SUBSURFACE STRUCTURE OF THE 1961 LAVA FLOWS AT ASKJA, ICELAND. E. S. Shoemaker[1], D. M. H. Baker[2], J. A. Richardson[2,3], S. P. Scheidt[2,4], P. L. Whelley[2,3], and L. M. Carter[1], [1]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ (eshoemaker@email.arizona.edu), [2]NASA Goddard Space Flight Center, Greenbelt, MD, [3]University of Maryland, College Park, MD, [4]Howard University, Washington, D.C.

Introduction and Motivation: Askja is a central volcano located in Northern Volcanic Zone of Iceland and part of the Pleistocene Dyngjufjöll massif [1]. This volcano has a large, 11 km^2 caldera created in the explosive 1875 eruption which is now occupied by Lake Öskjuvatn [2] (Fig. 1). This eruption produced a rhyolitic, sub-angular pumice fall deposit during its main Plinian phase which covers ~7500 km^2 of eastern Iceland [2,3]. In the 1961 eruption, 11 km^2 of basaltic lava was emplaced eastward from the northern rim of the caldera [2] over older, basaltic lavas from > 6.6. ka and < 2.9 ka [1,2]. The buff-colored, sub-angular-to-rounded pumice clasts from 1875 can be seen blanketing the region surrounding this flow (Fig. 1).

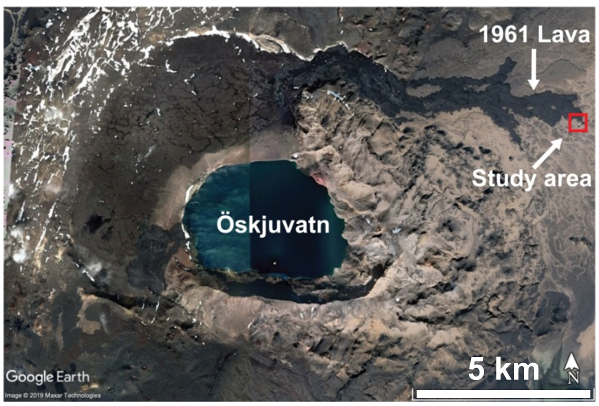

Figure 1. Lake Öskjuvatn sits in the center of the caldera. To the east the 1961 lava flow can be seen indicated by the white arrow. The study area in this investigation is enclosed in the red box at the easternmost margin. Aerial image of the Askja volcanic complex from Google Earth™.

This region serves as a layered-volcanics analog for the Martian Tharsis volcanic province where laterally extensive basaltic lava flows [4,5,6] have flowed over volcanic plains surrounding the central Tharsis Montes. The Shallow Radar (SHARAD) orbital radar sounder on the Mars Reconnaissance Orbiter (MRO) has detected contacts between the surrounding plains and the base of lava flows that can be seen in orbital topography data. However, numerous regions in the plains possess subsurface interfaces for which the stratigraphy is completely unknown [5,6]. Our investigation seeks to hypothesize what stratigraphy is present that SHARAD is detecting beneath these plains through comparison to GPR responses to various volcanic deposits on Earth where the subsurface structure is largely known.

Methods and data: *Ground Penetrating Radar.* We use ground penetrating radar (GPR) to examine the subsurface stratigraphy associated with these pumice-covered lava flows. We used the Geophysical Survey Systems Inc. (GSSI) GPR system 400 MHz (depth range 4-8 m, vertical resolution 6-12 cm) and 200 MHz (depth range 7-12 m, vertical resolution 12-25 cm) antennas connected to a Trimble Geo7x™ handheld GPS system to track the GPR system position along each traverse. We completed 16 traverses, 7 with the 400 MHz antenna and 9 with the 200 MHz antenna. These traverses can be seen as red lines within white boxes outlining the four survey locations along the lava flow (Fig. 2). These locations were chosen due to the abundant pumice cover which provided a smoother surface to operate the GPR system. Representative radargrams from these surveys are shown in Figures 4 and 5.

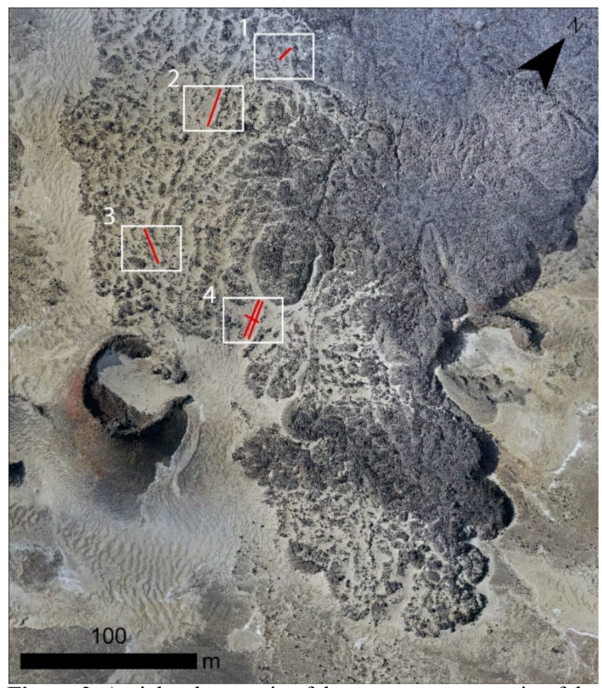

Figure 2. Aerial orthomosaic of the easternmost margin of the 1961 flow. Each numbered white box indicates a survey location. Red lines indicate the location of the GPR traverse using both the 400 MHz and 200 MHz antennas.

UAV. An aerial stereophotogrammetric survey was completed over the distal pumice-covered lava flow lobe in order to obtain an accurate assessment of the local morphology and geological context of the GPR transects. Image data from a DJI Mavic 2 Pro with a 24 MP camera were used to produce a digital terrain model (DTM, 5.8 cm/pixel) and an orthoimage (3 cm/pixel) using structure-from-motion processing software. Examples of these UAV products for this flow are shown in Figures 2 and 3. Markers were placed at the beginning and ending of each of the GPR transects so that UAV and GPR data could be accurately collocated, allowing an improved interpretation of surface-to-subsurface relationships of stratigraphy.

Results: Using the UAV-produced DTM, we determined the combined thickness of the flow and capping pumice layer to be ~9 m thick. Our surveys identified several subsurface interfaces in each radargram taken along this portion of the 1961 flow. Fig. 4 is a radargram from site 2 (Fig. 2) taken at 400 MHz. At least four interfaces are apparent. One interface spans the entire traverse and becomes shallower towards the flow center (Fig. 4, red arrows). Assuming a reasonable dielectric constant of 9 for basalt, this interface is at a depth of ~75-100 cm. After digging a trench along this traverse to a depth of ~1 m, we found that the pumice layer terminates at the bottom of the trench where the surface of the lava flow became visible. Two additional, discrete layers of darker material (~mm-sized) were mixed with smaller (~ mm-sized) pumice clasts at ~30 and 60 cm depth. The intermediate layers were a mixed, sandy sub-mm sized matrix of dark- and buff-toned grains. This layer is also visible in the 200 MHz traverse taken at site 2 (Fig. 5, red arrows).

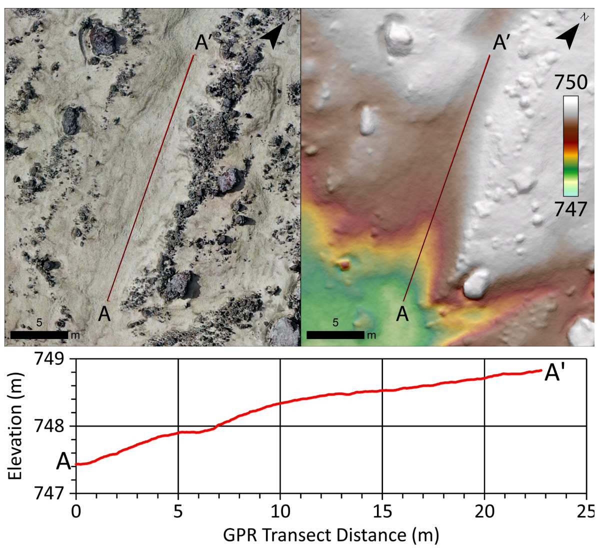

Figure 3. An orthomosaic (left panel) and hillshade map overlaid with a DTM (right panel) for site 2 in the study. A topographic profile extracted from GPR transect 2 from A to A'.

Discussion: The interface marked with red arrows in Figures 4 and 5 is likely the contact between the capping layer of pumice and the top of the lava flow. The topographic profile in Figure 3 corresponds to the radargram shown in Figure 4. The shallowing of this layer at this site corresponds well with the topography along the transect. The other reflectors above the red arrows in Figures 4 and 5 marked by white arrows may be related to the other layers identified in the trenches, but further analysis is required to confirm this. The dark-toned material may be eroded clasts of basalt mixed with the buff-colored pumice clasts. It is unlikely that we detected the base of the lava flow in contact with the surrounding plains at site 2 based on the inferred depths for the interfaces in Figures 4 and 5. Perhaps these deeper layers are the result of large voids within the flow or represent an internal change in vesicularity. Further investigation is required here to determine their origin. Despite the lack of detection of the basal interface, the internal layers and clear interface between the pumice and lava still serve as useful analogs to Mars in regions like the Medusae Fossae Formation and Tharsis where potential pyroclastic deposits have been identified using SHARAD [7,8].

Acknowledgments: This work was supported by the Goddard Instrument Field Team and part of a Volcanic Deposit Evolution and Origins (VIDEO) expedition.

References: [1]Graettinger, A. H., et al. (2013). *Int. J. Remote Sens.*, *34*, 7178–7198. [2]Thorarinsson, S., and Sigvaldason, G. E. (1962) *Am. Journal of Sci.*, *260*, 641–651. [3]Sparks, R. S. J., et al. (1981). *Phil. Trans. of the Royal Soc. of London. Series A, Math. and Phys. Sci.*, *299*, 241–273. [4]Carter, L. M., et al. (2009a) *GRL*, *36*, L23204. [5]Simon, M. N., et al. (2014) *JGR*, *119*, 2291-2299. [6]Shoemaker, E. S., et al. (2019) *LPS L,* Abstract #2611. [7]Carter, L. M., et al. (2009b) *Icarus, 199,* 295-302. [8] Ganesh, I., et al. (2020) *J. Volc. and Geo. Res.*, *390*, 106748.

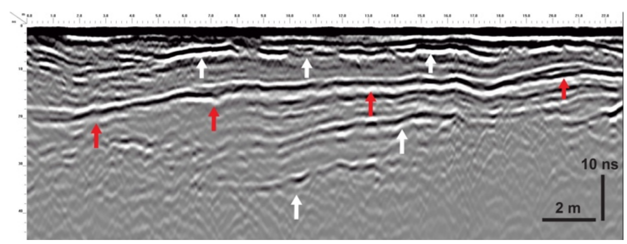

Figure 4. Preliminary radargram from site 2 taken at 400 MHz (corresponding topographic profile in Fig. 3. Along-track distance is along the x-axis and two-way time delay is in ns along the y-axis. At least four separate subsurface interfaces can be identified (arrows). One interface spans the entire length of the traverse (red arrows) and is likely the contact between the pumice layer and the lava flow.

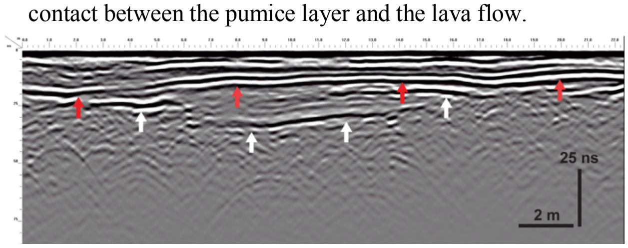

Figure 5. Preliminary radargram from site 2 taken at 200 MHz. Along-track distance is along the x-axis and two-way time delay is in ns along the y-axis. The same interface as Fig. 5 is marked with red arrows. Other deeper reflectors are marked with white arrows. A very near-surface interface can also be seen but is unmarked for clarity.