GROUND-TRUTHING SATELLITE SYNTHETIC APERTURE RADAR DATA OF A SAND-COVERED LAVA FLOW. S. M. Hibbard[1], R. Perkins[2], C. D. Neish[2], C. W. Hamilton[3], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA 91109 (shannon.m.hibbard@jpl.nasa.gov), [2]Institute for Earth and Space Exploration / Dept. of Earth Sciences, University of Western Ontario, London, ON, Canada, [3]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ, USA.

Introduction: The International Mars Ice Mapper (I-MIM) is proposed to carry an L-band synthetic aperture radar (SAR) to observe buried ice, lava flows, and other subsurface stratigraphy on Mars [1]. Martian lava flows are a particularly interesting target for SAR investigations as they show unusual roughness properties in Earth-based Arecibo radar imagery [2]. A SAR-based mission would provide much higher resolution data to help us better understand lava flow surface properties, which can tell us about lava flow emplacement and thermo-mechanical processes on Mars. As we prepare for I-MIM and other radar missions targeted for planetary observations, it is important that we utilize Earth analogues to assist in our interpretation of radar data of lava flows.

SAR has been utilized to identify lava types present across the Holuhraun lava flow field [3]. However, since the emplacement of the Holuhraun lava flow, katabatic-induced aeolian processes have rapidly been depositing sands onto the lava flow and completely burying the margins at many locations. The mantling of sediments on lava flows can change the surface texture of lava flows (i.e., reduces radar backscatter) [4]. This is dependent on the scale at which surface roughness is observed, the wavelength of the radar, and the thickness and sediment type of the mantling deposit [5]. Therefore, it is important that we measure the sediment thickness of the sand to calibrate the depth of the scattering layer (i.e., lava flow) observed with SAR.

Holuhraun presents a unique opportunity to observe a well-documented lava flow (with repeat satellite images, biweekly SAR coverage, and field observations since its eruption in 2015) undergo active burial from aeolian processes and determine how this affects remote sensing observations. In this study, we utilize Ground Penetrating Radar (GPR) and LiDAR to constrain the thickness of sand mantling the Holuhraun lava flow margins to determine the radar loss tangent, and ultimately penetration depth, of the Sentinel-1 C-Band ($\lambda = 5.6$ cm) dual-polarized radar [6] at Holuhraun.

Study Site: The Holuhraun lava flow-field is located in central Iceland within the northern part of the Bárðarbunga–Veiðivötn volcanic system. An extended eruption between August 31, 2014 through February 27, 2015. The dense rock equivalent volume produced from the eruptions is estimated to be 1.2 ± 0.1 km^3 [7] covering an area of 83.82 km^2 [8].

The lava flow lies within the outwash plains of the Dyngjujökull outlet glacier making it prone to fluvial and aeolian modification. Holuhraun has multiple lava types, ranging from very rough spiny and rubbly lava types to smooth platy lava types [3].

The study site is located on a breakout lobe along the northern margin of the Holuhraun lava flow at 16.746 °W, 64.920 °N (Fig. 1a). At the study site, the breakout lobe overlies an older, predominantly sand-covered, lava flow emplaced from the nearby Askja caldera between 1924–1930 [9].

Methods: A high-resolution mobile backpack laser scanning system (which produces DEMs with up to 1 cm/pixel resolution) and GPR (using Sensors and Software 100 MHz and 200 MHz PulseEKKO) were used to analyze the sand-mantled lava flow margins in July 2022.

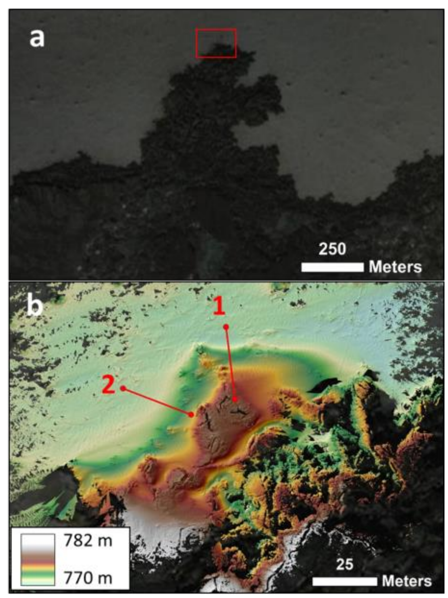

Figure 1. *(a) Breakout lobe of the Holuhraun lava flow studied in this work. Image is from 2015, prior to sand mantling [10]. (b) LiDAR Digital Elevation Model (DEM) and Hillshade of sand-mantled lava flow margin with GPR transects in red.*

Two 30 m GPR transects were collected at the flow margin across the sand ramps (Fig. 1b). In addition, 50 cm poles were used to probe and record depths to the buried lava flow every half meter along GPR Transect 1 (Fig. 2). Signal velocity was calibrated based on field observations of the geologic media, which is a mixture of dry and damp sands, air, and hard rock. All of these materials will affect the resulting vertical resolution and penetration depth of the signal. Signal loss for the 200 MHz and 100 MHz antennae occurs around 4 m and 8 m at Transect 1, respectively.

Preliminary Results and Interpretations: Over half of the field probe data along Transect 1 indicated a sand mantle thickness of ≤ 50 cm (Fig. 2).

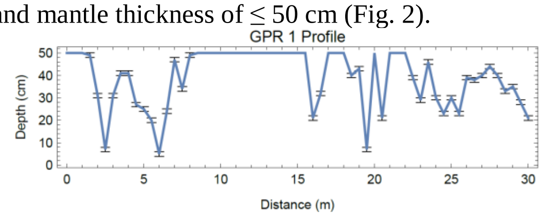

Figure 2. *Field probe measurements along GPR Transect 1. Any location with sand depth > 50 cm could not be measured.*

GPR data collected with the 200 MHz antennae generally supports the probe measurements for Transect 1, with a thinning sand layer at lower elevations at the start of the transect (Fig. 3b). However, a continuous sand–lava contact is not always visible across the length of the transect, possibly due to abundant signal scattering from the uneven blocky surface of the lava flow mixed with voids of air. Additionally, the vertical resolution is expected to range between ~20 and 70 cm making sand layers < ~20 cm not resolvable. The greatest sand layer thickness observed over Transect 1 occurs around 13 m with a thickness of ~ 70 cm. Sand layer thickness is not resolvable with the 100 MHz antennae (Fig. 3a). However, different components/layers can be observed between 0 and 20 m along the transect (Fig. 3a). The lava flow thins closer to the margin of the lobe as expected, with a thickness ranging from 2 to 7.5 m. This is similar to the lava flow thicknesses we observed in GPR at other northern margin locations, as well as estimated lava flow thicknesses reported across the northern margin of Holuhraun (~7–11 m) [11]. A change in flow/lava type can be observed in the 100 MHz transect (Fig. 3a). For example, at 20 m along the transect, the upper part of the lava flow (upper ~2.5 m) appears rough with evident scattering of the signal, which likely represents a more vesicular/less dense part of the spiny lava flow. The middle part of the lava flow (~2.5–5.5 m) shows less scattering, possibly representing a denser portion of the lava flow. The lower part of the lava flow (~5.5–7.5 m) appears linear which may represent a denser portion of the lava flow or a buried sediment layer deposited before Holuhraun emplacement.

Implications for SAR: Initial observations of Sentinel-1 radar data at the Holuhraun lava flow-field show a noticeable reduction in backscatter in regions covered with sand [12]. If we know the sand layer thickness we can constrain the loss tangent [5] of the C-band radar. Assuming a conservative sand thickness estimate of 0.5 m, the loss tangent is ~0.005 for the VV measurements, which is consistent with dry sand. If the average sand thickness is <0.5 m, the loss tangent would increase, which is consistent with wetter sand. The observed reduction in radar backscatter between 2015 and 2021 suggests that only a thin layer (10 of cms thick) of sand can obscure or completely prevent observations of lava flows by a C-Band SAR. Therefore, a C-band SAR would likely not be able to see lava flows on Mars covered by a cms-thick dust layer. The use of an L- or P-band radar, as proposed for I-MIM, would be more useful in characterizing buried lava flows on Mars.

References: [1] I-MIM MDT Final Report (2022). [2] Harmon J.K. et al. (2012) Icarus, 220, 2. [3] Tolometti G.D. et al. (2022) *JGR Solid Earth*, 127. [4] Rodriguez Sanchez-Vahamonde C. and Neish C.D. (2021) *PSJ*, 2, 15. [5] Campbell B.A. et al. (1997) *JGR*, 102. [6] Torres R. et al. (2012) *Rem. Sens. of Enviro.* 120. [7] Bonny E. et al. (2018) *JGR Solid Earth*, 123. [8] Voigt J.R. et al. (2021) *Journ. Volcan. Geotherm Res.* 419. [9] Hartley M.E. et al. (2016) *Bulltn. Volcan.* 78, 28. [10] Esri (2018) World Imagery. [11] Dumont S. et al. (2018) *Front. Earth Sci.* 6, 231. [12] Perkins R. and Neish C. (2022) *DPS*, 54, 8.

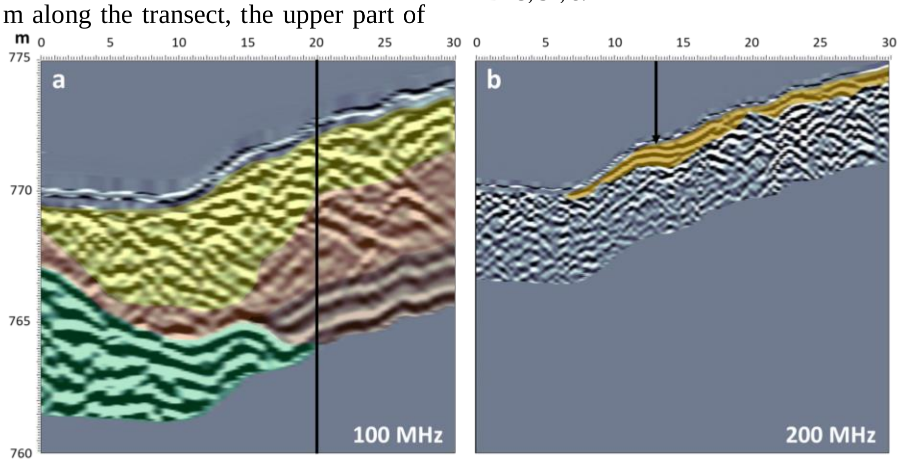

Figure 3. *GPR data collected at Transect 1. Elevation on vertical axis. (a) 100 MHz. Lava flow broken into 3 flow types (yellow, orange, and brown). Green represents the underlying lava flow. (b) 200 MHz. Tan represents resolvable overlying sand layer.*