CHARACTERIZING MORPHOLOGY OF LAVA TUBES IN EL MALPAIS NATIONAL MONUMENT USING GROUND PENETRATING RADAR AND LIDAR. N. M. Bardabelias[1,2], J. W. Holt[1,2], C. W. Hamilton[1,2], M.S. Christoffersen[2], and N. K. Hadland[2], [1]University of Arizona Department of Geosciences (nmb23@email.arizona.edu), [2]University of Arizona Lunar and Planetary Laboratory.

Introduction: Lava tubes are subsurface structures formed by cooling the exterior of effusive volcanic flows while molten material continues moving internally [1, 2]. Gradually thickening the lava tube walls results in a thermally insulated interior, allowing low-viscosity flows to travel long distances along the tube before beginning to cool and crystallize [3]. As the eruption rate slows, the lava level within the tube decreases, eventually creating a partially or fully hollow tunnel-like feature.

Motivation. For planetary bodies without substantial atmospheres, lava tubes provide refuge from harsh surface environments which are susceptible to high radiation fluxes, significant diurnal temperature swings, and micrometeorite bombardment [4]. In this way, subsurface caverns may preserve pristine lava flow textures, biosignatures, and/or volatiles, which make lava tubes an ideal exploration candidate for terrestrial bodies. Identifying lava tubes or other highly sheltered areas on neighboring planetary bodies is of geologic and astrobiological significance for studies of past habitability or future human exploration.

Lava tubes on Earth and beyond are recognized in visual remote sensing data by their collapse features, which include partial ceiling collapses known as skylights or full failure of the lava tube ceiling. Intact lava tubes have no obvious surface expression, which make them indistinct and difficult to identify [1]. Additional methods of detection exist for terrestrial lava tubes, including thermal infrared remote sensing, seismicity, detection of gravity anomalies, magnetic field perturbations, and measuring low-frequency sounds [1, 2]. However, these methods only apply to lava tubes that are actively serving as conduits for molten material and would not be suitable for the motivations of this study. Ground penetrating radar (GPR) uses radio-wave pulses into the subsurface to highlight differences in material permittivity, enabling users to detect changes in structure or bulk material properties at depth [5]. This makes GPR an excellent candidate for detecting intact, inactive lava tubes. Prior work has shown that differences in permittivity at the air-rock interface from lava tube ceilings result in a strong tube signature in GPR data [6]. This work aims to determine whether GPR data can definitively prove the existence of intact lava tubes in the subsurface, and how variations in radar response may be able to reveal the shape and extent of a single tube or tube network.

El Malpais Geologic Setting. The El Malpais National Monument is located near Grants, NM and contains the Quaternary lava flow units that comprise the Zuni-Bandera flow field [7]. The field site for this study, the Big Tubes area, is located within a subset of the Zuni-Bandera flow field known as the Bandera Crater flow, which is approximately 11.2 ka [8]. The lava tubes in this area of El Malpais National Monument were not formed in the classical sense from channelized low-viscosity flows – rather, they are remnants of inflationary lobes connected by an internal conduit. Despite this difference in formation, the morphology of these tubes is identical to typical lava tubes, and there is no expected impact of tube genesis on the results of this study.

Methods: This data set combines acquisitions from two field campaigns to the Big Tubes area of the El Malpais National Monument in July and November 2020. GPR data was collected during both campaigns using a Sensors and Software pulseEKKO GPR equipped with a pulseEKKO pE 100 400V transmitter and pulseEKKO Ultra receiver. LIDAR coverage was acquired only during the November campaign using a Riegl GeoSLAM ZEB Horizon scanner. Airborne LIDAR coverage of the Zuni-Bandera volcanic flow was gathered in February 2020 for context and surface roughness studies.

Prior to the initial field campaign, satellite imagery of the Big Tubes area was consulted to determine high-priority areas for data acquisition. Science priority was determined by the probability of an area to have a tube beneath it, which favored lava bridges and areas with visible skylights, in order to maximize chances of collecting data over a lava tube. Additionally, the area had to be spacious enough between collapse features that sufficient GPR data could be gathered without seeing noise from the edges of tube openings or walls of collapse pits. Giant Ice and Four Windows caves were selected as top priority sites, both of which are available for public caving with a permit (see Figure 1). The field team collected GPR data using both common offset and common midpoint surveys with a mix of at 50, 100, and 200 MHz antennas, depending on the geologic context. During the second campaign, LIDAR point clouds were gathered by manually operating the instrument while walking or caving. Multiple closed loop tracks with ground control points distributed along-path were acquired with the LIDAR for ease of co-registration in post-processing.

Using Sensors and Software's EKKO_Project program, the GPR dataset was processed using a Kirchhoff migration with speeds typical for terrestrial basalts. This migration will not give an accurate match for the position of the lava tube floor, as wave speeds in the air-filled tube are three times faster than in basalt, but should give an accurate position for the lava tube ceiling in comparison with LIDAR data [6]. LIDAR processing is currently ongoing.

Results & Discussion: Preliminary results from this project match those of other studies, showing that the air-basalt interface at lava tube ceilings are distinctive in ground penetrating radar data [6]. This work will expand on those findings by combining GPR data with ground-based and airborne LIDAR data sets to model the subsurface radar response both at the ground level and then (eventually) as seen from an airborne platform.

The results of this study will have implications for terrestrial planets and moons as well. Prior works searching for lava tubes using the Mars Reconnaissance Orbiter's Shallow Radar (SHARAD) have not yielded promising results despite visual imagery of collapse features, suggesting that Martian lava tubes may be at the limit of either horizontal or vertical resolution [9, 10]. Extrapolating our radar response model from an airborne terrestrial platform to a Mars-orbiting one should help determine why this discrepancy exists. Additionally, the potential lava tubes found by the SELENE Lunar Radar Sounder in the lunar subsurface can be further scrutinized to determine whether they match modeled echo patterns for lunar lava tubes [4].

With further analysis, future work aims to ultimately determine whether lava tube detection is plausible with currently operational radar systems at volcanic planetary bodies. These results may inform RIMFAX operations on the Mars 2020 rover [11], as well as design requirements for future landed or orbital radars to terrestrial planets and moons.

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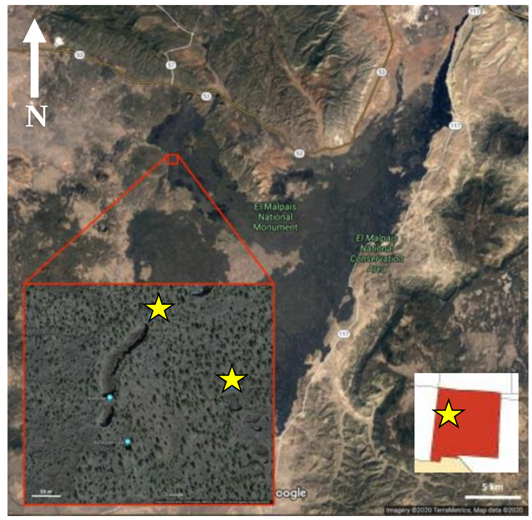

Figure 1: Satellite basemap showing the Zuni-Bandera lava flow field. Bottom right inset shows the location of the El Malpais National Monument in NW New Mexico, and the bottom left inset displays the Big Tubes area with field sites for this study denoted by yellow stars.

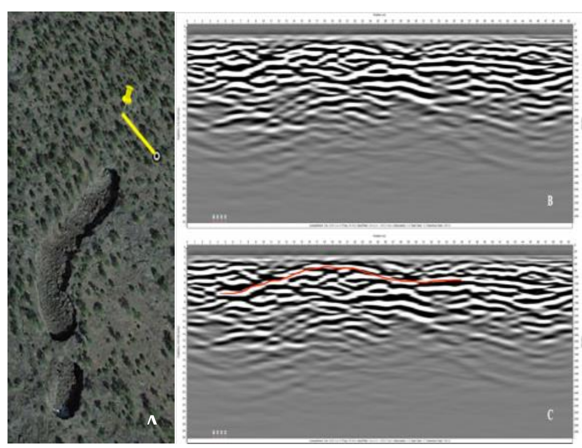

Figure 2: (A) Satellite basemap showing the study area near Giant Ice cave, with one GPR line traced in yellow. (B) 50 MHz GPR data for that line (C) 50 MHz GPR data with interpretations of lava tube ceiling location in red. Interpreted ceiling height is about 3.5 m below the surface with v = 0.1 m/ns.