THE APPLICABILITY OF 3D GROUND-PENETRATING RADAR AND PERIGLACIAL SEDIMENTOLOGY FOR SUBSURFACE ICE VOLUME ESTIMATION IN ICE-RICH, PLANETARY POLYGONAL NETWORKS. C. N. Andres[1], G. R. Osinski[1], and E. Godin[2]. [1]Department of Earth Sciences/Institute for Earth and Space Exploration, University of Western Ontario, London, ON, Canada, N6A 5B7, candres5@uwo.ca, [2]Centre d'Études Nordiques, Université Laval, Québec, QC, Canada, G1V 0A6.

Introduction: Ice-wedge polygons are periglacial landforms of high interest as they house specific volumes of water-ice in the subsurface, which is a highly sought after resource in planetary exploration. Polygons are one of the most common landforms in the Arctic and on Mars formed via repeated freeze-thaw and meltwater infilling [2, 5]. Noninvasive 3D ground-penetrating radar (GPR) imaging in correlation with sedimentological sample analysis was used to delineate the internal architecture and processes of the shallow subsurface in ice-wedge polygons, that of which satellite imagery simply cannot provide. The GPR method records the two-way travel time of electromagnetic (EM) waves reflected at boundaries between subsurface layers with contrasting relative permittivity, which is indicative of variations in sediment grain size, water content, and mineral composition [1,2]. This study asks the questions: *Is it possible to tell if there is water- ice in a polygon network by investigating its morphology remotely or in-situ? If so, how much ice?*

Study Site and Methods: Using *Sensors and Software Noggin* 250MHz GPR, *Ekko_Project* software and *MatLab 9.6 (R2019a)*, we conducted an in-depth study of subsurface ice and sedimentology in Strand Fiord, Axel Heiberg Island (79°09'43"N, 90°13'44"W), with implications to radar imaging and modelling of the shallow subsurface on mid-high latitude regions of Mars (**Fig. 1**). GPR models such as in **Fig. 2 & 3** were generated using several processing techniques in order to filter the noise from the dataset and further extrapolate these line scans. Respectively, the processing elements that were used were the *dewow filter*, *background subtraction (total background)*, *gain* (with a signal attenuation of 16db/m), *envelope filter*, and *migration* filter (frequency-wave number).

Fig. 1. A localized mapping area of ice-rich polygon networks on Strand Fiord, Axel Heiberg.

Radargram Profiles and Sedimentology. GPRplanview maps (**Fig. 2A)** are able to highlight surface structures and concentrations of ice at different depths, this patterning are often the most important indicator of contrasting boundaries and key signatures [2, 4].

The topographically corrected radargram in **Fig. 3** shows a single 25 m line profile within GPR_G1 straddling two secondary high-centre polygons showing radar signatures of a single ice wedge inside the trough and interpreted sedimentological correlation. At the first ~0.5-0.75 m, we see chaotic and oblique (non-parallel) radar signature returns that equate with deformed and massive fine silts with some organic matter/plant inclusions confirmed from trench excavations.

3D-GPR Model*: Ice Volume Calculation*. In order to model GPR data, an isosurface was created in order to illustrate 3D shaded renderings from lattice files They reflect the concept of a contour line (2D) and frames it in 3D space using matrices (**Fig. 2B)**. Using the Voxler 4 software, a 3D simulation of ice-wedges was modelled not only as a visualization tool but also as a calculator for subsurface ice volume. Volume calculations were

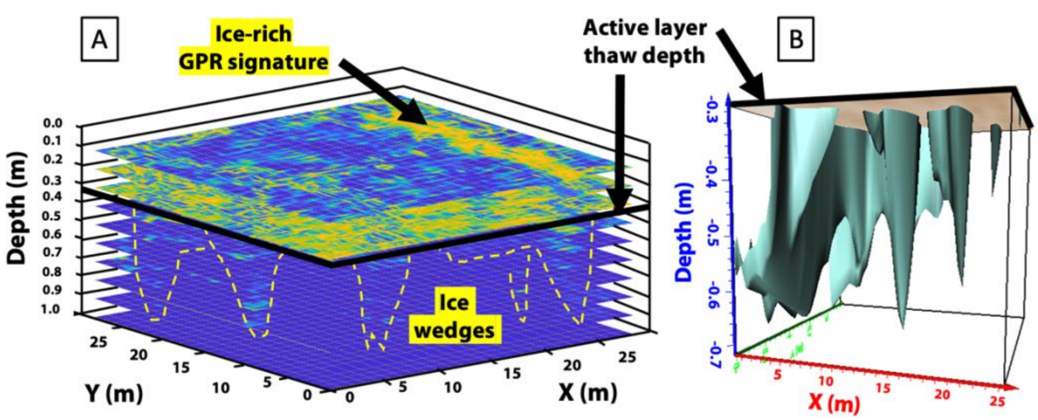

Fig. 2. (A) Stacked GPR depth slices rendered using MATLAB. Probable ice-rich areas and ice-wedges are highlighted in yellow mostly saturated in polygon troughs. (B) Voxler model of ice-wedge isosurfaces using isolated data from GPR radargrams. The active layer thaw depth is illustrated by the black bolded line in both images.

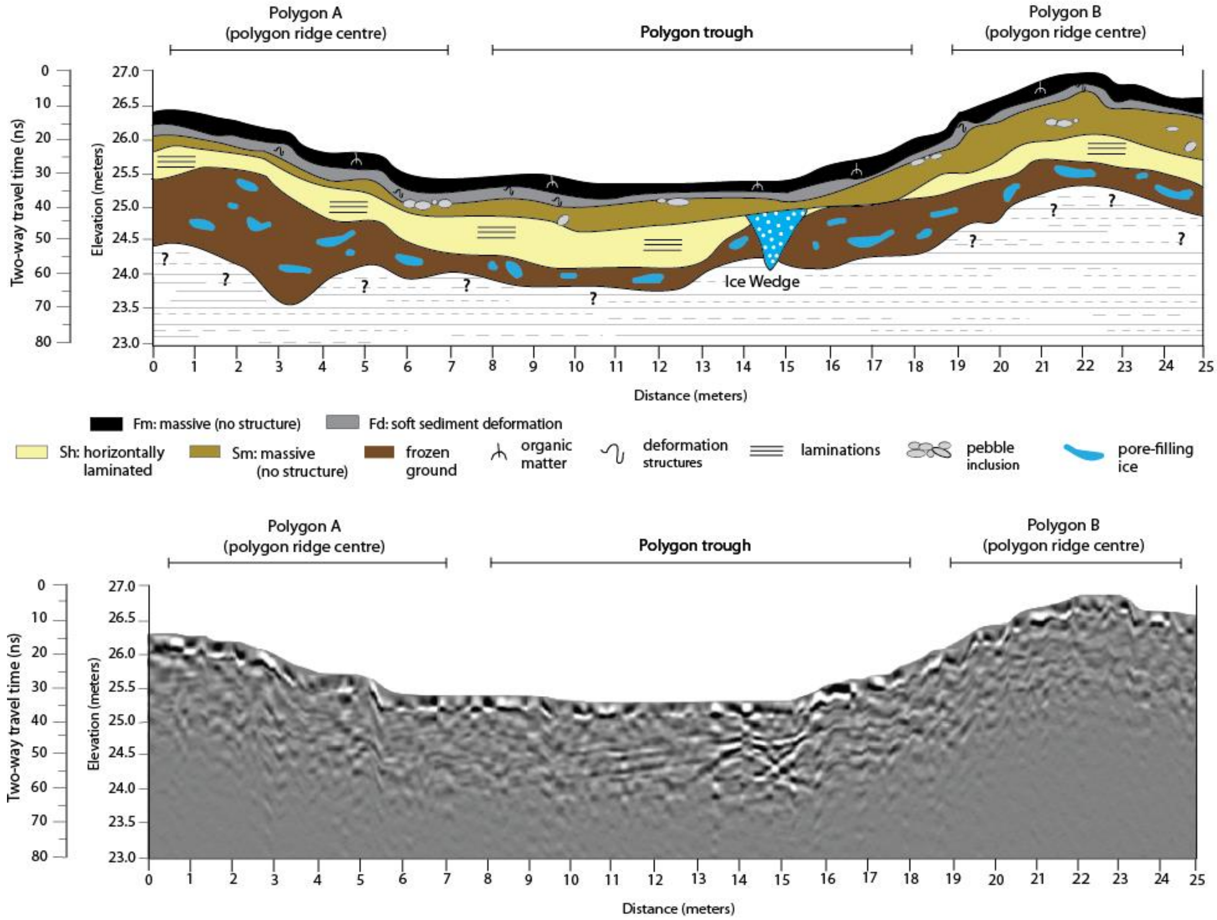

Fig. 3. (Top) Stratigraphic reconstruction of an ice-wedge-polygon system using data from cross sections, GPR profiles and sedimentological analyses. (Bottom) 25m GPR profile conducted at 250 MHz straddling polygons A and B within the 25m x 25m grid. Radargram interpretation has been incorporated into (Top).

generated from voxels (3D pixels) that are either partially or fully included in the isosurface. The total volume (isovalue) is the sum of the individual volumes from these voxels. Using this approach, the volume of the ice-rich isosurface within the 25 m x 25 m GPR survey grid has been calculated to contain 43.28 m^3 of ice. It is important to note that in both 3D-GPR subsurface ice-wedge models that ice-wedge morphology is complex.

Discussion: ***Heterogeneity of Ice Distribution.*** The radargram profiles show ice-wedges that appear as chevron-shaped intersections (**Fig. 3**). There is a clear three-dimensional asymmetry to these forms that are highly be dependent on *slope*, *sediment matrix permeability* (for water seepage), as well as *stratigraphic discontinuities for preferential sites of ponding,* in which ice-wedges could begin to grow larger and assume expansive and more complex morphologies

3D modelling of GPR data can be limited by several factors, two of which are near-surface water and mineral concentration. Due to the soil's conductive nature, the GPR signals get "scattered" before it can return to the antenna when travelling through damp or wet soils, especially when they have high salt content or have a diverse lithology. For example, Strand Fiord is located in a silty-sand fluvial basin, which can heavily impact signal attenuation due to differential dielectric constants. The next step could be a temporal 3D GPR experiment in order to see fluctuations in ice volumes seasonally, which can give insight to secondary polygon and ice-wedge initiation [3,4].

Future Work: Since water-ice is one of the many potential subsurface signatures that can be seen on Earth and on Mars, GPR and sedimentology has applications to planetary exploration with specific relevance to the *Water Ice Subsurface Deposit Observation on Mars (WISDOM).* Although GPR is a powerful tool in subsurface modelling, high-resolution surface ground-truthing and correlation using other datasets, such as LiDAR, high resolution images (i.e. drone, helicopter) and stratigraphic sampling/architectural analyses are necessary to validate these top-of-the-surface expressions with subsurface processes towards more stratigraphic detail and effective site selection towards more ice-rich regions using periglacial geomorphology.

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