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Discussions

Interactive comment on "Ground ice, organic carbon and soluble cations in tundra permafrost and active-layer soils near a Laurentide ice divide in the Slave Geological Province, N.W.T., Canada" *by* Rupesh Subedi

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Comments to tc-2020-33 Discussion Paper by Subedi, Kokelj and Gruber

Stephen Wolfe - Geological Survey of Canada

Introduction

The paper under review by Subedi, Kokelj and Gruber provides data on ground ice, organic carbon, and soluble cations from drill holes in the Lac de Gras region of the

Slave Geological Province, Canada. The authors indicate that their results differ from observations made in western Arctic Canada and they make specific comparisons to field studies within the Mackenzie Delta region. They further indicate that the study provides quantitative data for a region that has few previous studies.

However, several statements and conclusions by the authors require reappraisal and revision in light of existing literature. Three issues in particular merit attention. Regarding the glacial context, the authors contend that the site is near the Keewatin Ice Divide, although it is more than 500 km distant. In reporting ground ice, they interpret model outputs prepared at a national scale in a local context, and combine surficial units with critically different properties. Lastly, the authors overlook relevant studies published from the Slave Geological Province, including from the study area.

Literature from the Slave Geological Province is discussed here to assist the authors in their task.

Glacial Context

The authors represent the study site as near a Laurentide Ice divide and having been influenced directly by it when, in fact, the Keewatin Ice Divide is distal to the study area.

The title of the paper indicates that the study area is "near a Laurentide ice divide", while line 29 states that the Lac de Gras region "is situated close to the Keewatin Ice divide of the Laurentide Ice Sheet". The term "Laurentide ice divide" should not be used. "Laurentide Ice sheet ice divide" or" Keewatin Sector ice divide" are appropriate alternatives. Laurentide Ice Sheet ice divides comprise named ice divides (with capital letters: Keewatin Ice Divide, Labrador Ice Divide, M'Clintock Ice Divide, etc.) and unnamed ice divides (see Dyke and Prest, 1987). However, the Keewatin Ice Divide (KID) is by definition "the zone occupied by the last glacial remnants of the Laurentide Ice Sheet west of Hudson Bay" (Lee et al., 1957). Therefore, the KID was situated at least 500 km east of the study area (e.g. McMartin and Henderson, 2004). All the other ice divide positions in Keewatin are not located closer to the study area and cannot be termed “Keewatin Ice Divide”.

If the authors wish to consider features 500 km from their study area as proximal, then a reader would further expect literature that reports conditions in the glacial sediments near Yellowknife, only 310 km from the study area (line 79), to be fully considered. This is addressed further below.

Basal ice sheet conditions, as discussed by Rampton (2000) and Utting et al. (2004), influence the source materials for shield-derived tills of the Slave Geological Province. Glacial conditions in the Slave Geological Province differed significantly from those of western Arctic Canada. Such differences had a profound effect on ground ice development (Wolfe et al., 2017). The authors compare their results with conditions in western Arctic Canada, where the source materials for till were derived from the sedimentary basins of the Interior Plains as opposed to the Canadian Shield. It is not evident why this setting is the primary reference for comparison with results from this study without relevant details on conditions in the Slave Province.

Ground ice reporting

Use of model outputs

The authors apply national-scale modelling results to local site conditions.

The authors state that “the new Ground Ice Maps for Canada (O’Neill et al., 2019) show the study area (50 km $\times$ 50 km) to contain no or negligible wedge ice, negligible to low segregated ice and no relict ice, which includes buried glacier ice.” (lines 40-42). In fact, the new Ground Ice Maps for Canada depict wedge ice from none to low; segregated ice from none to medium, and relict ice (which includes buried glacier ice) from none to low (Figure 1). The authors thereby under-report the amount of ground ice depicted for the study areas by O’Neill et al. (2019).

Nevertheless, differences between the authors’ reporting and the model results are due, in part, to site-specific surficial geology. The surficial geology used in modelling

is at scale of 1:5 M (GSC - Surficial Geology of Canada, 2014). For associations between ground ice and surficial geology to be appropriately considered at the local scale of 1:125,000, Dredge et al. (1995) and Ward et al. (1997) may be consulted.

Use of surficial geological units

The authors combine surficial units with critically different properties in the context of reporting excess ice.

The authors combine drill cores into “upland tills”, which they define as “smoothly rounded hills comprised of thick till and in till veneer over bedrock” (line 187-188). Combining drill cores from till veneers, which are tills that are less than 2 m in thickness, with the drill cores of thick till misrepresents the extent of “upland till” and therefore of ground ice contained within till terrain. To this end, Ward et al. (1997) and Dredge et al. (1995) provide more suitable spatial depiction of till veneer, till blankets, and hummocky till that permit the drill cores to be allocated to these specific till units. Such separation is appropriate for depicting depth versus water content and excess ice (as in Figure 3A and 4A). This approach may highlight the lower excess ice abundance in till veneers and at depths above 4 m, and higher amounts in thicker tills (and at depths below 5 m). These data may further inform understanding of the proportion of hummocky till, and thus potentially preserved Laurentide basal ice, in the area.

In addition, in presenting “fluvially reworked till (the Valley)” (line 185) where “silts and sands are well sorted and likely derived from fluvial reworking of local tills” (line 191) and in presenting evidence of post-glacial ground ice melt features (e.g. Figure C1) the authors might acknowledge alternative interpretations by Rampton (1999) and by Utting et al. (2009) to account for fluvial activity. Alternative classification of the terrain types is required because the current terms conflate categories of phenomena, e.g. till and valley.

Incorporation of comparative literature

The authors overlook existing regional and local literature with similar conclusions, thereby claiming undue precedence.

Solutes in mineral soils

The authors' state that "the concentration of total soluble cations in mineral soils is much lower than at other previously studied locations in the western Canadian Arctic" (lines 14-15) and that "the absolute concentrations of soluble cations obtained in the study area near Lac de Gras are low compared to previous studies from northwestern Canada that report higher concentrations in active layer and permafrost across diverse terrain types (Table D2)." (lines 302-304). These remarks assume that all comparable previous studies have taken place in the Mackenzie delta area or Herschel Island (Table D2). The authors indicate that "The low concentrations in our study area are associated with the contrasting nature and origins of surficial materials. Tills in our study region are generally coarser grained than many glacial deposits studied in the western Arctic, are regionally sourced from mostly granitic rocks and have been exposed only to minor postglacial landscape modification (Haiblen et al., 2018; Rampton and Sharpe, 2014)". (lines 311-314).

Gaanderse et al. (2018) originally reported on solute concentrations from glaciolacustrine deposits within the shield area that indicate low values similar to the Lac de Gras area. Gaanderse et al. (2018, p. 1039 noted that "Total soluble ions concentrations decreased with depth from the active layer to the underlying glaciolacustrine clays in permafrost (Figure 8). This trend contrasts with observations in the western Arctic, where low ion concentrations occur within sediments of the active layer and near-surface permafrost, relative to the underlying permafrost (Kokelj et al., 2002; Kokelj and Burn 2003, 2005; Lacelle et al., 2014). Unlike the predominantly marine origin and the mixed-layered clays of the western Arctic (Dewis et al., 1972; Kodama, 1979), the glaciolacustrine clays of the Great Slave region are not inherently solute-rich or weathered." And "These fine-grained glaciolacustrine, lacustrine and alluvial sediments belong to the same generation of glacially-derived sediments with a regional

mineralogical composition from igneous and metamorphic sources (Aden et al., 2015). The clays and clay-sized glaciolacustrine sediments are predominantly unweathered, with major soil ion abundances likely reflecting the mineralogy of local rocks, including Ca2+, Na2+, and K+ from the weathering of feldspars; Mg2+ and Ca2+ from amphiboles, pyroxenes and olivine; S042- from sulphides and Cl- from igneous sources."

Additional supporting data on low concentrations of soluble cations from the Slave Geological Province and in the Lac de Gras area are also presented in Wolfe et al. (1997a) and Wolfe (1998) who describe low cation concentrations in buried ground ice in glaciofluvial delta sediments, and in Wolfe et al. (1997b), who include borehole logs, geophysical surveys, cation concentrations and oxygen isotopes from a 14-m borehole at the BHP Airstrip Esker within the authors' Lac de Gras study area.

Ground ice expectations

The authors state that "permafrost in the study area contains much more ground ice than expected" (line 16). As noted above, several studies have illustrated the presence of high ground ice contents in outwash sediments in the area. In addition to these, Dredge et al. (1999), referenced by the authors, clearly present expected ground ice conditions and terrain sensitivity in line with the authors observations. The importance of the geological legacy in determining the characteristics of permafrost and potential responses of this system of disturbance and change is further summarized in Wolfe et al. (2017), who conclude that "Glacially-derived ground ice includes buried glacial ice within glaciofluvial outwash deposits and buried glacial and meltwater ice within eskers. Sediment-rich ice has also been encountered within hummocky till terrain during mine development operations. Surficial features attributed to partial thawing and creep of massive ground ice are regionally apparent. Although massive ice has been encountered in only a few locations to date, buried ground ice may be common within this glaciated region of the Tundra Shield."

Nevertheless, the authors are still cautioned about asserting that "Tills in our study areas ... have been exposed to only minor post-glacial modification (Haiblen et al., 2018; Rampton and Sharpe, 2014)", noting the evidence of Holocene warming and tree-line advance in the region as noted by the authors (lines 83-84) and in Moser and MacDonald (1990) and MacDonald et al. (1993).

The authors state in the abstract that "thaw subsidence of metres to more than ten metres is possible" due to ground ice that may be buried Laurentide basal ice (line 8 – 9). Within the paper, the authors write: "A potential surface lowering of many metres, up to more than ten metres, is thus to be expected from areas of thick till if this permafrost was to thaw completely" (lines 271-272). Again, in the conclusions, the authors state: "Thaw-induced terrain subsidence on the order of metres to tens of metres is possible in ice-rich till" (line 326). The statements are based upon data from only one borehole with samples from below 6 m depth. The borehole terminated at 9.5 m depth. The authors assume that conditions in this borehole are representative of all till "estimated to be 10-30 m thick in the area (Haiblen et al. 2018)" (line 270). In other words, the authors assume, without disclosed evidence, that the excess ice profile presented in Fig. 4 extends indefinitely downwards with high values, that it applies consistently throughout an extensive till unit, and that the unit is sufficiently thick to contain excess ice tens of metres thick. Readers should be made aware of the assumptions upon which these statements are based and, in particular, should be able to recognize that the principal data contributing to these assertions are derived from 3.5 m of drill core, from 6 to 9.5 m in the profile.

Summary and Conclusion

The paper by Subedi, Kokelj and Gruber (in review) provides an added contribution to the growing knowledge of permafrost and ground ice in the Slave Geological Province. The purpose of these comments is to provide an appropriate regional context for the observations. The authors may take advantage of these comments so that their contribution to the literature will complement, and be informed by, the existing knowledge of permafrost, environmental change and ground ice conditions in this region.

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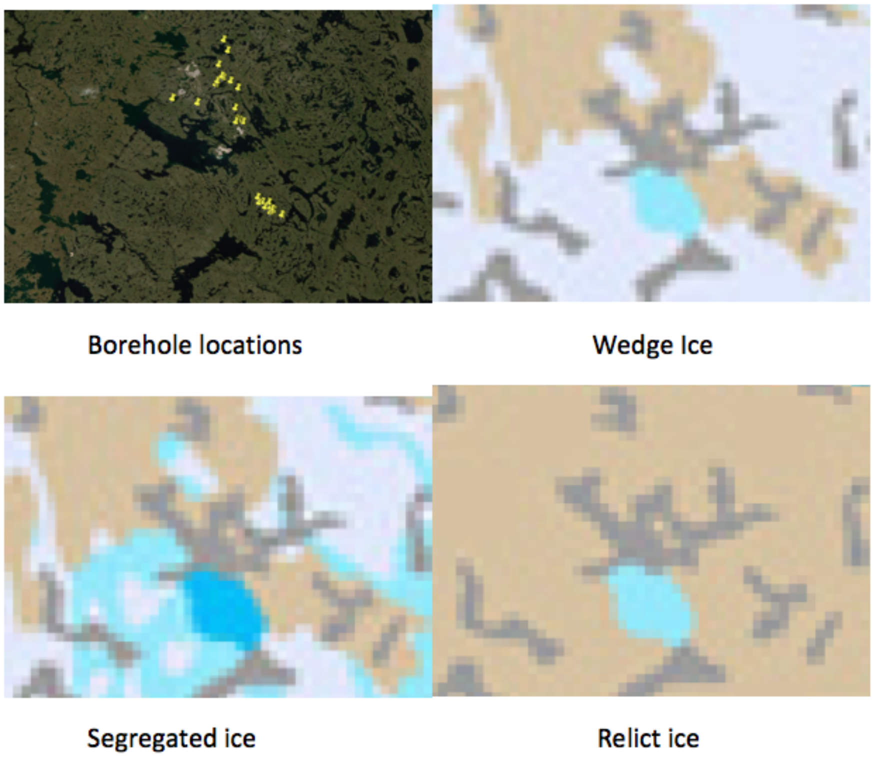

Fig. 1. Figure 1. Google Earth image of study area (pins are specific borehole locations from the present study) and model output results from O'Neill et al. (2019).