and water and sewer mains all require ongoing maintenance due to ground settlement. Figure 15 shows the results of a study using satellite data to determine areas of ground movement in Yellowknife. The zones of highest subsidence are related to areas with fine-grained ice-rich sediments, or areas where peatlands or ponds existed prior to development. Surfaces that exhibit significant movement include the road access to the Legislative Assembly and areas surrounding Fritz Theil Park (see field stops 8 and 11).

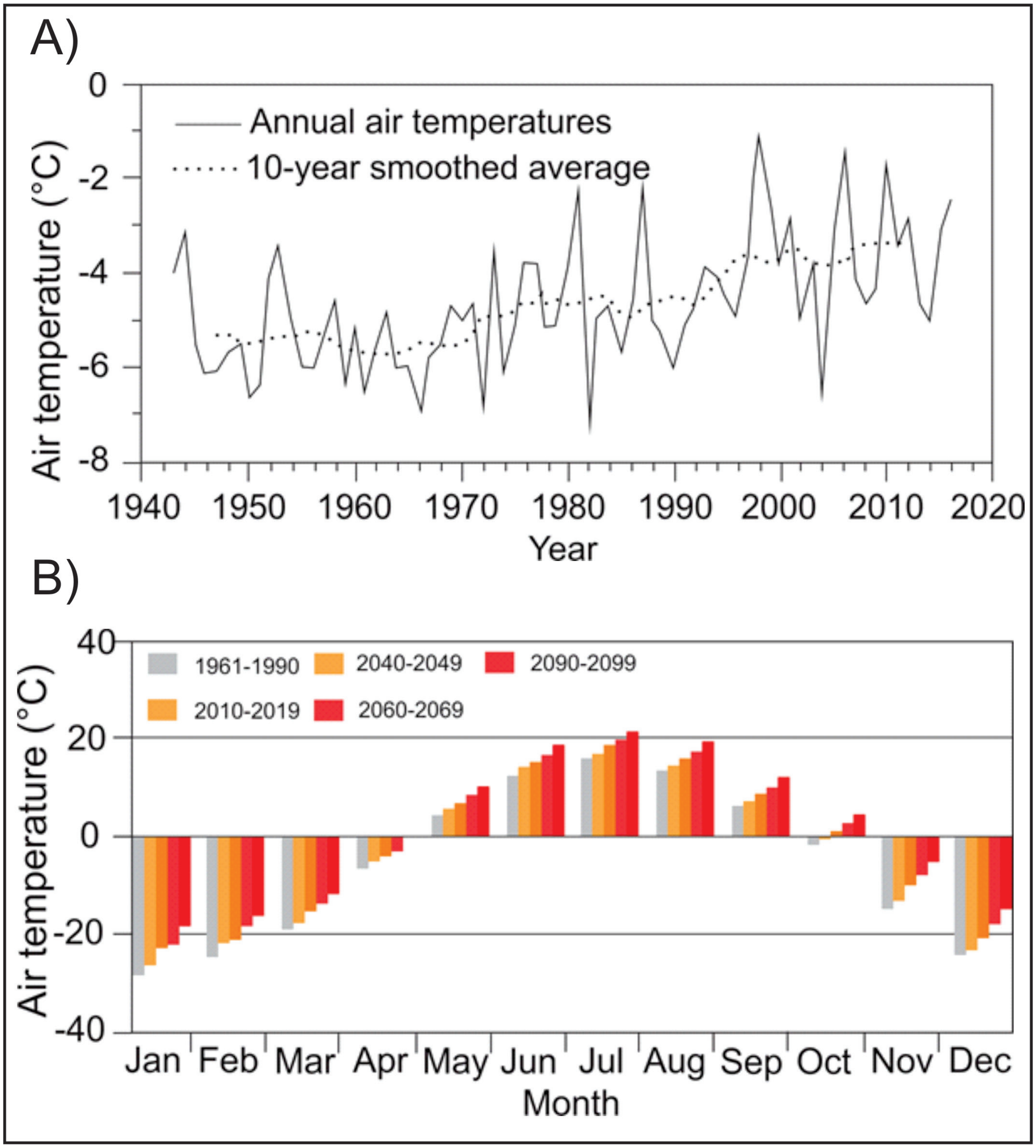


Figure 14. a) Mean annual air temperatures, 10-year smoothed average, and recent warming trend for Yellowknife b) Mean monthly temperature projections for Yellowknife based on CRU 3.2 modeled historical baseline and 5-model projected average. Output based on high range emissions (RCP 8.5) continuing through the 21st Century, developed at the International Institute for Applied Systems Analysis, Australia. For more information see https://www.snap.uaf.edu.

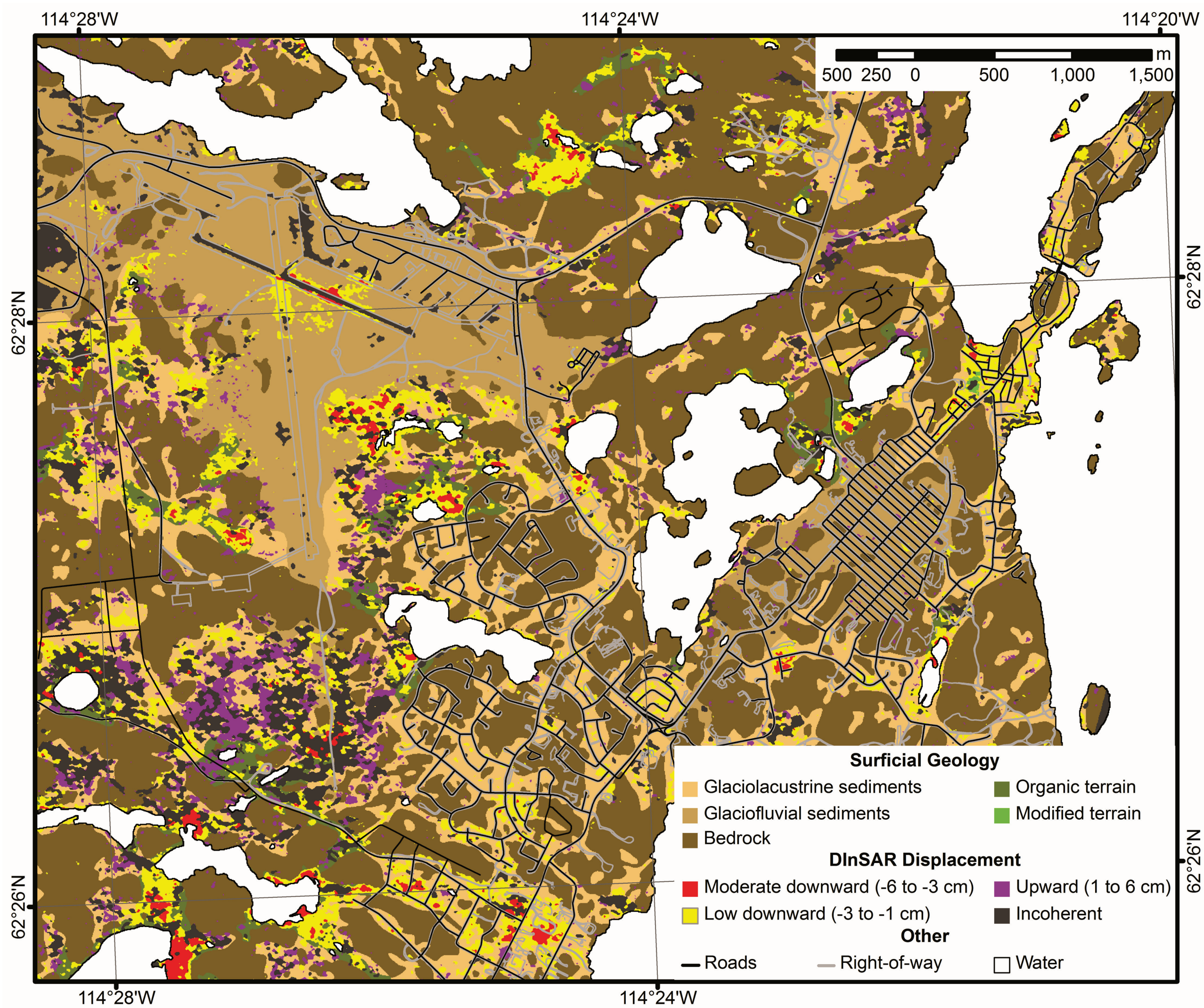


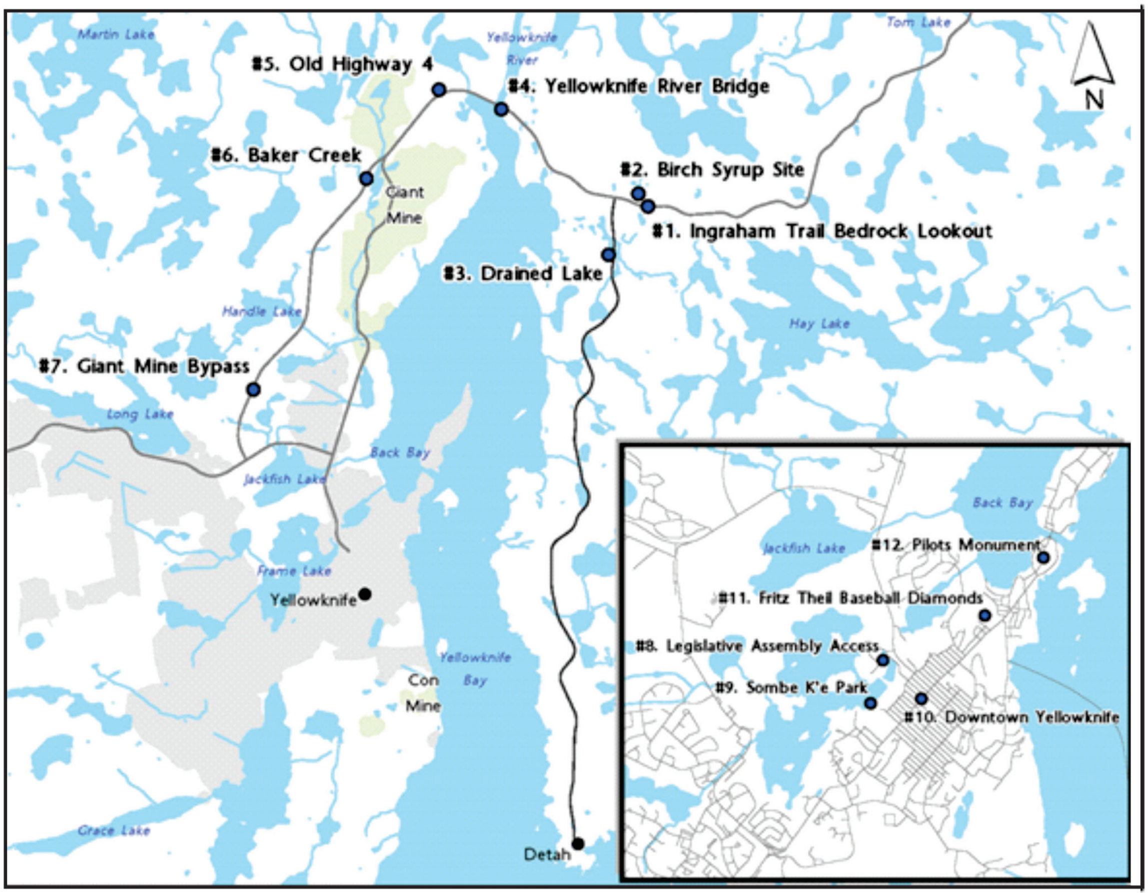
Figure 15. Map of ground surface displacement and surficial geology, City of Yellowknife. Surface displacement was determined by satellite radar. Extensive areas of bedrock are stable. Areas showing the greatest subsidence occur in organic terrain and fine-grained sediments present at the airport, and in several residential and industrial areas known to experience permafrost-related issues. (Adapted from Wolfe SA, Short NH, Morse PD, Schwarz SH, Stevens CW. 2014. Evaluation of RADARSAT-2 DInSAR seasonal surface displacement in discontinuous permafrost terrain, Yellowknife, Northwest Territories, Canada, Canadian Journal of Remote Sensing, 40:406-422).

Permafrost in the Great Slave Lowland is commonly associated with forested, fine-grained deposits and small patches of peatland. Modeling studies project that climate warming will significantly reduce permafrost distribution in this region, and that by the end of this century permafrost may only persist in isolated pockets in association with organic soils. The reduction in permafrost extent will have significant infrastructure and environmental consequences to this region. Linking scientific, engineering and practitioner knowledge is required to solve problems that society is facing as a result of climate-driven permafrost thaw. Transferring this knowledge into practical solutions and ensuring that the best-possible information is available for planning climate change mitigation and adaptation will necessitate northern technical capacity, adapting codes and standards, and fostering better interaction between technical experts, practitioners, infrastructure managers and policy makers.

Conclusions

The environment of the Great Slave Lowland illustrates the influence of glacial legacy and cold climate on present-day permafrost conditions. The deposition of fine-grained sediments in proglacial lakes, isostatic uplift and aggradation of permafrost into the emergent terrain has provided conditions favourable to the development of ice-rich permafrost interspersed between stable bedrock uplands. Current permafrost temperatures near 0 °C, evidence of lithalsa decay, and damage to road and community infrastructure highlight the sensitivity of permafrost terrain in the North Slave region and indicate that thaw-driven landscape change will continue with anticipated climate warming through the coming century. Given that the North Slave region contains the highest density of people and infrastructure developed on ice-rich terrain in northern Canada, it is critical that permafrost conditions are considered when planning development and climate change adaptation strategies.

Part 3: Permafrost Tour Field Stops



Map 1. Yellowknife area permafrost tour field stops. Ingraham Trail (Highway 4) stops 1-7 shown on main map and Yellowknife City stops 8-12 shown on the inset.

HIGHWAY 4 STOPS

1. Ingraham Trail high bedrock lookout – ancient lake history

The top of the lookout half a kilometre east of Detah Road provides a view of the Great Slave Lowland with Yellowknife Bay and the City of Yellowknife in the distance (Figure 16). The bedrock ridge is a segment of the Duck Lake Sill. This igneous rock body is of Proterozoic age and intrudes much older Archean sedimentary rocks of the Burwash Formation. The more resistant sill forms a prominent ridge for a distance of about 12 km between the Yellowknife River and Duck Lake just east of Detah. Although the sill, radiometrically dated as 2.18 billion years old, is one of the youngest rock units in the region, in the foreground, the sediment-filled lowland and the permafrost it hosts is only a few thousand years old.

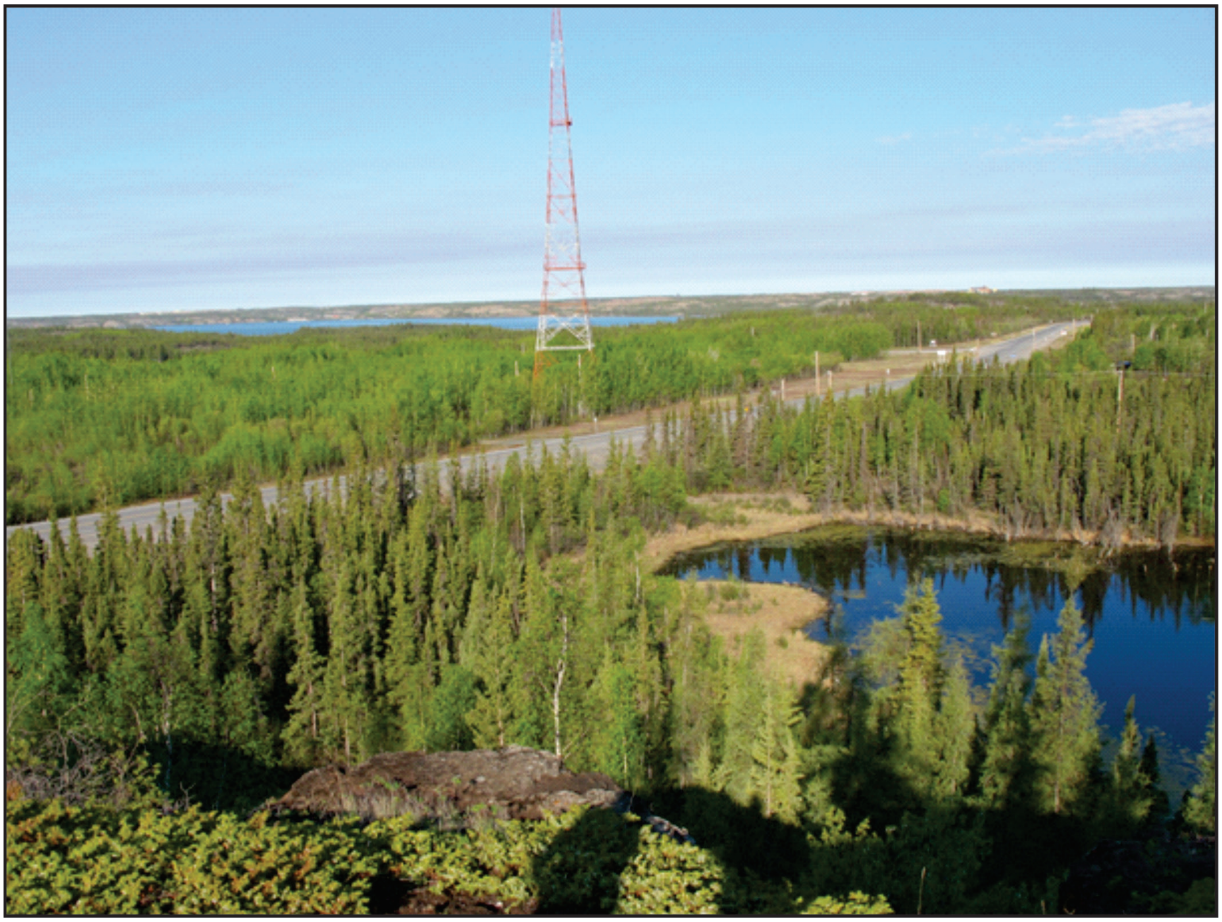


Figure 16. View of Great Slave Lowland in the foreground and Yellowknife Bay, Giant Mine and the City of Yellowknife (left) in the background.

When the Laurentide Ice Sheet receded, Glacial Lake McConnell inundated this area beneath more than 150 m of water (Figure 13). This means that even the highest land visible from the lookout was beneath almost 100 m of water. After the weight of the ice sheet was gone, the land rebounded upward and Lake McConnell gradually decreased in size. By about 9500 years ago the proglacial lake divided into several smaller basins, including ancestral Great Slave Lake, which was much larger and deeper than Great Slave Lake is today. Water levels and the size of the lake declined rapidly until about 8000 years ago. At that time, the water level of ancestral Great Slave Lake was at about the elevation of the Yellowknife airport, 50 m higher than the present lake level (Figure 17). The level of Great Slave Lake has been decreasing at a rate of about 0.5 m each century over the past 8000 years.

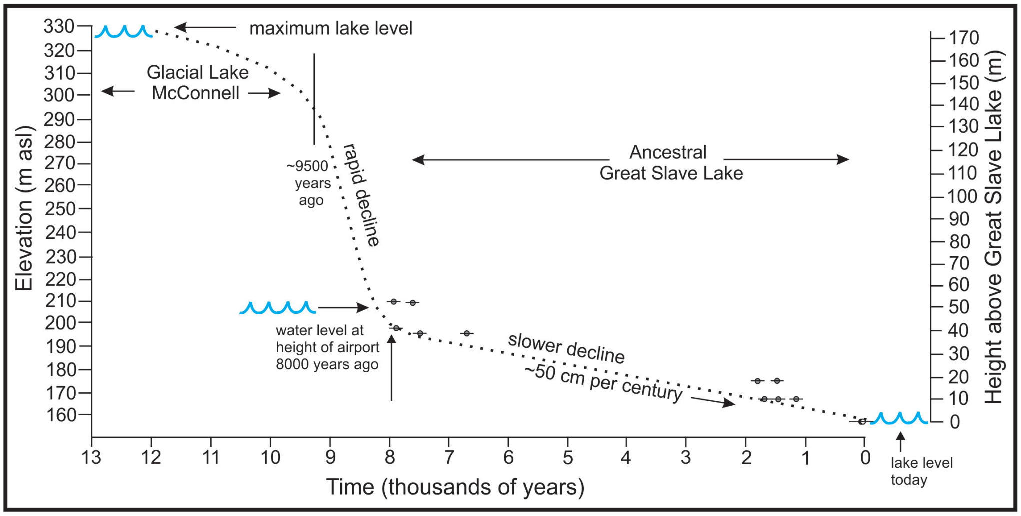


Figure 17. Recession curve showing lake levels in the Yellowknife area since deglaciation. Glacial Lake McConnell divided into discrete basins, including ancestral Great Slave Lake about 9500 years ago. The rate of lake-level decline was initially rapid but has slowed in the last 8000 years (adapted from Wolfe SA, Morse PD. 2017. Lithalsa Formation and Holocene Lake-Level Recession, Great Slave Lowland, Permafrost and Periglacial Processes, 28: 573-579).

About 70% of the Great Slave Lowland surface is comprised of fine-grained silt and clay deposits and much of the remainder is exposed bedrock, with a few sand and gravel areas representing outwash or beach deposits. Major drainages such as the Yellowknife River have continued to transport sediments from the landscape to the nearshore environments of receding Great Slave Lake, such as in the shallow area downstream of Yellowknife River bridge (Figure 18). The shorelines of the Yellowknife River upstream of the bridge are also characterized by fine-grained deposits which can be disturbed by winds, rainfall or boat traffic, increasing turbidity of the river water.

Figure 18. Shallow bays are areas of fine-grained sediment deposition. These productive aquatic environments are also great fishin' holes!

2. Birch syrup site – permafrost, ground ice, and soil temperatures

The shrinking of Great Slave Lake has caused the gradual exposure of new terrain (Figure 19). Permafrost grows downward into these emerging environments as the terrain is exposed to cold sub-Arctic winter temperatures, and vegetation develops an insulating organic layer that keeps ground cooler in summ.

The small birch-covered hill at this site is an example of an ice-cored mound called a lithalsa. These small undulating hills formed when permafrost aggraded into the saturated, fine-grained sediments causing ice lenses to grow and the ground surface to heave (Figure 20). Radiocarbon dates obtained from peat deposits enable scientists to determine when this site emerged from the receding water and estimate the maximum age of permafrost in the lithalsa. Radiocarbon dates from the oldest peat at this site indicates that the terrain emerged and permafrost developed here some time before 2000 years ago. As you walk along the hilltop beside the pond, you will notice that trees and soil are collapsing into the water. This is an example of thermokarst caused when ice-rich permafrost thaws.

Figure 19. Recently-exposed land and offshore islands along the North Arm of Great Slave Lake. As land emerges with lowering lake level, permafrost can become established in fine-grained soils beneath vegetated forests (from Wolfe, SA, Morse, PD, Kokelj, SV, Gaanderse AJ. 2017. Great Slave Lowland: The Legacy of Glacial Lake McConnell. In: O. Slaymaker (Ed.) Landscapes and Landforms of Western Canada. 87-96 pp).

Figure 20. An ice-cored hill (lithalsa) covered by birch forest. Note the tilting trees that are collapsing into the pond on the left side of the photograph.

Ground temperatures are measured in this birch forest and at natural sites in black spruce forest and peatlands throughout the Yellowknife area. The vegetation cover, thickness of the surface organic material, soil type, drainage, and ice content at depth combine to influence ground temperatures and permafrost thicknesses in the Yellowknife area.

Figure 21 shows ground temperature envelopes from boreholes in different settings in the area. The envelopes depict the highest and the lowest temperatures that occur at different depths over the year for each site. Since temperatures at depth in all of these boreholes remain below 0 °C we can conclude that permafrost is present at all of the sites. The differences in ground temperatures between peatlands, black spruce forest, and birch forest are mostly due to the soil and moisture conditions in the active layer and permafrost. Surface soils in white birch forests tend to be dry, and the organic cover is thin, so these sites typically have a thick active layer and warm ground temperatures (Figure 21a). In black spruce forests the active layer is usually thinner and permafrost temperatures are lower because the thicker organic (moss) cover insulates the ground from warming in summer and coniferous forest cover intercepts snow allowing the ground to cool in winter (Figure 21b). In the study region, localized organic deposits ranging from about 0.4 m to 4 m thick typically host permafrost. The presence of permafrost can elevate the organic terrain surface resulting in the formation of a permafrost peat plateau (Figure 21c). However, at shoreline sites adjacent to lakes, the permafrost is warmer and typically less than 10 m thick (Figure 21), reflecting the influence of water bodies on the temperature and configuration of permafrost (see Figure 2).

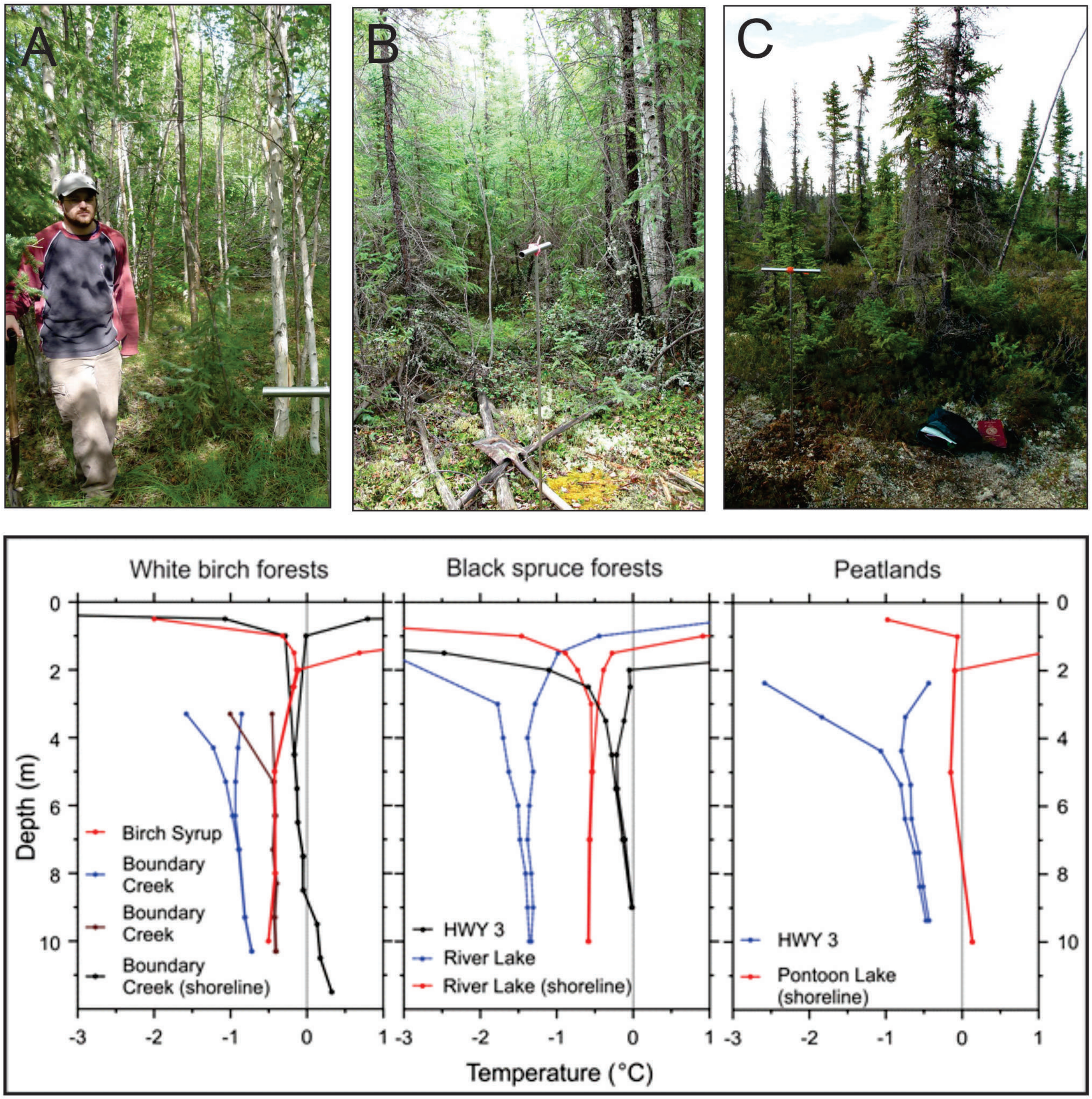


Figure 21. Ground temperature envelopes (warmest and coldest temperatures over the year) at: A) white birch forest, B) black spruce forest, and C) peatland sites. Permafrost occurs at all sites, but is very warm and shallow along lake and pond shorelines (after Morse PD, Wolfe SA, Kokelj SV, Gaanderse AJR. 2016. The Occurrence and Thermal Disequilibrium State of Permafrost in Forest Ecotopes of the Great Slave Region, Northwest Territories, Canada. Permafrost and Periglacial Processes 27: 145–162).

In the zone of discontinuous permafrost, frozen ground persists in peatlands because the organic soils are typically dry in summer and function as good insulators, maintaining lower soil temperatures during the thaw season. In late summer and fall, rain or snowmelt can saturate the peat so that once it freezes it becomes a good conductor of heat, promoting ground cooling in winter. However, if the peat is saturated, the insulating effects in summer are reduced, and in winter the wet peat is difficult to refreeze due to the large volume of water that it contains. Under saturated conditions, ground temperatures can increase and the permafrost may thaw, causing peat plateaus to collapse and ponds or wet fens to form. Disturbances, including forest fires can have a significant impact on peatland terrain causing formerly dry peatlands to subside and become saturated after the surface organic materials and protective vegetation cover is removed. Along Highway 4 near Tibbitt Lake, fires from 2015 have transformed peatlands with permafrost into saturated terrain where subsidence and permafrost degradation is underway (Figure 22).

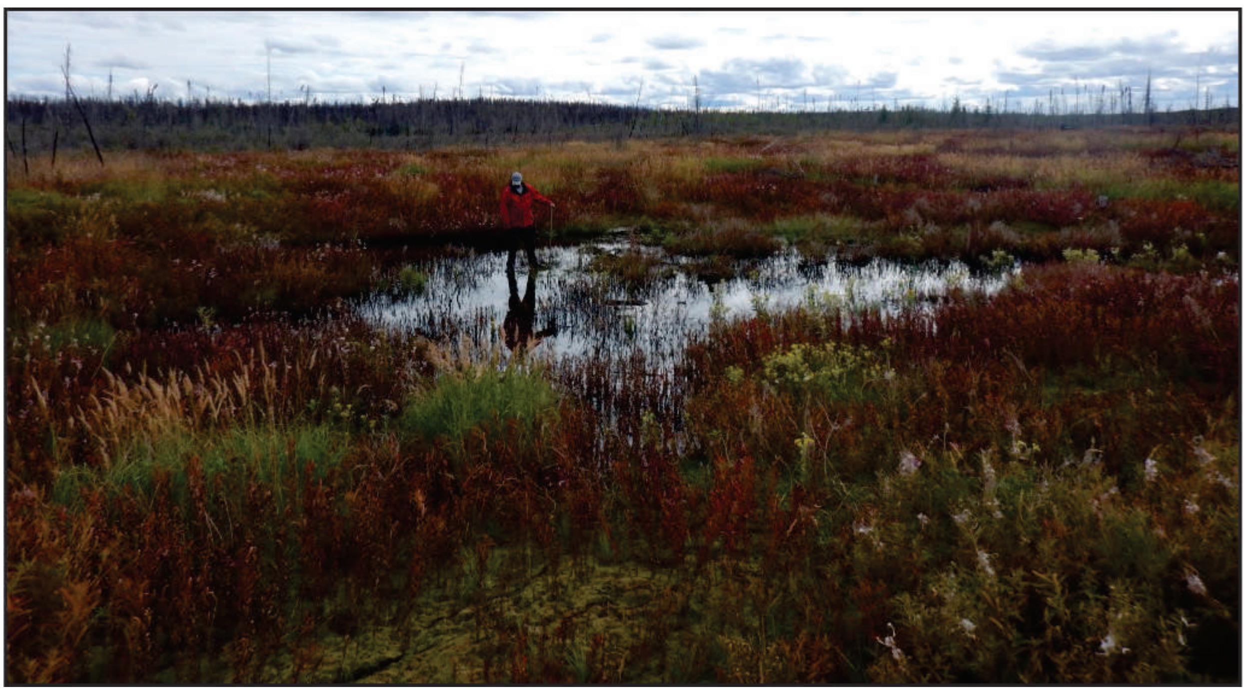


Figure 22. Saturated and subsiding peatland along Highway 4 near Tibbitt Lake following forest fires in 2015.

3. Drained lake - changing hydrology and permafrost

Between summer 2012 and 2013, a small lake drained along Detah Road, about one kilometre south of the Ingraham Trail (Figure 23). The lake drained through a narrow permafrost ridge comprised of fine-grained materials that divided two small lakes.

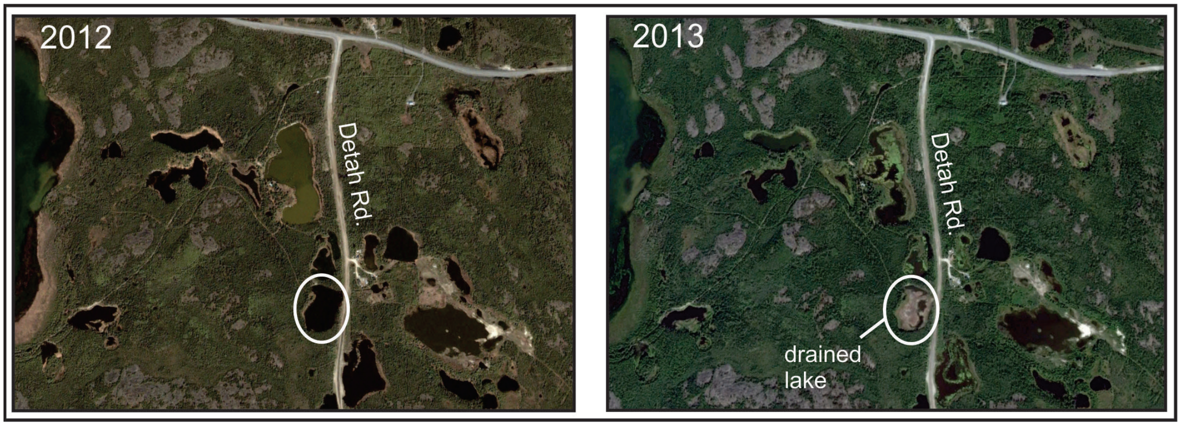


Figure 23. Drained lake along Detah road, 1 km south of Ingraham Trail.

In September 2013, a ground temperature cable drilled to 9 m depth was placed in the exposed lakebed to determine whether permafrost would establish (Figure 24). Drilling in the former lake bottom confirmed that the sediments were unfrozen. Following drainage, the floor of the lake was exposed to cold winter temperatures, altering conditions to potentially permit the formation of permafrost. However, saturated soils, proliferation of shrubs and thick snow accumulation has inhibited permafrost aggradation into this environment under contemporary climate conditions. Monitoring indicates that, although the ground has cooled consistently at depths below 5 m, permafrost has not yet developed in this emergent environment in the Great Slave Lowlands. (Figure 25).

Figure 24. Students and instructors stand on the floor of the drained lake in the summer of 2013.

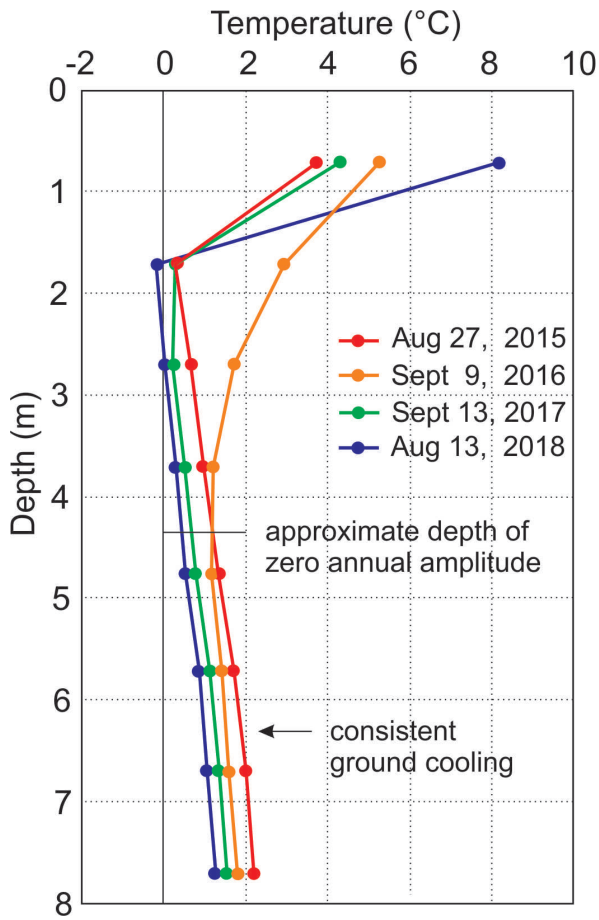


Figure 25. Ground temperatures recorded at a drained lake site indicating consistent ground cooling at depth, but an absence of permafrost formation since the lake drained.

4. Yellowknife River bridge day use area - ground ice in a new landscape at the Weledeh site

The boat launch on the Ingraham Trail at the Yellowknife River bridge is a popular picnic spot, an area of cultural significance for the Yellowknife Dene, and one of the youngest ground ice formations in the region. A lithalsa about 5 metres high and more than 100 m long is located in the deciduous forest immediately south of the picnic area (Figure 26). Yellowknives Dene oral tradition indicates that it was near here that Dene culture hero Yamǫǫ̀zha pushed aside the dam of a giant beaver, allowing the water upstream to flow freely (Glen MacKay, pers. comm., 2019).

Figure 26. The wooded mound beside the Yellowknife River day use area is one of the youngest lithalsas in the region. The shallow terrace in the foreground comprised of silty sediments could eventually develop permafrost and cause a lithalsa to grow as terrain emerges with receding water levels.

This lithalsa developed when permafrost aggraded into saturated silty sediments, forming segregated ice lenses (Figure 27) and causing surface heave. This is probably one of the youngest lithalsas in region because it is very close to the present water level of Great Slave Lake, indicating that the land here only recently emerged.

Figure 27. Segregated ground ice (dark) in a lithalsa along the Yellowknife River. Ice-poor permafrost transitions into ice-rich permafrost at the bottom of the profile.

There are about 100 lithalsas in the Yellowknife area, and most occur adjacent to the Yellowknife River between Yellowknife Bay and Tartan Rapids at the outlet of Prosperous Lake. Figure 28 shows the distribution of lithalsas relative to elevation above Great Slave Lake and their approximate ages based on the estimated rate of lake-level recession. About 70% of the lithalsas occur within 10 m elevation of the present-day lake level, suggesting that most of these landforms developed with initial permafrost aggradation into emergent terrain and that they are less than 2000-3000 years old (Figure 13). The decrease of lithalsa abundance with increasing elevation also suggests that they do not re-establish following collapse or degradation (as in Figure 13e). Although the surrounding Precambrian shield is comprised of rocks that are billions of years old, the permafrost environments of the Yellowknife region represent a younger and more dynamic component of the region's geological heritage.

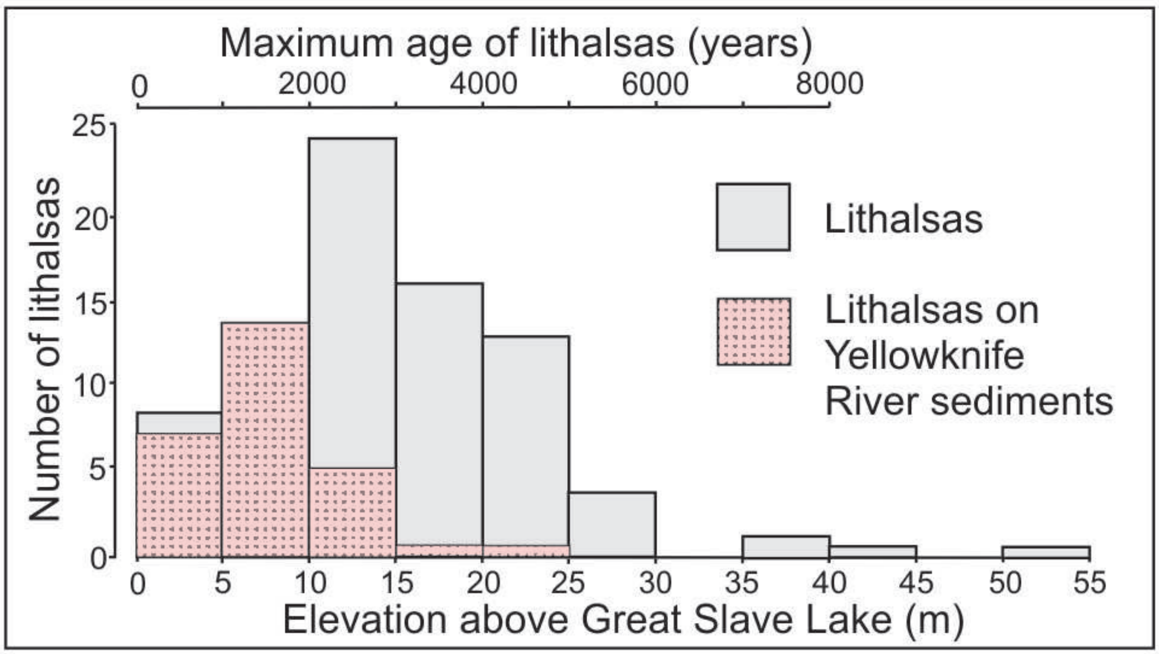


Figure 28. Lithalsa occurrence by elevation in the Yellowknife area (grey shading) and lithalsas on Yellowknife River sediments (pink dotted), with maximum age approximations based on Holocene lake-level recession rates (adapted from Wolfe SA, Morse PD. 2017. Lithalsa Formation and Holocene Lake-Level Recession, Great Slave Lowland, Permafrost and Periglacial Processes, 28: 573-579).

5. Old Highway 4 – roller coaster road

The effects of permafrost thaw on an abandoned section of road can be seen along the Ingraham trail one kilometre west of the Yellowknife River bridge. A pullout on the south side of the road is located where a sign welcomes travellers to the Ingraham Trail. The abandoned section of road is accessible by carefully crossing the Ingraham Trail just upslope (south) of the rock cut that was blasted to re-route the highway in 1999. A short walk along the abandoned road reveals a remarkably undulating and uneven surface demonstrating what can happen when road maintenance is discontinued and the underlying ice-rich permafrost thaws (Figure 29).

Figure 29. Abandoned section of Highway 4, east of Yellowknife. The paved road surface has continued to settle due to permafrost thaw after it was abandoned in 1999.

6. Baker Creek – bridge over troubled waters

A small bridge on the Giant Mine by-pass road crosses over Baker Creek south of the Vee Lake road junction. The drainage is fault controlled and the watershed is characterised by an abundance of lakes. The large volume of water storage in this small basin produces contrasting flow conditions during extended periods of dry or wet weather. These basin conditions are also conducive to sustained low-flows during winter months. During fall and winter 2010 – 2011, late fall rain recharged Baker Creek so that by mid-December the creek at Giant Mine began to flow. Low discharge over a frozen stream channel caused the formation of a large sheet-like mass of layered ice known as an *icing or aufeis* to develop at this location (Figure 30). There was cause for concern because the icing filled the engineered channel through Giant Mine property. The channel was designed to accommodate a 500-year flood and to prevent flooding into the open pits and underground chambers containing stored arsenic trioxide. The icing also filled a small canyon and blocked water flow over the waterfall at the present-day bridge location (Figure 30). When Baker Creek discharge increased in spring, the ice-filled canyon diverted runoff through a tailings pond shown below the right branch of the icing in Figure 30. This situation required immediate mitigation, and shows the potential influence of icings on flow diversion during spring runoff. Evidence of smaller icing development in Baker Creek upstream of the bridge occurred at least six times since 1982. This cold-region hydrological phenomenon must be considered when planning northern infrastructure because winter streamflow has become increasingly common with wetter fall conditions and warmer winters, increasing the potential for icing development.

Figure 30. Large icing that formed in Baker Creek in winter 2010-11 at Giant Mine. Grey line indicates the approximate present day location of the Giant Mine by-pass portion of the Ingraham Trail (Highway 4).

Icings develop in winter when groundwater, or water flow in stream channels or through the active layer, is forced to the surface and freezes. Icings commonly occur along streams and rivers throughout the continuous and discontinuous permafrost zones (Figure 31). Their development requires a water supply during the winter period, a confining layer such as permafrost or bedrock that keeps discharge close to the ground surface, and cold winter air temperatures to freeze surface water. Impedance of flow due to freezing of a channel, or an obstruction such as a beaver dam, roadbed, or culvert can increase upstream water pressure and force discharge to the surface causing an icing. In the Slave Geological Province, a combination of geologic and hydrologic controls cause icings to recur at the same locations when meteorological conditions such as late fall precipitation or a prolonged freeze-back period occur. In the Taiga Shield biophysical region, an abundance of lakes store large volumes of water so that runoff may be released gradually through winter to maintain the base flow of ephemeral streams. This combination of geological, hydrological and climate conditions can produce consistent flows through winter causing large icings to develop downstream of many subarctic shield lakes (Figure 31).

Figure 31. Icings or aufeis typical of the Slave Geological Province. The thick accumulations of ice that develop in winter can persist into June or even later into the summer season.

7. Giant Mine bypass – peat pockets whisper of former lake levels

The Giant Mine by-pass road, between Fred Henne Park and Baker Creek, reaches 210 m asl, or about 50 m above the level of nearby Great Slave Lake. Throughout this bedrock-dominated landscape, organic material has accumulated in low-lying depressions to form peatlands that archive a story of lake-level change and permafrost evolution (Figure 32).

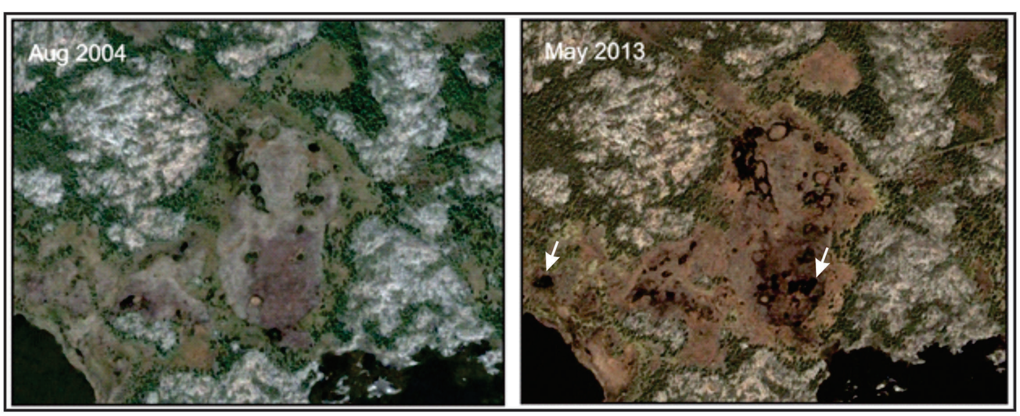


Figure 32. Permafrost peatlands along the Giant Mine by-pass road are about 8000 years old. Climate-induced permafrost thaw is converting peat plateau into small ponds and fens (water-logged areas with grasses and sedges). Comparison of these aerial photographs shows that ponding and waterlogged areas have increased since 2004 (white arrows point to new ponds).

Ancestral Great Slave Lake once inundated the Yellowknife area and as lake levels declined, more land was gradually exposed. This peatland, situated on a topographic high, was one of the first parts of the landscape to emerge from the receding lake. Organic material began to accumulate within wetter soil-filled depressions. Permafrost established due to the insulating effect of organics and preserved the peat deposit from decomposition. By coring peatlands scientists can determine the thickness of the deposit and age of the oldest organic material at the bottom of the core. Radiocarbon dating of the organic materials in these peatlands indicates that the lake receded from this location at least 8000 years ago.

It is possible to determine the past shoreline configurations of ancestral Great Slave Lake by identifying elevations of former beach ridges above the current lake level and extending these contours. Only about 8,000 years ago, most of the area covered by the City of Yellowknife was submerged (Figure 33). The Yellowknife River started to flow into Yellowknife Bay about 6000 years ago. Prior to this time Prosperous Lake would have been the northern extension of Yellowknife Bay. Tartan Rapids, a well-known fishing and camping spot where Yellowknife River flows from Prosperous Lake is a relatively new feature on the landscape, forming only about 4000 years ago with the lowering of Great Slave Lake levels.

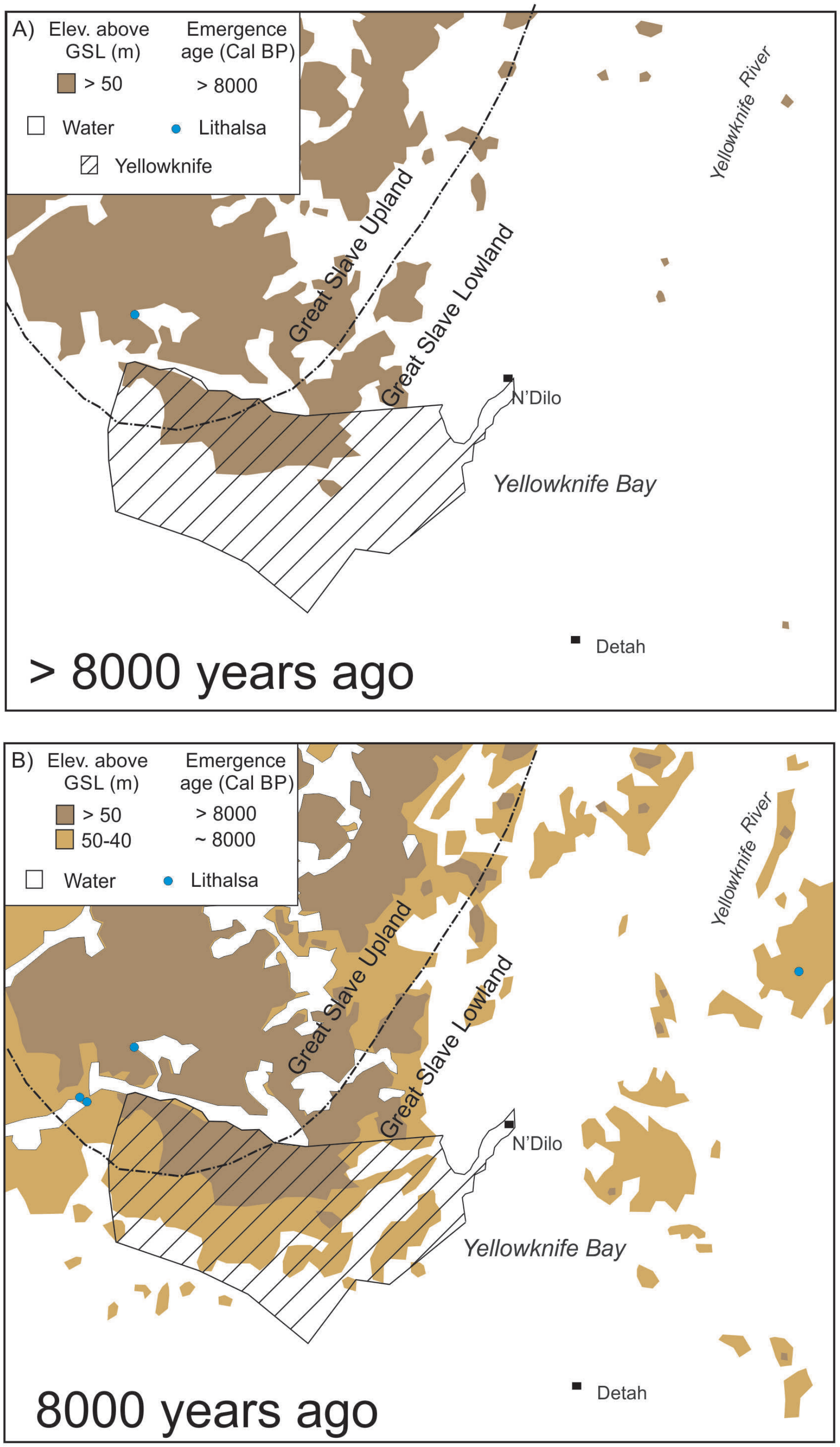


Figure 33. Changing shorelines of Yellowknife Bay from past to present. A) Shoreline when water levels were 50 m above present; B) shoreline when water levels were 40 – 50 m above present, more than 8000 years ago.

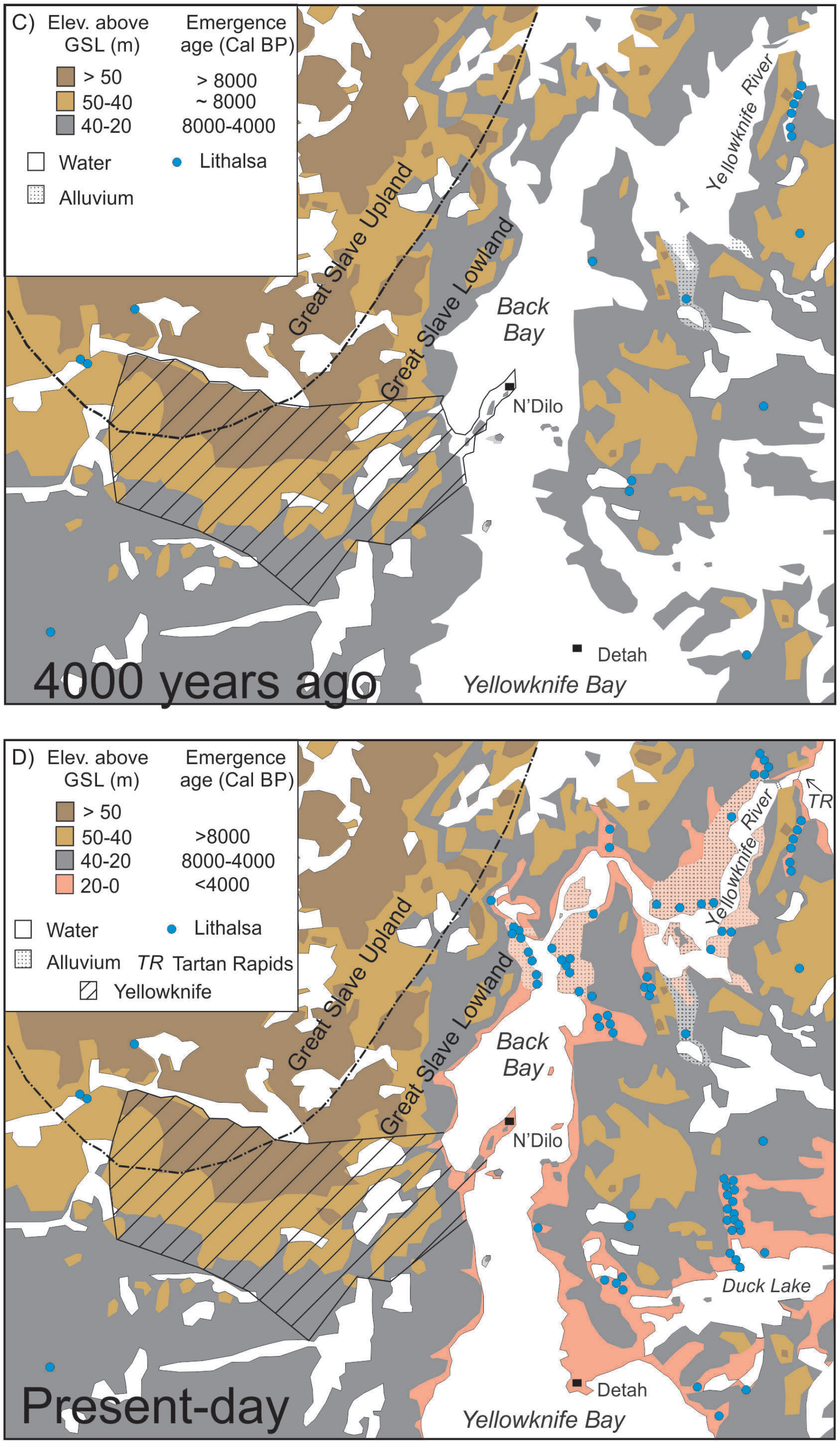


Figure 33 (continued). Changing shorelines of Yellowknife Bay from past to present. C) Shoreline between 8000 and 4000 years ago; D) Shoreline between 4000 years ago and today.

YELLOWKNIFE CITY STOPS

8. The Capital Site – disappearing peatlands

The area around the Legislative Assembly and Prince of Wales Heritage Centre is called the Capital Site. A large peat plateau is located in the centre of a road loop around these sites. The peatland is about 250 m long, 150 m wide, and it is bordered by bedrock to the north, west, and south (Figure 34). Permafrost is present under the insulating peat cover in ice-rich silty clay, underlain by a sandy silt containing little or no ice. The mineral sediments were deposited when the area was inundated by Glacial Lake McConnell and later, ancestral Great Slave Lake.

Figure 34. Google Earth images of the Capital Site area in 2004 and 2012, showing the degradation of peatland and increase in ponded water and trees in the area.

In the early 1950s, much of the southwest portion of the plateau was stripped of the upper layer of peat in an unsuccessful attempt to create a market garden. The surface disturbance accelerated the thawing of underlying ice-rich permafrost, causing a series of ponds up to 1.5 m deep to develop. Depressions in the peatland surface have also formed near the Legislative Assembly indicating that the permafrost is thawing at these locations.

Construction of a roadway to access the Prince of Wales Heritage Centre first began in the 1980s. A gravel road and parking lot were completed in 1993 with the opening of the Legislative Assembly. The road was constructed by laying gravel on fabric placed on top of the peat to protect the underlying organic material. Boreholes drilled beneath the roadway in August 1996 confirmed permafrost to a depth of more than 10 m and that clays in the top 5 m contain up to 50% visible ice (Figure 35). The temperature of the permafrost in the boreholes was up to -0.1 °C indicating that the materials were thawing, however the base remained frozen and no significant settlement had yet occurred along the roadway.

In summer 1997 the roadway was paved and several mitigations were implemented to inhibit permafrost thaw. Prior to paving, a section of the gravel road surface was removed and rigid Styrofoam insulation was laid within the gravel roadbed above the peat. The insulation layer was added to maintain permafrost within the peat layer for 10 to 15 years, delaying the thaw of underlying ice-rich clays. However, by 2010 the road had settled by up to 50 cm in some sections and required repair and re-paving in 2012. Settlement continues along this road as the underlying ice-rich permafrost thaws and materials consolidate.

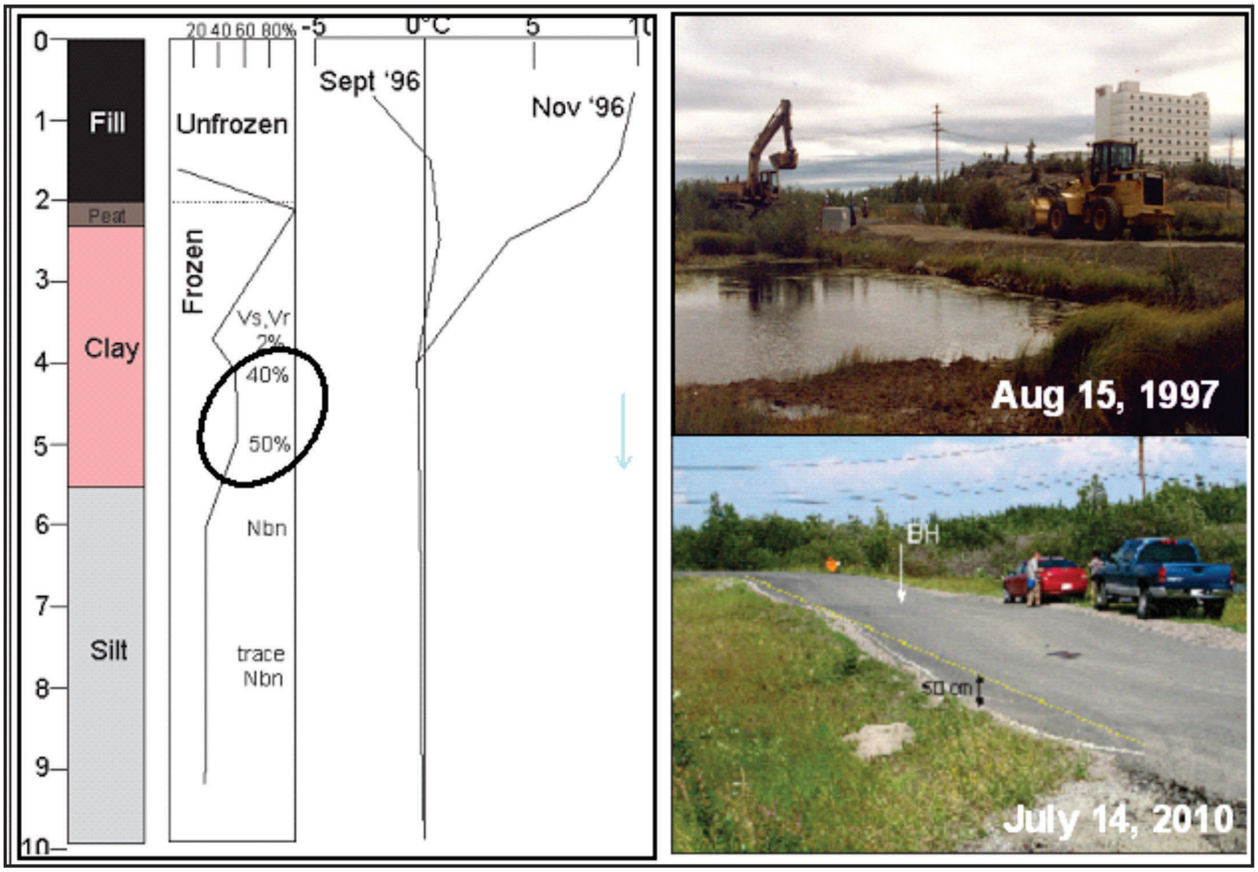


Figure 35. A borehole drilled in 1997 shows frozen ice-rich clays with percent (%) visible ice beneath the access road to the Prince of Wales Heritage Centre. The road was insulated and paved in 1997 and by 2010 had settled by up to 50 cm. Driving the road today illustrates that settlement continues and that ongoing maintenance will be required.

9. Sombe K'e Park – ancient beach beneath our feet

When traveling between the Legislative Assembly and Sombe K'e Park, changes occur in the materials that are beneath your feet. The underlying sediments at the Legislative Assembly are comprised of lake-deposited silts and clays, but these change to outwash-deposited sands and gravels (Figure 36). The ancient sands were deposited by glacial meltwaters more than 10 000 years ago along the what is today the eastern shore of Frame Lake and the downtown area. These sediments remained submerged beneath ancestral Great Slave Lake until the shoreline receded about 7000 years ago. At that time, wave action reworked the sands into a beach – the perfect place for a summer picnic!

Figure 36. An ancient beach deposited by glacial meltwater lies beneath the waterfront at City Hall, creating a stable platform for construction.

10. Downtown Yellowknife- safe on sand

These permafrost-free sandy materials also provided an area of stable terrain to build the "New Town" of Yellowknife, which by 1945 had to expand to accommodate the influx of people, industry and government in this rapidly growing gold mining town (Figure 37). The flat sandy plain was easy to build on and contained only a few patches of frozen ground because thin surface organic cover and sandy soils are not conducive to permafrost formation in the Great Slave Lowland. Prior to the development of New Town, this area supported scattered black and white spruce, Jack pine, birch, and poplar trees, similar to other permafrost free areas around Yellowknife.

Figure 37. Downtown Yellowknife in August, 1949.

11. Fritz Theil baseball diamonds – from pond to park

Fritz Theil baseball diamonds and park are nestled between Franklin Avenue, the neighborhood of "Willow Flats" on Back Bay and a large outcrop where the Yellowknife Racquet Club is now located. Originally, this field was the location of a large pond and wetland just slightly above the present-day elevation of Great Slave Lake (Figure 38). From the mid-1940s to the 1950s, it was used as the main dump site for Old Town. Later, it became a trailer park until the site was cleared for the baseball diamonds.

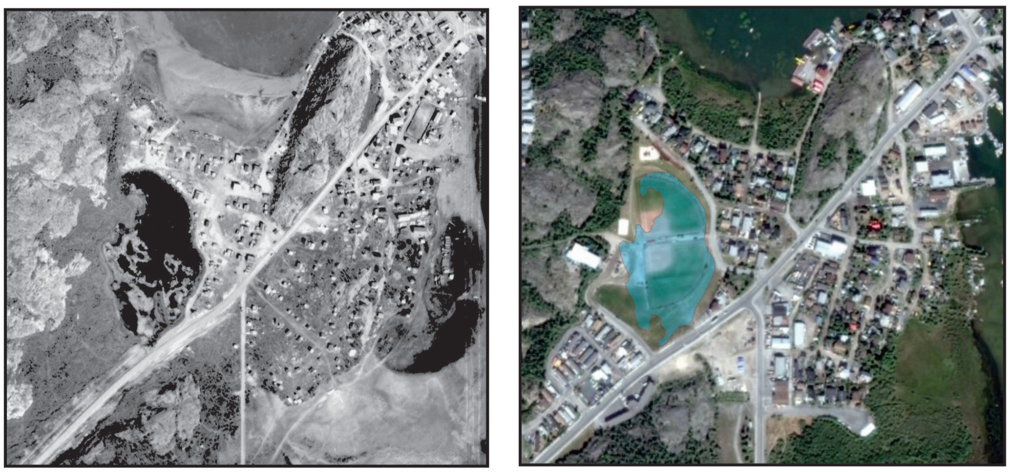


Figure 38. A 1946 airphoto and 2013 Google Earth image showing changes to the Fritz Theil park area.

Ground at the baseball diamonds is stable because permafrost did not exist beneath the former pond, but subsidence and instability characterize terrain around the perimeter of the old pond on Franklin Avenue and on Stout Road caused by thaw of ice-rich clay underlying these poorly-drained areas (Figure 39).

Figure 39. Fritz Thiel Park. A) The fence line indicates subsidence and surface movement. B) Infilling of subsided terrain and repair of the road embankment and fence on Stout Road.

12. Pilots Monument – a geological review

The City of Yellowknife is situated on the Precambrian Shield on the north shore of Great Slave Lake. Great Slave lake level is at an elevation about 156 m asl (Figure 40). The local relief across the city is about 50 m. The terrain consists mainly of bare rocky outcrops, and as discussed earlier in this report, glacial, lake, river and organic deposits are scattered across the area. Marshes, fens, peat bogs, and small lakes occupy many of the basins and valleys.

Bedrock geology

The bedrock in the region is part of the Canadian Shield, the stable cratonic core that underlies almost two thirds of Canada. Yellowknife straddles two main bedrock types generally referred to as granitic and volcanic. Most of the rocks around Yellowknife are about 2.5 to 2.7 billion years old. Massive granite occurs to the north and west, and dark-coloured volcanic rocks and less abundant sedimentary rocks are found in the downtown area and along Yellowknife Bay. Several major fault lines divide the granitic rocks from the older volcanic rocks, such as the Kam Lake Fault and West Bay Fault that run through Yellowknife. Throughout the area, younger igneous rocks have intruded along weaker planes in both main bedrock types.

Figure 40. View of Yellowknife Bay from Pilot’s Monument.

The bedrock geology has played a significant role in Yellowknife's economic history. Gold was discovered in 1898 along the mouth of the Yellowknife River. The Yellowknife volcanic rocks host the gold that was mined at both the Con and Giant mines. West of Kam Lake, the granite bedrock contains joints and fractures that provide good crushed rock for construction material.

Surficial Geology

The Yellowknife region has been subject to numerous periods of glaciation that have shaped the bedrock surface. During the most recent glaciation, the Laurentide Ice Sheet advanced to the southwest and retreated to the northeast. This period of glaciation reached a maximum approximately 20 000 years ago during the Late Wisconsinan when most of Canada was covered by ice.

The legacy of glaciation is most clear in the striations, polished surfaces, grooves, and whalebacks imprinted on the ancient bedrock surfaces throughout town and in the surrounding area, including at Pilots Monument. These features left by the erosional power of the ice sheet indicate the general northeast direction of ice movement.

During glaciation, the weight of glacial ice depressed the land surface near Yellowknife by up to 130 m. As the ice receded, the newly exposed land to the west rebounded upwards while the area to the east remained depressed. Near the end the last glaciation about 13 000 years ago, meltwater was released in enormous volumes from the ice sheets and surged through the region, depositing sand and gravel.

As these sandy plains were deposited, Glacial Lake McConnell began to form. The size of Lake McConnell rapidly increased and the Yellowknife area was inundated by up to about 160 m of water. During this period, lake silts and clays were deposited in the topographic lows that formed deep-water basins. These sediments are distributed in low-lying areas within Yellowknife including Willow Flats, where they pose challenges to construction and maintenance of infrastructure because they typically host warm, ice-rich permafrost. At higher elevation, wave action reworked sandy sediments into beaches such as in downtown Yellowknife and Frame Lake South. As you stand on top of Pilots Monument, imagine yourself at the bottom of an enormous lake. At its greatest extent, Glacial Lake McConnell was more than 1000 kilometres long and larger than any freshwater lake in existence today.

SUMMARY

This field guide describes the intimate relationship between glacial history and permafrost conditions of the Yellowknife area. In this region, the distribution of permafrost and ground ice is associated with a cold subarctic climate, patterns of vegetation cover and deposits of fine-grained sediments in low-lying areas between intervening bedrock outcrops. Significant changes have occurred over the last 10 000 years including deglaciation, development and recession of glacial Lake McConnell and the associated deposition of sands and fine-grained sediments throughout the region. The more recent changes have involved uplift of the land, gradual lowering of lake levels and alteration of drainage patterns that have resulted in the exposure of bedrock outcrops and lake sediments. The cold climate and subarctic forest cover has favoured the development of permafrost and ground ice in emergent terrain underlain by fine-grained deposits. Despite variation in climate over the past 10 000 years, the Yellowknife region currently resides near the southern limit of permafrost within forested lowland areas. More recent and rapid anthropogenic climate warming is placing new stresses on permafrost and the environment. Increasing air temperatures and changes to precipitation patterns are altering surface and ground water conditions, increasing frequency of forest fire and causing permafrost loss in many areas. These changes are inducing a cascade of terrain, ecological and societal impacts. In built environments, mitigating the effects of climate change and permafrost thaw are increasingly a focal point of planning, maintenance, and management efforts. Techniques to slow the rate of permafrost loss, and others that attempt to preserve it have been implemented in the Yellowknife area over the past several decades. Knowledge of permafrost conditions and projected patterns and rates of change are now critical for infrastructure planning and developing adaption strategies to increase resilience of northern society. For the Great Slave Lowland region, development and adaptation planning must consider degradation of ice-rich permafrost areas as this subarctic landscape with extensive discontinuous permafrost transitions to a region of sporadic permafrost with more extensive areas of seasonally frozen terrain.

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