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Abstract

The Kivalliq region, Nunavut, is an area with significant proposed infrastructure development, including a 1,200 km long hydroelectric/fibre optic link from southern Canada. Knowledge of ground ice conditions is important to assess potential impacts of climate change and permafrost thaw on existing and planned infrastructure. However, limited information on ground ice exists for this region. The Geological Survey of Canada (GSC) developed updated ground ice mapping at the national scale for Canada and tested the modelling framework at regional scales using more detailed surficial geology mapping from Canadian Geoscience Maps (CGMs). The modelling outputs depict the estimated relative abundance of relict (buried glacial) ice, segregated ice, and wedge ice in the upper five metres of permafrost. Here we provide spatial data files for modelling for the Kivalliq region based on standardized 1:125,000 scale surficial geology mapping. For this region, the modelling routine was updated to include the latest interpretation of the maximum regional marine limits following deglaciation, which likely improves the accuracy of the relict ice model output. Relict ice is predicted in limited areas above the postglacial marine limit. High segregated ice abundance occurs in fine-grained marine deposits below the marine limit. Segregated ice abundance is modelled as medium or low in thicker till deposits. Wedge ice abundance is predicted as negligible or low due mainly to the relatively short period since the terrain was exposed following deglaciation. Although the relative abundance is commonly modelled as negligible, ice wedges represent localized hazards to infrastructure due to the differential subsidence that accompanies permafrost degradation in polygonal terrain.

Introduction

Information on ground ice is critical for assessments of terrain stability in the context of climate change and permafrost thaw (Kokelj et al., 2023; O'Neill et al., 2023; Smith et al., 2022). This Open File accompanies O'Neill et al. (2024a) and provides the geospatial files of model outputs from that manuscript. This ground ice mapping may be useful for reconnaissance-level planning to guide more detailed field investigations of ground ice in the Kivalliq region, Nunavut.

This Open File includes a .zip file of the following folders/files:

- | | |
|------------------------|---|
| 1) KIV_relict.zip | Modelled relict ice abundance geotiff |
| 2) KIV_seggregated.zip | Modelled segregated ice abundance geotiff |
| 3) KIV_wedge.zip | Modelled wedge ice abundance geotiff |
| 4) KIV_abundance.zip | Modelled combined ice abundance geotiff |
| 5) KIV_surficial.zip | Surficial geology mapping compilation geotiff |

The geotiff files each have an attribute table indicating the relative abundance of each ice type, including none, negligible, low, medium, and high classes (Table 1). Water coverage is based on 1:250,000 scale data. The surficial geology geotiff attribute table includes unit codes from the GSC's Surficial Data Model (Deblonde et al., 2019), and the unit descriptions in text form (Table 2).

Table 1. Example of the attribute table format for geotiffs of modelled relative ice abundance and water. Note that the "Value" numeric code is categorical.

Value	Class
0	Water
1	None
2	Negligible
3	Low
4	Medium
5	High

Table 2. The attribute table format for the KIV_surfacial geotiff of surficial materials codes (Unit) and descriptions (Descrip). Note that the “Value” numeric code is categorical. Interpreted fine- and coarse-grained dominated till deposits, determined using underlying bedrock geology (see methods) are indicated by capital “F” and “C” following the standard surficial unit code (E.g., TbC indicates coarse-grained till blanket).

Value	Unit	Descrip
0	None	None
1	A	Alluvial - Undifferentiated
2	Ap	Alluvial - Floodplain sediments
3	GF	Glaciofluvial - Undifferentiated
4	GFc	Glaciofluvial - Ice-contact sediments
5	GFf2	Glaciofluvial - Outwash fan sediments
6	GFp	Glaciofluvial - Outwash plain sediments
7	GLd	Glaciolacustrine - Deltaic sediments
8	GLn	Glaciolacustrine - Littoral and nearshore sediments
9	L	Lacustrine - Undifferentiated
10	Ld	Lacustrine - Deltaic sediments
11	M	Marine - Undifferentiated
12	Mb	Marine - Blanket
13	Md	Marine - Deltaic sediments
14	Mi	Marine - Intertidal
15	Mn	Marine - Littoral and nearshore sediments
16	Mo	Marine - Offshore
17	Mr	Marine - Ridged
18	Mv	Marine - Veneer
19	R	Bedrock - Undifferentiated
20	TF	Till - Undifferentiated (fine)
21	TC	Till - Undifferentiated (coarse)
22	TbF	Till - Blanket (fine)
23	TbC	Till - Blanket (coarse)
24	ThF	Till - Hummocky (fine)
25	ThC	Till - Hummocky (coarse)
26	TmF	Till - Moraine complex (fine)
27	TmC	Till - Moraine complex (coarse)
28	TpF	Till - Plain (fine)
29	TpC	Till - Plain (coarse)
30	TrF	Till - Ridged till (fine)
31	TrC	Till - Ridged till (coarse)
32	TvF	Till - Veneer (fine)
33	TvC	Till - Veneer (coarse)

Study area

The study area extends from the Manitoba/Nunavut border (60°N) to beyond Baker Lake, NU (65°N), along the western coast of Hudson Bay, and inland to 98°W (Figure 1). The region was covered by the Laurentide Ice Sheet during the Wisconsin Glaciation. Following deglaciation, which occurred between about 9,000-7,000 years ago, inundation by the Tyrell Sea was up to about 170 m above the modern sea level, which extended up to 150 km inland (Dyke, 2004). Isostatic rebound following deglaciation drove emergence and subsequent permafrost development within previously inundated areas.

Surficial geology includes exposed bedrock, glacial tills, and marine, glaciofluvial, glaciolacustrine, lacustrine, and alluvial deposits (Figure 1). Organic deposits, 30 to >100 cm thick, occur in pockets in flat areas and predominantly overlie fine-grained materials (Arsenault et al., 1981; Forbes et al., 2014; McMartin, 2002). Topography is subdued and comprises bedrock hills and eskers, moraines, and drumlins that are widespread in the region (McMartin et al., 2021).

The study area is within the continuous permafrost zone. Mean annual air temperatures (1990-2020) at Arviat, Rankin Inlet, and Baker Lake are -8.9, -10.0, and -10.8 °C, respectively (Environment Canada, 2025). At Rankin Inlet, annual mean ground temperatures (2016-2019) near the top of permafrost ranged from -9.5 to -5.5°C (LeBlanc and Oldenborger, 2021). Annual mean ground temperatures at Baker Lake in 1998-2003 were about -7 to -8 °C (Smith et al., 2005).

Limited information exists on ground ice conditions in this region. Faucher et al. (2024) observed high excess ice contents in two cores that included marine and alluvial sediments with individual samples having up to 85% excess ice. Lower excess ice contents occurred in a dominantly till core. McQuaig et al. (2022) estimated volumetric ice content visually from cores drilled along the proposed Kivalliq Hydro-Fibre Link infrastructure corridor. Samples from organic and finer-grained marine sediments had moderate to high ice contents (up to 50-60%) comprising mainly segregated ice. Fluvial sands and silts had moderate ice contents (10-20%), whereas coarser grained till and glaciomarine deposits had low ice contents (5-10%). Elevated segregated ice content may also be inferred by the presence of solifluction lobes over fine-grained outwash deposits (e.g., Oldenborger et al., 2022).

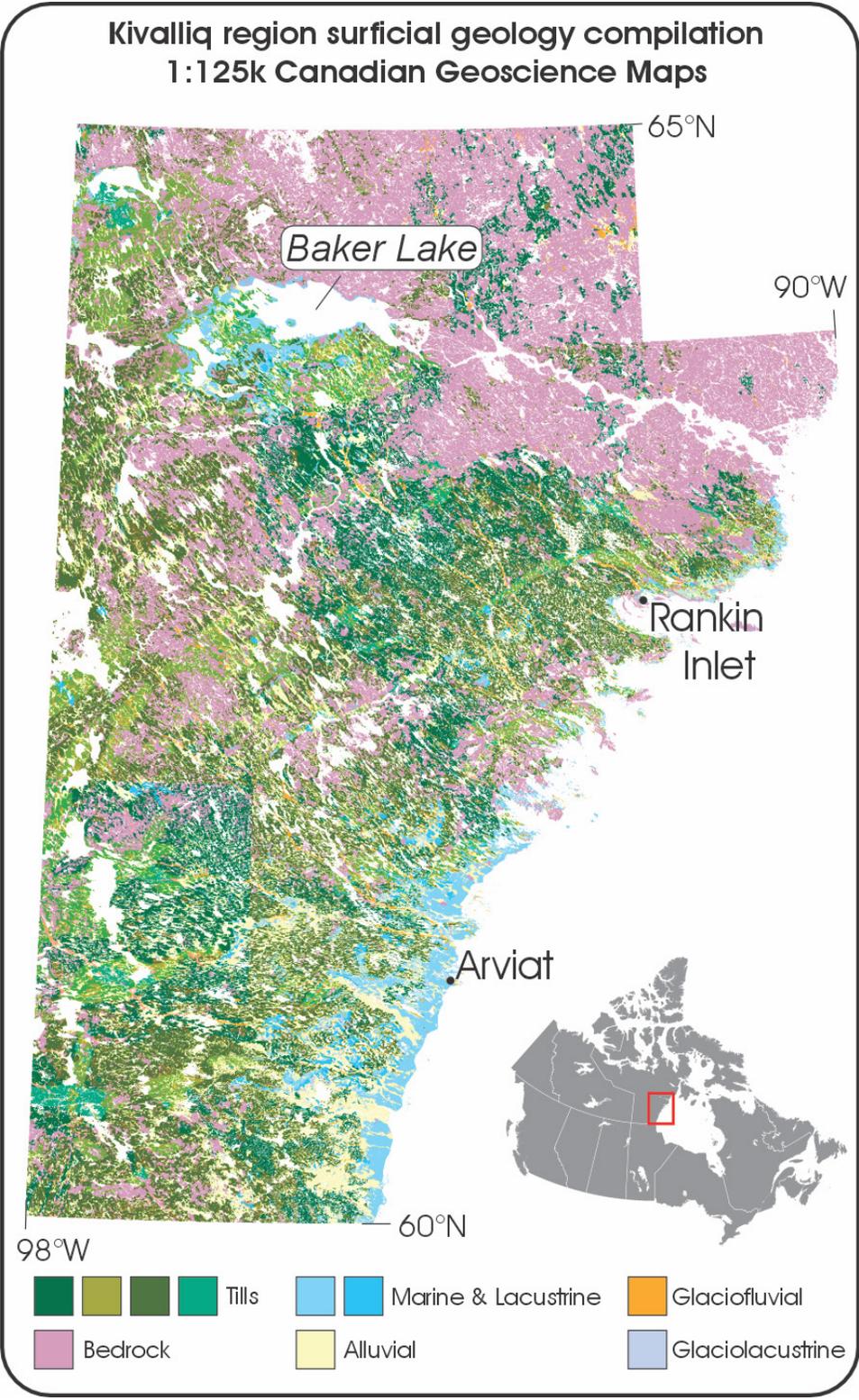


Figure 1. Surficial geology compilation depicting the modelled study area, with a simplified legend depicting the main depositional types (total unique surficial units n = 33).

Polygonal ground, interpreted as ice wedge polygons, are mapped extensively along the proposed Kivalliq Hydro-Fibre Link in coarse-grained glaciofluvial, beach ridge, and nearshore marine sediments, and in fine-grained fluvial, offshore marine, and organic deposits (McQuaig et al., 2022). Well-developed polygons are observed in marine sediments overlain with organic material near Arviat (Forbes et al., 2014). Ice wedge polygons are also mapped in various deposits near Rankin Inlet (McMartin, 2002; Oldenborger et al., 2022).

Methods

Details on the modelling approach and data processing for the Kivalliq region are presented in O'Neill et al. (2024a), and so are only briefly described here. Sixteen 1:125,000 scale Canadian Geoscience Maps formed the surficial materials compilation used for the modelling (Geological Survey of Canada, 2018a, 2018b, 2017a, 2017b, 2017c, 2017d, 2017e, 2017f, 2017g, 2017h, 2017i, 2017j, 2017k, 2017l, 2017m, 2017n). Original vector polygon shapefiles were combined and converted to rasters with 250 m pixels (O'Neill et al., 2024b). Till units were classified into fine- and coarse-grained dominant textures based on underlying bedrock geology (O'Neill et al., 2019). As a result, 33 surficial units were mapped in the study area, which comprise bedrock and multiple till, alluvial, marine, lacustrine, glaciofluvial, and glaciolacustrine units (Figure 1). The surficial geology information was altered on one map sheet where an inconsistency during the conversion from the paper map to the standardized digital form was noted (Geological Survey of Canada, 2018a). On this sheet, areas mapped primarily as bedrock with secondary coverage of till veneer or felsenmeer were mapped as till veneer in the digitized version, in contrast to adjacent map sheets. These areas were edited in the GIS to be mapped as bedrock for consistency. The compiled surficial geology included in this Open File reflects this correction. The modelling only considers the primary mapped surficial geology units, not secondary units or underlying stratigraphy.

Surficial units that appear on the national-scale mapping retained their model parameter values from the Ground ice map of Canada (GIMC; O'Neill et al., 2022). Units that are not represented are assigned parameters based on a review of surficial geology-ground ice associations informed by the surficial geology map unit legends and observations from prior investigations (Faucher et al., 2024; Forbes et al., 2014; e.g., McMartin, 2002; McQuaig et al., 2022; Oldenborger et al., 2022; Phillips and LeBlanc, 2024), including those west of the study region in the Slave Geological Province (e.g., Dredge et al., 1999).

The GIMC modelling routines are fully described by O'Neill et al. (2019). In contrast with the GIMC modelling, we used a recent, region-specific geospatial dataset of postglacial inundation to simulate the melt of relict ice in previously submerged areas (McMartin et al., 2022), rather than the Glacial map of Canada (Prest et al., 1968). The model results for the three ice types were combined using the methodology presented for the GIMC (O'Neill et al., 2022).

Results

Relict ice

Relict (buried glacial) ice is only predicted above the maximum marine limit produced by McMartin et al. (2022), far from the communities along the coast (Figure 2). Satellite imagery provides evidence of potentially ice-cored terrain in areas where relict ice abundance is modelled as medium and high. This evidence includes irregular topography, the presence of lakes with steep shores in the upslope direction, which may indicate slumping, and the presence of ponds and lakes that could be kettles. These could indicate past or current melt of glacial ice bodies (O'Neill et al., 2024a). The presence of this ice needs to be verified by field observations, but in the Slave Geological Province to the west, interpretations of preserved glacial ice have been recorded (Subedi et al., 2020; Wolfe, 1998; Wolfe et al., 1997).

Relict ice

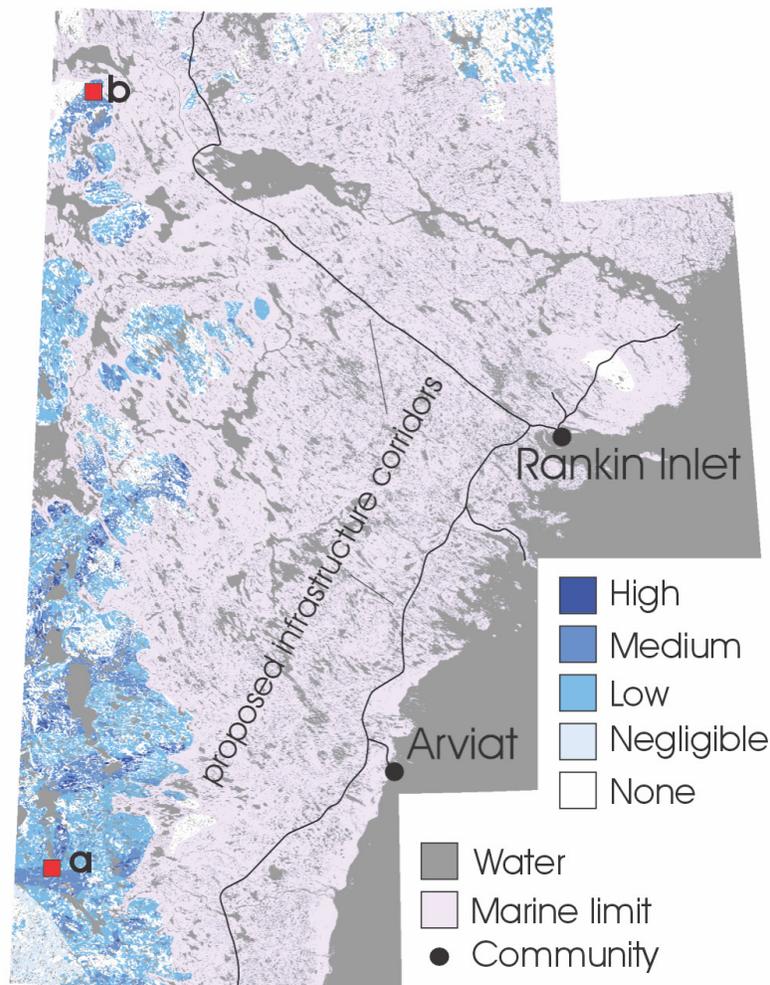


Figure 2. Modelled relict (buried glacial) ice abundance. Marine limit is from McMartin et al. (2022). Modified from O'Neill et al. (2024a). Locations from Figure 3 are shown indicated as red squares.

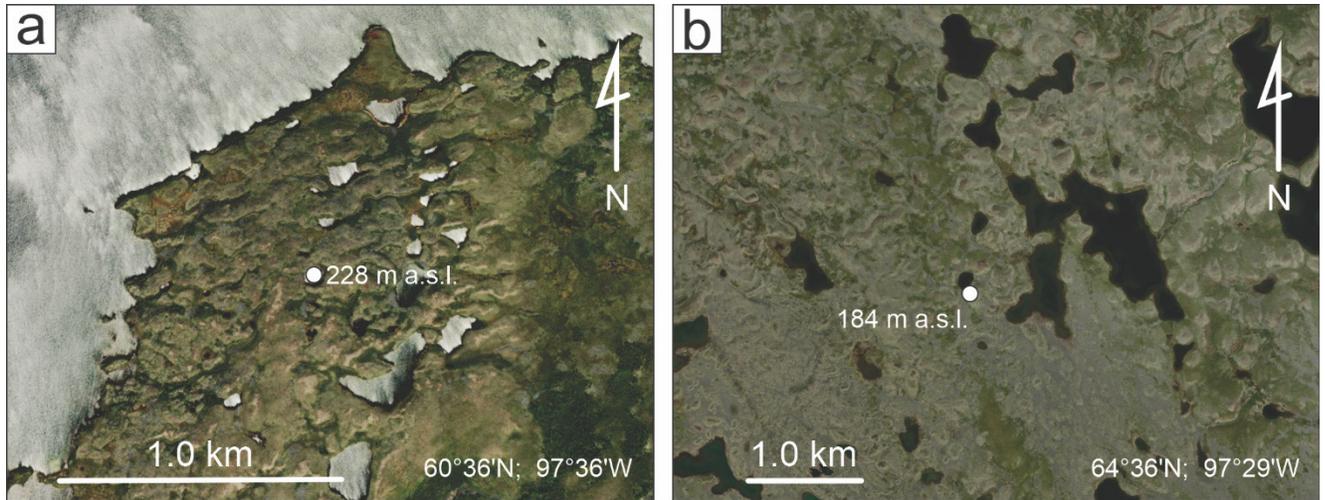


Figure 3. Potential ice-cored terrain in areas modelled with medium or high relict ice abundance, above the maximum marine limit. The locations are marked in Figure 2. Imagery from ArcGIS Earth.

Segregated ice

Segregated ice is modelled as widespread in the study area other than in the northern portion, where the surficial geology is mostly mapped as bedrock (Figure 4; Figure 1). The modelled segregated ice abundance reflects the inferred frost-susceptibility of material based on interpretation of the dominant grain sizes for each surficial unit. This is informed by field research from the Kivalliq region and adjacent Slave Geological Province. Consequently, the highest modelled segregated ice contents are in fine-grained marine sediments, while lower values are predicted over much of the area represented by coarser-grained tills. The fine-grained marine units are concentrated near the Hudson Bay coast and Baker Lake, posing the greatest hazards to development due to the potential for significant settlement as permafrost thaws.

Segregated ice

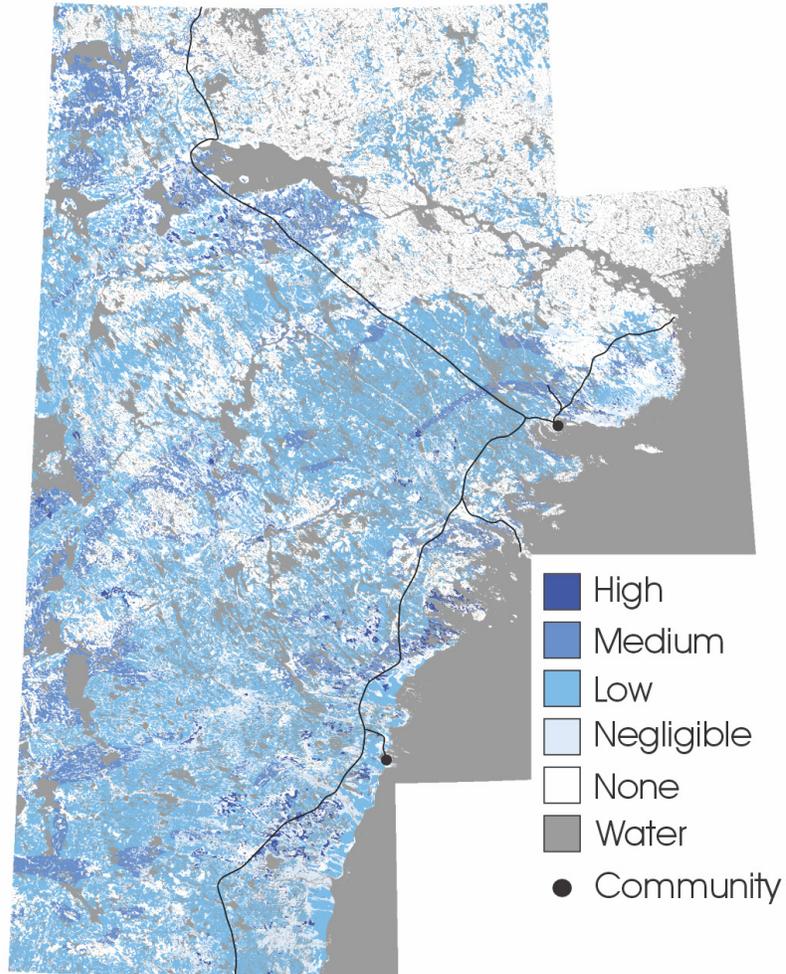


Figure 4. Modelled segregated ice abundance, modified from O'Neill et al. (2024a).

Wedge ice

The modelling indicates mainly negligible to low wedge ice content due the relatively short time available for ice wedge development since recession of the Tyrell Sea, and the dominantly coarse-grained sediments in the region (Figure 5). Estimates of the volumetric wedge ice content in the upper 5 m of permafrost based on field measurements and remote-sensing analyses are now available. The estimates use mapped lengths of polygonal trough networks (Figure 6), assumed ice wedge depths, and field measurements of representative ice wedge widths. The preliminary calculations agree with the modelling, generally indicating negligible (0-2%) *relative* wedge ice abundance below the marine limit (LeBlanc et al., 2024). The lower wedge ice abundance in the region is due to the presence of typically larger polygons and smaller wedges than in the western Arctic (O'Neill et al., 2024a). Nonetheless, because ice wedges are highly localized bodies of massive ice, they may pose significant hazards to infrastructure wherever they occur (Kanevskiy et al., 2017).

Wedge ice

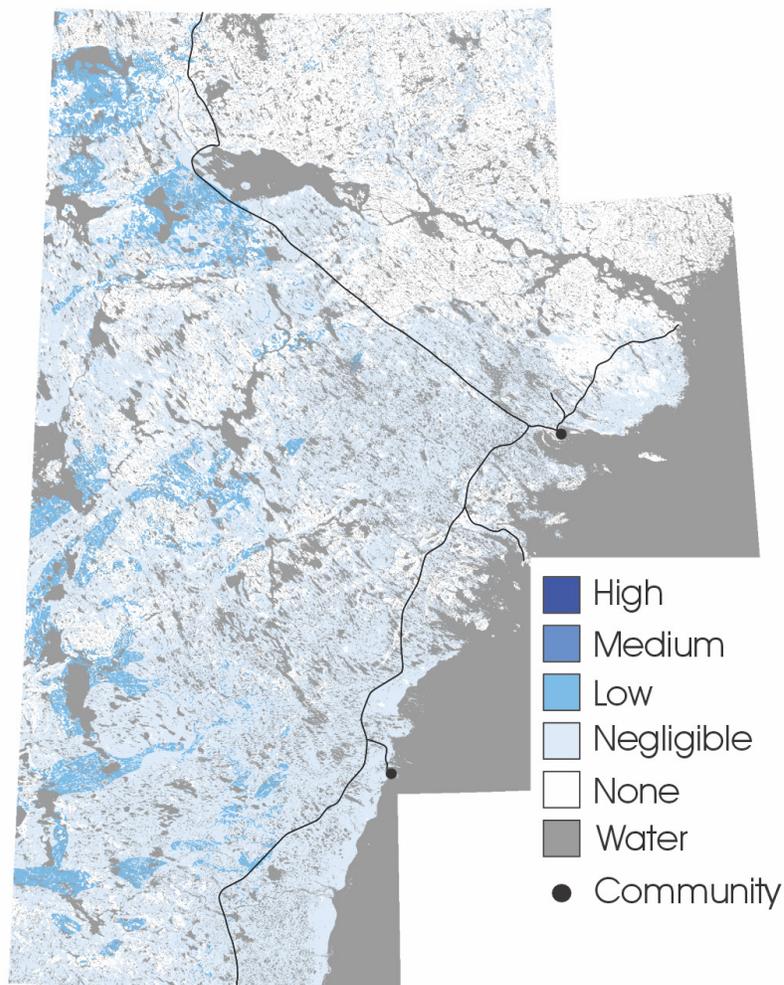


Figure 5. Modelled wedge ice abundance, modified from O'Neill et al. (2024a).

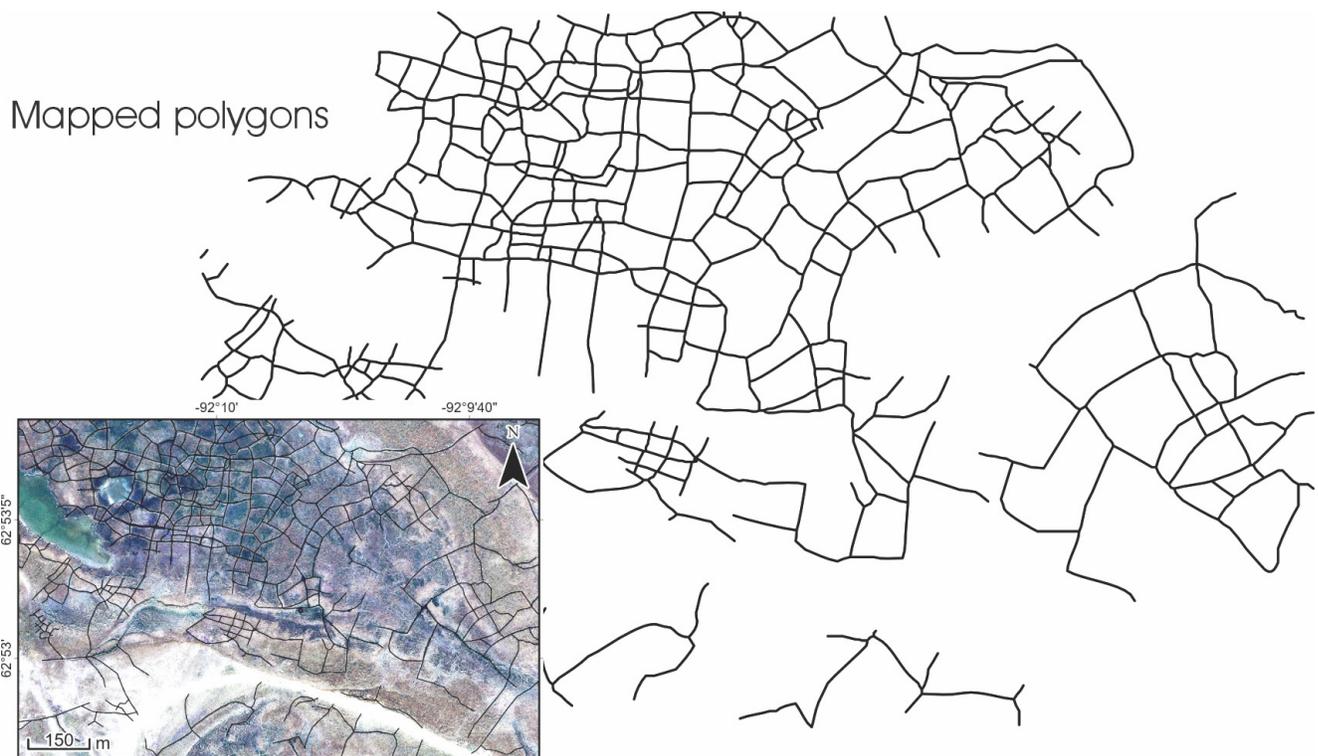


Figure 6. Example of mapped ice wedge polygon network in the Kivalliq region used to calculate volumetric contribution of wedge ice in the upper 5 m of permafrost (modified from Frappier and Vonk (2024)).

Combined ground ice abundance

The combined abundance map indicates that permafrost with the greatest excess ice content occurs above the maximum marine limit, where relict (buried glacial) ice may occur, where wedge ice is predicted in the highest relative abundance in the region (low) due to the greater time since deglaciation or marine recession, and where medium segregated ice abundance is modelled in fine-grained glacial till deposits (Figure 7). However, near the communities below the marine limit, fine-grained marine sediments are predicted to have high segregated ice content and to include wedge ice. These materials likely comprise the most thaw-susceptible settings near the coast. Though current field and modelling estimates of wedge ice volumes are far lower in the Kivalliq region than in the western Arctic (O’Neill et al., 2024a), ice wedges pose challenges to infrastructure stability due to the localized differential subsidence that accompanies permafrost thaw in polygonal terrain, and potential issues associated with water impoundment as runoff pathways are modified (Kanevskiy et al., 2022).

Combined abundance

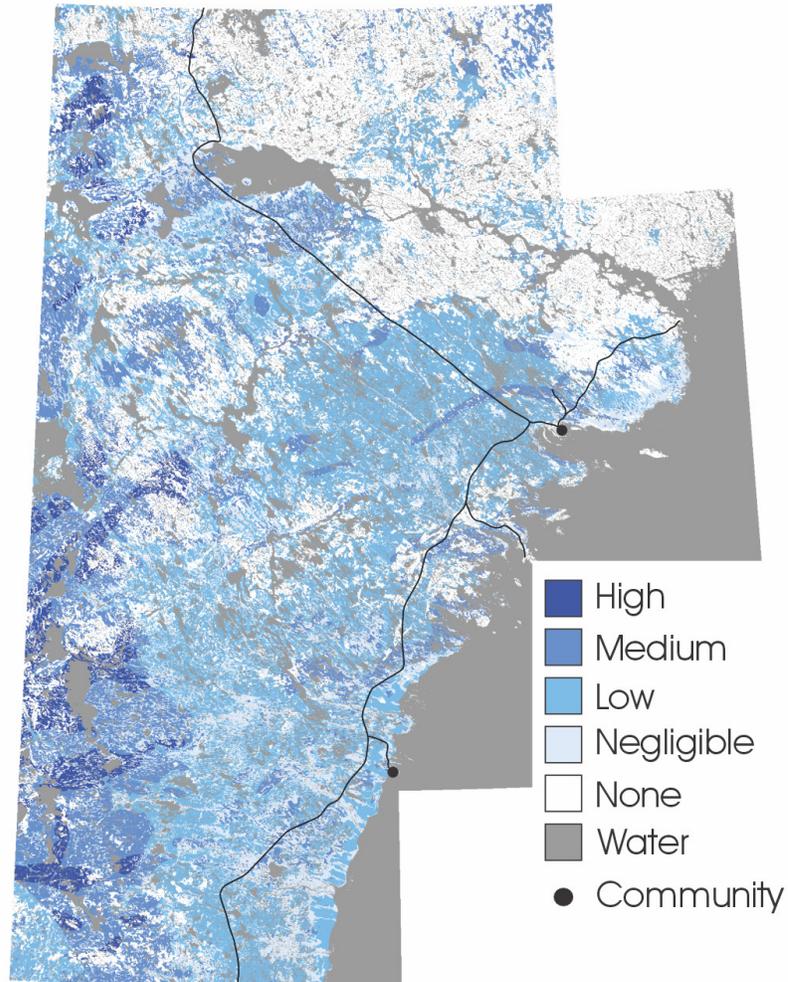


Figure 7. Modelled combined ground ice abundance (relict + segregated + wedge ice). See O'Neill et al. (2022) for the combination methodology. Modified from O'Neill et al. (2024a).

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