GROUND-PENETRATING RADAR AS A TOOL FOR PROSPECTING BURIED LUNAR ICE.
E. S. Shoemaker[1], D. M. H. Baker[2], J. A. Richardson[2], L. M. Carter[1], K. E. Young[2], P. L. Whelley[2,3], N. Schmerr[3], L. Wike[3], J. Coonan[4], & S. Kruse[4]. [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, (eshoemaker@email.arizona.edu), [2]NASA Goddard Space Flight Center, Greenbelt, MD, [3]Univeristy of Maryland, College Park, MD, [4]University of South Florida, Tampa, FL.

Introduction: Future in-situ resource utilization (ISRU) on the Moon will require the ability to efficiently prospect and access resources like buried water ice in the subsurface. Water ice deposits have been identified in permanently shadowed regions (PSRs) on the Moon [1], and stable ground ice deposits may be found preserved beneath regolith in former PSRs if these sites were maintained at temperatures <145 K [2]. Ground-penetrating radar (GPR) nondestructively sounds the shallow subsurface (0–20 m) and can map the extent and depth of ice deposits from the lunar surface at high resolutions (cm-scale). This geophysical method is complementary to both shallowly probing, surface-sensitive orbital methods like neutron and infrared spectroscopy and more deeply probing orbital radar systems. Additionally, rover-mounted GPR systems such as the Chang'E-4 Lunar Penetrating Radar have demonstrated their ability to penetrate through the lunar regolith to resolve subsurface structure and constrain properties such as permittivity and loss [3]. Our field team has tested GPR instruments and field methods at terrestrial sites analogous to sites of interest on the Moon such as the South Pole. We have found that multi-frequency GPR surveys operating between 200 and 900 MHz are effective at resolving layers of regolith and buried ice within the top 5 meters of the surface [4,5].

Identifying Buried Ice in GPR Data: We conducted GPR surveys of lithic-poor ice deposits buried by low density tephra within the caldera of the Askja Volcano in Northern Iceland as a geophysical and operational analog for ice detection in lunar polar regions. We conducted repeat GPR surveys at 200-900 MHz over tephra deposits from two eruptions in 1875 and 1961, which buried and preserved snowpack at the time of each eruption [6]; this compacted into the presently observed ice layers.

Results. GPR radargrams (2D images of returned subsurface power) at each frequency resolved the interface between the ice layers and the overlying tephra. From these, we mapped continuous, tens-of-meters-long, tephra layers 0.5-1 m in thickness and ice layers ~0.1-2.5 m thick [3].

We observed an increase in radar scattering in the overlying tephra layer as clasts approached the GPR wavelengths. Also, while pore ice (more likely for the Moon) was observed through boreholes and trenches in limited locations, GPR could not uniquely resolve the pore-ice-to-massive-ice transition. These observations suggest that sharper dielectric contrasts (e.g., more rapid transition between regolith and pore ice high ice contents) or thicker icy regolith are needed for confident GPR detections of ice-content. Further, other coordinated geophysical measurements and sampling (e.g., drive tubes) may be necessary for successful interpretation of ice and regolith structure.

Need for Coordinated Measurements: Our field observations in Iceland demonstrated that GPR is effective at resolving laterally extensive slab ice deposits beneath a thin layer (0.5-1 m) of regolith (tephra in our case). However, subsurface ice can present a non-unique radar signal when it is buried beneath material of a similar permittivity and loss like low density rocky materials such as tephra or lunar regolith [1,3]. Its identification becomes increasingly difficult as water ice content decreases (e.g., lunar pore ice < few wt%) [7, fig. 7] necessitating coordinated measurements by other geophysical methods and field tools. Coordinated geophysical field methods including magnetic, gravitational, and lidar surveys helped confirm detections made by a 100 MHz GPR of subsurface lava tubes, another key lunar resource for future human exploration, at Lava Beds National Monument (California) [8,9]. Detecting and characterizing the extent and physical properties of subsurface water ice will need to be accomplished through a series of complementary orbital and surface geophysical observations, including GPR, along with sampling the subsurface using astronaut or robotically-performed drive tubes, trenching, or drilling. While some resource detection methods are more capable of uniquely identifying ice deposits, the depth range accessible by GPR and its continuous subsurface mapping capabilities during robotic or crewed traverses make it a valuable tool in any coordinated resource evaluation campaign.

Acknowledgments: Support provided by the Goddard Instrument Field Team and the SSERVI GEODES team (NASA CAN #80NSSC19M0216).

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