Geological Survey of Canada
Scientific Presentation 77

MODELLING GROUND-ICE POTENTIAL IN CANADA

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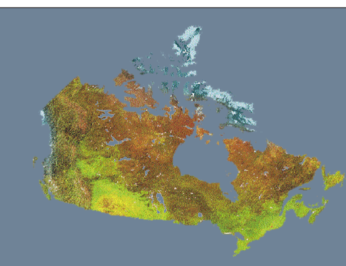
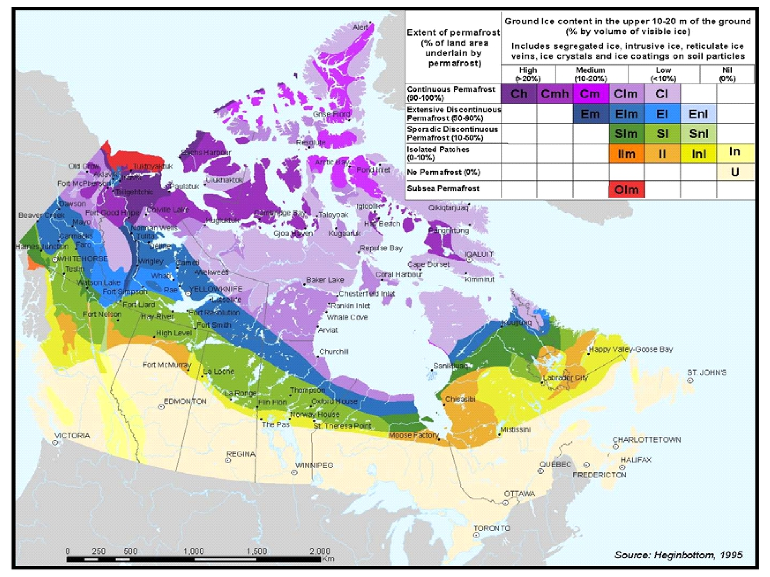
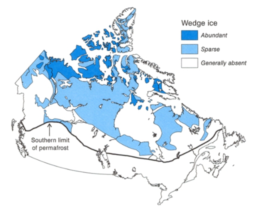


PRESENT KNOWLEDGE

The Permafrost Map of Canada (MCR 4177) is the primary source representing ground ice in Canada. However, this map has several limitations including a rudimentary differentiation of ground ice types, an absence of accessible source data and metadata, and coarse spatial resolution.

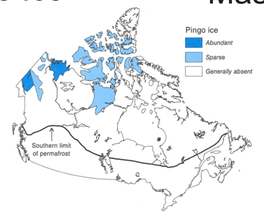


Heginbottom, J.A., Dubreuil, M.-A. and Harker, P.A.C. 1995. Canada – Permafrost. National Atlas Information Service and Geological Survey of Canada, Plate 2.1, MCR 4177



Wedge Ice

Massive Ice



Pingo Ice

Smith, S.L., Burgess, M.M., Heginbottom, J.A. 2001. Permafrost in Canada, a challenge to northern development; in, A synthesis of geological hazards in Canada; Brooks, G R (ed.). Geological Survey of Canada, Bulletin 548, p. 241-264, 1 sheet.

OUR APPROACH

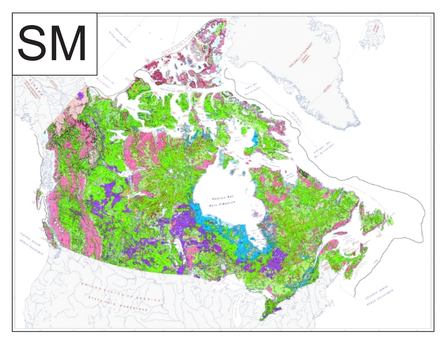
The depiction of ground ice at the national scale necessarily includes extrapolation based on limited field data and the application of expert knowledge. Our objective is to present a methodology and early results from a new national-scale modelling effort to depict three common ground ice types: segregated ice, buried (glacigenic) ice, and wedge ice.

Segregated ice forms during initial permafrost aggradation, and by accumulation over time from repeated freezing and thawing of the active layer. Buried ice, represented here primarily by glacigenic ice, is preserved within permafrost by a sediment cover. Wedge ice forms within permafrost in regions where air temperatures are conducive to thermal contraction cracking of the ground.

Surficial geology, glaciation, paleo-biome, and permafrost map data combined with knowledge-based associations between environmental conditions and ground ice are used in a model within a GIS to determine ground ice potentials for these three ice types.

THE DATASETS

Modelled ground-ice potentials are based on knowledge of glacial and post-glacial sedimentary processes as well as past and present environments from existing national-scale datasets. These include: **GM** - the Glacial Map of Canada (*GSC Map 1253A*), **SM** - the Surficial Geology of Canada (*GSC CGM 195*), **Bh** - the combined Paleovegetation Maps of Northern North America (*GSC Open File 4682*) and Deglaciation of North America (*GSC Open File 1574*), and **Pf** - the Permafrost Map of Canada (*MCR 4177*).

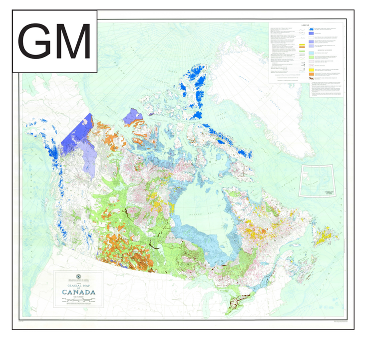


The Surfical Geology of Canada (SM) provides a dataset of surficial geology, which is simplified in the model to 22 unique surficial geology units.

The surficial geology units are used to define the initial potentials for each of the three ice types based on frost susceptibility, buried ice potential, and ice wedge cracking susceptibility.

Ice preservation and ice wedge cracking potentials under various biome and permafrost distributions are also determined for each surficial unit.

Surficial geology of Canada / Géologie des formations superficielles du Canada; Geological Survey of Canada. Geological Survey of Canada, Canadian Geoscience Map 195, (ed. Prelim., Surficial Data Model V.2.0 Conversion of "A" Map Series 1880A), 2014, 1 sheet.



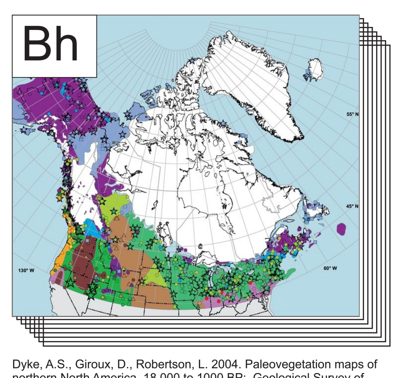
The Glacial Map of Canada (GM) provides the distribution of hummocky moraines, and glacial lake and marine limits. The addition of hummocky moraines to the surficial materials (SM) data provides a modified surficial materials (SM+) dataset.

GM + SM = SM+

These data layers are used to modify buried ice potentials based on hummocky moraine distribution (with high glacigenic ice potential) and lake or marine inundation (which reduces potential for buried ice preservation).

The maximum marine limit further defines the extent of potentially saline permafrost.

Prest, V.K., Grant, D. R., Rampton, V. N. 1968. Glacial map of Canada; Geological Survey of Canada, "A" Series Map 1253A, 1 sheet.



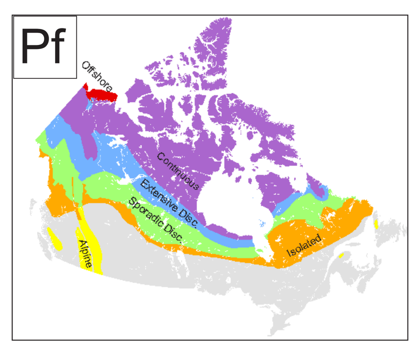
The combined paleovegetation and deglaciation maps (Bh) provide biome, ice sheet, and glacial lake distribution for the last 16,000 years BP.

These are used to determine the limits of preserved ice based on tundra and forest biome distributions.

The relative frequency of ice wedge cracking are modelled through time from herb tundra, shrub tundra, alpine and forest tundra biome distributions.

Dyke, A.S., Giroux, D., Robertson, L. 2004. Paleovegetation maps of northern North America, 18 000 to 1000 BP; Geological Survey of Canada, Open File 4682, 1 sheet; 1 CD-ROM.

Dyke, A.S., Moore, A., Robertson, L. 2003. Deglaciation of North America; Geological Survey of Canada, Open File 1574, 2 sheets; 1 CD-ROM.



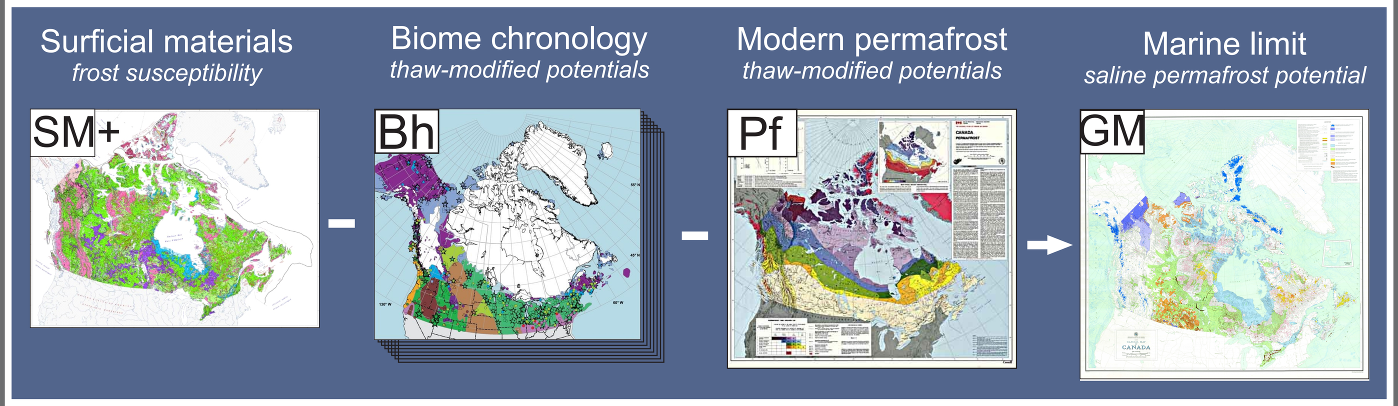
The Permafrost Map of Canada (Pf) provides "present-day" permafrost distributions which constrains the ground ice potential.

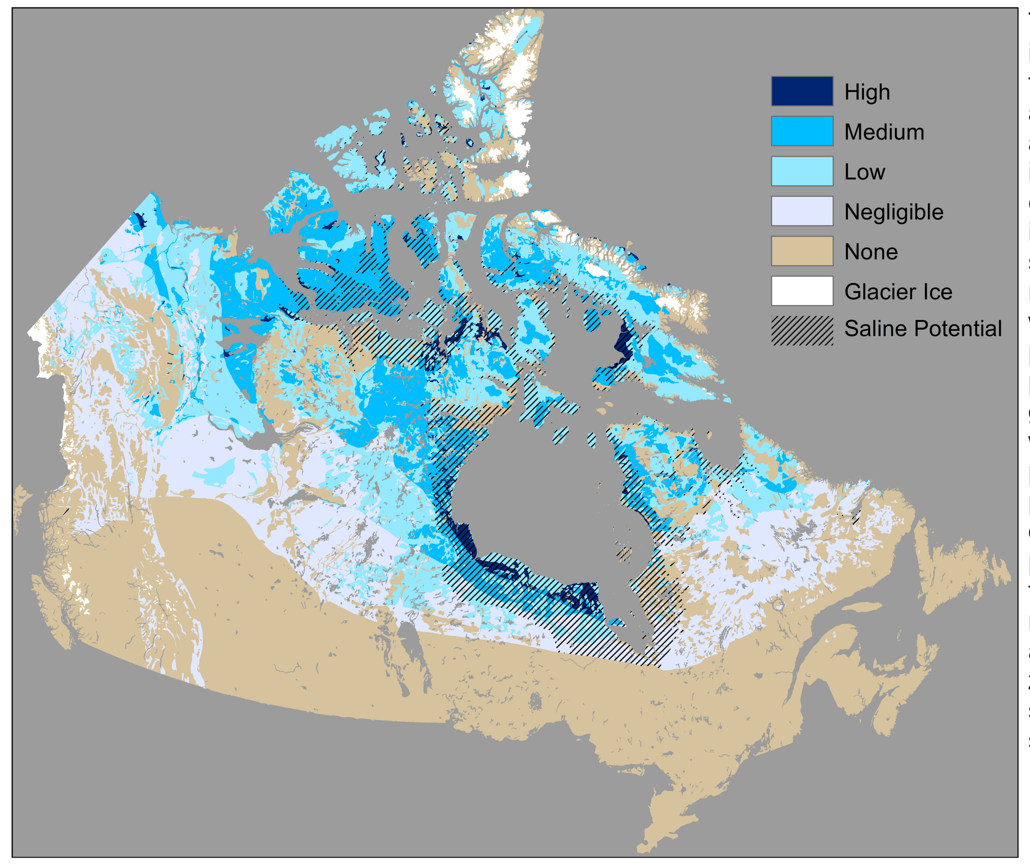
Heginbottom, J.A., Dubreuil, M.-A. and Harker, P.A.C. 1995. Canada – Permafrost. National Atlas Information Service and Geological Survey of Canada, Plate 2.1, MCR 4177

PRELIMINARY RESULTS

SEGREGATED ICE

Segregated ice potentials are assessed initially by the frost susceptibility of each surficial material type. The potentials are then thaw-modified based on past biomes and present-day permafrost distributions. Areas of marine inundation also define the potential for saline permafrost.

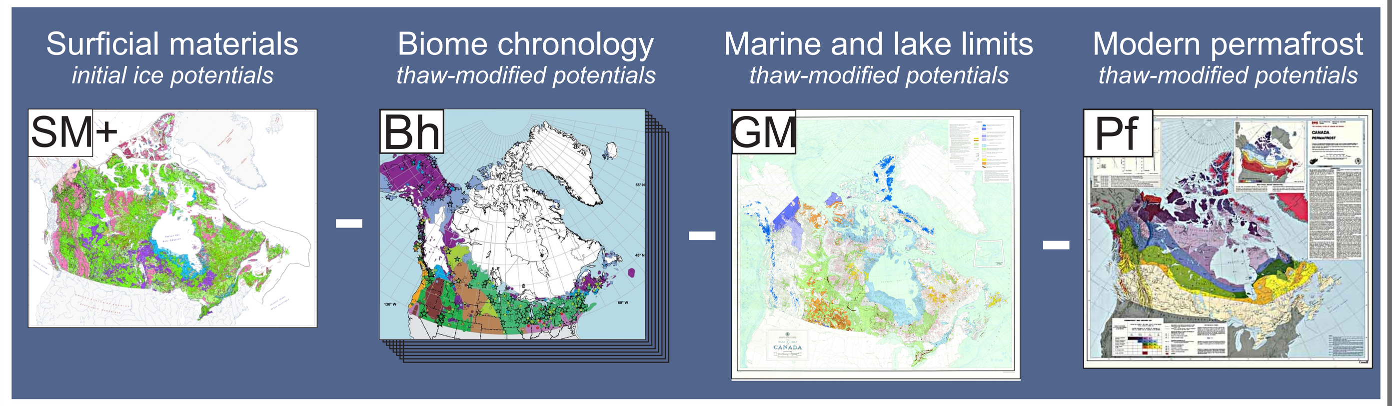


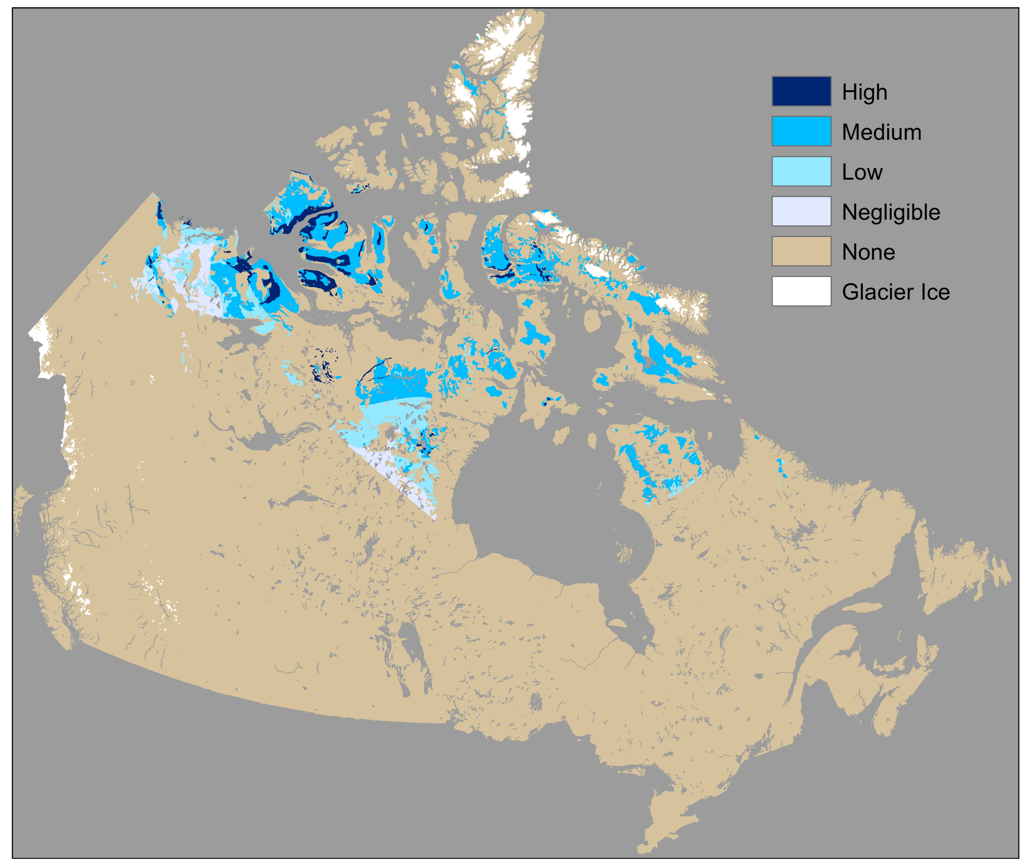


The present-day segregated ice potential illustrates where this ice may occur in relative abundance today. Notable areas of high potential include the Hudson Bay coastlands and arctic islands, where fine-grained sediments exposed following marine recession occur within continuous permafrost. Other high potential areas include glaciolacustrine sediments within continuous permafrost. There is potential for segregated ice occurrence throughout all permafrost zones today, though it is generally low to negligible in discontinuous and isolated permafrost zones. The hatched area shows the limit of potential saline permafrost.

BURIED (GLACIGENIC) ICE

Buried ice potentials are defined for surficial material types. Potentials are highest within thick till, moderate within glaciofluvial sediments, and absent in sediment veneers and bedrock. Buried ice potential is thaw-modified by past biome distributions and is reduced in areas of marine and lake inundation. The potentials are further thaw-modified based on the modern permafrost distribution.

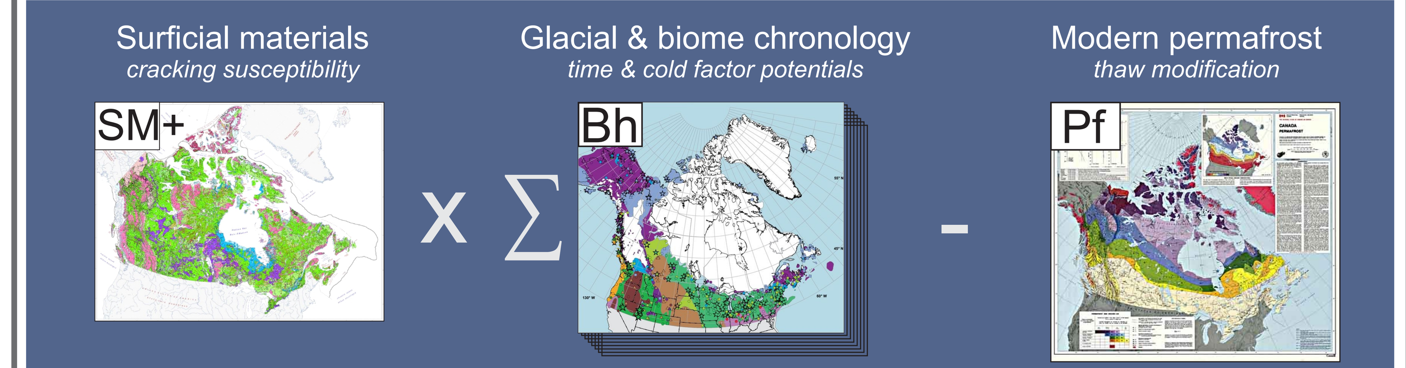


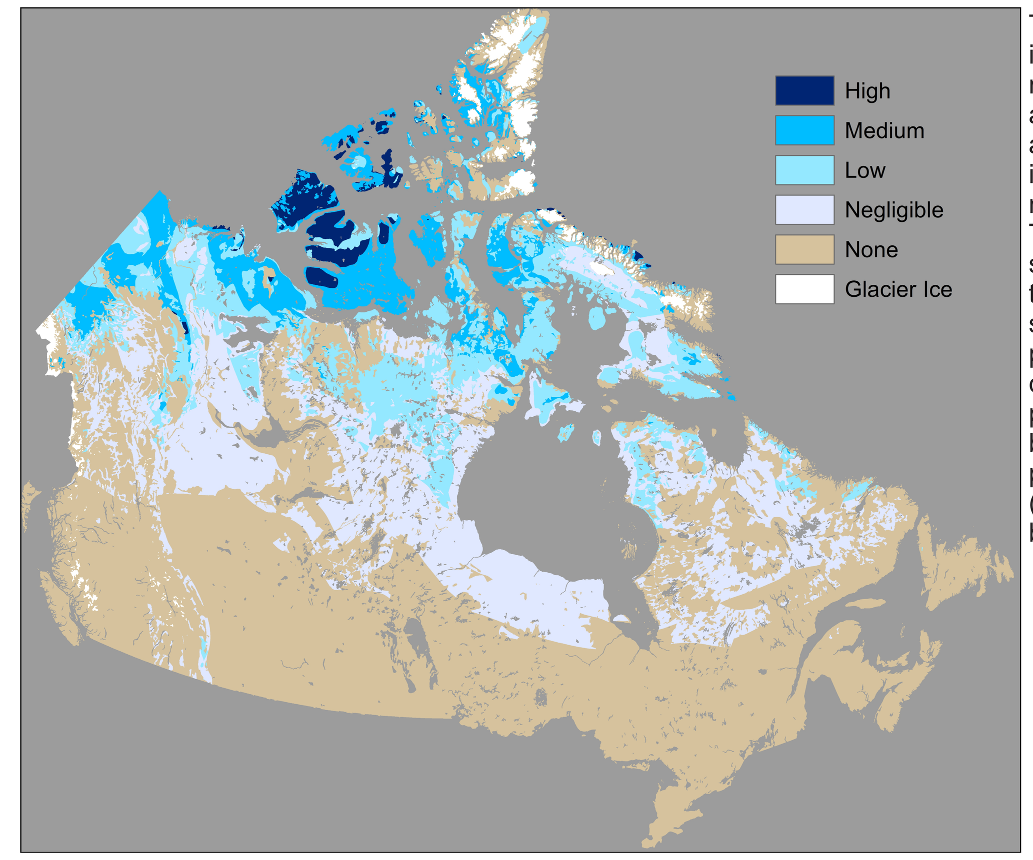


The present-day buried glacigenic ice potential illustrates where this ice may occur in relative abundance today. Notable areas of high potential include Banks Island, Victoria Island and the western Arctic mainland. Here, buried glacigenic ground ice contained within hummocky moraines has been preserved within herb and shrub tundra in continuous permafrost since deglaciation. Other notable areas of high to medium potential include the northern Slave Geological Province, the Keewatin, northernmost Nunavik, and Baffin Island. Buried ground ice is considered absent beyond present-day continuous permafrost.

WEDGE ICE

Wedge ice potential is determine based on surficial material types and time/cold factor potentials, which are then set in relation to biomes (high in herb tundra, medium in shrub and alpine tundra, low in forest tundra, and absent in boreal forest and all other biomes). The biome-based potentials accumulate in time steps since deglaciation or terrestrial exposure following lake or marine inundation. The wedge ice potential is then thaw-modified by the present-day permafrost distribution.





The wedge ice potential illustrates where this ice may occur in relative abundance today. Notable areas of high potential include Banks Island, northern Victoria Island, the Tuktoyaktuk peninsula, and small areas on Baffin Island that have been unglaciated since 16 ka BP. Wedge ice potential is largely contingent upon the time period that the terrain has been subjected to cold permafrost environments (i.e., within the herb tundra biome).

1 Old Crow Basin

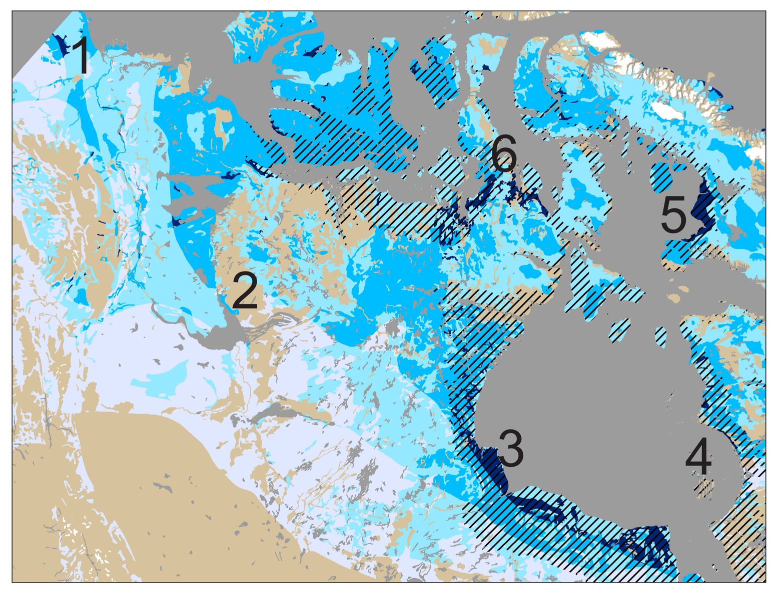
Thaw lakes observed within fine-grained lacustrine sediments

2 Great Slave Lowlands

Lithalsas observed extensively in glacio-lacustrine sediments

3 Wapusk

Extensive raised peat plateaus in marine sediments



4 Umiujac

Abundant lithalsas in marine sediments

5 Foxe Basin

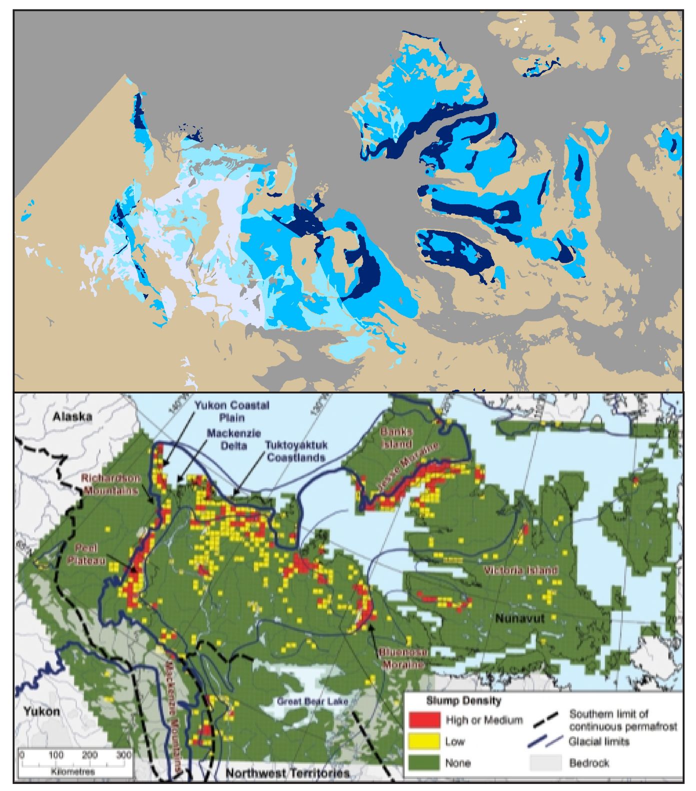
Extensive shallow thaw lakes within raised marine sediments

6 Boothia Peninsula

Shallow thaw lakes in raised marine sediments

Segregated ground ice potential is broadly modelled across the permafrost-affected regions of Canada due to the widespread distribution of frost-susceptible sediments. Five areas of high segregated ice potential and one area of medium potential are notable. The Old Crow Basin (1) and the Great Slave Lowlands (2) are both areas with fine-grained lacustrine sediments. There is widespread excess ice throughout the sediments in the Old Crow Basin, whereas excess ice occurs in localized mounds (i.e., lithalsas) in Great Slave Lowlands. Within the Hudson Bay Lowlands, areas of high segregated ice potential contain extensive raised peat plateaus as at Wapusk (3), or lithalsas as at Imuijac (4) in raised marine sediments. The Foxe Basin (5) and southern Boothia Peninsula (6) in the northeastern Arctic are both within the limits of marine inundation and contain fine-grained sediments. Shallow thaw lakes are abundant at both locations.

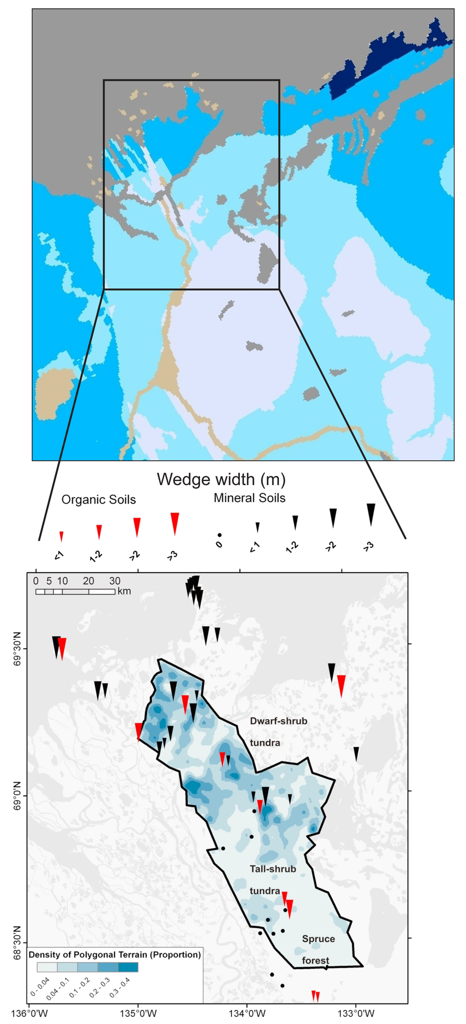
PRELIMINARY TESTING



Comparing buried glacigenic ground ice potential (top) to slump mapping in the Northwest Territories (bottom), areas of high buried glacigenic ground ice potential correspond generally to areas of observed high-to-medium slump density mapped by Kokelj et al. (2017). These areas are notably mapped as hummocky moraine on the Glacial Map of Canada (GSC Map 1253A) and have remained within tundra biomes and continuous permafrost since deglaciation.

The modelled buried glacigenic ice in the western arctic strongly reflects the distribution of hummocky moraines but is significantly modified by former marine limits, northward Holocene treeline advances and present-day permafrost.

Kokelj et al. 2017. Climate-driven thaw of permafrost preserved glacial landscapes, northwestern Canada. Geology; doi: 10.1130/G38626.1



Comparison of ice wedge potential (top) to width of ice wedges in the forest-tundra transition zone of the western Arctic Canada by Kokelj et al. (2014) (bottom), show that areas of negligible wedge ice potential generally correspond to smaller ice wedges observed only within organic soils. Low wedge ice potential corresponds to small-to-moderate sized ice wedges observed within both mineral and organic soils, and areas of medium ice wedge potential correspond to medium-to-large ice wedges observed in both soil types further north.

The modelled output of ice wedge potential in this region strongly reflects the combined effects of timing since deglaciation, past and present biome distributions (including hypsithermal tree-line advance), and the present-day permafrost distribution.

Note that high ice wedge potential is modelled on the northwestern Tuktoytakuk Peninsula. This is due to the persistence of herb and shrub tundra biomes there since deglaciation.

Kokelj, S.V., Lantz, T.C., Wolfe, S.A., Kanigan, J.C., Morse, P.D., Coutts, R., Molina-Giraldo, N., Burn, C.R. 2014. Distribution and activity of ice wedges across the forest-tundra transition, western Arctic Canada. *J. Geophys. Res. Earth Surf.*, 119, 2032–2047, doi:10.1002/2014JF003085.

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