UTILIZING THE SPECIALIZED PENETROMETER FOR ICE DETECTION. B. C. Thrift[1] and C. B. Dreyer[1], [1]Colorado School of Mines Center for Space Resources (1310 Maple St GRL 140, Golden, CO, 80401, benthrift@mines.edu, cdreyer@mines.edu)

Introduction: Penetrometers are useful geotechnical tools that are widely used both on Earth and off. In general, only the penetration response is evaluated, however, the viscoelastic response after motion has stopped can also reveal information about the surface being tested. Atkinson, et al. [1] showed that this relaxation response was sensitive to various parameters including ice content. By enabling the detection of ice and the characterization of surfaces, a specialized penetrometer is a useful resource prospecting tool.

A specialized penetrometer was developed at the Colorado School of Mines along with the ISRU Experimental Probe (IEP) as a part of the Institute for Modeling Plasma, Atmospheres, and Cosmic Dust (IMPACT) of NASA's Solar System Exploration Research Virtual Institute (SSERVI) [2]. The IEP consists of a zero backlash three-axis translation stage, a highly sensitive force-torque sensor, and a probe. The IEP is used to conduct specialized penetrometer operations in the lab. The Commercial Lunar Payload Service (CLPS) Masten Mission One will carry a specialized penetrometer as part of the Sample Acquisition, Morphology filtering, and Probing of Lunar Regolith payload. The mission is set to fly to the South Pole region of the Moon in late 2023 and will serve as a technology demonstration of the specialized penetrometer and other instruments.

Data Analysis: The penetrometer data are split into penetration and relaxation responses. Curves are fit to the penetration and relaxation data, and the curve fitting coefficients from different test conditions are examined. The penetration curve is a second-order polynomial of the form:

$$F(z) = \alpha z + \beta z^2$$

where F(z) is the force as a function of depth, α is the first-first order coefficient, and β is the second-order coefficient.

The α coefficient represents the general slope of the penetration curve, while the β coefficient represents the non-linearity of the curve. In the non-compacted, low-relative density samples, the penetration response is effectively linear, so the β coefficients are near zero. In the compacted, high-relative density samples, the β coefficients are significant allowing the final force at depth to be much higher in the compacted samples despite similar values of α, the linear slope term.

The relaxation curve is more complex. The model used for the relaxation is based on a Maxwell rheological model made up of an external Hookean spring in parallel with two Maxwell arms comprised of a Hookean spring in series with a viscous Newtonian dashpot. The relaxation curve fits the form:

$$\sigma(t)/\sigma_{max} = \epsilon\left(k_e + k_1 e^{(-t/\tau_1)} + k_2 e^{(-t/\tau_2)}\right)$$

where $\sigma(t)$ is the vertical stress exerted on the probe tip as a function of time, σ_{max} is the maximum penetration resistance experienced by the probe. The strain experienced by the sample after penetration is represented by ϵ, and k_e is the residual load the material supports after relaxation. The elastic components of the Maxwell arms are represented by k_{1-2} and the associated viscous time-dependent terms are represented by τ_{1-2} while e is Euler's constant.

The relaxation response was shown to be sensitive to ice content within permafrost style samples [1]. The external spring constant, εk_e, increases with ice content, while the internal spring constants, εk_{1-2}, decrease. The viscous, time-dependent terms, τ_{1-2}, generally increase with ice content.

Conclusion: Using a specialized penetrometer can provide useful information about the characteristics of a surface. The penetrometer data can be useful in resource prospecting, not just through ice detection, but by providing geotechnical information about a surface to aid in excavation and transport across the surface. By examining both penetration and relaxation data acquired during a penetrometer operation, information about the geotechnical properties of a surface and the potential ice content of the test surface can be gathered. A specialized penetrometer is a low-cost, low-complexity, and low-mass geotechnical tool that can provide useful geotechnical information and initial indications of the presence of ice.

References: [1] Atkinson, J., et al. (2020) *Icarus, 346,* 113812. [2] Dreyer C., et al. (2018) *Review of Scientific Instruments, 89, 6,* 064502.