Can molar gas ratios positively identify the nature and origin of massive ground ice of Herschel Island, Yukon?

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ABSTRACT
A new tool has been developed in recent years that enables geocryologists to accurately identify the origin and nature of massive ground ice features. The molar ratios of O_2, N_2 and Ar gases entrapped in massive ground ice is a novel, periglacial field technique that results in a positive disassociation between buried glacial and non-glacial intrasedimental ice (Lacelle et al., 2007 and Cardyn et al., 2007). Massive ground ice, large tabular ice bodies with a volumetric ice content exceeding 95%, is a unique permafrost feature that persists throughout permafrost landscapes (International Permafrost Association, 1998). Massive ground ice features, discovered in the headwalls of retrogressive thaw slumps on Herschel Island, Yukon, have been analyzed extensively in order to comprehend the structure, composition and spatial extents. However, the origin of this buried ice, be it buried glacial or non-glacial intrasedimental ice, is a fundamental question that has yet been fully understood. Field work for this research will commence during the 2010 summer field season. Following this samples will be analyzed during the fall of 2010 at the G.G. Hatch Stable Isotope Laboratory at the University of Ottawa, Canada.

RÉSUMÉ
Un nouvel instrument a été développé au cours des dernières années qui permet à geocryologists d'exactement identifier l'origine et la nature de caractéristiques de glace de terre massives. Les rapports de molaire d'O2, N2 et les gaz Ar pris au piège dans la glace de terre massive sont un roman, periglacial la technique de terrain qui s'ensuit dans une dissociation positive entre la glace d'intrasedimental glaciale et non-glaciale enterrée (Lacelle et d'autres., 2007 et Cardyn et d'autres., 2007). La glace de terre massive, les grands corps tabulaires de glace avec un contenu volumétrique de glace excédant 95 %, est une caractéristique de permagel unique qui persiste partout dans les paysages de permagel (l'Association de Permagel internationale, 1998). Les caractéristiques de glace de terre massives, découvertes dans le headwalls d'effondrements de dégel régressifs sur l'Île de Herschel, Yukon, ont été analysées abondamment pour comprendre la structure, la composition et les mesures spatiales. Pourtant, l'origine de cette glace enterrée, être cela a enterré la glace d'intrasedimental glaciale ou non-glaciale, est une question fondamentale qui a encore été complètement comprise. Le travail de terrain pour cette recherche commencera pendant la saison 2010 de terrain d'été. Après cela les échantillons seront analysés pendant la chute 2010 au G.G. Faites éclore le Laboratoire d'Isotope Ferme à l'Université d'Ottawa, Canada.

1 INTRODUCTION

With the advent of advanced mass spectrometer laboratory equipment in recent years a new tool has been developed in recent years that enable geocryologists to accurately identify the origin and nature of massive ground ice features. The molar ratios of CO_2, O_2, N_2 and Ar gases entrapped in massive ground ice is a novel, periglacial field technique that results in a positive disassociation between buried glacial and non-glacial intrasedimental ice (Lacelle et al., 2007 and Cardyn et al., 2007). Massive ground ice, large tabular ice bodies with a volumetric ice content exceeding 95%, is a unique permafrost feature that persists throughout permafrost landscapes (International Permafrost Association, 1998). Massive ground ice features, discovered in the headwalls of retrogressive thaw slumps on Herschel Island, Yukon, have been analyzed extensively in order to comprehend the structure, composition and spatial extents. However, the origin of this buried ice, be it buried glacial or non-glacial intrasedimental ice, is a fundamental question that has yet been fully understood.

It is the aim of this research to better understand the origin of this less understood irregularly-shaped ice bodies of Herschel Island. With the use of the newly developed molar gas ratio technique the origin of buried glacial ice and segregated-intrusive ground ice bodies will be positively identified with a higher degree of confidence.

To understand the origin of massive ground ice features is to understand the paleoclimates and environments that spawned their creation. Moreover, ground ice features have a major influence on the geomorphology of permafrost landscapes and directly control rates of coastal erosion, active layer depth migrations and thermokarst activity, all of which are projected to increase under many climate change scenarios. The established research sites of Herschel Island offer a unique opportunity to employ new scientific methods to understand this longstanding question.

1.1 Study Area

The field research will take place on Herschel Island (69° 42'N, 139° 01W). Located in the Beaufort Sea, Herschel Island is the most northern point of the Yukon Territory, Canada. Herschel has an area of approximately 108 km^2 (approximately 15 km x 8 km) and is characterized by rolling topography, figure 1 (Lantuit and Pollard, 2008).

The island is rife with massive ground ice and ice rich sediments in some location it constitutes up to 60-70% of the upper 10-15 m of permafrost (Pollard, 1990). Horizontally foliated segregated ice and ice wedges are most prevalent and are readily observed in coastal sections, stream valleys an retrogressive thaw slumps (Pollard , 1990).

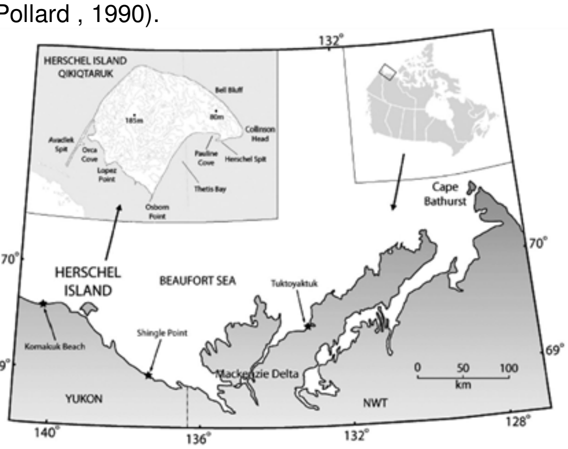

Figure 1: Location of Herschel Island, Yukon. Topology of island in upper left (Lantuit and Pollard, 2008).

It is understood that the Yukon Coastal Plain near Herschel Island was glaciated at least once. A glaciotectonic origin is assigned to Herschel Island formed by an ice-pushed structure by the westward advance of the Laurentide ice sheet during the Buckland Stage of the Wisconsin Glaciation (Mackay, 1959; Rampton, 1982). The island is composed of mainly fine-grained marine sediments dredged from the Herschel Basin and coarser grained coastal deposits (Lantuit and Pollard, 2008). Post glaciation, this material has been reworked primarily by alluviation, thermokarst, mass wasting and ground ice formation (Rampton, 1982). Permafrost, up to 600m deep along the Yukon Coastal Plain, is a permanent fixture of Herschel as it lies within the zone of continuous permafrost, ground ice is widespread and underlies most of the island (Smith and Burgess, 2000).

1.2 Massive Ground Ice

Ground ice may be either *epigenetic* which develops after the enclosing sediment has been deposited or *syngenetic* which forms at, or almost at, the same time as the enclosing sediments are deposited, classified by Mackay (1972), figure 2 (French, 2007). The massive ground ice identified at Herschel island is of both classes in forms that include buried snow bank ice (syngenetic), intrusive ice (epigenetic) and irregularly-shaped ice bodies in highly deformed materials within ice ridges (Pollard, 1990). It is these irregularly-shaped ice bodies that are most unknown and are believed to be either buried glacier ice or intra-sedimental ice within permafrost that occurs when water freezes within the sediment (Pollard, 1990) and (Couture, 2000).

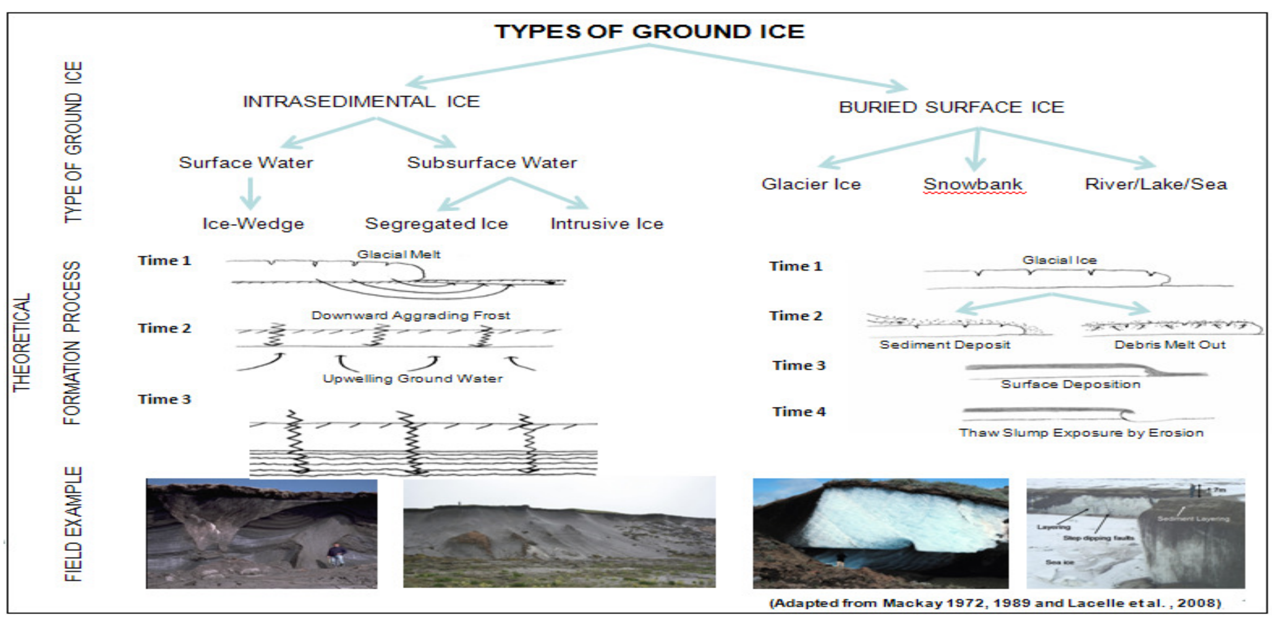

Figure 2: A classification of massive ground ice and illustrations of hypothetical formations.

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1.2.1 Intrasedimental Ice

Intrasedimental Ice/Massive Segregated-Intrusive Ice – The growth of ice lenses several meters thick fed by ground water migrating toward a freezing front during permafrost aggradation (Mackay, 1972).

1.2.2 Buried Glacial Ice

Glacial ice buried by a layer of till that exceeds the active layer thickness providing a layer of insulation preventing the glacial ice from thawing (French, 2004).

2 PREVIOUS RESEARCH APPROACHES

Intensive studies to determine the origin and nature of massive ice on Herschel Island were first carried out in 1986, this work focused primarily on cryostratigraphic and petrographic methods (Pollard, 1990). Cryostratigraphic methods can be useful in the reconstruction of permafrost conditions. However, such an approach is limited by the number of exposures present and is complicated by the deformed nature of the sediments making regional interpretation and correlation very difficult (Pollard, 1990). Petrographic studies consider the colour, appearance, size, shape, orientation, bulk pattern and crystal characteristics of the ice and can give clues on the nature and pattern of gas and sediment inclusions as well as the rate and direction of freezing influences (Pollard, 1990). However, this science is based on several assumptions and is highly dependent on the skill of the interpreter and the quality of samples, which are easily altered due to increased temperatures during transport. More recently, work has focused on stable water oxygen isotope (^{18}O) concentrations of various ground ice types (Fritz et al. 2009). Cycles in the ratios of ^{16}O and ^{18} reflect past climates and since ground ice is a valuable record of climate information it can be used for paleoenvironmental interpretation. However, using $^{15}N_{N2}$ and $^{18}O_{O2}$ to distinguish intra-sedimental ice from buried ice are understood to be inconclusive as they are affected by various physical processes during formation such as gravitational settling, excess air addition, mixing with snow pack and respiration (Cardyn et al., 2007). None of these methods, when used alone, unambiguously distinguishes between buried glacial ice and segregated-intrusive ground ice bodies (Cardyn et al., 2007, p 240).

The concentration and molar ratios of CO_2, O_2, N_2, and Ar gasses entrapped in the ice is a new tool that allows the differentiating between ground ice of glacial (firnified glacier ice) and non-glacial intra-sedimental origin (Lacelle et al., 2007). The principle behind this novel technique is that molar ratios of gases (0_2/Ar and N_2/Ar) entrapped in glacier ice tend to preserve an atmospheric signature modified by firn diffusion and gravitational settling, whereas the molar gas ratios of ice of a segregated-intrusive origin are significantly different from those found in the atmosphere and glacier ice due to the different solubilities of the gases in water (Lacelle et al., 2007, p 240). Measuring the relative abundances of 0_2, N_2 and Ar gasses entrapped in the ice and comparing this to their stable isotope ratios can determine the origin of massive ground ice and icy sediment bodies (Cardyn et al., 2007). Atmospheric gas ratios change little over time and can now be measured with great precision and accuracy. Only with the advent of precision, continuous flow or dual inlet isotope ratio mass spectrometers can this technique be employed to better identify the origin of ground ice with a high degree of confidence (Cardyn et al., 2007). Results of initial studies by Cardyn et al. (2007) have produced standard values comparing the molar ratios of 5 different ice types from known origins, refer to figure 3.

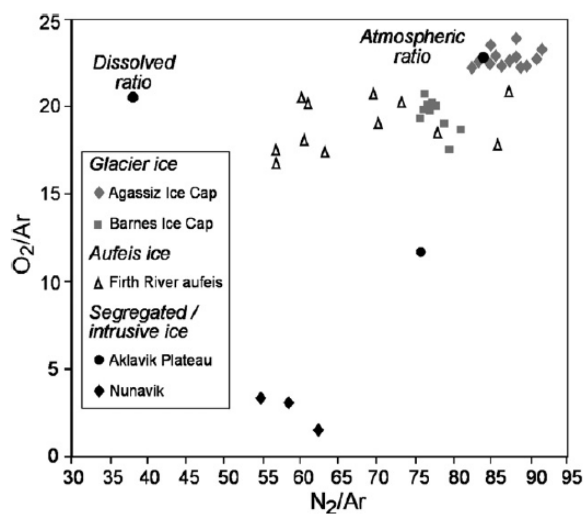

Figure 3: Summary of molar gas ratios of air entrapped in glacier ice, aufeis ice, and intra-sedimental ice (Cardyn et al., 2007).

Table 1. Gas composition of the atmospheric air compared to water. The solubility of gases such as argon in water produces values lower than atmospheric ratios.

Gas Ratios	Atmospheric Ratio	Aquatic Ratio
O_2/Ar	22.42	20.83
N_2/Ar	83.60	35.00

Gases Entrapped in Glacier Ice

The ratio of atmospheric gases is considered constant with an O_2 (20.94%) to Ar (0.93%) ratio of 22.42 and a N_2(78.08%) to Ar ratio of 83.60, refer to table 1. These atmospheric ratios are entrapped into glacier ice through the processes of firn densification and occlusion of porosity with only slight modifications resulting from gravitational fractionation and the presence of micro-fissures (Cardyn et al., 2007).

Gases Entrapped in Intrasedimental Ice

Molar gas ratios in intrasedimental ice formations including pore, wedge, segregated and intrusive ice contain different atmospheric gas ratios due to the different solubilities of the gases in water (Cardyn et al., 2007, p 240). The concentration of dissolved gas in water is expressed volumetrically based off of Henry's solubility constant.

3 METHOD

Field sampling of exposed icy sediments will take place on the head walls of six previously established retrogressive thaw slumps on Herschel Island. Employing a method described by Pollard (1990), an initial cryostratigraphic approach will attempt to reconstruct the permafrost conditions with stratigraphic observations and interpretations. Geochemical analysis of the massive ground ice in each exposure requires both liquid and frozen ice block samples.

3.1 Liquid Samples

Samples allowed to melt in the field, will be measured for acidity (pH), conductivity, salinity and DOC with a VWR symphony Multiparameter Research Meter. These same samples, measuring ~30mL, will be poured into HDPE bottles and shipped to the G.G. Hatch Laboratory at the University of Ottawa in order to analyze stable isotope ratios of oxygen and hydrogen (Lacelle et al, 2007). To reduce the possible mixing of liquid runoff with the ice sample the method developed by Lacelle et al (2007) will be used which removes and outer layer of ~30cm of surface ice. Moving from the upper contact downwards, several dozens of samples will be extracted with drill mounted corer at high resolution, 10cm intervals.

3.2 Frozen Samples

Frozen block samples will be extracted with the use of a chainsaw and axe hammer at each of the six head wall exposures. Where identified by cryostratigraphic analysis upwards of three block samples measuring ~25cm^3 will be kept frozen in thermally insulated boxes and shipped to the G.G. Hatch Laboratory. Frozen samples will be processed within the lab using the technique developed by Clark et al (2007) to measure CO_2, O_2, N_2 and Ar gas ratios. Additionally, petrographic crystallography studies will be carried out on these samples.

4 DISCUSSION

The molar ratios of atmospheric gases change during dissolution in water due to differences in their relative solubilities. With the development of more advanced mass spectrometers, molar gas ratios of trace gases including argon and carbon dioxide are able to be measured with greater precision. Molar ratios of atmospheric gases change during their dissolution in water due to differences in their relative solubilities, thus providing distinctive ratios for dissolved gases. The composition of air entrapped in massive ground ice bodies is able to distinguish between vapor and liquid derived water sources (Lacelle *et al.,* 2008).

Research commenced on Herschel Island in 1986, at this time the most up to date field methods and technologies were used in an attempt to answer the most fundamental question; where did this ground ice come from? Although significant discoveries have been made throughout the last few decades, this question still persists. Molar gas ratio analysis will conclusively determine the origin of massive ground ice found at Hershel Island. This work will provide greater insight on the geologic history of Herschel Island. This is highly transferable knowledge to adjacent permafrost landscapes of Arctic Canada and the United States and will also serve as another field site to further this new geochemical research. With conclusive results on the origin of Herschel's ground ice, all other work conducted here will be further validated.

5 CONCLUSION

The anticipated results with the use of his new technique of molar gas ratios will conclusively identify the massive ice ground ice bodies on Herschel Island, Yukon. Moreover, this work will further validate the past here decades of work that has been conducted throughout Herschel Island.

As this is a newly developed technique applying this approach to Herschel Island also serves as a new test site for this fledgling geochemical approach to fundamental ground ice questions. This paper simply outline the work that is to be conducted within the next year but will be quickly followed up with a more extensive review on both the actual field methods and results.

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