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A ground ice atlas of Canada

S.A. Wolfe, H.B. O'Neill, and C. Duchesne

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Canada

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

Abstract

This Open File summarizes ground ice information from 31 sites across the permafrost regions in Canada. The poster presents a map with photographs from each site, and estimates of ground ice abundance from segregated, wedge, and relict ice in top 5 m of permafrost, derived from national-scale mapping by O'Neill et al. (2019; 2020). The sites represent a range of environmental conditions (climate, surficial geology, geological history, vegetation) spanning the continuous and discontinuous permafrost zones in Canada. The report in the Open File provides detailed site descriptions, comments on the modelled ground ice abundance compared to observations of ground ice from the area, the implications of ground ice conditions for thaw processes (thermokarst), and references to key literature. The atlas illustrates the varied ground ice conditions in northern Canada and the associated environmental conditions that control ice type and abundance. Furthermore, the atlas serves as a means to validate and improve recent national-scale ground ice mapping by identifying conditions not well represented by the modelling. This validation has highlighted that an updated national surficial geology dataset that incorporates the latest large-scale GSC mapping would improve the model outputs in many areas by more accurately depicting the distribution of frost-susceptible sediments.

Disclaimer

Publications associated with this Open File

The references below form the basis of the modelled ground ice information within this atlas. The first describes the modelling methodology for each ground ice type, and the second describes the combined map and volumetric ground ice estimates.

O'Neill, H.B., Wolfe, S.A., and Duchesne, C., 2019. New ground ice maps for Canada using a paleogeographic modelling approach. The Cryosphere 13, 753–773. https://doi.org/10.5194/tc-13-753-2019

O'Neill, H.B., Wolfe, S.A., and Duchesne, C. 2020. Ground ice map of Canada; Geological Survey of Canada, Open File 8713, 7 p. https://doi.org/10.4095/326885

Files included in this Open File

OF8770_Poster.pdf – *Wall map/poster*
OF8770_Text.pdf – *Open File report (this document)*
OF8770_Readme.rtf– *Publication information*

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The Atlas

Permafrost, also called perennially-frozen ground, is ground that remains at or below 0 °C for at least two consecutive years. In addition to temperature, the distribution and abundance of ground ice strongly controls the physical properties of permafrost. Many features and landforms in permafrost areas owe their existence to the occurrence of ground ice, formed by a variety of processes. The nature and extent of thaw processes (thermokarst) in ice-rich permafrost terrain are also controlled by ground ice type and abundance. Therefore, knowledge of ground ice is required to ensure robust construction practices, and to implement appropriate adaptation measures to mitigate impacts associated with the thaw of ice-rich permafrost. Information on ground ice is also important for understanding the geomorphic and environmental changes resulting from climate change.

The purpose of this atlas is to provide information on ground ice types and abundance in 31 locations in northern Canada. The locations were chosen to represent a range of ground ice conditions across the continuous and discontinuous permafrost zones, and in many cases are areas where previous permafrost research has occurred. The atlas allows a comparison between observed and modelled ground ice conditions from The Ground ice map of Canada for each area (O'Neill et al. 2019, 2020).

The atlas entries include the location, modelled ground ice conditions, a detailed site description, comments on modelled versus observed ground ice conditions, thermokarst implications, and references to supporting literature. Site descriptions typically include the bedrock and surficial geology, a brief Late Quaternary environmental history, vegetation information, permafrost and climatic conditions including, where possible, the active-layer thickness, mean annual air temperature (MAAT), mean annual precipitation (MAP), and mean annual ground temperature (MAGT), and observed ground ice types. MAAT and MAP are reported for the 1981-2010 period from the nearest Environment Canada weather station where possible, and otherwise are from the cited literature. A brief section on thermokarst implications provides insight into the nature of observed thaw processes in the area, and potential for future changes relating to ground ice melt, which is valuable for both infrastructure planning and understanding the environmental consequences of thawing permafrost.

Legends

Symbols in the photographs for each site represent the modelled abundance of relict ice, segregated ice, and wedge ice in the area (Figure 1). The legend under the central map on the poster defines the combined volumetric percentage of excess ice in the top 5 m of permafrost from all ice types (Figure 2), which is also represented by the coloured border around each photograph.

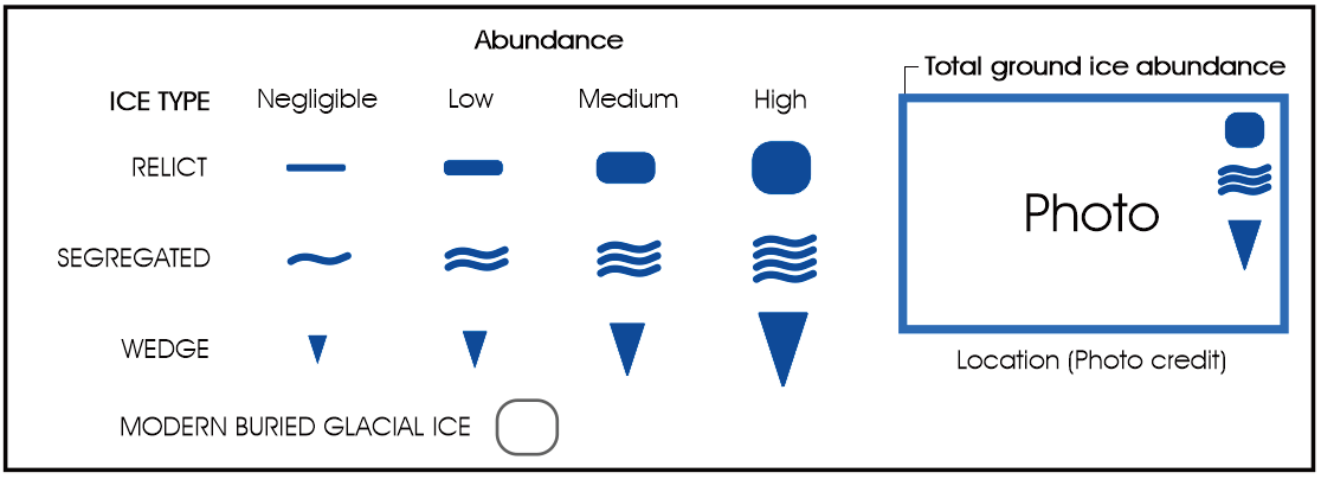


Figure 1. Legend indicating ground ice type and relative abundance depicted in photographic examples.

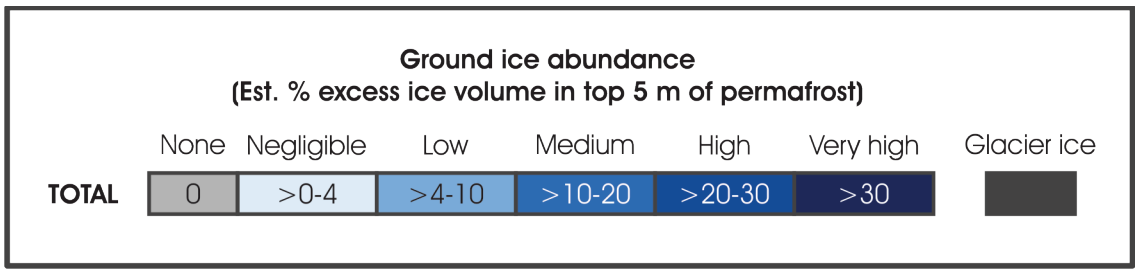
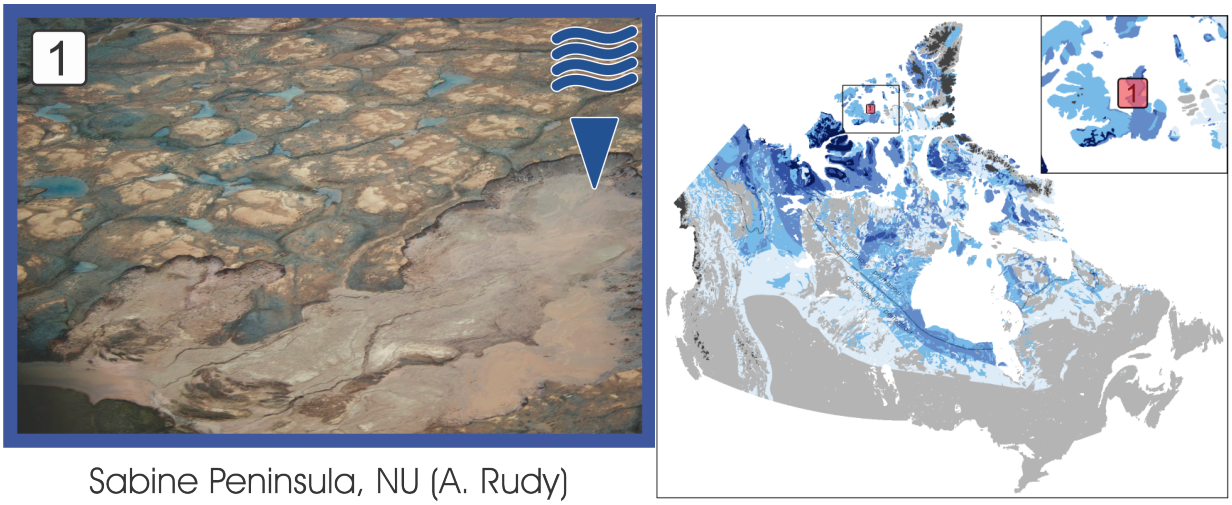


Figure 2. Legend for estimated combined volumetric percentage of excess ice in the top 5 m of permafrost from all ice types

1. Sabine Peninsula, NU



Sabine Peninsula, NU (A. Rudy)

Figure 3. Sabine Peninsula, Melville Island, Nunavut. Left panel) Photo showing shallow slumps and ponding of ice-wedge terrain. Photograph courtesy of A. Rudy. Right panel) Inset map showing site location at 76.4883°N; -108.6563°W.

Modelled ground ice abundance: no relict ice; high segregated ice; medium wedge ice

Description: Sabine Peninsula is on northeastern Melville Island in the Canadian Arctic Archipelago. Parent materials consist of Devonian clastic bedrock (sandstone, siltstone, and shale), weathered silt, or gravelly silt. The area underwent post-glacial marine submergence and Holocene sea level recession. Surficial sediments include silt and clay marine sediments in previously-inundated areas, deltaic and alluvial sands, and silty, sandy, and gravelly colluvium. Few climate data exist, but short-term mean annual air temperature (MAAT) at Mould Bay, 275 km to the west, is -17.3 °C. Vegetation cover is a well-to-poorly vegetated herb tundra characteristic of a high arctic polar desert. Permafrost is continuous and estimated to be more than 500 m thick, with active-layer thicknesses typically 60-80 cm but as thin as 20 cm. Mean annual ground temperature (MAGT) has been measured at about -17 °C. Excess ice typically ranges between 30-70 % by volume in the top 2 m of permafrost, consisting primarily of pore ice and segregated ice. Well-developed ice wedge polygons are clearly visible in satellite imagery in areas with fine-grained deposits.

Comments on modelled versus observed ice: All ground ice abundances appear to be modelled well. The high segregated ice and the absence of relict ice are appropriate given the prior marine inundation and frost-susceptible sediments. Wedge ice modelling appears reasonable given the surficial materials, age of surface exposure, and cold climatic regime.

Thermokarst implications: Despite the cold continuous permafrost, this area includes significant thermokarst features in the form of active-layer detachments, shallow thaw slumps, ice wedge gullying, and melt ponds. Due to the thin active layer and limited vegetation cover, it is susceptible to future thermokarst induced by warming air temperatures.

References: French, H.M., Bennett, L. and Hayley, D.W. 1986. Ground ice conditions near Rea Point and on Sabine Peninsula, eastern Melville Island. *Can. J. Earth Sci.* 23, pp. 1389-1400.
Rudy, A.C., Lamoureux, S.F., Treitz, P., Ewijk, K.V., Bonnaventure, P.P. and Budkewitsch, P. 2017. Terrain Controls and Landscape-Scale Susceptibility Modelling of Active-Layer Detachments, Sabine Peninsula, Melville Island, Nunavut. *Perm. Peri. Proc.* 28, pp. 79-91.

2. Eastern Banks Island

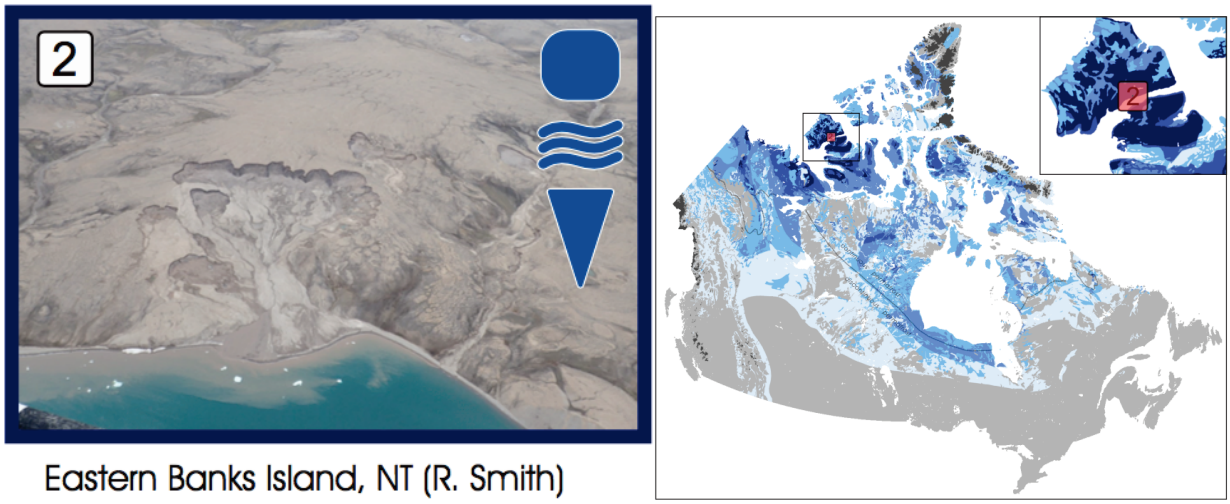


Figure 4. Eastern Banks Island, Nunavut. Left panel) Photo showing deep slumps and sediment discharge into ocean. NRCan photo 2020-069 by R. Smith. Right panel) Inset map showing site location at 73.0132°N; -117.5945°W.

Modelled ground ice abundance: high relict ice; medium segregated ice; high wedge ice

Description: This area on eastern Banks Island consists of hummocky terrain of the Jesse Moraine. Underlying geology constitutes middle to upper Devonian stratified bedrock. Surficial sediments are primarily till blanket (known to be ice cored), and glaciofluvial or glaciodeltaic sediments. Local elevations of <80 m asl underwent Holocene marine inundation following deglaciation and may include surficial marine sediments. Vegetation cover is well-to-poorly vegetated herb tundra within this low arctic polar desert. Permafrost is continuous, with MAAT about -13 to -14 °C, MAP of about 141 to 200 mm, MAGT from -10 to <-12 °C, and active-layer thicknesses of 50 to >70 cm. Observations indicate high abundance of relict ice (buried glacial) ice and wedge ice.

Comments on modelled versus observed ice: Relict ice appears to be modelled well, owing to the preserved glacial ice in the till moraine. The high modelled abundance of wedge ice also appears reasonable given the observed high abundance and large size of wedges. The medium segregated ice is appropriate in areas with finer-grained till, but may be underestimated in some areas as marine inundation and associated sediments are likely not fully accounted for in this area in the national-scale modelling.

Thermokarst implications: Widespread thaw slumping, ice-wedge gullying, ponding, and surface involutions highlight significant active thermokarst processes in the area. With high relict and wedge ice abundance near the permafrost table, the area is also highly susceptible to future thermokarst processes stemming from climate change.

References: Fraser, R.H., Kokelj, S.V., Lantz, T.C., McFarlane-Winchester, M., Olthof, I. and Lacelle, D., 2018. Climate sensitivity of high Arctic permafrost terrain demonstrated by widespread ice-wedge thermokarst on Banks Island. *Remote Sensing*, 10(6), p. 954.
Segal, R.A., Lantz, T.C. and Kokelj, S.V., 2016. Acceleration of thaw slump activity in glaciated landscapes of the Western Canadian Arctic. *Environmental Research Letters,* 11(3), p. 034025.

3. Sachs Harbour, NT

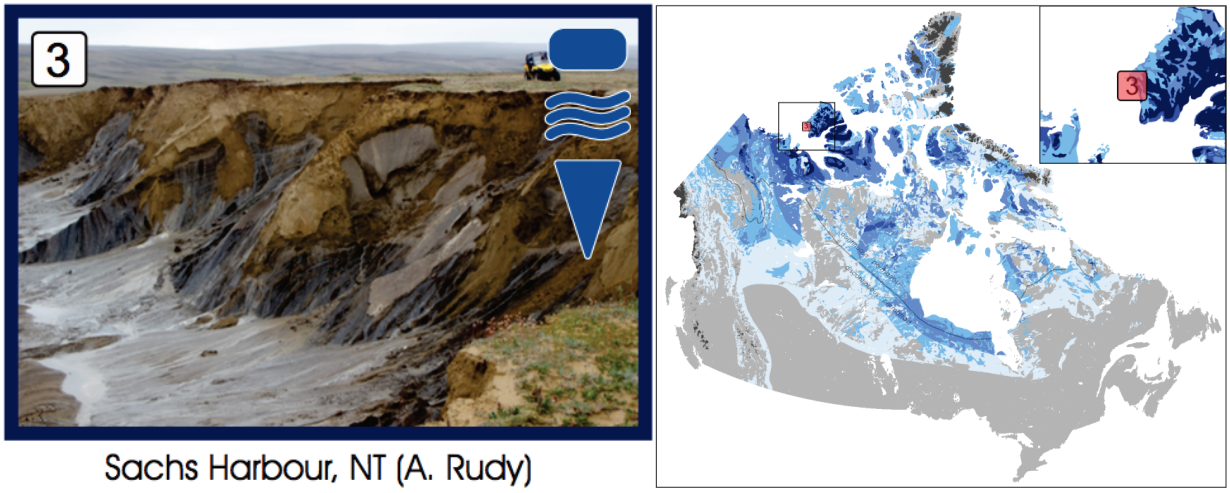


Figure 5. Sachs Harbour, Nunavut. Left panel) Photo showing slumping in Sandhills Moraine. Photograph courtesy of A. Rudy. Right panel) Inset map showing site location at 71.9855°N; -125.2466°W.

Modelled ground ice abundance: medium relict ice; medium segregated ice; high wedge ice

Description: Located on the Sandhills Moraine southwest of the community of Sachs Harbour, NT, the area is underlain by Neogene and Cretaceous stratified bedrock. It is a well-developed lateral moraine deposited during the Sandhills Readvance phase of the late Wisconsinan retreat of Amundsen ice from its maximum limit. The moraine is composed of silty-clay till with numerous large boulders and cobbles and foliated massive ice and icy sediments interpreted to be of buried glacier ice origin. Overlying sediments include diamicton, stratified outwash sand, and ice-contact deposits. Sand wedges and ventifacts that post-date glacial sediments are also observed in sections. An early Holocene thaw unconformity is present. Vegetation cover is herb tundra. Permafrost is continuous, with MAAT about -13 to 14 °C, MAP about 141 to 200 mm, MAGT <-10 °C, and active-layer thicknesses of 30 to 50 cm. Observed relict ice abundance is high and ice wedge polygons are observed on the surface.

Comments on modelled versus observed ice: The abundance of all ground ice types appears to be modelled reasonably. Medium relict ice reflects buried ice within moraine deposits, reduced by effects of early Holocene thaw into upper permafrost. Segregated ice appears to be present, though the extent and abundance is not well verified by field measurements. The high modelled wedge ice abundance is reasonable given the sediments and long time period of exposure to cold conditions.

Thermokarst Implications: Present-day thermokarst activity includes thaw slumps, gullying from thawing of ice wedges, and drained lakes. The potential for increased thermokarst activity due to climate warming is high.

References: French, H.M. and Harry, D.G. 1988. Nature and origin of ground ice, Sandhills Moraine, southwest Banks Island, western Canadian Arctic. *J. Quat. Sci.*, 3, pp. 19-30.
Worsley, P. 1999. Context of relict Wisconsinan glacial ice at Angus Lake, SW Banks Island, western Canadian Arctic and stratigraphic implications. *Boreas*, 28, pp. 543-550.

4. Herschel Island, YK

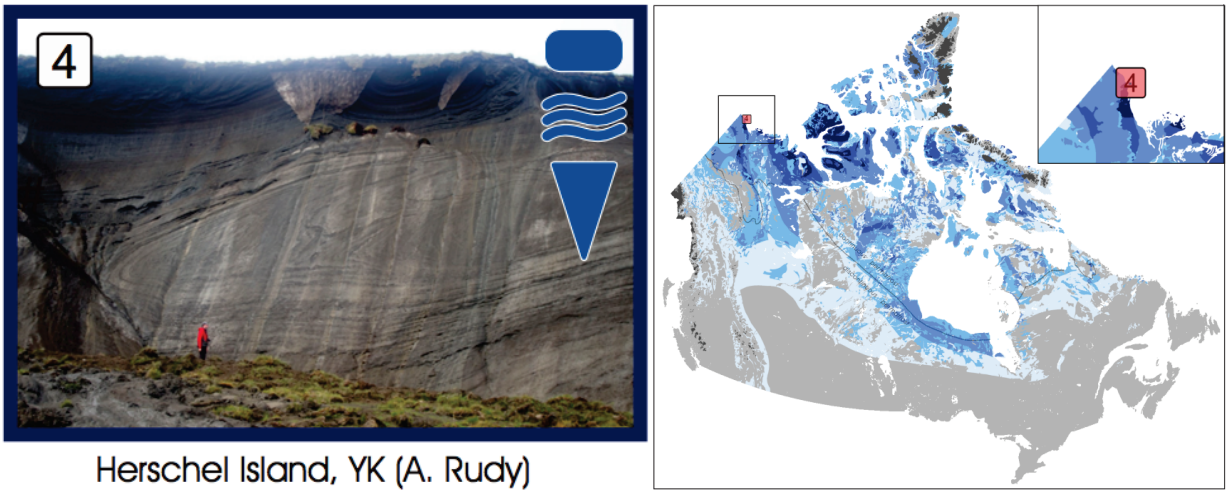


Figure 6. Hershel Island (Qikiqtaruk), Yukon. Left panel) Photo showing exposure of deformed relict ice and ice wedges in a deep slump headwall. Photograph courtesy of A. Rudy. Right panel) Inset map showing site location at 69.5662°N; -139.1464°W.

Modelled ground ice abundance: medium relict ice; medium segregated ice; high wedge ice

Description: Herschel Island, in the southern Beaufort Sea, is approximately 100 km^2 with a maximum elevation of 50 m. It is considered a push moraine at the northwestern-most limit of the Laurentide Ice Sheet with thick sequences of stacked Quaternary-age deposits. Surficial material is primarily glacial diamicton, and underlying sediments consist of ice-thrusted unconsolidated marine and mixed terrestrial deposits. Ground ice may constitute >50% by volume of near-surface permafrost and is composed primarily of deformed basal-regelation ice of glacial origin or segregation-intrusive ice. Wedge ice from multiple time periods is also present. The island is well vegetated by shrub tundra. MAAT is about -10 °C and MAP is about 161 mm (at Komakuk Beach). Permafrost is continuous and the MAGT is about -8.0 °C. Measured active-layer thicknesses are about 55 cm.

Comments on modelled versus observed ice: All ground ice types appear to be modelled well as all ice types are present in the area. Relict and/or segregated ground ice may be underestimated as abundance could be high within the push moraine deposits.

Thermokarst implications: Thermokarst activity includes numerous large thaw slumps and active-layer detachment slides. Coastal erosion of unconsolidated permafrost sediments is also ubiquitous. The area is highly susceptible to future thermokarst processes due to climate warming, and likely enhanced by coastal erosion processes.

References: Burn, C.R. and Zhang, Y., 2009. Permafrost and climate change at Herschel Island (Qikiqtaruq), Yukon Territory, Canada. *J. Geophys. Res.: Earth Surface* 114(F2).
Fritz, M., Wetterich, S., Meyer, H., Schirrmeister, L., Lantuit, H. and Pollard, W.H. 2011. Origin and characteristics of massive ground ice on Herschel Island (western Canadian Arctic) as revealed by stable water isotope and hydrochemical signatures. *Perma. Peri. Pro.*, 22, pp. 26-38.
Pollard W.H. 1990. The nature and origin of ground ice in the Herschel Island area, Yukon Territory. In: *Proceedings, Fifth Canadian Permafrost Conference,* Québec, pp. 23-30.

5. Old Crow Flats, YK

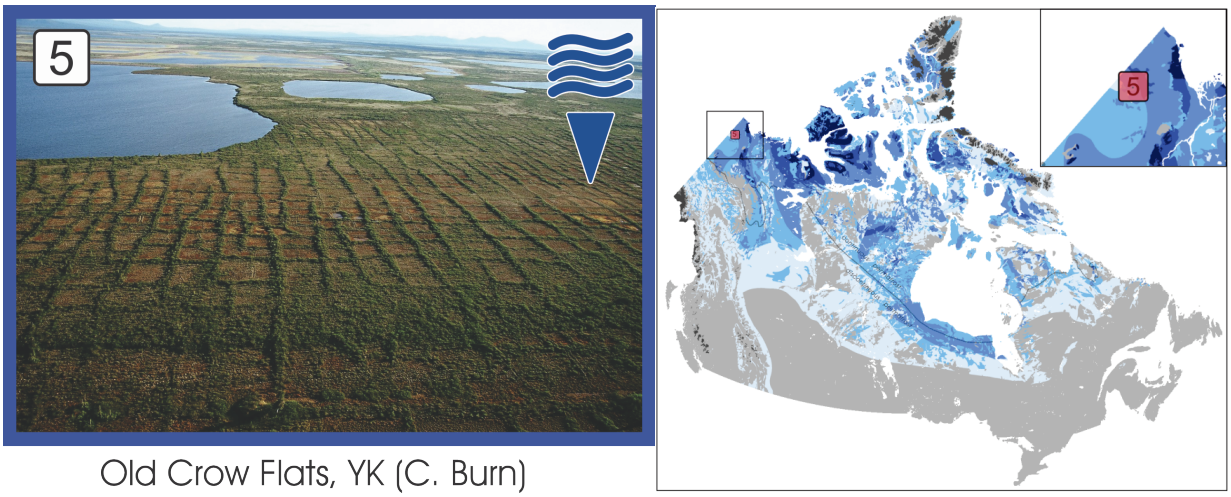


Figure 7. Old Crow Flats (Van Tat K'atr'anahtii), Yukon Territory. Left panel) Photo showing ice wedge polygons and thaw-lake terrain. Photograph courtesy of C. Burn. Right panel) Inset map showing site location at 68.2200°N; -140.1758°W.

Modelled ground ice abundance: no relict ice; high segregated ice; medium wedge ice

Description: Old Crow Flats is a 5600 km^2 glaciolacustrine plain in the northern Yukon forest-tundra ecozone. It was unglaciated in the Wisconsinan, and Laurentide ice meltwater flooded the basin to form Glacial Lake Old Crow, depositing up to 10 m of silty-clay sediments. The lake drained between 14 – 12000 yr BP, and permafrost aggraded subsequently. The flats contain over 2700 oriented lakes, many with rectilinear shorelines oriented either NE-SW or NW-SE. Vegetation varies from open tundra with shrub patches to open spruce shrubland. MAAT for Old Crow Flats is about -9 °C (1971–2000). MAP is 265 mm, about half falling as snow. MAGT varies between -5.1 °C beneath low shrubs and -2.6 °C beneath tall shrubs. Permafrost is continuous, and occurs everywhere except perhaps beneath lakes deeper than 4 m and within deep river sections. Active-layer thickness ranges between 30 and 60 cm, and permafrost is about 60 m thick. High and low centred ice-wedge polygons occur in tundra areas, but wedges are less common in open spruce shrubland, and absent in forested areas. Lake expansion occurs through erosion by high water levels, wind-induced wave action and ice push and thaw of ice-wedge networks.

Comments on modelled versus observed ice: The modelled absence of relict ice is appropriate due to the past inundation by Glacial Lake Old Crow. The high modelled segregated ice abundance is reasonable given the fine-grained glaciolacustrine sediments, and presence of thaw lakes even in areas without ice-wedge polygons. Modelled wedge ice abundance seems appropriate for tundra settings.

Thermokarst Implications: Melting of segregated ice and wedge ice is a main contributor to lake expansion, and thaw lake development is not restricted to areas with ice-wedge polygons. Thaw slumps are also common along river bluffs. Subsidence, lake expansion, and minor slumping will likely persist with longer open-water conditions, thickening of the active layer, and talik formation.

References: Labrecque, S., Lacelle, D., Duguay, C.R., Lauriol, B. and Hawkings, J., 2009. Contemporary (1951-2001) evolution of lakes in the Old Crow Basin, Northern Yukon, Canada: Remote sensing, numerical modeling, and stable isotope analysis. *Arctic,* pp. 225-238.
Roy-Léveillée, P., Burn, C.R. and McDonald, I.D., 2014. Vegetation-permafrost relations within the forest-tundra ecotone near Old Crow, Northern Yukon, Canada. Perm. Peri. Pro., 25, 127-135.
Roy-Léveillée P & Burn CR. Permafrost conditions near shorelines of oriented lakes in Old Crow Flats, Yukon Territory. In: *Proceedings of GEO 2010* Sep 12, pp. 1509-1516.

6. Yukon Coastal Plain, YK/NT

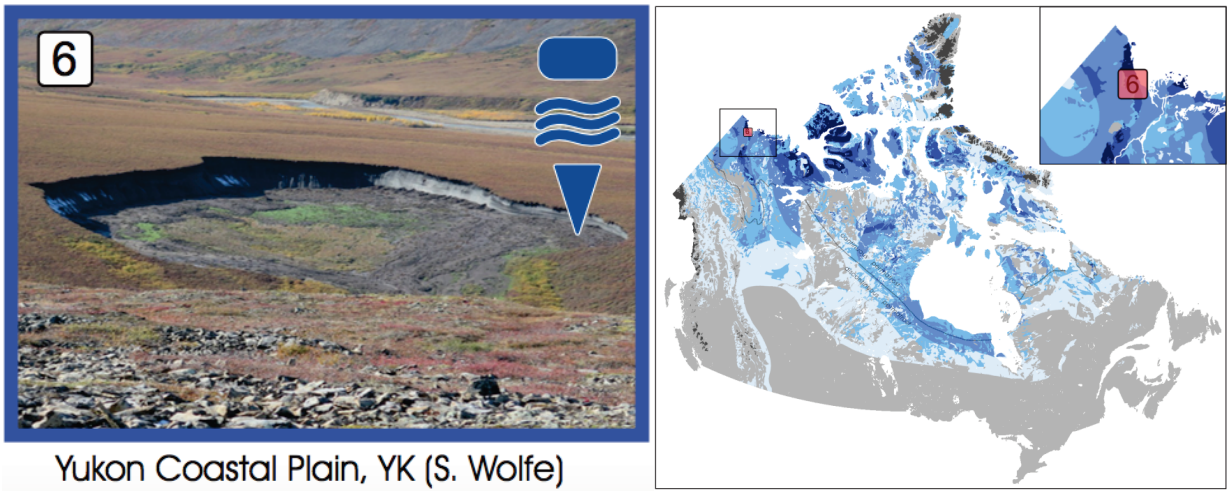


Figure 8. Yukon Coastal Plain, Yukon Territory. Left panel) Photo showing slump in till terrain. NRCan photo 2020-073 by S. Wolfe. Right panel) Inset map showing site location at 68.7539°N; -137.3240°W.

Modelled ground ice abundance: medium relict ice; medium segregated ice; medium wedge ice

Description: Numerous exposures of ground ice occur within the westernmost glaciated terrain of northern Canada on the Yukon Coastal Plain adjacent to the Richardson Mountains, and along the Aklavik Plateau. The area 45 km west of Aklavik, NT is at an elevation of 457 m asl in ground moraine at the limit of the late-Wisconsinan Laurentide Ice Sheet, and typifies stratigraphy of the Yukon Coastal Plain. Sediment-rich ice is overlain by an icy silty-clay diamicton. An early Holocene thaw unconformity at about 2.5 m below the ground surface is common in exposures. Climate is continental sub-arctic and permafrost is continuous, ranging from 100 to 300 m thick. MAAT at Inuvik is about -8.5 °C. MAP is about 250 mm with about half falling as snow. Vegetation is shrub tundra. Ice-wedge polygons are well-expressed on moraine surfaces. Ice-rich sediments are abundant beneath moraine sediments, and may be of buried glacial or segregated origin. On the nearby Aklavik Plateau, Lacelle et al. (2004) considered undeformed debris-rich ice with suspended fine-grained sediments as segregated-intrusive ice formed during permafrost aggradation in a proglacial, semi-confined aquifer fed by Laurentide ice meltwater. In contrast, other exposures near the Late Wisconsinan limit likely include relict buried glacier ice.

Comments on modelled versus observed ice: Modelled abundance appears reasonable for all three ground ice types in this moraine terrain. The distribution of relict ice is likely irregular and varied in such settings, though no distributed observations of abundance exist from which to assess average conditions.

Thermokarst implications: Thermokarst activity includes thaw slumps with headwalls to 20 m high and active-layer detachment slides. Polygonal terrain with ponding in ice-wedge troughs is apparent in low-lying areas. The Holocene thaw unconformity may impede greater thermokarst activity at present, but could increase with continued climatic warming and erosion causing exposure of thick relict ice bodies.

References: Lacelle, D., Bjornson, J. and Lauriol, B., 2010. Climatic and geomorphic factors affecting contemporary (1950–2004) activity of retrogressive thaw slumps on the Aklavik Plateau, Richardson Mountains, NWT, Canada. *Perma. Peri. Pro.*, 21, pp. 1-15.
Lacelle, D., Bjornson, J., Lauriol, B., Clark, I.D. and Troutet, Y., 2004. Segregated-intrusive ice of subglacial meltwater origin in retrogressive thaw flow headwalls, Richardson Mountains, NWT, Canada. *Quat. Sci. Rev.*, 23, pp. 681-696.

7. Peel Plateau, NT

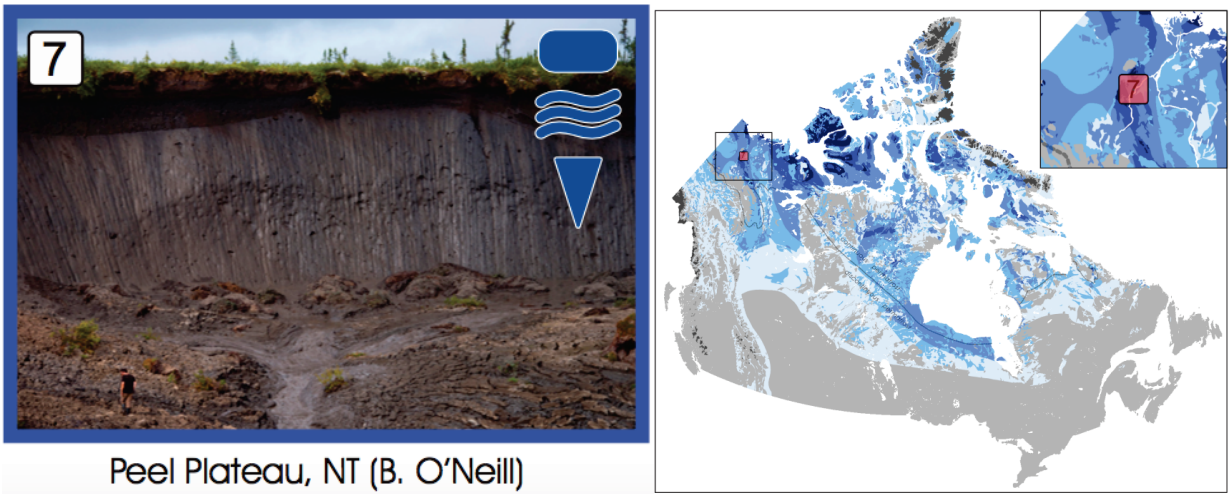


Figure 9. Peel Plateau, Northwest Territories. Left panel) Photo showing relict ice in a deep slump. NRCan photo 2020-074 by H.B. O'Neill. Right panel) Inset map showing site location at 67.2528°N; -135.2299°W.

Modelled ground ice abundance: medium relict ice; medium segregated ice; medium wedge ice

Description: Peel Plateau is a broad, eastward-sloping plateau with elevation ranging from 650 m asl in the Richardson Mountains to 100 m asl west of the Peel River, NT. The plateau consists of up to 60 m of glaciogenic materials, including hummocky moraine, glaciofluvial and glaciolacustrine sediments, which overly Cretaceous marine shales and siltstone. The area lies at the maximum extent of the Laurentide Ice Sheet (18000 yr BP), which extended to local elevations of about 750 m asl. Colluvium covers valley slopes and alluvium occupies the valley bottoms. The regional climate is continental. The MAAT at Fort McPherson is about -6.8 °C. MAP averages 295 mm, with rainfall accounting for approximately half (148 mm). Vegetation cover is open spruce woodlands in valley bottoms and south-facing slopes, transitioning to dwarf shrub and sub-Arctic tundra on the plateau. Permafrost is warm but continuous in the Richardson Mountains and Peel Plateau region, with MAGT about -2 °C below tundra and up to 125 m thick. Ground ice content in the uppermost 10 m of permafrost ranges from 50% by volume to tabular bodies of massive ground ice. Ice wedges are only apparent in small pockets where peat has accumulated.

Comments on modelled versus observed ice: Modelled abundance of relict and segregated ice are probably reasonable, but observations are limited. Medium to high relict ice abundance is likely, owing to hummocky moraine deposits and tabular ice. Ice wedge abundance is likely lower than modelled, as polygons are only apparent in peatlands, at least in the tundra areas surrounding the Dempster Highway.

Thermokarst implications: The high relief of the fluvially-incised, ice-rich landscape provides sufficient transport gradients to evacuate slumped materials, promoting the development of large "mega" slumps (5–40 ha) and debris tongue deposits. Whereas thick colluvial materials and vegetation provides thermal protection of underlying ground ice, thermokarst is promoted by incision of slopes. The area is very susceptible to increased erosion by thermokarst activity.

References: Kokelj, S.V., Lacelle, D., Lantz, T.C., Tunnicliffe, J., Malone, L., Clark, I.D. and Chin, K.S., 2013. Thawing of massive ground ice in mega slumps drives increases in stream sediment and solute flux across a range of watershed scales. *J. Geophys. Res.: Earth Surface*, 118, pp. 681-692. Lacelle, D., Brooker, A., Fraser, R.H. and Kokelj, S.V., 2015. Distribution and growth of thaw slumps in the Richardson Mountains–Peel Plateau region, northwestern Canada. *Geomorphology*, 235, 4 pp. 0-51.

8. North Head, NT

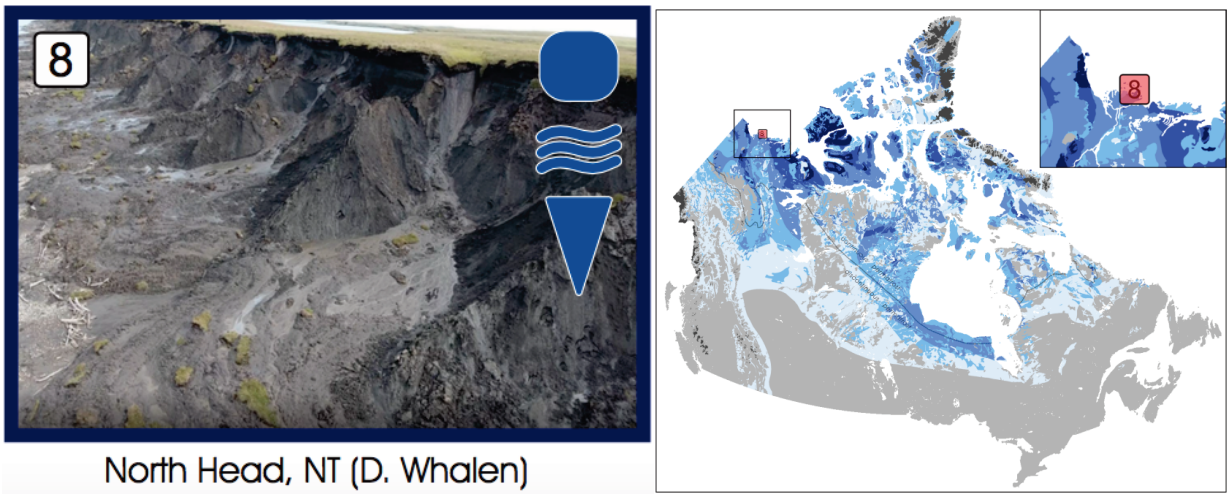


Figure 10. North Head, Richards Island, Northwest Territories. Left panel) Photo showing coastal erosion exposure of wedge ice and relict ice. NRCan photo 2020-075 by D. Whalen. Right panel) Inset map showing site location at 69.7134°N; -134.4866°W.

Modelled ground ice abundance: high relict ice; medium segregated ice; high wedge ice

Description: Northern Richards Island is generally rolling terrain with local relief of 10-30 m. Near-surface materials are mainly Quaternary-aged fluvial and eolian sands, glacial till, and glaciofluvial sands and lacustrine sediments. Shallow lakes and drained-lake basins comprise about 50% of the area. MAAT is -9 °C to -12 °C, and regional MAGTs are -6 °C to -10 °C. Local MAGT is about -8 °C and the active layer is up to 60 cm thick. Permafrost is continuous, extending to more than 700 m depth. Vegetation is low-arctic tundra, comprising sedge- and shrub-tundra. Massive ground ice at North Head includes glacially deformed or eroded ice from beneath the cold-based margin of the Laurentide Ice Sheet including buried basal ice, and massive segregated ice and ice clasts sub-glacially eroded from preexisting ground ice. Additional ground ice formed during or after deglaciation includes dykes and sills of intrusive ice, massive segregated-intrusive ice, ice wedges, segregated ice lenses and pool ice. Observed excess ice volumes are estimated at 9% for relict ice, 8-16% for segregated ice, and 6.5% for wedge ice. General estimates of excess ice on Richards Island are 9.2% for segregated ice, 12% for wedge ice, and 14.3% for all ice types.

Comments on modelled versus observed ice: Modelled abundances for all ice types appear reasonable in comparison to observed volumes, although all may vary between medium and high values.

Thermokarst implications: The area is susceptible to slumping, and to thermal and physical erosion by wave action along the Beaufort Sea Coast. Recent thickening of the active layer has induced thaw truncation of the top of ice wedges and increased the size of polygonal troughs.

References: Dallimore, S.R., Wolfe, S.A. and Solomon, S.M. 1996. Influence of ground ice and permafrost on coastal evolution, Richards Island, Beaufort Sea coast, NWT. *Can. J. Earth Sci.*, 33, pp. 664-675.
Kokelj, S.V., Lantz, T.C., Wolfe, S.A., Kanigan, J.C., Morse, P.D., Coutts, R., Molina-Giraldo, N. and Burn, C.R. 2014. Distribution and activity of ice wedges across the forest-tundra transition, western Arctic Canada. *J. Geophys. Res.: Earth Surface*, 119 pp. 2032-2047.
Murton, J.B. 2005. Ground-ice stratigraphy and formation at North Head, Tuktoyaktuk Coastlands, western Arctic Canada: a product of glacier–permafrost interactions. Perma. Periglca. Proc., 16(1), pp.31-50. Murton, J.B., 1996. Thermokarst-lake-basin sediments, Tuktoyaktuk Coastlands, western arctic Canada. Sedimentology, 43(4), pp. 737-760.
Pollard, W.H. and French, H.M. 1980. A first approximation of the volume of ground ice, Richards Island, Pleistocene Mackenzie Delta, Northwest Territories, *Canada. Can. Geotech. J.*, 17, pp. 509-516.

9. Husky Lakes, NT

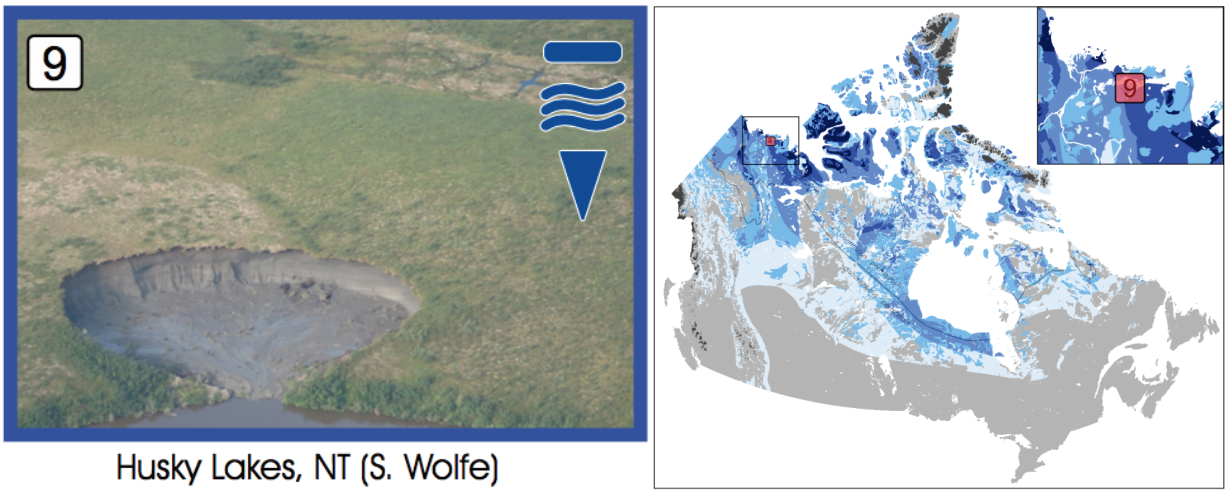


Figure 11. Husky Lakes (Imaryuk), Northwest Territories. Left panel) Photo showing slump exposing relict ice in till terrain. NRCan photo 2020-076 by S. Wolfe. Right panel) Inset map showing site location at 69.4576°N; -131.6323°W.

Modelled ground ice abundance: low relict ice; medium segregated ice; medium wedge ice

Description: Husky Lakes is a broad area east to southeast of Tuktoyaktuk, NT. Finger-like lakes and peninsulas characterize the area. MAAT is -9 °C to -12 °C, and regional MAGTs are -6 °C to -10 °C. Local MAGT is about -8 °C and the active layer is up to 60 cm. Vegetation is predominantly shrub tundra, with increasing density of spruce groves to the south. Permafrost is continuous. The area contains numerous slumps with ground ice exposures overlain by glacial diamicton, glaciolacustrine silts and clay, and outwash sands. Much of this ice is interpreted as basal glacier ice and deformed pre-glacial ice of segregation-injection origin. Undeformed segregation ice and injection ice is found in glaciolacustrine sediments as are isolated intrusive ice dykes. The area contains Holocene and pre-Holocene ice wedges. An early Holocene thaw unconformity at about 2.5 m below the ground surface is present in many exposures. Pingos are also common.

Comments on modelled versus observed ice: Comparison of modelled and observed ice is complicated by ice origin interpreations. Low modelled relict ice may be underestimated, as observations suggest higher abundance. However, much of this ice may be pre-glacial or formed as segregation-intrusive ice that was subsequently deformed, and these conditions are not accounted for in the modelling. Modelled relict ice abundance is reduced to low in the simulations due to biome changes and associated thaw during the Holocene, which is reasonable given the observed thaw unconformity. Medium modelled segregated ice abundance is reasonable given the frost-susceptibility of the till material. Wedge ice abundance appears reasonably modelled given the common occurrence of wedges in the region.

Thermokarst implications: The area is susceptible to thermokarst primarily via slumping. Wedge ice is susceptible to thaw truncation, which could form gullies on hillslopes or increased ponding in lowlands.

References: Kokelj, S.V., Lantz, T.C., Wolfe, S.A., Kanigan, J.C., Morse, P.D., Coutts, R., Molina-Giraldo, N. and Burn, C.R., 2014. Distribution and activity of ice wedges across the forest-tundra transition, western Arctic Canada. Journal of Geophysical Research: Earth Surface, 119(9), pp.2032-2047

Mackay, J.R. and Dallimore, S.R. 1992. Massive ice of the Tuktoyaktuk area, western Arctic coast, *Canada. Can. J. of Earth Sci.*, 29, pp. 1235-1249.

Murton, J.B., Whiteman, C.A., Waller, R.I., Pollard, W.H., Clark, I.D. and Dallimore, S.R. 2005. Basal ice facies and supraglacial melt-out till of the Laurentide Ice Sheet, Tuktoyaktuk Coastlands, western Arctic Canada. *Quat. Sci. Rev.*, 24, pp. 681-708.

10. Smoking Hills, NT

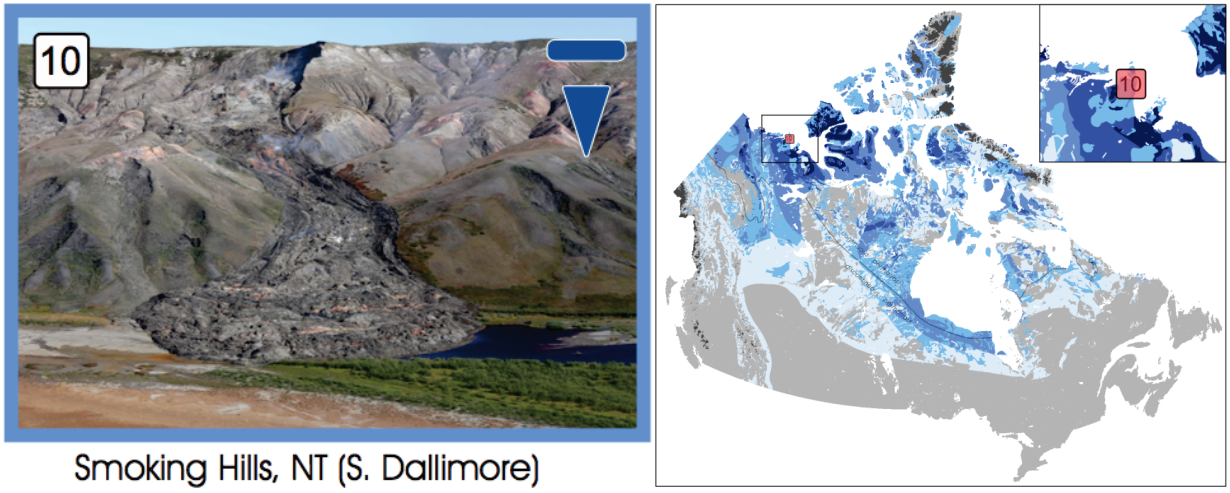


Figure 12. Smoking Hills, Northwest Territories. Left panel) Photo showing debris flow resulting from thaw by an active bocanne. NRCan photo 2020-077 by S. Dallimore. Right panel) Inset map showing site location at 69.8000°N; -126.8000°W.

Modelled ground ice abundance: low relict ice; no segregated ice; medium wedge ice

Description: Smoking Hills is an upland area adjacent to a wave-cut escarpment along the Arctic Coast, 130 km northwest of Paulatuk, NT. The hills derive their name from emissions of hot sulphurous fumes from the Cretaceous mudstones in the region, known also as bocannes. The uplands are believed to have been glaciated and glacially thrusted in the mid-Pleistocene. Unconsolidated sediments that include evidence of glacial and interglacial periods generally cap the area. It was considered to be unglaciated during the Wisconsinan, during which ice abutted the margins of the uplands folding and faulting the Cretaceous strata, though re-interpretations consider it to have been glaciated in the Late Wisconsinan. Very little permafrost data exist for the area. It is within the continuous permafrost zone, vegetated with herb shrub tundra. The MAAT at Paulatuk is -9 °C, with about 73 mm of annual precipitation, of which 60% falls as snow. The terrain includes well-developed ice-wedge polygons. Slumping occurs primarily in association with areas of active bocannes, releasing heat and melting ice within sediment.

Comments on modelled versus observed ice: Despite few field observations, the low relict ice abundance is likely reasonable given the potential for preservation in coarse glaciofluvial sediments mapped in the area. The lack of modelled segregated ice is appropriate for these coarse sediments but is likely underestimated due to the presence of finer-grained deposits not mapped at the national scale. Medium modelled wedge ice abundance seems reasonable given observable polygonal terrain in satellite imagery.

Thermokarst Implications: Gullying and ponding due to thaw truncation of wedges is apparent and likely to continue with increases in temperature or precipitation. Slumping, which is controlled mainly by occurrence of bocannes, may be enhanced by shoreline erosion.

References: Mathews, W.H., Mackay, J.R. and Rouse, G.E. 1989. Pleistocene geology and geomorphology of the Smoking Hills Upland and lower Horton River Arctic coast of mainland Canada. *Canadian Journal of Earth Sciences,* 26(9), pp. 1677-1687.
Smith, I.R., Bringué, M., Bryant, R; Evans, D.J.A., Galloway, J.M. and Grasby, S.E. 2018. Multidisciplinary study of Cretaceous, Neogene, and Quaternary stratigraphy, and bocannes and their associated mineralogy and hydrochemistry, Smoking Hills, Northwest Territories: GEM-2 Western Arctic Project, report of activities 2018. *Geological Survey of Canada, Open File 8482*.

11. Bluenose Lake Moraine, NU

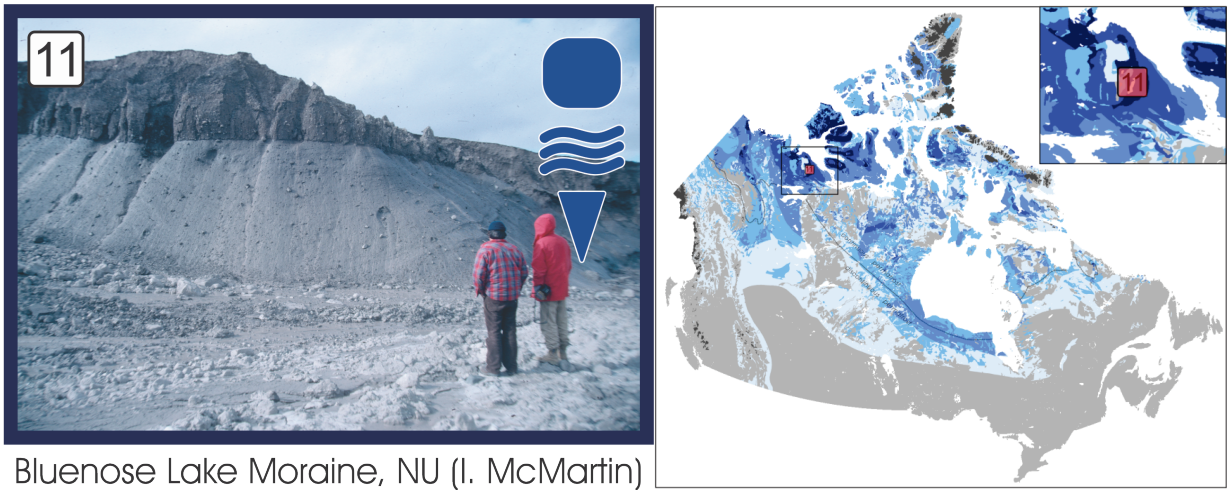


Figure 13. Bluenose Lake Moraine, Nunavut. Left panel) Photo showing slump headwall exposing relict ice and till. NRCan photo 2020-078 by I. McMartin. Right panel) Inset map showing site location at 68.5912°N; -119.0816°W.

Modelled ground ice abundance: high relict ice; medium segregated ice; medium wedge ice

Description: Bluenose Lake Moraine is on the Horton Plains about 200 km west of Kugluktuk, NU. Horton Plains is a gently dipping dolomite plateau mantled by drumlinized till, moraines, outwash, and marine deposits. Bedrock outcrops are common with periglacial features including rock pingos, rock mounds and felsenmeer. The plateau rises from the Coronation Gulf to an elevation of 300-350 m. The moraine is an ice-thrust feature with rugged relief, including ridges and kames, and adjacent glaciolacustrine and deltaic sediments. Pitted deltas attest to sedimentation onto masses of inactive ice and collapse of sediment around kettle holes following ice melt. The 20-30 km wide Bluenose Lake Moraine likely marks the part of the ice margin that was buried and preserved as an ice-cored moraine, detached from the melting ice sheet. Numerous slumps occur around lakes on the moraine, exposing up to 20 m of icy sediments overlain by 2-5 m of silty sand and bouldery massive diamicton. The massive icy sediments are interpreted as basal glacier ice buried by debris within a westward-thrusting Late Wisconsinan ice frontal moraine. Permafrost is continuous. MAAT at Kugluktuk is -10.6 °C , with cold dry winters. Horton Plains is sparsely covered by lichens and mosses. The maximum active layer thickness is less than 2 m in the diamicton and is well above an unconformity between the diamicton and the underlying icy sediment at a depth of 5 m. Climatic conditions since deglaciation may preclude this as a thaw unconformity, but rather represent the contact between basal glacier ice and overlying glaciogenic debris.

Comments on modelled versus observed ice: High modelled relict ice abundance is reasonable in this ice-cored setting. Direct evidence of amounts of wedge ice and segregated ice are not available, though these are likely reasonably modelled as medium in the Bluenose Moraine area, within glaciolacustrine and deltaic sediments, but may be overestimated on thinner sediments of the Horton Plain.

Thermokarst implications: Thermokarst processes are presently active and slumping, ponding, sediment flux and incision due to melting of medium to high amounts of ground ice are likely to increase with higher temperatures or rainfall.

References: St-Onge, D.A. and McMartin, I. 1995. Quaternary Geology of the Inman River Area, Northwest Territories. *Geological Survey of Canada, Bulletin 446*. Map 1846A, 59 p.

12. Lac de Gras, NT

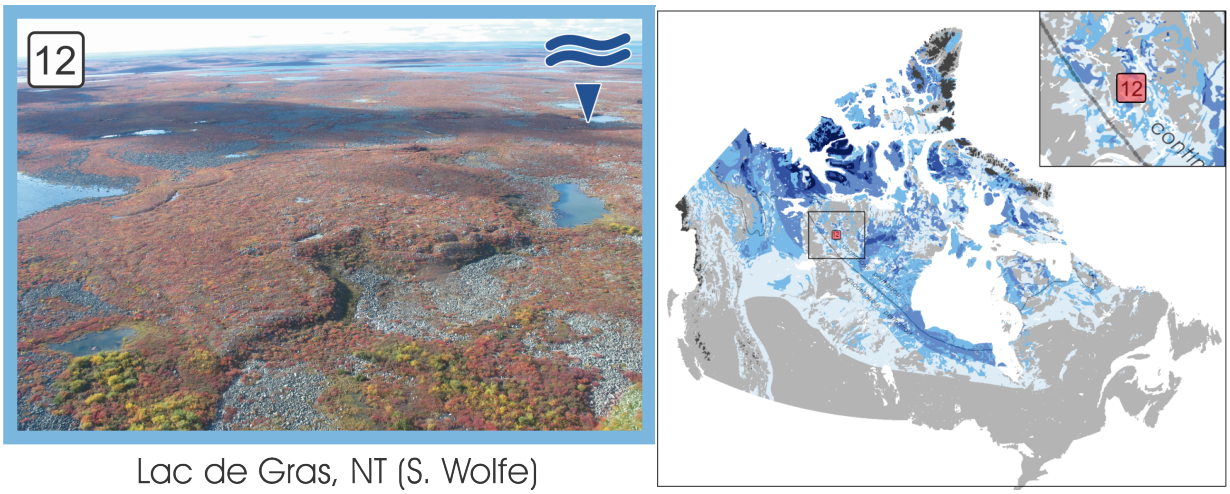


Figure 14. Lac de Gras, Northwest Territories. Left panel) Photo showing differential subsidence in till terrain. NRCan photo 2020-080 by S. Wolfe. Right panel) Inset map showing site location at 64.5862°N; -110.3046°W.

Modelled ground ice abundance: no relict ice; low segregated ice; negligible wedge ice

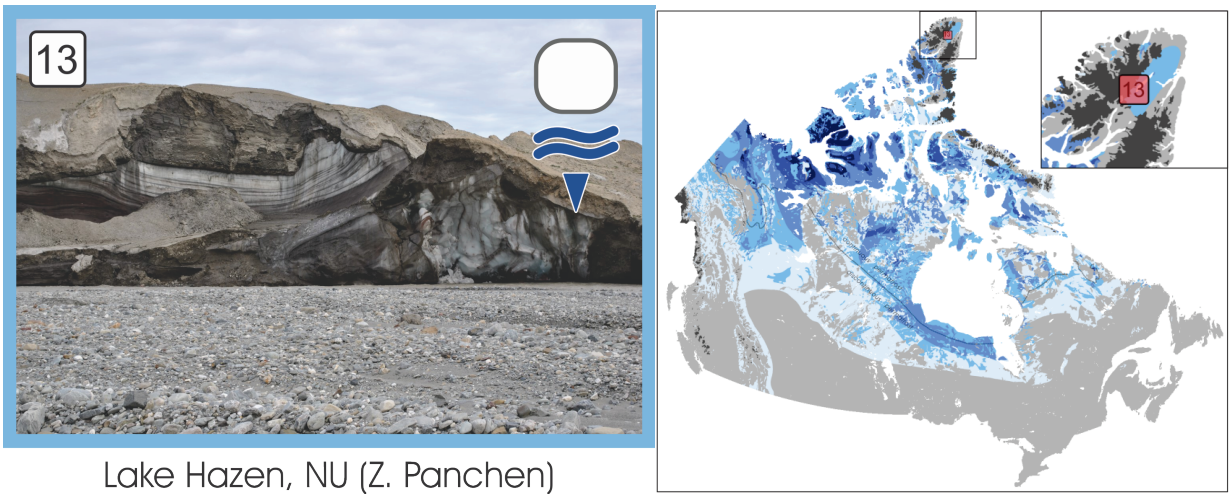
Description: Lac de Gras is 310 km northeast of Yellowknife, NT, in the Slave Geological Province. Shield-derived bedrock is near the surface, with between 10 to 20 m of sediment occurring in areas with eskers, streamlined till, or hummocky till. The region was deglaciated approximately 10000 cal yr BP. The current climate is cold and continental with MAAT about -9 °C and MAGTs about -6 °C. Permafrost is continuous and vegetation is predominantly shrub tundra, with treeline about 100 km to the south. However, forest tundra advanced northward over the area about 5600 cal yr BP. Regionally, buried ice, segregated ice and wedge ice may all be present, but few direct observations have been made to date. Massive buried ice is recorded in esker sediments and excess ice was encountered in till to depths of 10 m. Ice wedge troughs are apparent on glaciofluvial sediments and organic terrain. Past melt of ground ice is apparent through features resembling stabilized slumps and meltout features on till terrain.

Comments on modelled versus observed ice: Relict ice is under-represented by modelling, owing to the under-representation of till terrain in the national-scale surficial geology. Segregated ice and wedge ice may be more appropriately modelled, but might also be under-represented due to the surficial geology representation. The effect of past climate warming, represented both in the model and as noted in field observations in the form of meltout features, indicates that ground ice abundance in the near surface has been reduced during the Holocene.

Thermokarst implications: The region has undergone partial thaw due to late Holocene warming, but is still susceptible to climate warming. In coarse surficial sediments, the primary thermokarst process is subsidence and slow lateral translocation induced by melt of near-surface segregated and wedge ice. Slumping and ground ice exposures in permafrost are unlikely. The removal ofsurficial materials for resource development activities may induce additional thermokarst processes.

References: Dredge, L.A., Kerr, D.E. and Wolfe, S.A. 1999. Surficial materials and related ground ice conditions, Slave Province, NWT, Canada. *Canadian Journal of Earth Sciences*, 36(7), pp. 1227-1238.
Subedi, R., Kokelj, S.V. and Gruber, S. 2020. Ground ice, organic carbon and soluble cations in tundra permafrost soils and sediments near a Laurentide ice divide in the Slave Geological Province, Northwest Territories, Canada. *The Cryosphere*, 14(12), pp. 4341-4364.

13. Lake Hazen, NU



Lake Hazen, NU (Z. Panchen)

Figure 15. Lake Hazen, Ellesmere Island, Nunavut. Left panel) Photo showing relict ice beneath outwash sediments. Photograph courtesy of Z. Panchen. Right panel) Inset map showing site location at 81.8661°N; -70.9931°W.

Modelled ground ice abundance: no relict ice; low segregated ice; negligible wedge ice

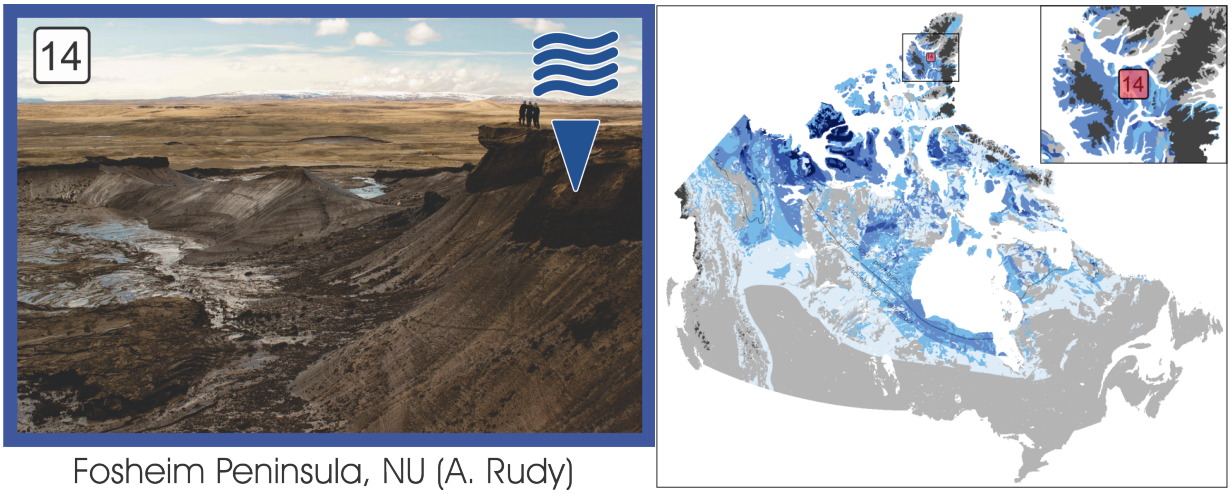
Description: Lake Hazen is the world's largest (by volume) high arctic lake, located on northern Ellesmere Island at an elevation of about 157 m asl. The lake basin is surrounded by mountains rising to more than 2600 m, which consist of Paleozoic limestone, sandstone, slate, and chert pebble conglomerate covered by glacial ice of up to 900 m thick. The Lake Hazen Basin is a polar desert, with a MAAT of -20 °C and a MAP of <150 mm. Winter monthly temperatures are typically <-40 °C owing to cold-air drainage and strong temperature inversions, but summer temperatures may exceed 18 °C. Permafrost is continuous. Glaciers retreated from the Lake Hazen Basin around 5300-5000 yr BP. Recessional moraines and lateral meltwater channels surround much of the lake. Buried glacier ice has been noted in elevated moraine deposits capped by 1 m of colluvium, and exposed beneath outwash sediments near the lake level. Summer air temperature warming of about 1 °C has induced an increase in active layer thickness and mass losses from glaciers resulting in a large increase in delivery of glacial meltwater.

Comments on modelled versus observed ice: Relict ice is not modelled because the area is mapped as thin till veneer in the national-scale dataset; however, relict and modern glacial ice appear buried within recessional moraines, and capped by glaciofluvial sediments. Modelled low abundance of segregated ice and negligible wedge ice are reasonable owing to the thin, commonly coarse-grained overburden and comparatively recent timing of deglaciation.

Thermokarst implications: Continued melt of permafrost-preserved buried glacial ice in modern moraines, enhanced by air temperature warming, will induce further ground subsidence, slope failures and slumping as well as enhanced fluvial delivery of water and sediment into the lake basin and ocean.

References: Lehnherr, I., Louis, V.L.S., Sharp, M., Gardner, A.S., Smol, J.P., Schiff, S.L., Muir, D.C., Mortimer, C.A., Michelutti, N., Tarnocai, C. and Pierre, K.A.S. 2018. The world's largest High Arctic lake responds rapidly to climate warming. *Nature Communications*, 9(1), pp. 1-9.
Smith, I.R. 1999. Late quaternary glacial history of lake Hazen basin and eastern Hazen Plateau, northern Ellesmere Island, Nunavut, Canada. *Canadian Journal of Earth Sciences*. 1999 Dec 1;36(9), pp. 1547-1565.

14. Fosheim Peninsula, NU



Fosheim Peninsula, NU (A. Rudy)

Figure 16. Fosheim Peninsula, Ellesmere Island, Nunavut. Left panel) Photo showing exposed segregated ice in slumps. Photograph courtesy of A. Rudy. Right panel) Inset map showing site location at 79.9801°N; -84.1266°W.

Modelled ground ice abundance: no relict ice; high segregated ice; medium wedge ice

Description: The area lies on the central-western part of Ellesmere Island, with gently rolling montane-intermontane relief. Elevation is below 300 m asl except for some ridges rising to 840 m asl in areas of intact sedimentary bedrock. The surficial geology is dominated by unconsolidated silty-clay marine sediments below about 150 m asl, with fluvial, glacial, and glaciofluvial deposits. It has a cold polar desert climate with MAAT of -19.7 °C and MAP of about 68 mm, falling mostly as snow. The area is underlain by continuous permafrost 500 m thick and MAGT is about -16.5 °C. The active layer is typically about 57 cm thick. Surface cover is patchy, varying between bare surfaces and herb tundra. The upper 20–30 m of permafrost in some areas is ice-rich, containing ice wedges, massive intrasedimental ice, and extensive thin layers of segregated ice. The massive ice occurs primarily within fine-grained marine sediments below the Holocene marine limit. It is estimated that the wedge ice occupies about 3.8% of the top 5.9 m of permafrost. Active-layer detachments and thaw slumps are common in areas underlain by massive ice.

Comments on modelled versus observed ice: The region is reasonably modelled with regard to the absence of relict ice due to marine inundation in areas with marine sediments. High segregated and wedge ice abundance is appropriate for the fine-grained marine sediments. Modelled medium wedge ice abundance is reasonable for higher elevations, but may be too high for areas that were more recently inundated. Much of the area at lower elevations has low modelled wedge abundance, in agreement with the estimates available in the literature.

Thermokarst implications:
Thaw slumps and active-layer detachment slides have increased recently, and are anticipated to increase further given projected warming in air temperatures. Increased erosion of ice wedges and gullying is also likely on slopes, contributing water and sediment into fluvial and marine systems.

References: Bernard-Grand'Maison, C. and Pollard, W. 2018. An estimate of ice wedge volume for a High Arctic polar desert environment, Fosheim Peninsula, Ellesmere Island. *Cryosphere*, 12(11).
Jones, M.K.W., Pollard, W.H. and Jones, B.M. 2019. Rapid initialization of retrogressive thaw slumps in the Canadian high Arctic and their response to climate and terrain factors. *Environmental Research Letters*, 14(5), p. 055006.

15. King William Island, NU

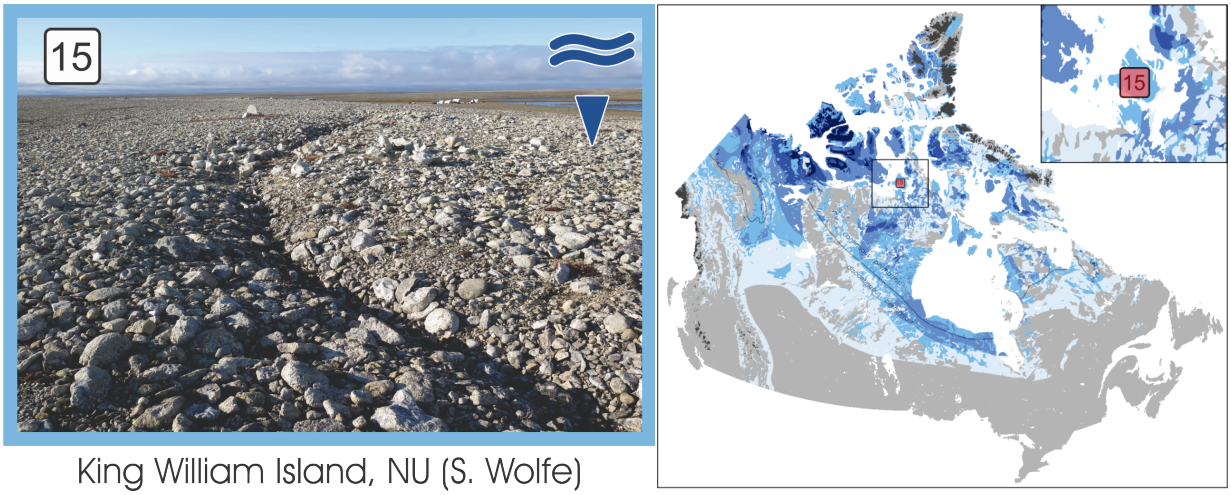


Figure 17. King William Island, Nunavut. Left panel) Photo showing ice wedge trough in marine gravel terrace. NRCan photo 2020-082 by S. Wolfe. Right panel) Inset map showing site location at 68.9983°N; -96.5797°W.

Modelled ground ice abundance: no relict ice; low segregated ice; low wedge ice

Description: King William Island is a part of the Arctic Island Lowlands. Bedrock is typically near the surface, and consists of Cambrian to Silurian sedimentary carbonates and sandstones. A marine veneer of washed till covers much of the island, as marine inundation occurred following glaciation. Raised gravel and sandy beaches formed on glaciofluvial and glaciomarine terraces occupy a lot of the periphery of the island, which is undergoing isostatic rebound at a rate of about 1mm/yr. Gjoa Haven has an maritime arctic climate with MAAT -14 °C and MAP of about 200 mm, of which about 60% falls as snow. The region is underlain by continuous permafrost and MAGT is about -8.5 °C. Vegetation is primarily herb tundra, with some low willow shrubs. As a consequence of marine inundation and deposition of predominantly coarse sandy sediments, excess ground ice abundance is generally low, taking the form primarily as ice wedges. Thermokarst processes and features are rare, occurring mostly in areas of human-disturbed terrain.

Comments on modelled versus observed ice: Although field observations of ground ice are generally lacking, modelled abundance of no relict ice can be considered appropriate, owing to marine inundation and thin surficial sediments. Low modelled abundance of segregated ice and wedge ice is also reasonable given the generally thin surficial material cover.

Thermokarst implications: Beyond thermokarst and gullying caused by human-induced disturbance of the near surface, additional evidence is rare. Warming may induce minor ground surface settlement from melt of segregated ice and small ice wedges.

References: Ednie, M. and Smith, S L. 2015. Permafrost temperature data 2008-2014 from community based monitoring sites in Nunavut *Geological Survey of Canada, Open File 7784*, 18 pages (1 sheet).
Catto, N.R. and Parewick, K. 2008. Hazard and vulnerability assessment and adaptive planning: mutual and multilateral community–researcher communication, Arctic Canada. *Geological Society, London, Special Publications*, 305(1), pp. 123-140.

16. Darby Lake, NU

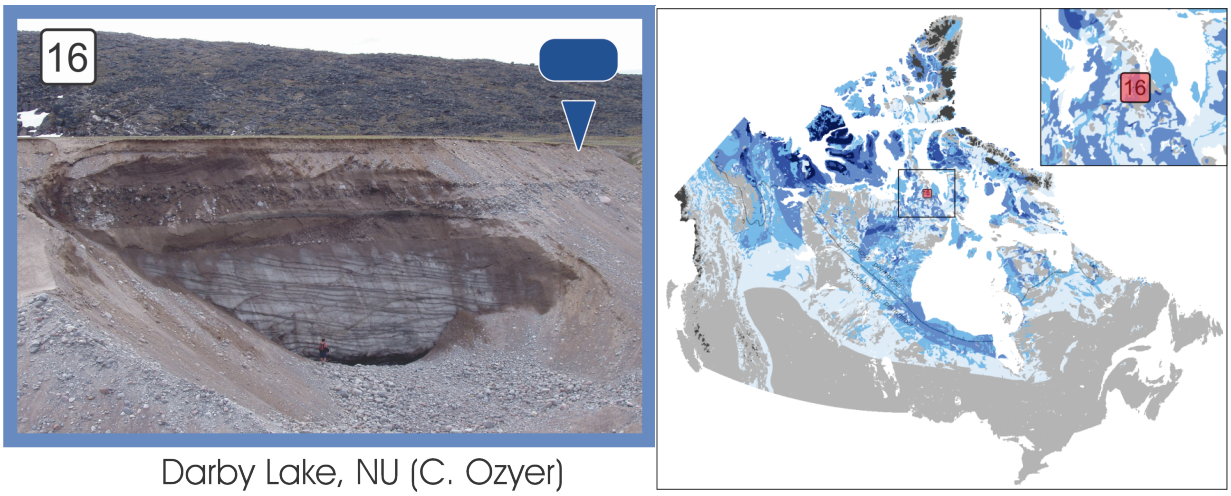


Figure 18. Darby Lake, Nunavut. Left panel) Photo showing relict ice exposed in glaciofluvial sediments. NRCan photo 2020-083 by C. Ozyer. Right panel) Inset map showing site location at 67.7987°N; -92.0706°W.

Modelled ground ice abundance: medium relict ice; no segregated ice; low wedge ice

Description: Darby Lake is on southern Boothia Peninsula, lying on the northeastern Canadian Shield about 125 km SE of Kugaruuk, NU. The pictured site is 3.5 km west of the lake within a series of interconnected lakes among outwash sediments. The surface has a till cover of variable thickness and glaciofluvial sediments consisting of eskers, kames, deltas and terraced valley-fill deposits. Adjacent lower elevation terrain underwent marine inundation following deglaciation around 10000 cal yr BP but the pictured site appears located at or above the marine limit. The MAAT at Kugaruuk is -13.5 °C and MAP is 260 mm, with just over half falling as snow. The area is underlain by continuous permafrost, though ground temperatures and active layer thicknesses have not been recorded in the area. Vegetation cover is generally herb to shrub tundra, but with significant areas of exposed bedrock. Massive ice has been observed at this location, buried by outwash sediments. This ice is presumably of glacial origin. Kettle lakes are common in outwash areas. Ice wedge polygons are visible on outwash surfaces and on Holocene alluvial terraces and most unconsolidated surface sediments.

Comments on modelled versus observed ice: Although few observations of ground ice are available in the area, the modelled medium abundance of relict ice appears reasonable, as ice underlies most outwash sediments. The modelled low wedge ice abundance also seems appropriate, but may be higher in areas with more fine-grained sediments. There is no modelled segregated ice at the provided by coordinates because the surficial geology is represented as coarse-grained glaciofluvial sediments at the national-scale. Segregated ice is therefore likely under-represented, as smaller areas of fine-grained sediments are not accounted for.

Thermokarst implications: Gullying of ice-wedge polygons and occasional slumping within outwash sediments are both observed and can be expected to continue. In addition, subsidence on most unconsolidated sediments may also be expected.

References: Ozyer, C. 2011. Ice-movement history and kimberlite indicator mineral dispersal study, Pelly Bay, lower Boothia Peninsula, and Wager Plateau areas, Nunavut, Canada. *Unpublished PhD Thesis*. University of Western Ontario. 187 p.

17. Pond Inlet, NU

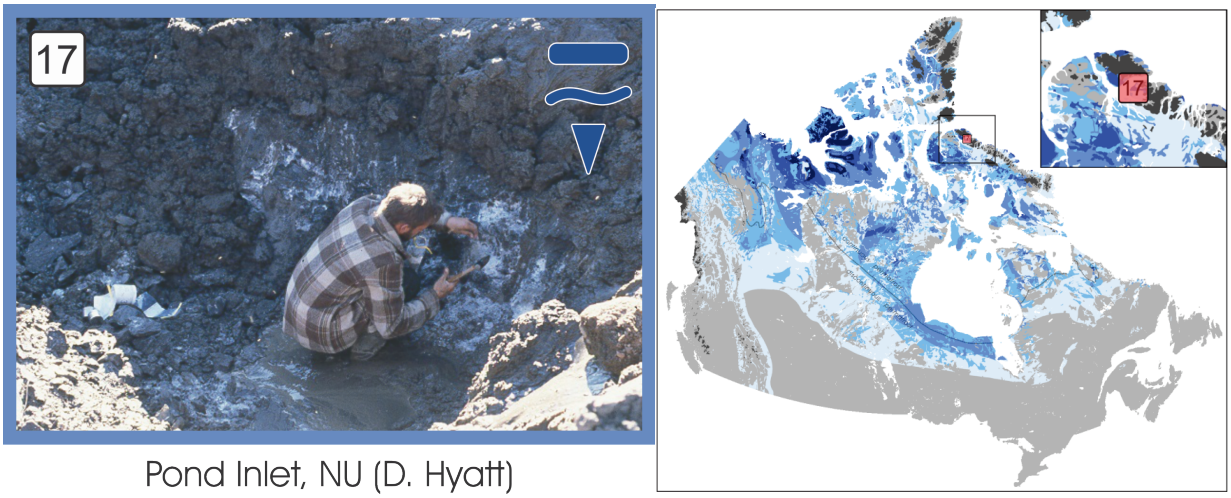


Figure 19. Pond Inlet, Nunavut. Left panel) Photo showing exposed segregated ice. Photograph courtesy of D. Hyatt. Right panel) Inset map showing site location at 72.6967°N; -77.8938°W.

Modelled ground ice abundance: low relict ice; low segregated ice; low wedge ice

Description: Pond Inlet is on a small coastal lowland segment between 0 to 100 m asl within the Davis Highlands of northern Baffin Island. It is underlain by granitic bedrock of the Canadian Shield and Cretaceous sedimentary rocks. Topography near the coast is undulating, bounded further inland by greater relief. The area was a major zone of outflow for ice from northern Baffin Island during the last glaciation. Following deglaciation, inundation and subsequent isostatic rebound formed marine deposits up to about 65 m asl. Surficial materials include primarily till of varying composition and thickness, bedrock, coarse-grained nearshore marine deposits, and minor units of alluvium and outwash. Numerous small lakes occur in the area with thicker till cover, through which runs the Salmon River. MAAT is -14.6 °C, and MAP is about 230 mm with 60% falling as snow. Permafrost is continuous. Segregated ice, possibly related to permafrost aggradation following glacial retreat, has been observed about 95 m asl.

Comments on modelled versus observed ice: At elevations above 65 m asl, the low modelled abundance of all ice types appears reasonable, though there is a lack of observations. Modelled relict ice abundance ranges from none in thin till veneer to medium in thicker till blanket. Modelled segregated and wedge ice abundance ranges from negligible to medium, which may be appropriate considering the variation in thickness and texture of the till in the region.

Thermokarst implications: Primary thermokarst processes appear to be ground surface subsidence in disturbed terrain. Subsidence and localized gullying may remain the primary processes active in the area.

References: Andrews, J.T. 1989. Quaternary Geology of the northeastern Canadian Shield. In: Fulton, R.J. ed. *Quaternary geology of Canada and Greenland* (Vol. 2). Ottawa, Ontario: Geological Survey of Canada.
Hyatt, J.A. 1998. The origin of lake-bed ground ice at Water Supply Lake, Pond Inlet, Nunavut, Canada. In: *Proceedings of the 7th International Conference on Permafrost*, Yellowknife. Canada, Lewkowicz AG, Allard M.(eds.). Université Laval, Canada. Collection Nordicana (No. 57, pp. 757-762).

18. Pangnirtung, NU

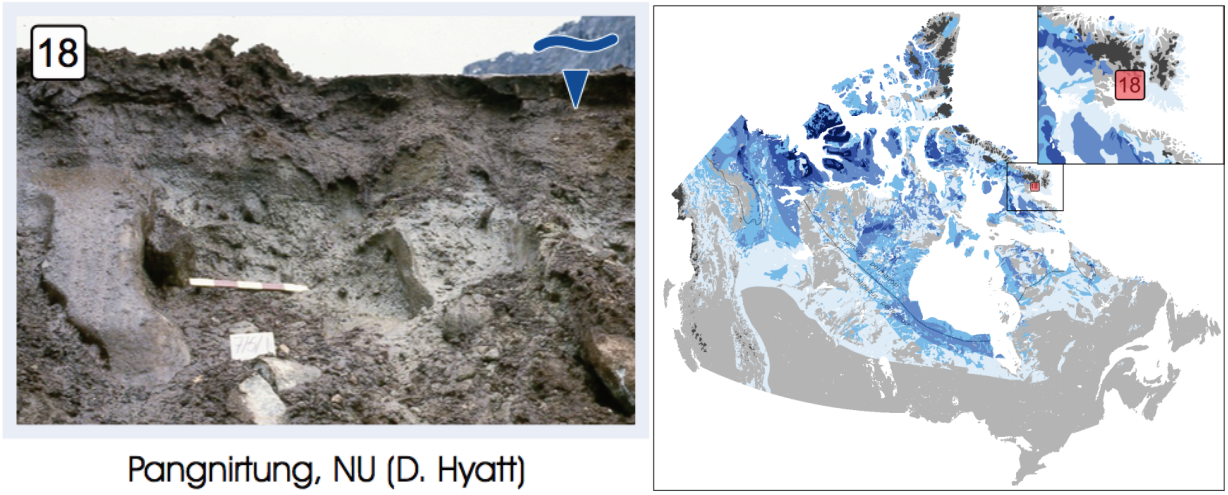


Figure 20. Pangnirtung, Nunavut. Left panel) Photo showing exposed wedge ice. Photograph courtesy of D. Hyatt. Right panel) Inset map showing site location at 66.1511°N; -65.6723°W.

Modelled ground ice abundance: no relict ice; negligible segregated ice; negligible wedge ice

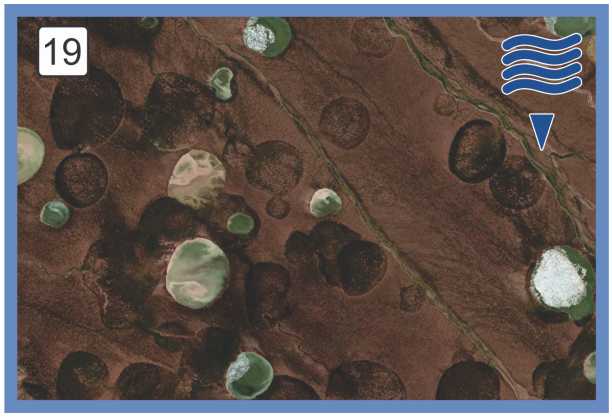
Description: Pangnirtung is on east-central Baffin Island, Nunavut, at an elevation of 0 to 55 m asl. The area underwent marine inundation following advances of Laurentide and alpine ice sheets, and may have become terrestrially exposed about 9800 cal yr BP. Climate during the Holocene varied between warm-wet and cold-dry conditions, although permafrost has remained continuous. MAAT is about -9 °C and MAP is about 395 mm, with about 65% falling as snow. MAGT ranges between -8 and -9 °C and active-layer thickness ranges from 0.8 to 1.6 m. The local surficial stratigraphy includes deltaic sands and gravels overlain by coarse-grained colluvium. Ice wedges are observed with maximum widths of 75 cm. The wedges are small but abundant and show both evidence of past thaw truncation from active-layer thickening, and more recent aggradation resulting from active-layer thinning. Cavity-fills within ice wedges are also present. Rain events have produced cavities and gullying in permafrost. At an elevation of about 110 m asl, ground ice with lenses up to 0.5 m thick has been observed and interpreted as buried subglacial regelation (i.e. segregation) ice.

Comments on modelled versus observed ice: Relict ice is locally reasonably modelled as absent, owing to marine inundation at this location. Negligible wedge ice abundance is reasonable for elevations close to present-day sea level, but more wedge ice may occur at elevations above 50 m asl. The modelled negligible segregated ice abundance is appropriate for the coarse sediments prevalent in the area.

Thermokarst implications: Gullying and the formation of cavities within permafrost have been, and will likely continue as the main thermokarst process in the area. Low ground ice contents in the upper layers of permafrost will generally restrict subsidence or slumping.

References: Hyatt, J.A., Michel, F.A. and Gilbert, R. 2003. Recognition of subglacial regelation ice near Pangnirtung, Baffin Island, Canada. In: *Proceedings of 8th International Conference on Permafrost*. Edited by M. Phillips, SM Springman, and LU Arenson. Zurich Switzerland. AA Balkema. Vol. 1, pp. 443-448.
Hyatt, J.A. 1990. Reconstruction of Holocene periglacial environments in the Pangnirtung area based on ice wedge characteristics. In: *Fifth Canadian Permafrost Conference*. Quebec City. p. 17-21.

19. Great Plain of the Koukdjuak, NU



Great Plain of the Koukdjuak, NU (©Digitalglobe)

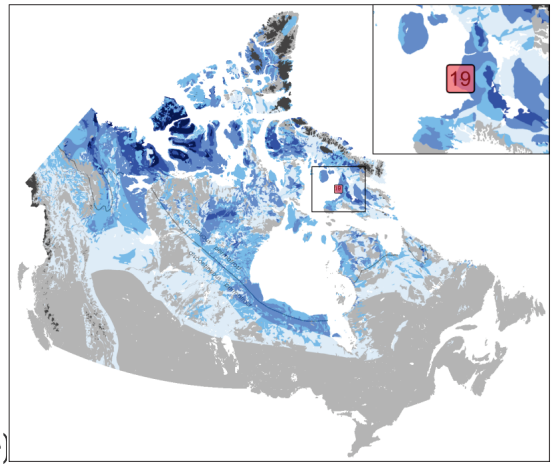


Figure 21. Great Plain of the Kouddjuak, Nunavut. Left panel) Photo showing thaw-lake terrain. Imagery from Digitalglobe. Right panel) Inset map showing site location at 66.1354°N; -73.7051°W.

Modelled ground ice abundance: no relict ice; high segregated ice; negligible wedge ice

Description: The Great Plain of the Koukdjuak is on western Baffin Island adjacent to the Foxe Basin, about 350 km northwest of Iqaluit. The plain slopes gently and is blanketed mainly by marine silt, clay, and mud, deposited when the area was inundated and isostatically depressed following the last glaciation. Ephemeral streams traverse the plain, exposing underlying glaciofluvial sands and gravels in some areas. Emergence of the plain has occurred in the last ca. 5000 years. The plain rises from the sea level to an elevation of about 50-60 m over a distance of 70 km at its widest point. MAAT at Iqaluit is -9.3 °C. Permafrost is continuous and reaches depths of up to ca. 400 m. The plain includes a wide, muddy intertidal zone at the coast, which transitions to coastal marshes and wet tundra further inland. The plain includes numerous near-circular thaw lakes and drained basins, indicating spatially uniform segregated ice content in the near surface. Well-developed ice wedge networks are not apparent, though incipient wedges have been observed.

Comments on modelled versus observed ice: No relict ice is modelled, which is accurate given the post-glacial inundation and subsequent emergence of the plain. Modelled wedge ice abundance is negligible, in agreement with observations of only incipient features in the region. The relatively short time since terrestrial emergence has limited time for ice wedge growth. The high modelled segregated ice appears reasonable considering the widespread shallow thermokarst lakes (ca. 2 m depth), within frost-susceptible fine-grained marine sediments on the plain.

Thermokarst implications: The numerous thaw lakes and drained basins highlight ongoing thermokarst evolution on the plain, with repeated flooding and desiccation of lake basins. This activity is anticipated to continue in the future.

References: Dredge, L.A. 1992. Breakup of limestone bedrock by frost shattering and chemical weathering, eastern Canadian Arctic. *Arctic and Alpine Research*, 24(4), pp. 314-323.

Harris, J.R., Parkinson, W., Dyke, A., Kerr, D., Russell, H., Eagles, S., Richardson, M. and Grunsky, E. 2012. Predictive surficial geological mapping of Hall Peninsula and Foxe Basin Plateau, Baffin Island using LANDSAT and DEM data. *Geological Survey of Canada, Open File 7038,* 22 pages.

Martini, I.P. and Morrison, R.G. 2014. Coasts of Foxe Basin, Arctic Canada. *Geological Society, London, Special Publications*, 388(1), pp. 165-198.

20. Iqaluit, NU

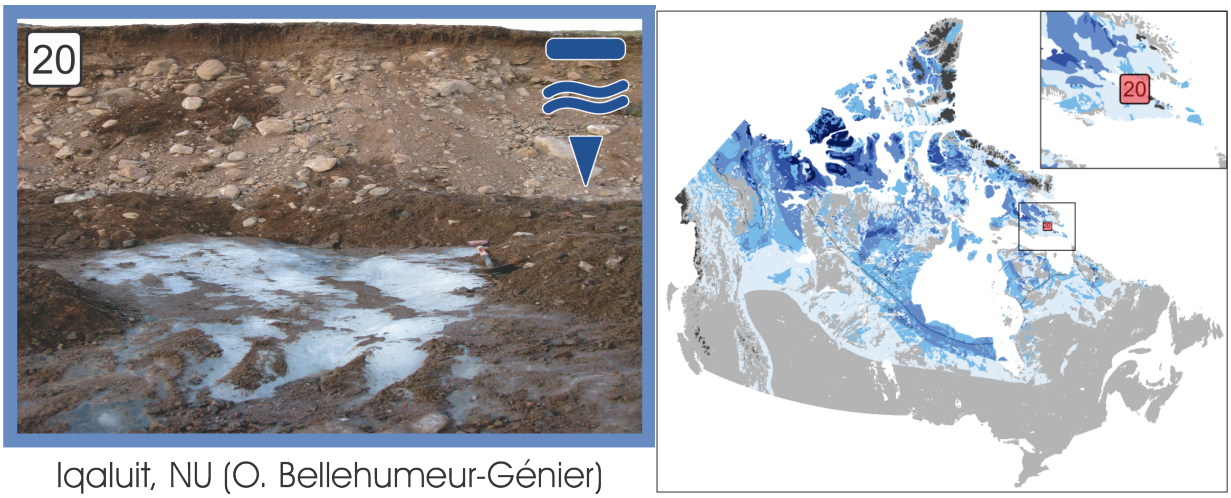


Figure 22. Iqaluit, Nunavut. Left panel) Photo showing massive ice exposed in glaciofluvial sediments. Photograph courtesy of O. Bellehumeur-Génier. Right panel) Inset map showing site location at 63.7906°N; -68.5652°W.

Modelled ground ice abundance: low relict ice; low segregated ice; low wedge ice

Description: Iqaluit is at the head of Frobisher Bay on southeast Baffin Island. The area is underlain by Precambrian bedrock, and topography includes flatter plateau areas and rocky hillslopes. The region was deglaciated by about 9500 yr BP, and areas near the coast were subsequently inundated. Surficial materials identified on large-scale maps include mainly tills of varied thickness, bedrock, and marine sediments near the coast. Areas of glaciofluvial, alluvial, and organic deposits are also present. The MAAT at Iqaluit is -9.3 °C. Permafrost is continuous, and MAGTs range from about -4 to -10 °C. Permafrost has recently warmed together with increases in active layer thickness. Vegetation cover is generally continuous other than on bedrock outcrops, and consists of low shrub tundra. Ice wedges are apparent within fine-grained marine deposits, and their melt and associated subsidence has influenced the runway of the Iqaluit Airport.

Comments on modelled versus observed ice: Low modelled relict ice is reasonable as glacial deposits in the area may preserve glacier ice. Modelled segregated ice abundance varies from negligible to medium in the region; the variation and range of abundance is reasonable, however fine-grained marine units are not represented in the national-scale surficial dataset and thus areas of high abundance may not be adequately represented locally. Low modelled wedge ice abundance is reasonable given the scale of mapping, though may underestimate abundance locally in marine deposits not mapped at the national scale.

Thermokarst implications: Ground subsidence in fine-grained deposits is associated with melt of ice wedges and segregated ice. Ponding occurs as ice wedges melt in poorly drained areas. Till blankets on slopes are susceptible to slumping. Subsidence and slumping activity may accelerate with warming.

References: Allard, M., Doyon, J., Mathon-Dufour, V., Leblanc, A.-M., L'Hérault, E., Mate, D., Oldenborger, G.A. and Sladen, W.E. 2012. Surficial geology, Iqaluit, Nunavut. *Geological Survey of Canada, Canadian Geoscience Map 64*, (ed. prelim.), 1 sheet; 1 CD-ROM.
LeBlanc, A.M., Oldenborger, G.A., Short, N., Sladen, W.E., Allard, M. and Mathon-Dufour, V. 2015. Ground temperatures and spatial permafrost conditions in Iqaluit, Baffin Island, Nunavut. *Canada-Nunavut Geoscience Office Summary of Activities*, pp. 161-170.
Oldenborger, G.A. and LeBlanc, A.M. 2015. Geophysical characterization of permafrost terrain at Iqaluit International Airport, Nunavut. *Journal of Applied Geophysics*, 123, pp. 36-49.

21. Rankin Inlet, NU

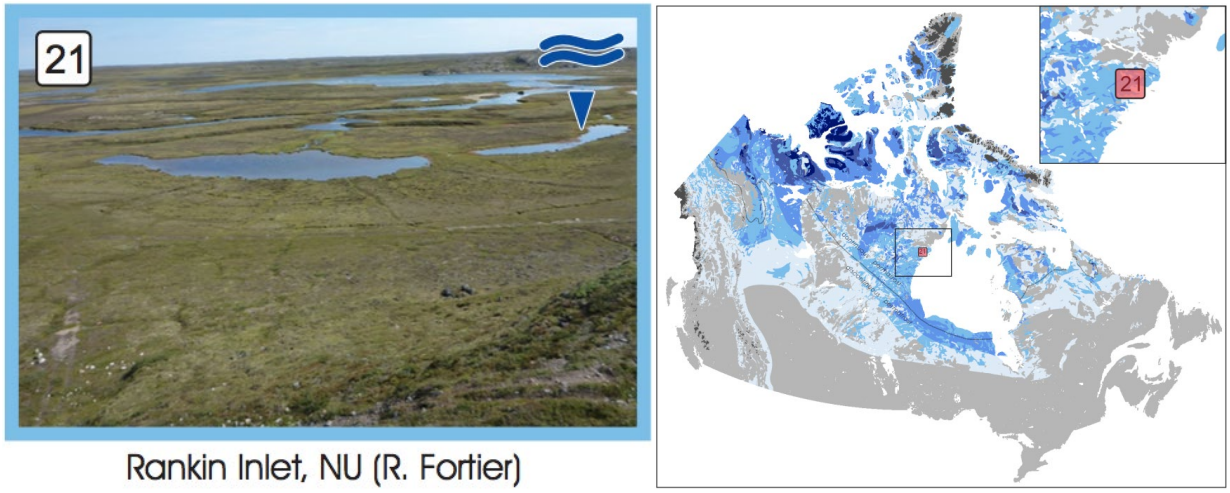


Figure 23. Rankin Inlet, Nunavut. Left panel) Photo showing ice-wedge terrain. Photograph courtesy of R. Fortier. Right panel) Inset map showing site location at 62.8444°N; -92.1532°W.

Modelled ground ice abundance: no relict ice; low segregated ice; negligible wedge ice

Description: Rankin Inlet is on the western coast of Hudson Bay, lying on the western Churchill Province of the Canadian Shield. The region was covered by the Laurentide Ice Sheet until about 5000 years ago and subsequently inundated by the sea, which extended up to 150 km inland. Surficial materials include glacial, marine, and glaciofluvial deposits, with numerous bedrock outcrops. The topography undulates over moraines, eskers, and bedrock outcrops. The MAAT is -10.5 °C. Permafrost is continuous, with thicknesses of about 300 m near the coast, increasing to about 500 m inland. Permafrost established as the terrain emerged due to isostatic rebound. MAGTs range from about -5 to -8 °C. Vegetation includes low tundra species, lichen, grass, mosses, and shrubs. Abundant polygonal networks have been observed in some marine units outlined on larger-scale surficial geology maps, and the top of permafrost in fine-grained materials is ice rich.

Comments on modelled versus observed ice: The modelled absence of relict ice is reasonable given the post-glacial inundation of the area by the sea. Modelled segregated ice abundance varies from negligible to medium in the area; the variation and range of abundance is reasonable based on field measurements, however fine-grained marine units are under-represented in the national-scale surficial dataset and thus areas of high abundance may not be adequately represented. Modelled wedge ice abundance may also be under-represented in some areas with marine sediments, but polygonal terrain is rare in most other surficial units.

Thermokarst implications: The thaw of segregated ice has been linked to gradual ground surface subsidence and thaw lake expansion in the region. Increasing subsidence and thaw at lake margins can be expected under continued warming.

References: McMartin, I. 2002. Surficial geology, Rankin Inlet, Nunavut. Geological Survey of Canada, Open File 4116, 1 sheet; 1 CD-ROM, Leblanc, A.M. and Oldenborger, G.A. 2021. Ground temperature, active layer thickness and ground ice conditions in the vicinity of Rankin Inlet, Nunavut. In press.

22. Salluit, QC

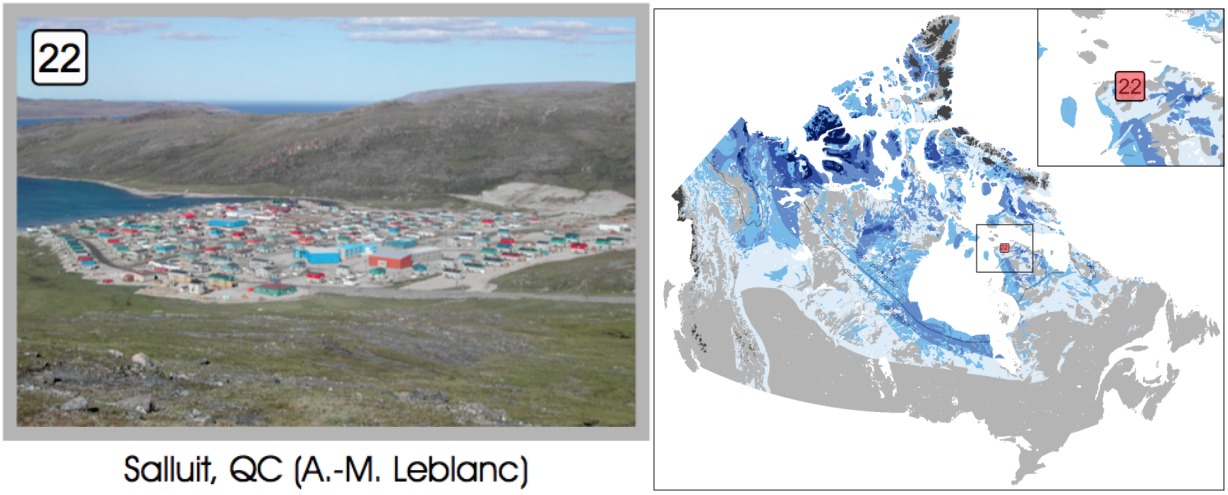


Figure 24. Salluit, Quebec. Left panel) Photo showing Salluit community situated on marine sediments. NRCan photo 2020-088 by A.-M. LeBlanc. Right panel) Inset map showing site location at 62.2032°N; -75.6425°W.

Modelled ground ice abundance: no relict ice; no segregated ice; no wedge ice

Description: Salluit is on Sugluk Inlet adjacent to the Hudson Strait in northwest Quebec. Silty-clay marine deposits occur between bedrock outcrops in the area. Till and deltaic sand deposits are also present, with thicker units commonly containing ice wedges. Permafrost is continuous, MAAT is about -8 °C, and MAGTs are about -6 °C. The active layer typically ranges from 1.5 – 2.5 m thick in unconsolidated sediments, and up to 3.5 m in bedrock. Ice-rich layers have been noted in marine clay deposits within permafrost, of segregated origin with ice volumes as high as 30 to 100%. Vegetation is predominantly herb to shrub tundra with considerable exposures of bedrock. Active-layer detachment slides have occurred during the end of warm summer seasons due to increased thaw penetration into the ice-rich top of permafrost. Annual air temperatures and total precipitation are projected to increase, with a decreased proportion of precipitation falling as snow. Model outputs indicate that ground temperature and active layer thicknesses are projected to increase, with permafrost thawing beginning by 2060.

Comments on modelled versus observed ice: The modelled absence of relict ice is appropriate due to the past marine inundation. The absence of segregated ice is poorly modelled, as segregated ice is encountered in the near surface and active-layer detachments have occurred. The inaccuracy in the modelling is attributable to the underrepresentation of fine-grained surficial units in the national-scale dataset in the model. Similarly, the inaccurate modelled absence of wedge ice stems from the surficial materials dataset.

Thermokarst implications: Ground surface subsidence and active-layer detachment slides are the primary implications from melt of near-surface segregated ice. Subsidence, ponding, and drainage is also likely as ice wedge networks thaw with climate change.

References: Gagnon, S. and Allard, M. 2020. Changes in ice-wedge activity over 25 years of climate change near Salluit, Nunavik (northern Québec, Canada). *Permafrost and Periglacial Processes*, 31(1), pp. 69-84.

Gauthier,S., Allard, M. and Mathon-Dufour, V. 2019. Climate and Permafrost Data Integration in Support of the Development of the Community of Salluit, Nunavik.18th International Conference on Cold Regions Engineering and 8th Canadian Permafrost Conference.

23. Kangiqsualujjuaq, QC

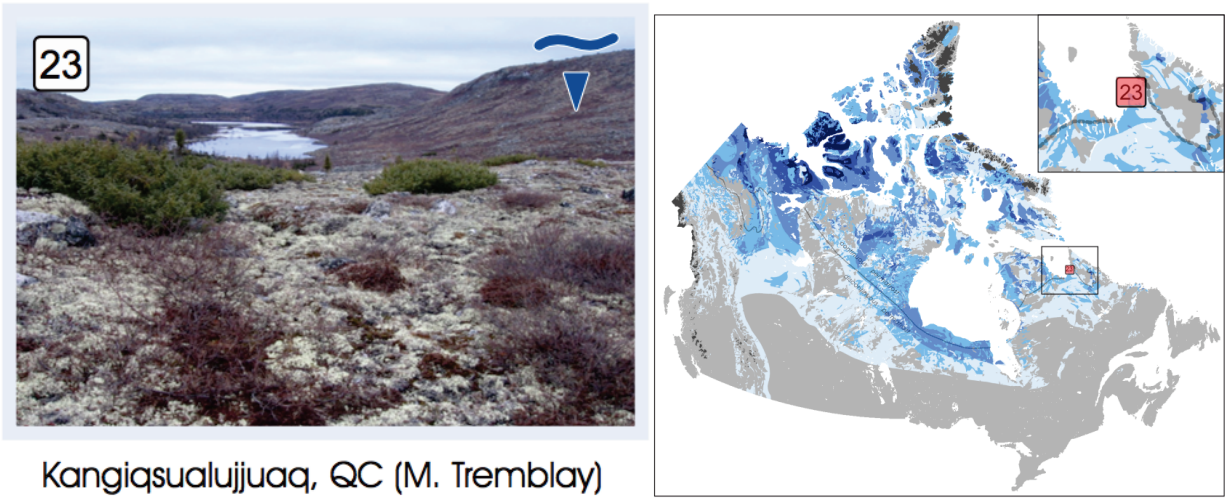


Figure 25. Kangiqsualujjuaq, Quebec. Left panel) Photo showing forest tundra terrain. Photograph courtesy of M. Tremblay. Right panel) Inset map showing site location 58.7071°N; -65.9618°W.

Modelled ground ice abundance: no relict ice; negligible segregated ice; negligible wedge ice

Description: Kangiqsualujjuaq is a community in northern Quebec on the eastern shore of Ungava Bay and George River. The underlying granitic gneisses constitute part of the Canadian Shield. Following deglaciation at about 9000 yr BP, the area was submerged by the D'Iberville Sea to a local elevation of about 150 m asl until about 7400 yr BP. Inland, areas were also affected by glacial lake Naskaupi until drainage about 6800 yr BP. Bedrock outcrops occur in much of the area, but can be overlain by till of variable thickness, with valleys occupied by coarse-grained glaciomarine sands and gravels with occasional silt lenses, and pockets of organic accumulation. MAAT is about -5.5 °C and MAP is about 400 mm, with 40% falling as snow. The area is located near the present-day treeline. Permafrost is discontinuous with MAGTs ranging from -3.0 to -0.25 °C, and the ground has been warming in response to air temperature increases. The active layer ranges from 0.5 to 2.8 m thick and permafrost may reach a depth of at least 20 m. Locally, permafrost has aggraded into fine-grained marine sediments and small permafrost mounds are evident within former estuary sediments.

Comments on modelled versus observed ice: The modelled absence of relict ice is appropriate due to post-glacial marine inundation. Both segregated ice and wedge ice appear to be modelled reasonably as negligible, because the generally coarse-grained sediments are not conducive to ice segregation, and the present-day discontinuous permafrost conditions near treeline inhibit thermal contraction cracking.

Thermokarst implications: Thermokarst in this region likely includes localized, low magnitude subsidence due to the melt of segregated ice and small ice wedges. With a warming climate, the rate of subsidence may increase but the magnitude will likely remain modest due to the low ground ice contents.

References: Allard, M., Seguin, M.K., Pelletier, Y. and Senneset, K. 1988. Shoreline permafrost in Kangiqsualujjuaq Bay, Ungava, Québec. In: *Fifth international conference proceedings on permafrost* .Vol. 1.

Seguin, M.K., Gahe, E., Allard, M. and Ben-Mikoud, K. 1988. Permafrost geophysical investigation at the new airport site of Kangiqsualujjuaq, Northern Quebec, Canada. In: *Proceedings of the Fifth International Conference on Permafrost*, Trondheim. Vol. 2, pp. 980-987.

24. Umiujaq, QC

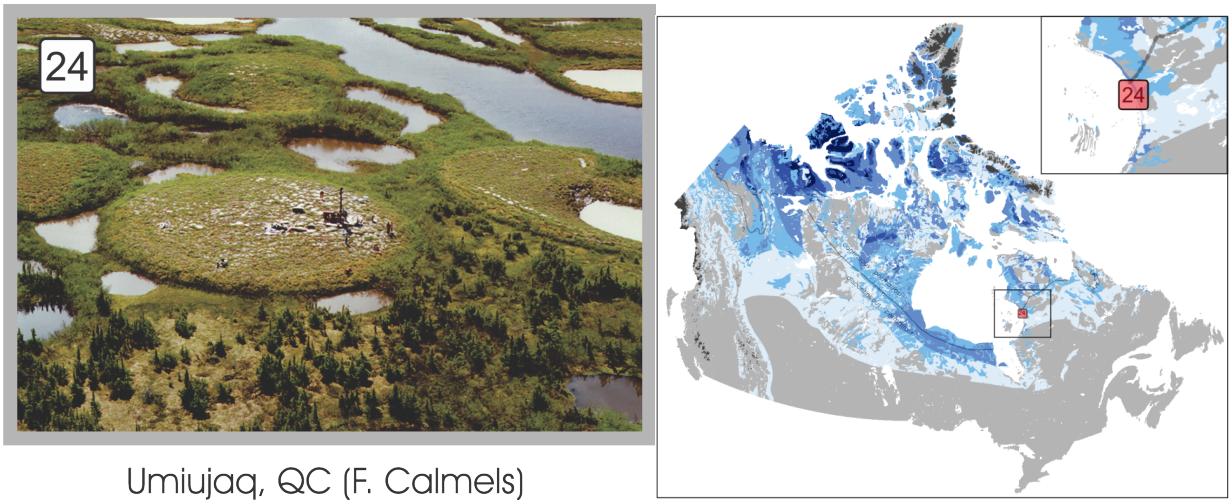


Figure 26. Umiujaq, Quebec. Left panel) Photo showing lithalsas in marine sediments. Photograph courtesy of F. Calmels. Right panel) Inset map showing site location at 56.6292°N; -75.8404°W.

Modelled ground ice abundance: no relict ice; no segregated ice; no wedge ice at location of photo. In region, zones of: no relict, medium segregated; negligible wedge ice (e.g., 56.987112 °N; -75.654419 °W)

Description: Umiujaq is on the eastern shore of Hudson Bay, Quebec. The region underwent marine inundation by the Tyrell Sea following deglaciation around 7500 yr BP. Bedrock includes brecciated basalts, with outcrops of underlying arenites and colluvium sediments on slopes. Fine-grained marine sediments and coarser littoral or deltaic sediments overlie low-lying areas. The climate is subarctic with MAAT of -5.5 °C and MAP of 500 mm, with about 40% falling as snow. MAGT of -2.5 °C has been measured at 10 m depth. Vegetation cover includes spruce forests and shrubs, with wetlands occupied by lichen or herb cover. The region is within the discontinuous permafrost zone along the southernmost boundary of widespread permafrost. Numerous palsas and minerogenic permafrost mounds, known as lithalsas, occupy the valley terrain in areas with fine-grained marine or littoral sediments. Most of these features are undergoing degradation and thermokarst ponds are common throughout the valleys.

Comments on modelled versus observed ice: No ice is modelled at the location of the photograph; this is inaccurate because the national-scale surficial materials dataset indicates this area is bedrock. In some other surrounding areas the surficial geology mapping similarly underrepresents fine-grained marine deposits. In areas surrounding the photo location, the modelled segregated ice abundance is more accurate where till or marine deposits are mapped at the national-scale. The absence of modelled relict ice is appropriate given past marine inundation. Negligible modelled wedge ice is also reasonable, as climatic conditions are marginal for thermal contraction cracking.

Thermokarst implications: Significant ground subsidence and formation of thermokarst ponds is and will continue to be the primary thermokarst processes in the area where fine-grained sediments occur. Increasing talik formation and groundwater flow can also be expected.

References: Fortier, R., LeBlanc, A.M., Allard, M., Buteau, S. and Calmels, F. 2008. Internal structure and conditions of permafrost mounds at Umiujaq in Nunavik, Canada, inferred from field investigation and electrical resistivity tomography. *Canadian Journal of Earth Sciences*, *45*(3), pp. 367-387.

Lemieux, J.M., Fortier, R., Murray, R., Dagenais, S., Cochand, M., Delottier, H., Therrien, R., Molson, J., Pryet, A. and Parhizkar, M. 2020. Groundwater dynamics within a watershed in the discontinuous permafrost zone near Umiujaq (Nunavik, Canada). *Hydrogeology Journal*, pp. 1-19.

25. Mayo, YK

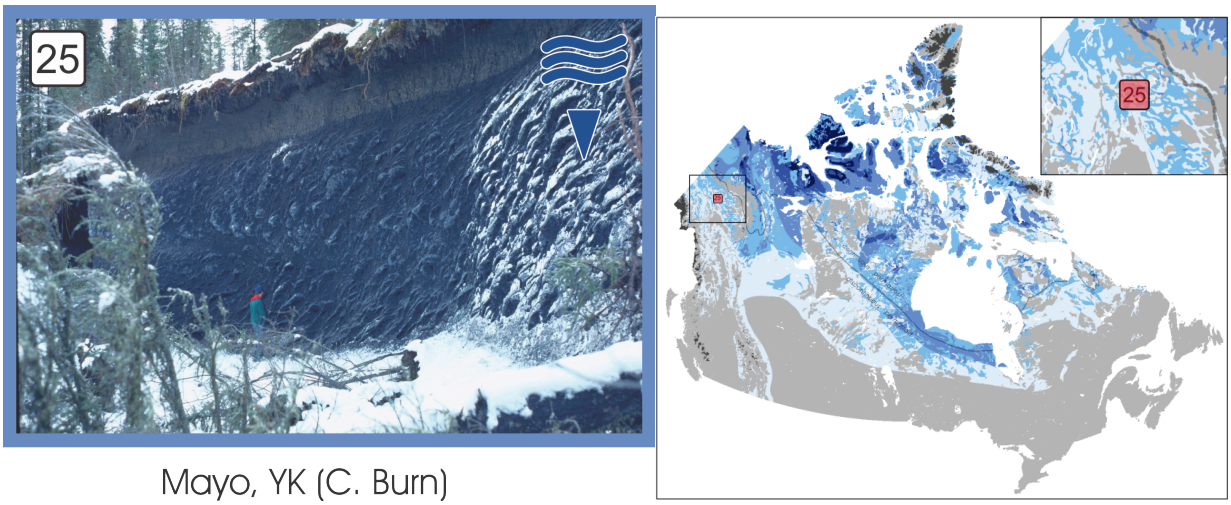


Figure 27. Mayo, Yukon Territory. Left panel) Photo showing segregated ice exposed in slump headwall. Photograph courtesy of C. Burn. Right panel) Inset map showing location at 63.5644°N; -135.8917°W.

Modelled ground ice abundance: no relict ice; medium segregated ice; low wedge ice

Description: Mayo is in central Yukon in the Stewart River Valley. The area is underlain mainly by quartzite and quartz-mica schist bedrock. Sediments in the valley bottom include alluvial and glaciofluvial deposits, and glaciolacustrine sediments deposited in a proglacial lake during the late-Wisconsinan McConnell glaciation. On valley sides and at higher elevation, surficial materials include moraine and colluvial deposits, and bedrock. The climate is continental, with warm summers and cold winters, a MAAT of -2.4 °C, and MAP of 314 mm, with 204 falling as rain. Permafrost is discontinuous with MAGTs typically >-2 °C, and maintained where thick organic layers are present. Vegetation includes coniferous and deciduous trees, shrubs, and mosses. Glaciolacustrine deposits include permafrost with high segregated ice content, which can average up to 90% ice by volume. Thaw slumps and thaw lakes occur in these deposits.

Comments on modelled versus observed ice: The absence of relict ice in glaciolacustrine sediments is reasonable given the prior inundation by a proglacial lake. The modelled medium segregated ice content under represents the volume of ice observed in local exposures at thaw slumps, but on a broader areal basis may be a more reasonable estimate. Low modelled wedge ice abundance seems reasonable given the small size of features observed at thaw slump headwalls, and the lack of expression of polygonal terrain in high-resolution satellite imagery.

Thermokarst implications: The high segregated ice content in glaciolacustrine sediments drives the formation of thaw slumps along the Stewart River and thaw lakes in flat, valley bottom terrain. Thaw lakes may expand and slumping activity could accelerate given anticipated climate change.

References:

Burn, C.R. 1990. Implications for palaeoenvironmental reconstruction of recent ice-wedge development at Mayo, Yukon Territory. *Permafrost and Periglacial Processes*, 1(1), pp. 3-14.

Burn, C.R. 1988. The development of near-surface ground ice during the Holocene at sites near Mayo, Yukon Territory, Canada. *Journal of Quaternary Science*, 3(1), pp. 31-38.

Hughes, O.L. 1983. Surficial Geology and Geomorphology, Janet Lake, Yukon Territory. *Geological Survey of Canada, Preliminary Map 4-1982*, 1 sheet.

26. Wolf Creek, YK

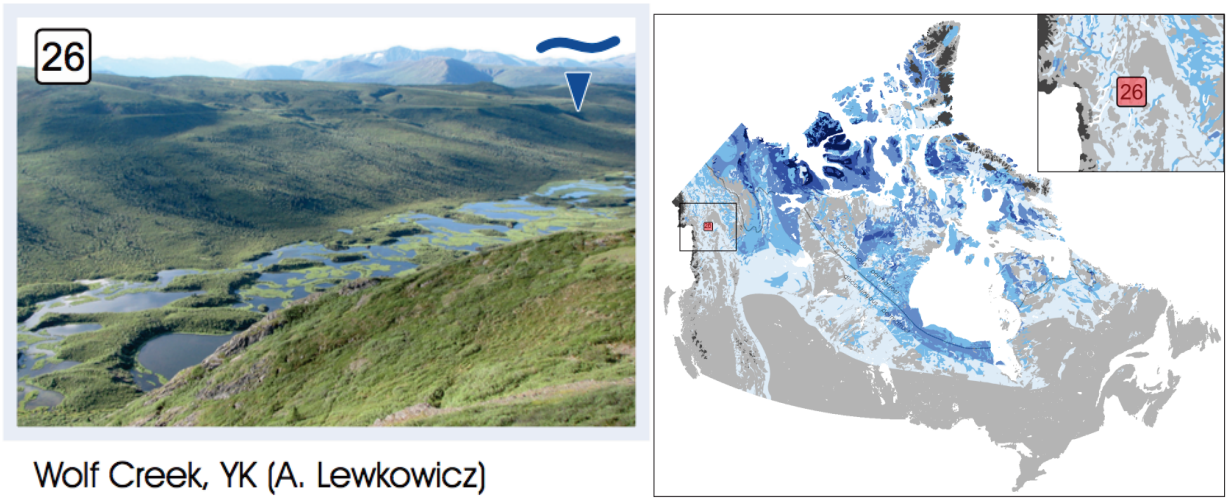


Figure 28. Wolf Creek, Yukon Territory. Left panel) Photo showing palsas in glaciolacustine sediments. Photograph courtesy of A. Lewkowicz. Right panel) Inset map showing location at 60.5000°N; -135.2167°W.

Modelled ground ice abundance: no relict ice; negligible segregated ice; negligible wedge ice

Description: Wolf Creek is about 20 km south of Whitehorse, Yukon. The local area is within a transitional zone between the Coast Mountains and the Yukon Plateau. Bedrock constitutes mid-Jurassic sandstones and in some areas, Whitehorse Suite mid-Cretaceous igneous dioritic intrusions. The area was glaciated by the Cassier lobe, and during deglaciation after about 11000 yr BP, this and other small valleys were occupied by glacial lakes, locally depositing fine-grained sediments. The MAAT is about -4.0 °C, and MAP ranges from 300 to 400 mm with about 40% falling as snow. Wolf Creek basin ranges in elevation from 800 to 2250 m asl and spans the altitudinal treeline, with vegetation ranging from sub-alpine forests below 1300 m asl to shrub tundra and bare surfaces at high elevations. Permafrost is sporadic, occupying about 30% of the area, mostly on north-facing slopes and at high elevations. More than 20 palsas have been observed in the area at an elevation of about 1250 m asl. These consist of a peat layer of 10 to 20 cm thickness, underlain by organic sands and silts containing segregated ice. Block collapse has occurred where water levels have risen, and mound development has occurred where ponds have drained.

Comments on modelled versus observed ice: The absence of modelled relict ice is appropriate because the area was inundated by a glacial lake. Negligible segregated ice abundance may be reasonable for the broader region, but may be higher locally as in areas with palsas. Negligible modelled wedge ice abundance is likely reasonable in this area with sporadic permafrost conditions.

Thermokarst implications: Some subsidence and degradation of palsas has been noted, but may arguably be due to water level changes controlled by beaver activity rather than climate. Nevertheless, with projected warming, subsidence and collapse of palas is probable, with likely effects on local surface hydrology.

References: Bond, J.D. 2004. Late Wisconsinan McConnell glaciation of the Whitehorse map area (105D), Yukon. *Yukon Exploration and Geology, 2003*, pp.73-88.
Coultish, T.L. and Lewkowicz, A.G. 2003. Palsa dynamics in a subarctic mountainous environment, Wolf Creek, Yukon Territory, Canada. In: *Permafrost, Proceedings of the Eighth International Conference on Permafrost*. Vol. 21, p. 25.

27. Scotty Creek, NT

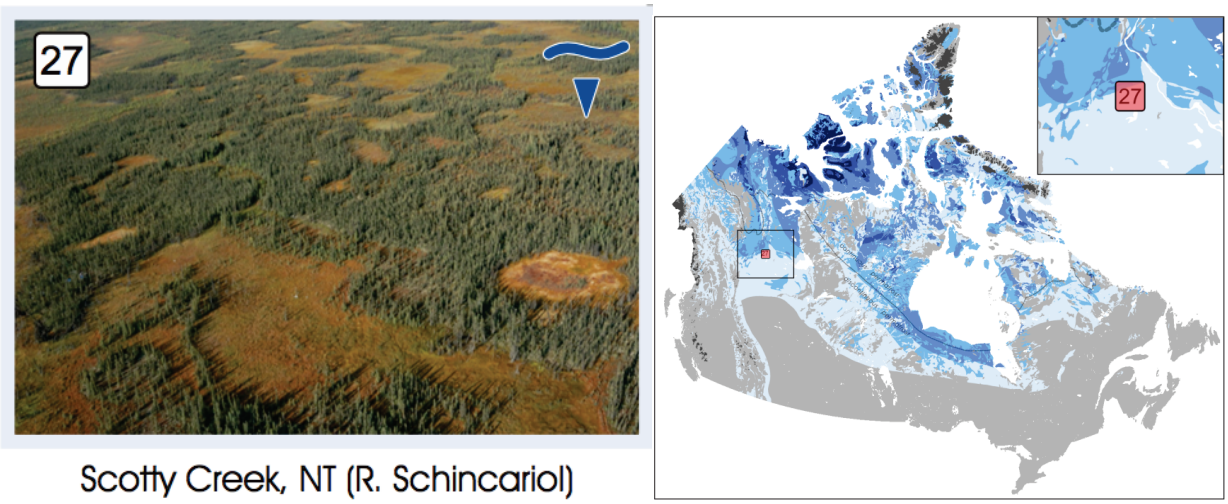


Figure 29. Scotty Creek, Northwest Territories. Left panel) Photo showing forested peatland terrain. Photograph courtesy of R. Schincariol. Right panel) Inset map showing site location at 61.1074°N; -120.2643°W.

Modelled ground ice abundance: no relict ice; negligible segregated ice; negligible wedge ice

Description: Scotty Creek is about 50 km south of Fort Simpson, NT. Sandstone and shale underlies the area and may be apparent as rounded hills covered by discontinuous reworked till, colluvium, and rubble. The region is poorly drained and of low relief, and includes large areas of bog and fen. The area includes a nearly continuous thick organic cover overlying mainly fine-grained till and glaciolacustrine deposits with a high clay and silt content. The climate is continental with a MAAT of -2.8 °C and MAP of 388 mm, with 239 mm falling as rain. Permafrost is sporadically distributed, maintained only on peat plateaus with thick and dry peat cover. Permafrost temperatures are very close to 0 °C. Vegetation includes black spruce trees, Labrador tea, and lichen on peat plateaus, and sphagnum moss species in bog areas. Segregated ice forms the foundation of the peat plateaus in the region. Though relict ice wedges have been observed near Fort Simpson, recent research in the area has not mentioned the presence of wedges in the area.

Comments on modelled versus observed ice: The absence of modelled relict ice is reasonable given the landscape history. Though locally on peat plateaus the segregated ice content may be high, permafrost is only present under 10-50% of the landscape, and so at the scale of the ground ice mapping, negligible ice abundance may be reasonable. The negligible modelled wedge ice abundance is appropriate considering that the climate is not conducive to thermal contraction cracking, and there is a lack of evidence of this ice form.

Thermokarst implications: Thermokarst processes are actively degrading peat plateaus in the region and causing bog expansion, accelerated by disturbance from wildfire and warming temperatures.

References: Geological Survey of Canada. 2018. Surficial geology, Fort Simpson, Northwest Territories, NTS 95-H. Geological Survey of Canada, *Canadian Geoscience Map 369*, (ed. surficial data model v.2.3.14 conversion), 1 sheet.
Quinton, W., Berg, A., Braverman, M., Carpino, O., Chasmer, L., Connon, R., Craig, J., Devoie, É., Hayashi, M., Haynes, K., Olefeldt, D., Pietroniro, A., Rezanezhad, F., Schincariol, R. and Sonnentag, O. 2019. A synthesis of three decades of hydrological research at Scotty Creek, NWT, Canada, *Hydrol. Earth Syst. Sci.*, 23, 2015–2039.

28. Great Slave Lowlands, NT

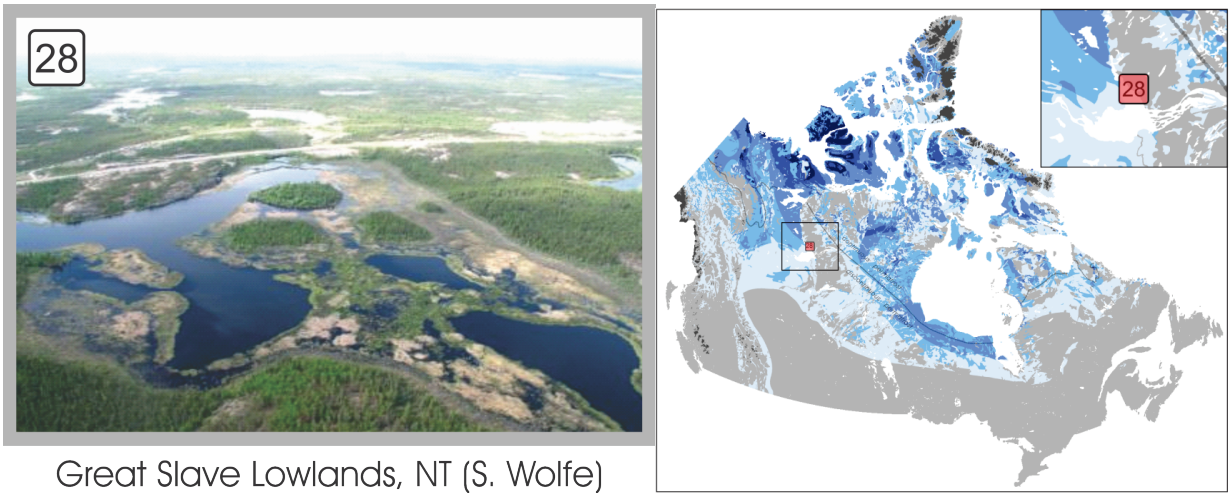


Figure 30. Great Slave Lowlands, Northwest Territories. Left panel) Photo showing lithalsas in glaciolacustrine sediments. NRCan photo 2020-094 by S. Wolfe. Right panel) Inset map showing site location at 62.5178°N; -114.8497°W.

Modelled ground ice abundance: no relict ice; no segregated ice ; no wedge ice

Description: The Great Slave Lowlands lie along the shore of Great Slave Lake. The area is characterized by low-relief Precambrian granitic bedrock with glaciolacustrine and alluvial sediments between bedrock outcrops. Following glacial retreat, the region was inundated by Glacial Lake McConnell to an elevation of about 250 m asl. Consequently, exposed till is rare, and typically occurs as washed sediments, but may underlie glaciolacustrine sediments. The area is underlain by discontinuous permafrost; permafrost is present beneath peatlands and spruce and mixed-forests underlain by silty clay sediments. MAAT at Yellowknife is about -4.1 °C and MAP is 291 mm, with 41% falling as snow. MAGTs range from -1.4 °C within black spruce forests to -0.02 °C in a burned peatland. MAGT at sites with visible signs of permafrost degradation are generally warmer than -0.2 °C. Ground ice is present in the form of segregated ice lenses within fine-grained sediments. Lithalsas are abundant as is evidence of lithalsa degradation. Buried ice is absent, owing to prior glacial lake inundation. Some ice wedge polygons are present within organic terrain, but wedge ice appears generally absent owing to past melting of ground ice.

Comments on modelled versus observed ice: Ground ice is poorly modelled with respect to segregated ice owing to the absence of glaciolacustrine sediments mapped in the region. Inclusion of revised surficial maps in the modelling would improve these conditions. Relict ice is reasonably modelled as none owing to glacial lake inundation. Wedge ice abundance is modelled as none, due to the lack of sediments mapped at the national scale, although this may be reasonable regardless of surficial cover because the past Holocene warm interval and present-day warm permafrost conditions, which limit the likelihood of wedge ice accumulation and preservation.

Thermokarst implications: Subsidence due to melting of segregated ice lenses within fine-grained sediments is both the present and the future major thermokarst concern. Localized subsidence of 2 to 4 m has occurred in association with disturbance at lithalsas.

References: Wolfe, S.A., Morse, P.D., Kokelj, S.V. and Gaanderse, A.J. 2017. Great Slave lowland: the legacy of glacial lake McConnell. In: *Landscapes and Landforms of Western Canada* (pp. 87-96). Springer, Cham.

29. Wapusk National Park, MB

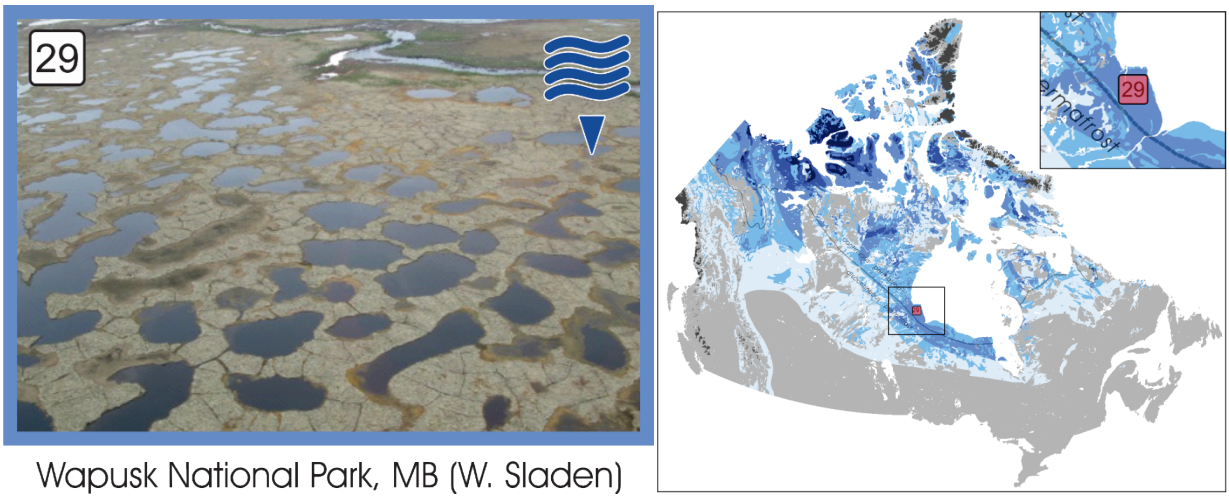


Figure 31. Wapusk National Park, Manitoba. Left panel) Photo showing ice wedges and melt ponds. NRCan photo 2020-095 by W. Sladen. Right panel) Inset map showing site location at 58.2061°N; -93.7501°W.

Modelled ground ice abundance: no relict ice; high segregated ice; negligible wedge ice

Description: Wapusk National Park, northern Hudson Bay Lowlands, is 45 km south of Churchill, MB. The region is underlain by Paleozoic limestone and covered by extensive post-glacial Tyrell Sea silt and clay marine deposits. Elevation ranges from 0 to about 70 m asl, and the area has undeegone marine emergence in the last ca. 8000 years. MAAT ranges from -6.5 °C at Churchill to -4.5 °C at the southern end of the park. MAP is about 430 mm at Churchill with 45% falling as snow. Air temperature and precipitation have increased historically. Permafrost is generally continuous, except in the southernmost corners of the park straddling the treeline. The area is covered by thick peat and exhibits local relief of less than 2 m. The landscape includes extensive polygonal peat plateau bogs, channel fens, and open water ponds. Peat plateaus have MAGT of around -4.0 °C, and fens about -2.0 to -3.0 °C. Summer thaw depths are typically <1 m, but range from <50 cm to >2 m. The peat plateaus in the area are the result of segregated ice accumulation in the fine-grained sediments. Pond sizes have not changed historically.

Comments on modelled versus observed ice: Modelled relict ice abundance is appropriate given postglacial inundation of the area. High modelled segregated ice content is reasonable as permafrost is continuous, sediments are highly frost-susceptible, and peat plateaus are common. Wedge ice may be under-represented as negligible in the modelling, as well-developed polygonal networks are evident; this may be because the model does not represent enhanced thermal contraction cracking and wedge ice accumulation in saturated organic materials.

Thermokarst implications: Continued warming will enhance permafrost degradation, resulting in subsidence of peat plateau bogs. Ice wedges will also likely melt, producing ponds and altering hydrological connectivity of surface waters. Permafrost thaw can collapse peat banks, and locally affect polar bear denning habitats, hydrology, vegetation and release of methane and carbon dioxide.

References: Dyke, L.D. and Sladen, W.E. 2010. Permafrost and peatland evolution in the northern Hudson Bay Lowland, Manitoba. *Arctic*, 63, pp. 429-441.
Zhang, Y., Li, J., Wang, X., Chen, W., Sladen, W., Dyke, L., Dredge, L., Poitevin, J., McLennan, D., Stewart, H. and Kowalchuk, S. 2012. Modelling and mapping permafrost at high spatial resolution in Wapusk National Park, Hudson Bay Lowlands. *Can. Journal of Earth Sciences*, 49, pp. 925-93.

30. Polar Bear Provincial Park, ON

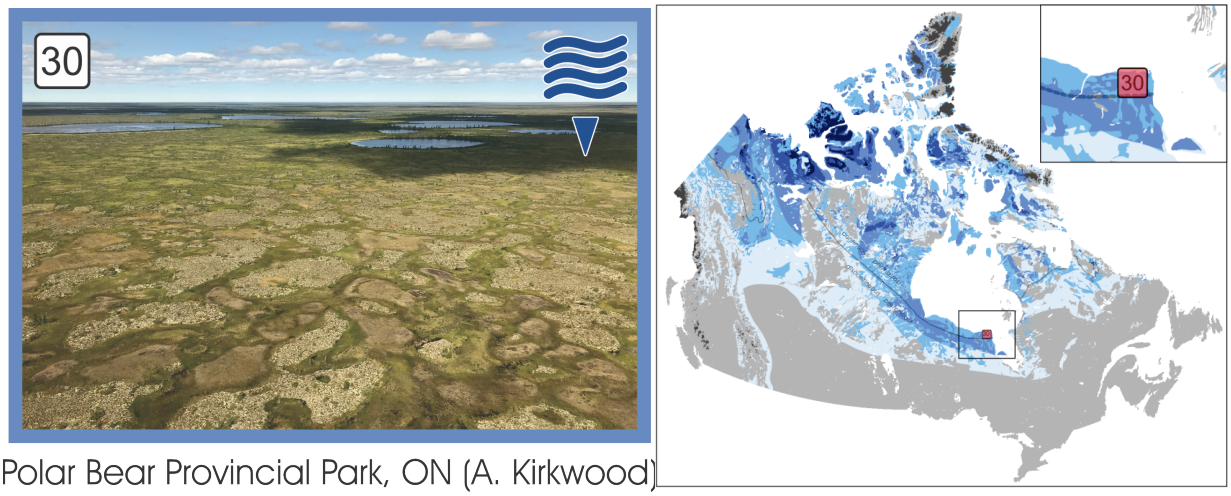


Figure 32. Polar Bear Provincial Park, Ontario. Left panel) Photo showing peatland terrain. Photograph courtesy of A. Kirkwood. Right panel) Inset map showing site location at 54.8195°N; -83.1048°W.

Modelled ground ice abundance: no relict ice; high segregated ice; negligible wedge ice

Description: Polar Bear Provincial Park is in Northern Ontario, at the juncture of James Bay and Hudson Bay in the eastern Hudson Bay Lowlands. This flat, low relief region is primarily underlain by Silurian limestones. The area was inundated by the Tyrell Sea following deglaciation and surficial sediments are primarily shallow coastal deposits with extensive beach ridges and some areas of silty-clayey till. Emergence due to isostatic rebound has occurred progressively over the last ~8000 years. Thick peat has accumulated on the surface, and the landscape includes peat plateaus, bogs, fens, and small ponds. MAAT at Peawanuk is -5.5 °C and MAP is about 600 mm with about 30% falling as snow. Permafrost is continuous near the coast, but transitions to discontinuous along a pronounced gradient with distance south. Low tundra vegetation covers the landscape, with lichens on dryer peat plateaus. The presence of shrub and small tree growth has been noted at margins of degrading palsas.

Comments on modelled versus observed ice: Relict ice is reasonably modelled as none owing to marine inundation following glaciation. High modelled segregated ice abundance is reasonable given the common occurrence of palsas and peat plateaus in the area and the frost-susceptible sediments. Negligible wedge ice is likely appropriate owing to the sustained relatively warm conditions through the Holocene.

Thermokarst implications: Degradation of palsas and peat plateaus is the primary ongoing process resulting in subsidence and the expansion of fens and ponds. Rising air temperatures will likely cause further degradation as permafrost thaws.

References: Kirkwood, A., Roy-Léveillée, P., Packalen, M., McLaughlin, J. and Basiliko, N. 2019. Evolution of Palsas and Peat Plateaus in the Hudson Bay Lowlands: Permafrost Degradation and the Production of Greenhouse Gases. In: *Cold Regions Engineering 2019* (pp. 597-606). Reston, VA: American Society of Civil Engineers.
Pironkova, Z. 2017. Mapping Palsa and Peat Plateau Changes in the Hudson Bay Lowlands, Canada, Using Historical Aerial Photography and High-Resolution Satellite Imagery. *Canadian Journal of Remote Sensing*, 43(5), pp. 455-467.

31. Big Bay, NL

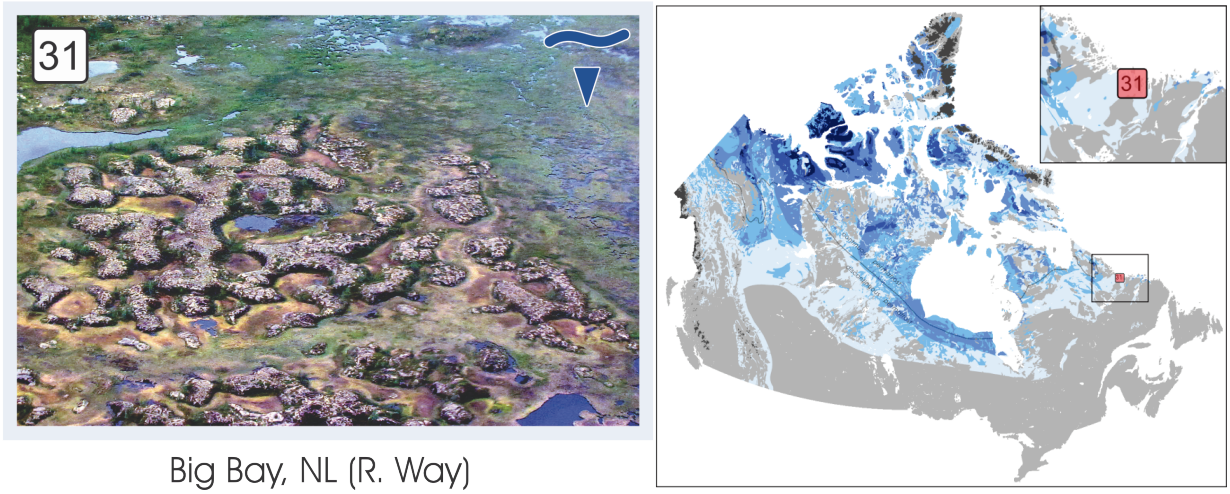


Figure 33. Big Bay, Newfoundland. Left panel) Photo showing peatland terrain. Photograph courtesy of R. Way. Right panel) Inset map showing site location at 55.6895°N; -60.4439°W.

Modelled ground ice abundance: no relict ice; negligible segregated ice; negligible wedge ice

Description: The area is located west of Big Bay and south of Nanaksaluk Island, about 32 km northwest of Hopedale, Labrador. The area lies on the southeastern part of the Canadian Shield on the Atlantic Coast at an elevation of about 40 m asl. Deglaciation occurred at about 10000 yr BP, and the area was subsequently inundated to an elevation of at least 100 m asl. MAAT at Hopedale is -1.0 °C and MAP is 346 mm, with about half falling as snow. The area is dominated by exposed bedrock, but coarse-grained marine and littoral deposits and finer-grained sub-littoral deposits occur in valleys. Pockets of organic terrain are common and may include permafrost terrain that is considered relict, as it would not form under the present-day climate.

Comments on modelled versus observed ice: The modelled absence of relict ice is appropriate given the past marine inundation. Segregated ice is likely reasonably modelled as negligible, as there are limited fine-grained materials and only localized pockets of peatland with permafrost. Wedge ice may be reasonably modelled as negligible, or may be absent in the area.

Thermokarst implications: Thermokarst activity may include localized subsidence of peatland terrain as underlying permafrost thaws.

References: Way, R.G., Lewkowicz, A.G. and Zhang, Y. 2018. Characteristics and fate of isolated permafrost patches in coastal Labrador, Canada. *The Cryosphere*, *12*(8), pp. 2667-2688.
Fulton, R.J. ed. 1989. *Quaternary geology of Canada and Greenland* (Vol. 2). Ottawa, Ontario: Geological Survey of Canada.