USING GPR, LIDAR, MAGNETOMETRY, AND IN SITU GEOCHEMISTRY TO DEVELOP A STRATEGY FOR THE EXPLORATION AND CHARACTERIZATION OF LAVA TUBES.

K. E. Young[1], P. L. Whelley[2], S. Kruse[3], S. Esmaeili[3], S. Jazayeri[3], E. Bell[4], W. B. Garry[5], J. E. Bleacher[5], and N. Schmerr[4], [1]UTEP/Jacobs JETS Contract at NASA Johnson Space Center, Houston, TX, 77058; [2]University of Maryland, College Park/CRESST at NASA GSFC; [3]University of South Florida; [4]University of Maryland – College Park; [5]NASA GSFC; corresponding author email: kelsey.e.young@nasa.gov.

Introduction: Lava tubes have long been identified as potential safe havens for human crews and life support equipment from radiation threats, extreme surface temperatures, and even impact events [1]. More recently, lava tubes of substantial size have been discovered beneath the lunar surface [2,3]. Despite recent interest in lunar lava tubes, it is unclear how astronauts might characterize a tube-rich environment on the Moon and select a tube for exploration and potential habitation. The TubeX project described here seeks to develop an exploration and characterization strategy for lava tube-rich environments using a combination of field portable instruments. The TubeX team has completed one field campaign at Lava Beds National Monument, CA, and initial field results are discussed here.

The Field Site: Lava Beds National Monument (LBNM) is located on the northern flank of Medicine Lake shield volcano in the Cascade Range in northern California. LBNM contains numerous cinder cones and volcanic flows as well as hundreds of lava tubes of varying size, shape, and geometry. By exploring a diverse set of tubes, we ensure that the selected field instrumentation will be able to detect and image the variety of tubes expected on other planetary surfaces. In the first TubeX field campaign, four tubes were explored with the instruments discussed below: Valentine, Skull, Indian Well, and Hercules Leg.

Light Detection and Ranging (LiDAR): LiDAR can produce high-resolution pointcloud models by bouncing light pulses off a surface, detecting their return, and precisely measuring the two-way travel time. Multiple scans are required to capture the surface and subsurface relationships of lava tubes, but the models provide spatial context for other instrument data [4-7]. In TubeX, we have collected detailed LiDAR scans in four lava tubes in LBNM. Using these data sets we will create cm-resolution models of each tube, which will be used to inform models for the surface geophysics work, discussed below. For example, Figure 1 shows part of the model for Valentine Cave generated from the LiDAR data [8].

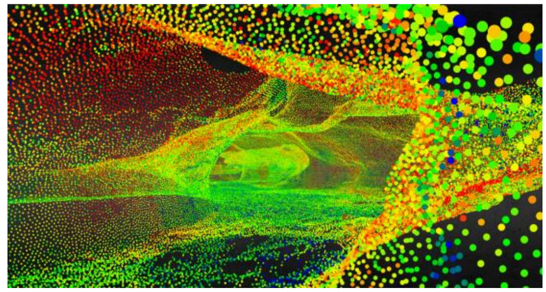

Figure 1: Snapshot of the LiDAR point cloud from inside Valentine Cave, LBNM.

Ground Penetrating Radar (GPR): GPR explores subsurface structure by emitting high frequency electromagnetic waves that are reflected off of contacts between materials with varying electromagnetic properties. The user must move the GPR across the surface, covering the mapping area. Crews can either deploy the GPR themselves or perhaps use robotic assistants or autonomous robotic assets and review the data once it's collected. In the TubeX study, we seek to develop a GPR library of different lava tube geometries. In this way we can determine the utility of deploying GPR technology in mapping a tube-rich environment.

By comparing data collected from instruments on the surface to the high-resolution, high-accuracy LiDAR data from inside each tube, we can determine the utility of surface instruments, which are far safer for surface explorers to use. For example, in Figs. 2 and 3, we compare a transect across one section of Valentine Cave [9]. Figure 2 shows the geometry model created from the LiDAR data on the surface and interior of Valentine Cave along one GPR transect line. Valentine Cave has two main tunnels, shown by the two openings in the LiDAR data in Figure 2. Figure 3 shows the GPR data collected on this transect. While the GPR is able to detect the tops of each of the Valentine's two tunnels in this location, it is unable to resolve the floors. Future field campaigns will focus on refining GPR antenna properties to optimize the resolution of both the tube floor and the tube ceiling.

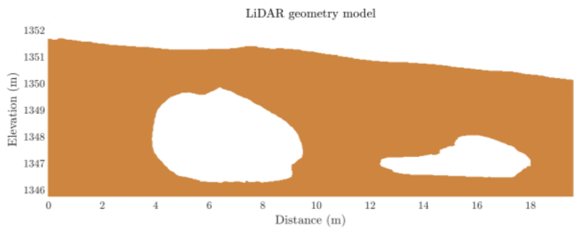

Figure 2: LiDAR geometry model across one GPR transect line at Valentine Cave, LBNM.

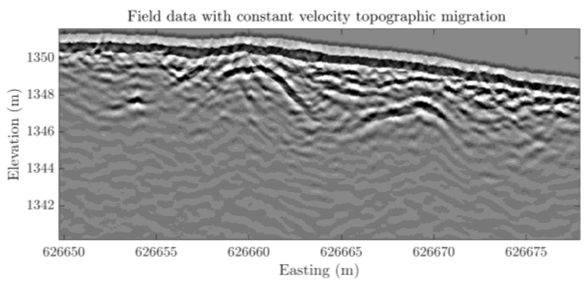

Figure 3: GPR data collected across the same transect line as shown in Figure 2, Valentine Cave.

Magnetometry: Magnetometry can be used by a crewmember on the surface, or via remote orbital sensing, to map the location of subsurface magnetic anomalies. We collected magnetic data on the four lava tubes, mentioned above in order to determine whether this technique is viable for locating lava tubes during future planetary surface exploration [10]. Fig. 4 shows magnetic data from Skull Cave, demonstrating that magnetometry can be an effective way to image lava tubes from the surface. [10] Similar to the GPR analysis, this surface magnetic data is being used, in correlation with transects of the LiDAR imaging, to create magnetic models of various cross-sections.

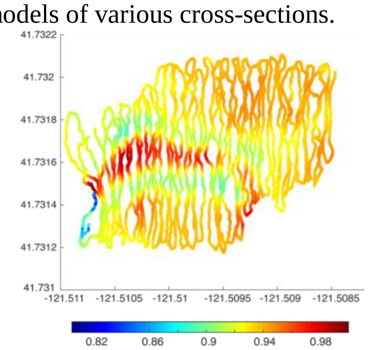

Figure 4: Magnetic survey of Skull Cave normalized to maximum recorded value. In this example, the lava tube is revealed as a magnetic high [10].

Handheld X-Ray Fluorescence Spectroscopy (hXRF): Laboratory XRF has long been used in geologic applications but recent technological advancements have miniaturized this technique, which is beginning to be used in other scientific applications [11,12]. Only recently has hXRF been calibrated for use in field geology [13] and hXRFs have been included in analog missions and architecture planning for future planetary exploration. We deploy hXRF in tubes, investigating how chemistry might impact data collection from the surface and how chemistry varies inside the tube. Data was collected from all four tubes, and initial results point to the differences between the melted basaltic veneer formed inside of each tube that masks the bulk of the tube composition underneath it (Fig. 5). Initial Valentine Cave results point to different compositions between the veneer and the bulk flow, exposed in areas where the former has chipped away. These areas are seen in the LiDAR models by their unique surface roughness, and we investigate whether this relationship can be seen at other LBNM tubes.

Figure 5: Field photo from Valentine Cave.

Future Work: Initial TubeX results are promising to identify both an optimal instrument suite for the exploration of a lava tube-rich environment as well as an exploration and characterization strategy for future lunar and martian explorers. However, more work is needed to develop data acquisition and processing strategies for the instruments described here. Ongoing TubeX work is focused on these strategies as well as expanding the number of LBNM tubes analyzed. By compiling a library containing LiDAR, GPR, magnetic, and hXRF data at tubes of varying sizes, shapes, and geometries, we can to assess the utility of all techniques as well as provide the volcanic, lunar, and martian communities with valuable data about the types of exploration environments we need to be prepared for.

References: [1] Horz F. (1975) *Lunar Bases and Space Activities of the 21st* Century, 4015-4120. [2] Haruyama J. et al. (2009) *GRL, 36*, L21206. [3] Robinson M. S. et al. (2012) *PSS, 69*, 18-27. [4] Garry W. B. et al. (2017) *48th LPSC*, Abs. 1207. [5] Bleacher J. E. et al. (2017) *48th LPSC*, Abs. 2634. [6] Whelley P. L. et al. (2017) *Bull. Volc.*, *79*, 75. [7] Whelley P. L. et al. (2017) *IAVCEI*, p. 1219. [8] Whelley P. L. et al. (2017) *AGU 2017*, Abstract T44D-04. [9] Esmaeili S. et al. (2017) *AGU 2017*, Abstract NS23A-0021. [10] Bell E. et al. (2018) *LPSC 49*, this meeting. [11] Shrivastava P. et al. (2005) *XRF for Geoarch., Springer*, 7-44. [12] Margui E. et al. (2012), *Spectro. Acta*, *67*, 17-23. [13] Young K. E. et al. (2016) *Applied Geochem.*, *72*, 77-87.