PROSPECTING BURIED ICE WITH GROUND PENETRATING RADAR AT ASKJA VOLCANO, NORTHERN ICELAND. J. A. Richardson1,2, D. M. H. Baker3, E. S. Shoemaker3, S. P. Scheidt4, P. L. Whelley1,2, K. E. Young2, T. G. Graff3, C. N. Achilles2, L. M. Carter3, C. W. Hamilton3. 1Department of Astronomy, University of Maryland, College Park, MD 20742, 2Solar System Exploration Division, NASA Goddard Space Flight Center, Greenbelt, MD 20771 (jacob.a.richardson@nasa.gov), 3Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, 4Planetary Science Institute, Tucson, AZ 85719. 5Jacobs/NASA Johnson Space Center, Houston, TX 77058.

Introduction: An important exploration objective for the Moon and Mars is to identify accessible buried water ice in the shallow (0–10 m) subsurface for in-situ resource utilization (ISRU). Such deposits have been identified or inferred in permanently shadowed regions (PSRs) of the Moon [1], martian poles and mid-latitudes [2], and buried under volcanic ash near the Tharsis Montes [3,4]. Ice deposits on Mars at depths of tens to hundreds of meters have been detected by the orbital radars, SHARAD (20 MHz) and MARSIS (3–5 MHz), but detection of ice at 1–20 meters depth on the Moon and Mars requires higher frequency orbital or landed radar instruments.

Field Analog. Eruptions in March, 1875 [5] and October to November, 1961 [6] within the caldera of the Askja central volcano (Northern Iceland, Fig. 1) produced analogous field settings to buried ice deposits on other planets by depositing pyroclasts on fresh snowfall. This snowfall then densified into solid ice and has remained buried since each eruption. Ice deposits are located in the southeast area of the caldera under meters of pumice erupted in 1875 and in the northeast of the caldera under decimeter to meters of basaltic ash and lapilli. We have surveyed both of these areas with ground penetrating radar (GPR) to identify buried ice from the surface as an analog for detecting ice in polar regions on the Moon and ice-laden areas on Mars.

Methodology: GPR. Transect surveys over pyroclasts from Askja eruptions were performed using two shielded GSSI GPR antennae with 200 and 400 MHz frequencies. Radar traces were recorded at a rate of 100/m and were triggered with a wheel odometer. A GPS was mounted to these antennae for geopositioning. Timeseries data resulting from each survey were then processed in Radan 7 software. Processing steps applied included dewow filtering, time zero corrections, ADC gain correction, and 2D migration.

Boring. A rotary hammer drill and a 2–3/8-inch core barrel auger were used to vertically sample the subsurface along GPR transects. Samples were collected in 15–30 cm increments to a total depth of up to 1.6 m. Cored material descriptions were logged, including the presence of water, ice, and basalt pyroclasts, pumice and/or soil. Similarly, trenches were also dug at times to validate GPR analysis results.

Aerial surveys. An orthoimage mosaic and a Digital Elevation Model (DEM) were produced for the Askja caldera study area using a Mavic 2 Pro quadcopter. Images collected by the quadcopter were processed using AgiSoft Metashape software.

Figure 1. Eruptions of light-colored pumice (1875 CE) and dark basaltic ash and lapilli (1961 CE), emplaced tephra over basalt lavas and snow within the caldera.

Figure 2. Pure ice deposits are found beneath eruption deposits at Askja Volcano. In this photographed trench, ice overlays pumice deposited in 1875 and is overlain by 1961 basalt pyroclasts. Our team surveyed this ice with a 400 MHz antenna in the background.
Results: Our team collected 50 GPR surveys of buried ice in the Askja region over a period of two weeks in August, 2019. A total of 11 boreholes were made along survey transects where radar reflectors were identified to verify the presence of ice. Several trenches were also dug on the sides of mounds when GPR surveys were collected over the mounds.

Our main finding in the caldera is the presence of two styles of ice deposits under both 1875 and 1961 pyroclasts. Shallow deposits of water ice exist ~15–30 cm below the subsurface (recorded at ~4–5 ns two-way travel time in radar data) within pore space between pyroclasts. Second, pure ice deposits are found at various depths at the base of eruption deposits (Fig. 2).

Aerial images also enabled us to identify and map several pit and moat-like morphological features (Fig. 3), related to ablation of subsurface ice. Cores at ring-shaped moats revealed shallow ice outside rings and deeper or no ice within rings. A shallow water table also rebounded in boreholes and was deeper within rings.

Discussion: Buried ice has continually existed at the Askja volcano for at least 144 years since the 1875 eruption. We interpret pure ice to be the product of snow that was rapidly buried by pyroclasts from two recent eruptions at Askja. Ice residing in pore space between pyroclasts might result from a number of processes. As a saturated layer was observed over frozen layers in the subsurface in many locations, this pore space ice might be refreezing of melted ice or freezing of later meteoric water.

GPR is effective in identifying changes in lithology at interfaces between dry pyroclasts and frozen deposits with a water ice matrix and between frozen deposits and pure ice. These interfaces were identified in radar data from both the 200 and 400 MHz antennae.

This work provides important insight into characterizing subsurface ice at planetary bodies: 1) GPR at frequencies of several hundred MHz is effective for defining the horizontal and vertical structure of buried ice deposits but additional measurements (e.g., cores) are crucial for interpretation; 2) Layers of volcaniclastic material and ice may build up over time from successive volcanic eruptions and snowfall events; 3) Ablation-related surface landforms can be tied to changes in subsurface ice depth and distribution, revealing the power of coordinated geomorphic and geophysical observations.

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