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PERMAFROST DEGRADATION, SUBARCTIC CANADIAN SHIELD

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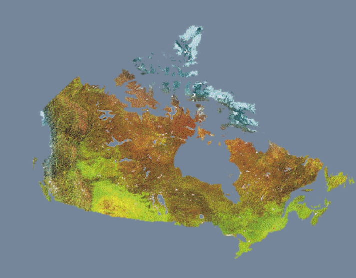

Abstract

Recent ground temperature and observational data for lithalsas in the subarctic Canadian Shield (permafrost mounds of ice-rich, fine-grained sediments) are examined in the context of an inventory of thermokarst ponding between 1945 and 2005. Results show that many lithalsas are thermally and physically degrading, and widespread thermokarst primarily relates to lithalsa distribution. Future thermokarst development in this region of extensive discontinuous permafrost will continue to be associated with lithalsas that often lack a protective surface organic layer.

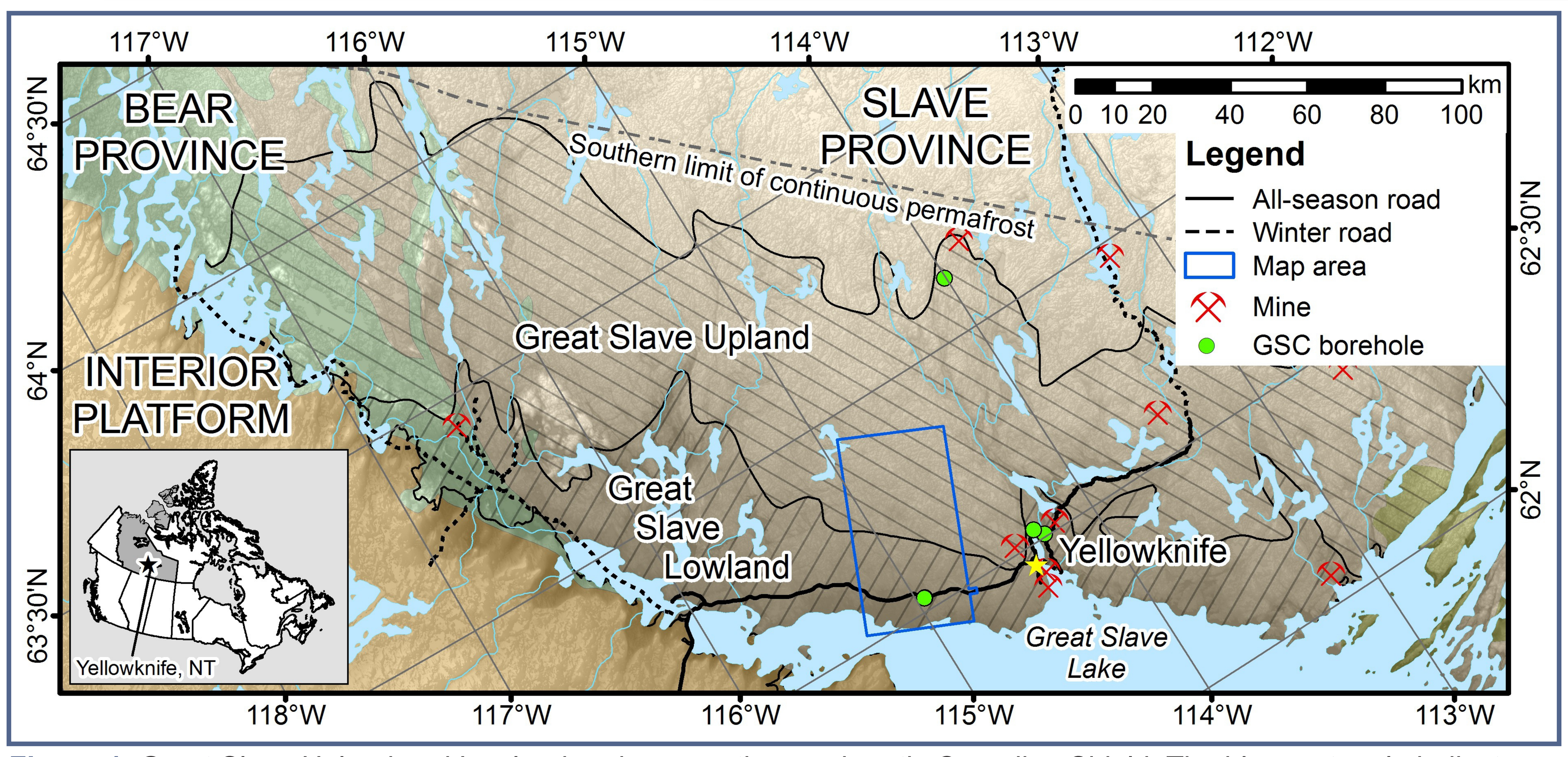

Figure 1. Great Slave Upland and Lowland regions, southern subarctic Canadian Shield. The blue rectangle indicates the thermokarst map area shown in Figure 7.

Introduction

Permafrost degradation in ice-rich, thaw-sensitive materials can result in terrain subsidence. With ecological and hydrological implications, ground stability has societal relevance in the southern subarctic Canadian Shield as this region (nearly the size of Belgium) contains the highest population and density of infrastructure in the Northwest Territories (**Fig. 1**).

Permafrost is discontinuous and is present in natural terrain beneath peatlands and forest on unconsolidated fine-grained (glacio) lacustrine sediments. Permafrost is warm and in disequilibrium with contemporary climate, which has warmed since at least the mid-1960s (**Fig. 2**) (Morse *et al*., 2015).

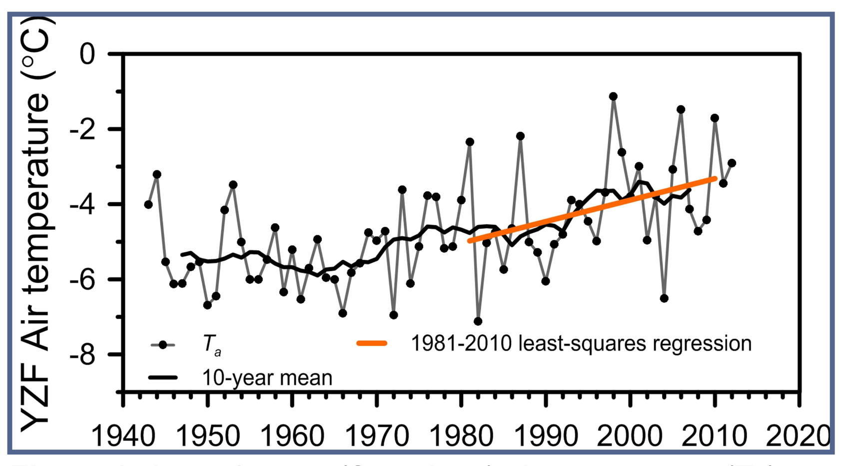

Figure 2. Annual mean (Sep.-Aug.) air temperature (Ta) and 10-year running mean for Yellowknife Airport (YZF). The warming trend of 0.06°C a^{-1} for 1981-2010 is statistically significant (p = 0.062) warming trend (Environment Canada, 2018).

Figure 3. Ground ice exposed at the headwall of a thaw slump that is retrograding into a lithalsa on the Yellowknife River. Fig. 6 shows the location of the slump. Note that alluvial sediments are light brown and volumetric ice content is greater than 50%.

Lithalsas, minerogenic permafrost mounds with cores of segregated ice (**Fig. 3**), and up to 8 m of relief (**Fig. 4**), are widespread in this area (Wolfe *et al*., 2014). With little-to-no surface organic layer, lithalsas are likely sensitive to climate change and disturbance, but the nature of permafrost degradation is not well documented. Here we present recently mapped thermokarst in the context of *in situ* ground thermal data and geomorphic observations.

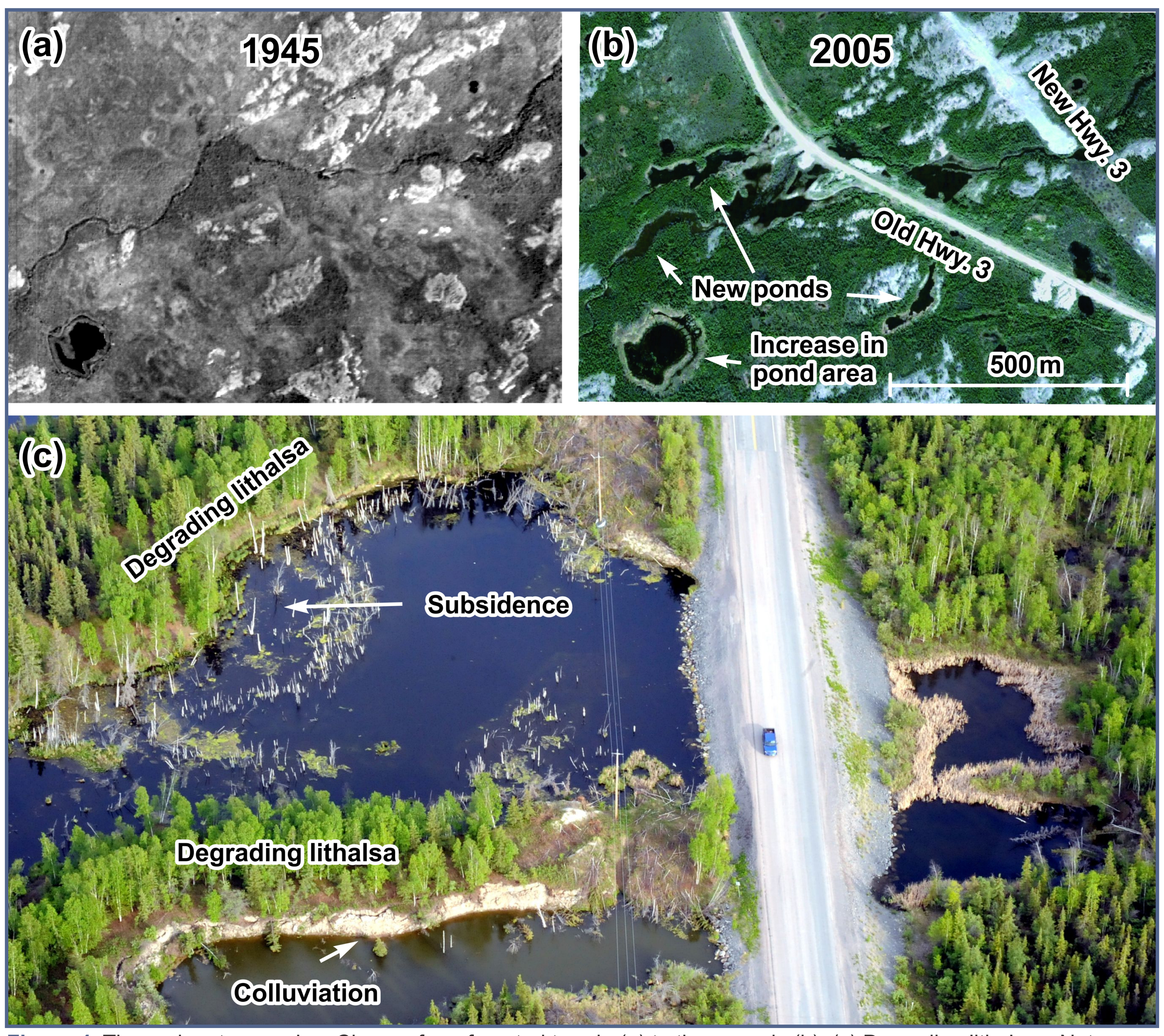

Figure 4. Thermokarst examples. Change from forested terrain (a) to thaw ponds (b). (c) Degrading lithalsas. Note submerged, standing dead birch (*Betula papyrifera*) indicating gradual subsidence, and colluviation at some lithalsa margins.

Methods

Ground temperatures

The lithalsa ground temperature monitoring network consists of 9 sites throughout the region (**Fig. 1**) with 1 to 6 years of data. Nine shallow boreholes (up to 11.5 m) instrumented for thermal monitoring (1 to 6 years of data) represent a range of lithalsa conditions in the region (**Fig. 1**). Factory calibrated thermistor strings connected to 8-channel data loggers record temperatures hourly. Accuracy and resolution is ± 0.1 °C and 0.001 °C, respectively.

Thermokarst mapping

An inventory of thermokarst ponding (1945 to 2005) was created from historical air photos and recent satellite images (Morse *et al*., 2017). Change from forest to water was based on differences in spectral characteristics, texture, and shape. The margin of error for an individual pond area is likely ± 50 m^2.

Results

Thermal degradation

Measured temperatures are generally higher than -1.5 °C with isothermal or inverted profiles (**Fig. 5a**). Temperatures near or below the depth of zero annual amplitude are either increasing or remain nearly static due to latent heat effects (**Fig. 5b**). Exceptions relate to site specific conditions such as WB-5 that is located at the degrading margin of a lithalsa and shows surface cooling, but is warming at depth (**Fig. 5**). Such warming is physically important as ice content in these lithalsas increases with depth (Wolfe *et al*., 2014).

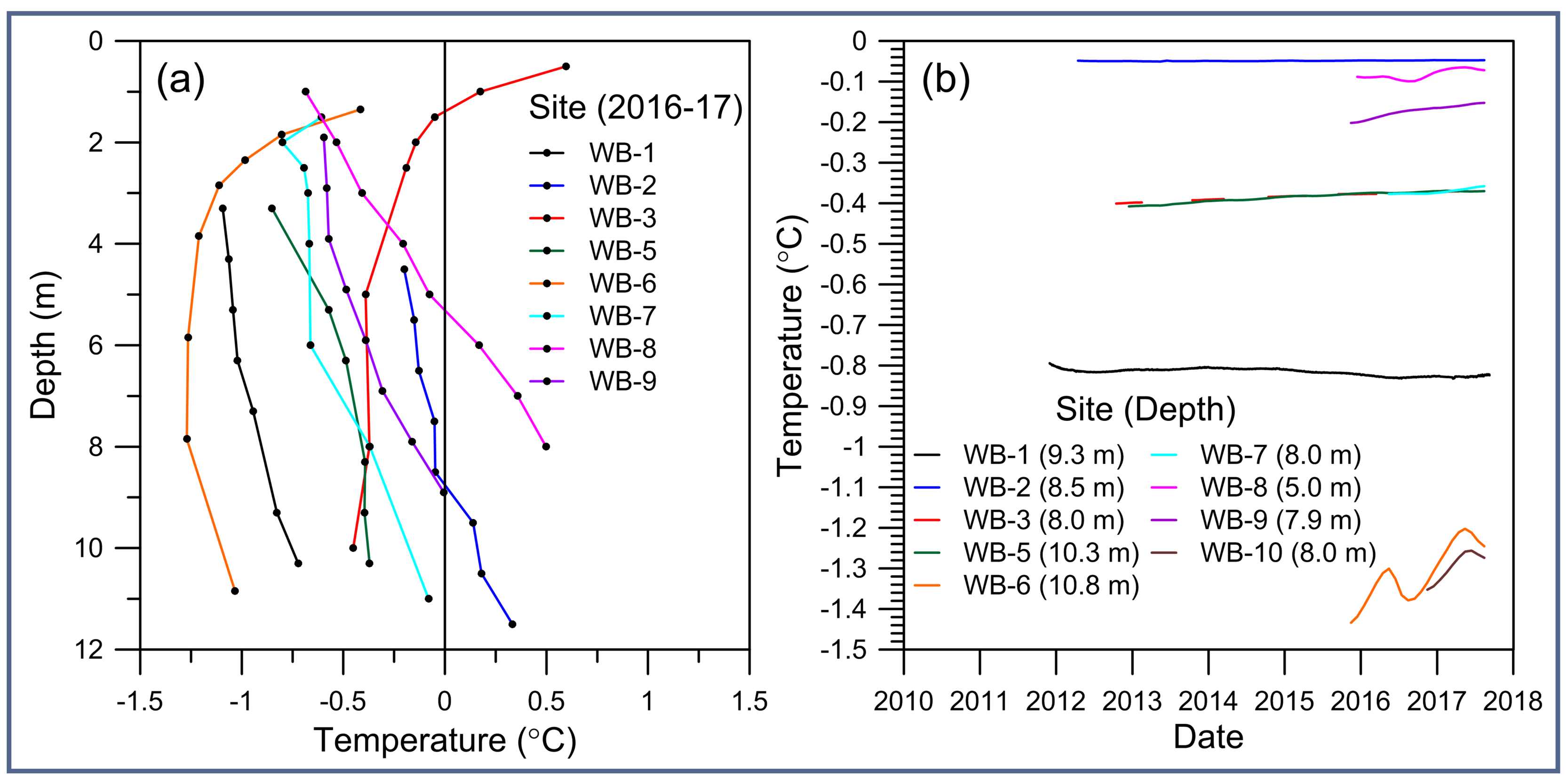

Figure 5. Ground temperature profiles (a), and trends below or near the depth of zero annual amplitude (b), in fine-grained sediments, southern subarctic Canadian Shield.

Physical degradation

Physical degradation associated with lithalsas takes two main forms (**Fig. 4c**): (1) simple subsidence indicated by the common occurrence of ponded water with partially submerged standing dead trees; and (2) colluviation and collapse at the lithalsa margin into the adjacent water body. Though rare, retrogressive thaw slumps can develop with sufficient relief and ground ice (**Fig. 6**).

Thermokarst, widespread throughout the study region (**Fig. 7**), predominantly relates to lithalsa degradation (**Fig. 4**). Accordingly, the distribution of thermokarst ponding is associated with fine-grained deposits and surface water sources, mirroring the reported controls on lithalsa distribution (Wolfe *et al*., 2014).

Figure 6. Retrogressive thaw slump on the Yellowknife River, north of NWT Highway 4, east of Yellowknife, NT. Inset shows the debris flow below the headwall.

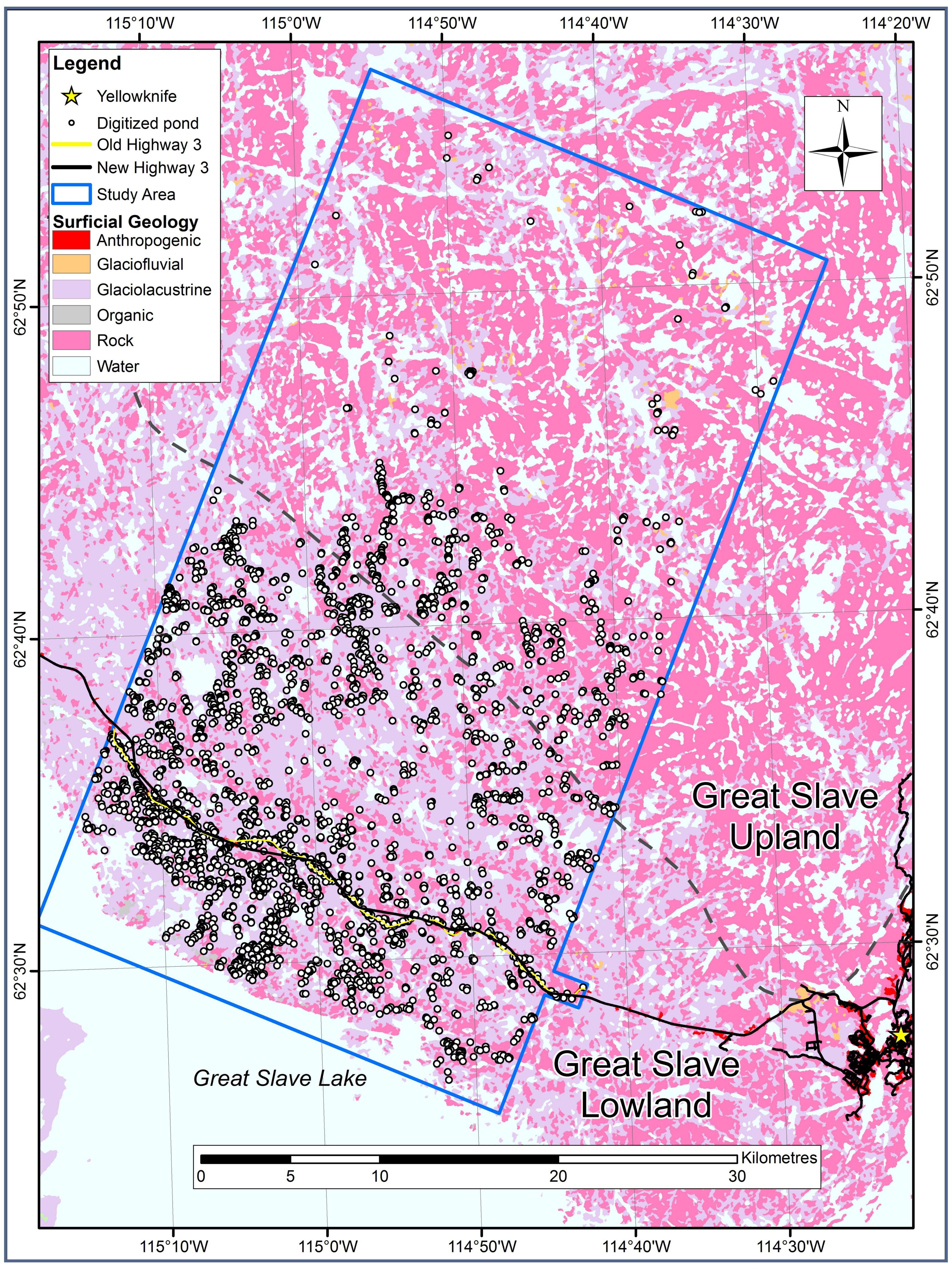

Figure 7. Thermokarst distribution, southern subarctic Canadian Shield. After Morse *et al*. (2017).

Conclusions

Lithalsas across the subarctic Canadian Shield are in a state of thermal and physical degradation. Widespread thermokarst relates directly to former lithalsa distribution. Continued thermokarst development will likely centre on these ice-rich permafrost mounds.

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