Origin of massive ground ice in the Eureka Sound Lowlands, Nunavut

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Introduction
Understanding the nature and origin of ground ice is an important component of reconstructing past climates and the evolution of permafrost landscapes. This study is concerned with revealing geochemical information concerning the origin of massive ground ice in the Eureka Sound Lowlands of Ellesmere and Axel Heberg Islands, Canada and the marine emergence history of the area. Pollard and Bell (1998) have proposed an origin linked to Holocene ice sheet change and postglacial aggradation with melt water from local ice caps providing the primary lake-sediment source. The primary objective of this research is twofold: to characterize the environmental chemistry of massive ground ice bodies for this area and to look at the environmental chemistry for massive ground ice from a range of locations and elevations examine the potential role of other mechanisms of ground ice formation. This research is timely in view of recent trends in the thermal state and landscape change in this area (Pollard et al. 2015).

Study Area
The Eureka Sound Lowlands are a flat to gently rolling area on central Ellesmere and Axel Heberg Islands in the Canadian High Arctic. The Eureka Sound Lowlands (ESL) cover an area of ~750 km² on the E coast of Axel Heberg Island and the W coast of Ellesmere Island, Nunavut.
- High Arctic polar desert
- Depth of permafrost: 500 m (Taylor 1991)
- Mean annual air temperature: -17 °C
- Mean annual precipitation: 780 mm (McGill Weather Station, Environment Canada)

Permafrost and Ground Ice
Deep continuous permafrost underlies the entire area. Ground ice is widespread; pore ice and thin lenses of segregated ice are found in abundance and often grade into massive ice. Ice wedges are ubiquitous over much of the ESL and occur in all surficial materials, although they vary in density, depending on soil type. Widespread massive ice is associated with marine sediments that lie below the Holocene marine limit. This stratigraphic setting is a key variable in the analysis of ground ice origin.

Methods
- Permafrost cores sampled into massive ice bodies using a SIPRE corer in summer 2017
- Corral cores into 2 cm sub-samples for high-resolution profiles
- Analyzed for water content (gravimetric and volumetric), stable isotopes (δD, δ18O, δ13C), and dissolved organic carbon (DOC)

δD-δ18O interpretation
Co-isotope plots (δD-δ18O) are often used to help determine the origin of ground ice, based on the theory that buried glacier ice will have a freezing slope close to the meteoric line (p.4), while segregated ice will have a slope ~6. However, in an open system where there is the input of isotopically-depleted water, the freezing, "meteoric" freezing slopes can be produced in segregated ice. Souchez and Jouzel (1994) give the following equation for a freezing slope (S) at 0°C for the case of a reservoir mixed with a ice water depleted water:

\[ S = \frac{\delta D - \delta_18O}{\delta D - \delta_18O_{\text{res}}} = 1 - \frac{\delta_18O_{\text{res}}}{\delta_18O - 10^a} = 1 + \frac{\delta D - \delta_18O_{\text{res}}}{\delta_18O - \delta_18O_{\text{res}}} \]

where \( a \) is relevant to the subsurface in Italy. 

Discussion and Conclusions
Pollard (2000a) concluded that tabular massive ground ice in the ESL is partly of segregated (unstratified) origin, as opposed to buried ice. The massive ice’s stratigraphy (origin within frazil-marine sediments and likely underlain by coarse-grained sediments with higher hydraulic conductivity), elevation (below Holocene marine limit) and petrography support a segregated origin and effectively preclude the preservation of buried Pleistocene glacial ice. A landscape model similar to Rampont (1995) was proposed whereby massive ice formed as permafrost aggraded into raised marine sediments, with water continuously supplied from beneath.

Our geochemical analysis, while on-going, seems to support a segregated origin. It implies an open-system freezing scenario, with an input of isotopically-depleted water (glacial meltwater), mixing with a reservoir of lithogenically-depleted water, possibly remnant seawater. The rate of freezing and the supply of glacial meltwater from upland around the time of marine emergence are key factors in explaining chemical and physical variability in massive ground ice in the ESL. For instance, the massive ice sampled from Black Top slump (sho 70 m a.s.l.) is isotopically heavier, has greater concentrations of dissolved ions and lower volumetric ice content. This could be a reflection of a more rapidly advancing freezing front, which limits the segregation process and the migration of water to the freezing front.

We will continue this geochemical work to increase its scope, in the hope of obtaining a more complete database of ground ice chemistry across the ESL. We are also working on constraining ground ice ages using 10Be.

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References

Elevations examine the environmental chemistry for massive ground ice from a range of locations and elevations examine the potential role of other mechanisms of ground ice formation. This research is timely in view of recent trends in the thermal state and landscape change in this area (Pollard et al. 2015).

**Table 1: Local water chemistry**

<table>
<thead>
<tr>
<th>Station</th>
<th>Concentration (mg/l)</th>
<th>Temperature (°C)</th>
<th>Depth (cm)</th>
<th>Elevation a.s.l. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dump Slump</td>
<td>Ca</td>
<td>4.6</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Station Creek</td>
<td>Mg</td>
<td>0.8</td>
<td>120</td>
<td>50</td>
</tr>
<tr>
<td>Black Top</td>
<td>SO4</td>
<td>1.1</td>
<td>140</td>
<td>70</td>
</tr>
<tr>
<td>Gemini</td>
<td>Cl</td>
<td>0.5</td>
<td>160</td>
<td>90</td>
</tr>
</tbody>
</table>

**Figure 1: Map of ESL, with ground ice locations in red (from Pollard et al. 2015)**

**Figure 2: Local meteoric water line**

**Figure 3: Origin of massive ground ice in the Eureka Sound Lowlands, Nunavut**

**Figure 4: Marine emergence history**

**Figure 5: Approximate marine emergences for sampling sites across elevational gradient, Fosheim Peninsula, Eureka Sound Lowlands, based data from Pollard and Bell (1998) and best-fit model from Simon et al. (2015)**