

THE ALASKAN PERMAFROST TUNNEL ANALOG FOR ICE SHEET PROFILES OF MARS J. M. Lorenzo¹, A. Bates¹, D. A. Patterson¹, T. A. Douglas², G. Tsoflis³, S. Karunatillake¹, H. Haviland⁴, M. Zanetti⁴, P.M. Bremner⁴, R. C. Weber⁴, C. Fassett⁴, ¹Dept. Geology and Geophysics, Louisiana State University, Cnr. Tower and S. Campus Drives, Baton Rouge, LA 70803, gllore@lsu.edu., ²U.S. Army Cold Regions Research & Engineering Laboratory, 9th Avenue, Building 4070 Fort Wainwright, AK, USA, thomas.a.douglas@usace.army.mil; University of Kansas, Geology, Ritchie Hall, room #354B, Lawrence, KS 66045-7613, tsoflis@ku.edu; ⁴NASA Marshall Space Flight Center, 320 Sparkman Drive, Huntsville, AL 35820, heidi.haviland@nasa.gov.

Introduction: Martian water ice is a precious resource for fuel and water to support future human explorers. Equally important, shallow ground ice (<10 m) also archives atmosphere-regolith interactions in the critical zone for habitability and records the signature of celestial mechanics [1]. Recent, Martian, mid-latitudinal ice discoveries emphasize these areas as key to future exploration [2]. Remote sensing suggests compaction resembling terrestrial glaciers, but with limited evidence for their flow [3]. Cold, dry-based glacier conditions currently dominate, as evident from both scarp activity and collapsed boulder fields [4]. However, englacial processes tied to the depth variability of ice composition and structure remains poorly modeled for Mars. This can be addressed in situ by, increasingly mature, compact nuclear spectroscopy, ground penetrating radar (e.g., dielectric properties) and seismic methods together to increase the capacity to effectively explore mid-latitudinal sites

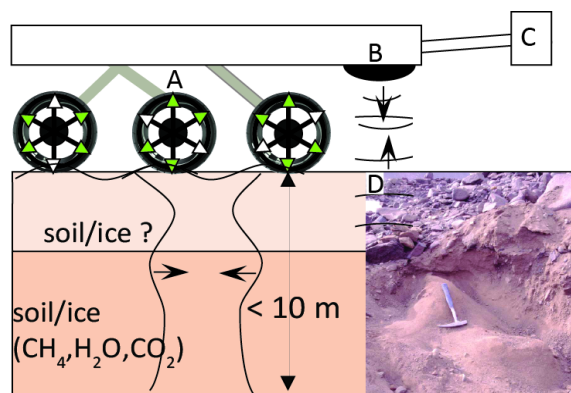


Figure 1. Conceptual, in-situ rover mission at a Martian ice sheet. A. Alternating seismic sensors (green) and sources (white) receive and send seismic waves. B. Ground-penetrating radar transceiver detects pore-space substituted with ice. C. A long-arm gamma- neutron spectrometer. Sensor collects nuclear spectra away from influence of rover. D. As a specific example for Mars, the Antarctic Dry Valleys analog [2] implies a potentially complex soil-ice mixture for Mars that requires an integrated suite of geophysical and geochemical tools.

in situ [5]. However, terrestrial analog studies are needed to calibrate and mature such instrument suites.

Non-invasive in-situ characterization can be the key to modeling the geology of ground ice and advancing prior, remote and in situ observations (Fig. 1). An integrated sensing and analytical approach is necessary

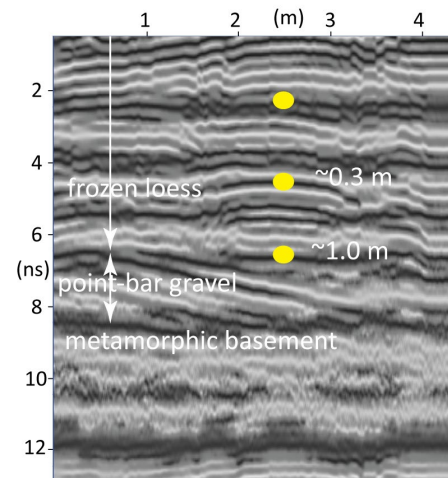


Figure 2. GPR constant-offset profile. Yellow dots mark reflector boundaries confirmed by separate, GPR, common-midpoint velocity analyses.

to constrain autonomous, real-time interpretations, e.g., simultaneous measurement of chemical (e.g., gamma-neutron spectrometers), seismic and dielectric properties. A multi-sensor approach reduces uncertainty in key properties such as the spatial distribution, depth, density, nature of overburden, and distinct stratigraphy of ice deposits within an area of interest along with gases and siliciclastic sediment they may entrain.

Permafrost Tunnel: We examine the U.S. Army Cold Regions Research and Engineering Laboratory's Permafrost Tunnel near Fairbanks, Alaska, as a terrestrial analog to cryospheric processes on Mars over geologic time. The tunnel is a unique [6] 500 m-long underground research facility excavated since the mid-1960s through intact, syngenetic, ice-rich permafrost, rarely accessible at analog field sites. The site is readily accessible with a full range of intact permafrost

structures as well as a 50-year sublimation record [7] through massive ice and undisturbed loess.

Ground-penetrating Radar and Seismic Data:

We select an inclined portion of the tunnel to allow an initial visual confirmation of the imaged radar stratigraphy. We collect (a) common-offset, ground-

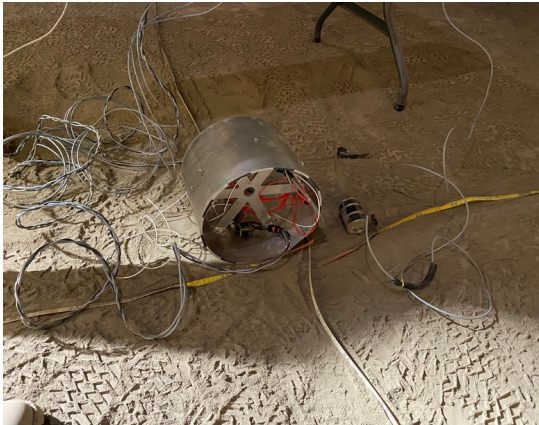


Figure 3. Three-component piezo-ceramic sensors on an aluminum wheel act as seismic receivers on floor of Permafrost Tunnel

penetrating radar (GPR) at a nominal 1 GHz, but which contains useful data up to ~ 2 GHz (Fig. 2), (b) high-frequency seismic (20 Hz- 4 kHz; Fig. 3) data and (3) continuous core of the permafrost loess down to 50 cm depth.

A small grid of constant-offset GPR profiles (~ 5 m x 5 m) provides an ice-stratigraphic framework. A common-mid-point survey provides radar velocity information for accurate time-to-depth conversion of key radar reflector boundaries-- these can be correlated to



Figure 4. Minimum water-ice content estimates from bulk wet and dry cores. Overall, content decreases with depth below floor of Permafrost Tunnel. Sharp change at ~ 0.3 m depth may correspond to observed GPR reflector (Fig. 2) at a similar depth.

minimum water-content-versus-depth estimates derived from cores (Fig. 4). Seismic data use a novel 3-component piezo-ceramic accelerometer sensors rigidly mounted to the interior of a small aluminum wheel (Fig. 3). A small 0.75 kg drop-weight provides a suitable low-energy seismic source (~ 0.75 J per blow). Good signal above any instrumental noise floor exists out to 3- m offsets.

Notably, key boundaries seen in constant-offset GPR profiles (Fig. 2) may correspond to *large variations in ice-water content* with depth (Fig. 4). As well, seismic attenuation (inverse of Q-quality factor) which measures the inelastic nature of the subsurface may be used as a *potential indicator* of the presence of rigidly frozen loess. Ice-frozen loess displays relatively large Q values of (~ 80) (Fig. 5). By comparison, Q values in laboratory-based estimations of loose, unconsolidated sands are an order of magnitude lower [8].

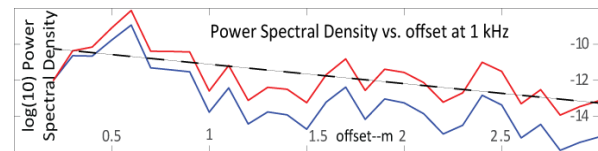


Figure 5. Linear, best-fit (dashed line) to power spectrum as a function of distance indicates a Q of ~ 80 for "frozen" loess. At chosen frequency (~ 1 kHz) raw values (blue line) are compensated for geometric spreading (red line).

Acknowledgments: Support from NASA EPSCoR Cooperative agreement 80NSSC20M0150 (CFDA #43.008) and Ernest & Alice Neal Professorship in Geology & Geophysics (J.M.L.)

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