Exploration of Lava Tubes Using Ground Penetrating Radar, TubeX project

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Abstract

Lava tubes on the Moon and Mars promise potential safe places for human crews and their instruments and unprecedented science investigations. These tunnel-like volcanic features offer protection from harmful radiation, thermal extremes and micrometeorite impacts. Therefore, developing exploration methods to evaluate and map lava tubes from the surface is important in order to identify and locate tubes suitable for habitation. Geophysical methods including Ground Penetrating Radar (GPR) are promising tools for quickly and nondestructively detecting such features from the surface. GPR instruments emit high frequency (~10-3000 MHz) electromagnetic waves into the subsurface and record the returned signal.

In this study we present the analysis of a few GPR profiles over terrestrial lava tubes. Our results indicate that GPR surveys are generally successful in resolving the ceilings of lava tubes, and in some cases, detecting the floor of the tubes.

Site and field measurements

Lava Beds National Monument (LBNM) in Northern California, USA, contains a variety of lava tubes with different sizes, shapes, and depths that serve as analogs for planetary lava tubes. We surveyed 7 tubes with various instruments during two field campaigns in 2017 and 2018 [1].

Data were collected using 100 MHz GPR antennas. An RTK GPS was used to record the location of each measurement. Light Detection and Ranging (LiDAR) surveys produced point clouds of the surface and tube interiors [1-2].

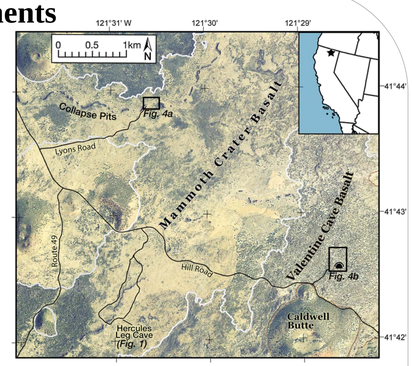

Figure 1. Study area within Lava Beds National Monument (California, USA). Pit chains are visible in this orthoimage basemap (National Agricultural Image Program Orthomosaic) where lava tubes have collapsed.

Figure 2. Left: GPR cart. The two cart legs carry the transmitting and receiving GPR antennas. A GPS sensor measures the location and elevation of the center of the cart (at a higher elevation in order to minimize the signal interference with the GPR sensors). Sensor tilt and height above the ground are corrected to obtain reliable RTK GPS measurements. Right: The LiDAR instrument. The in-tube and on-surface LiDAR measurements provide us a 3D representation of the ground surface and tube geometry.

Skull Cave

Skull Cave (entrance, 41.7314°N, 121.5107°W) is a multilevel segment of a 36 ± 16 ka 16-km-long lava tube system that originates from Modoc crater. There are two principal levels in Skull Cave.

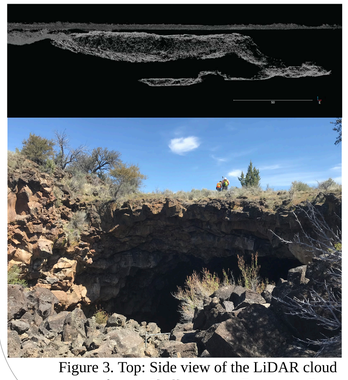

Figure 3. Top: Side view of the LiDAR cloud point from Skull cave. Bottom: Cave entrance.

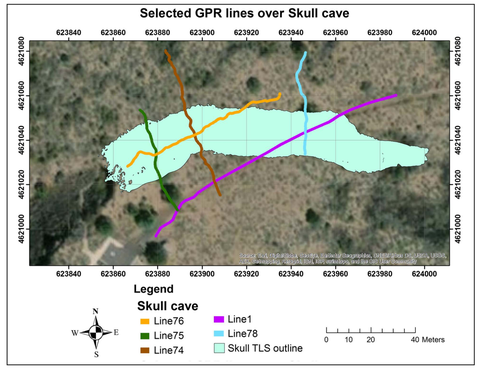

Figure 4. Location of the GPR profiles and the tube terrestrial LiDAR scan (TLS) over satellite image of the Skull cave.

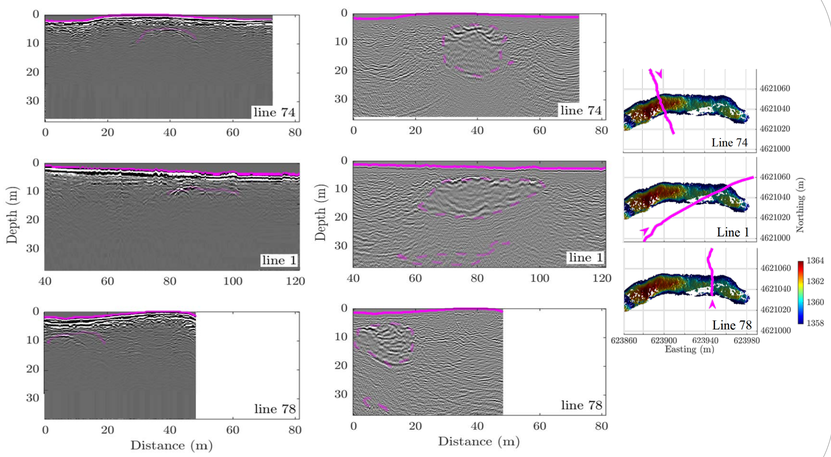

Figure 5. Left: Unmigrated topography-corrected GPR profiles on the Skull cave. Purple lines show LiDAR-mapped cave location. Middle: Migrated GPR profiles. Right: Color shaded relief LiDAR map of cave ceiling elevation (meters above sea level) with corresponding GPR profiles location and direction marked in purple.

Valentine Cave

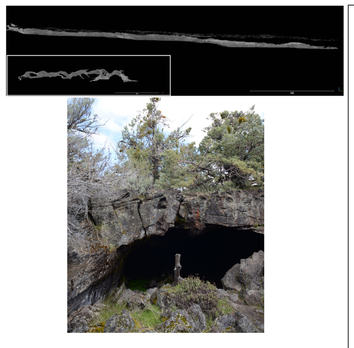

Figure 6. Top: Side view of the LiDAR cloud point from Valentine cave (small bow shows the top view). Bottom: Cave entrance.

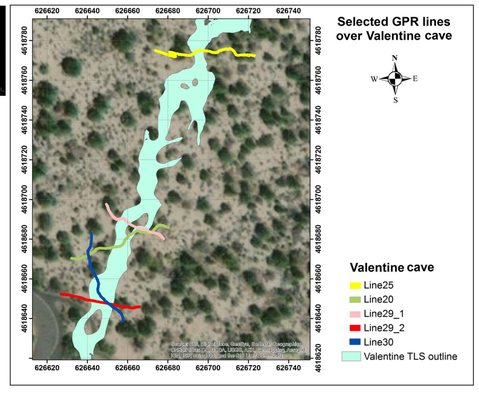

Figure 7. Location of the GPR profiles and the tube terrestrial LiDAR scan (TLS) over satellite image of the Valentine cave.

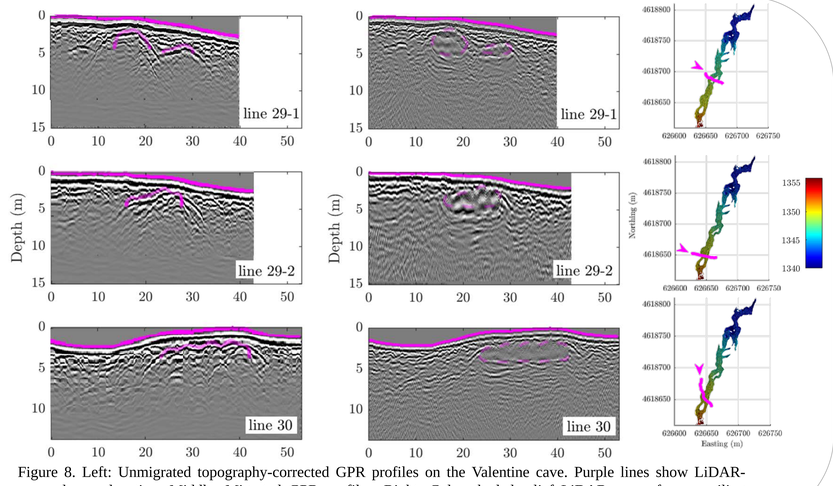

Figure 8. Left: Unmigrated topography-corrected GPR profiles on the Valentine cave. Purple lines show LiDAR-mapped cave location. Middle: Migrated GPR profiles. Right: Color shaded relief LiDAR map of cave ceiling elevation (meters above sea level) with corresponding GPR profiles location and direction marked in purple.

Modeling

Subsurface geometry models based on LiDAR data with extra features such as wall-lining, fractures, layers are used to create synthetic GPR data. Examining these modeled data is helpful in understanding the sources of complexities in the data and media surrounding the lava tubes.

Moreover, simulating the expected GPR returns from lava tubes on other planets, by creating synthetic models based on realistic settings can be useful in exploratory projects, and clarifies the potential challenges.

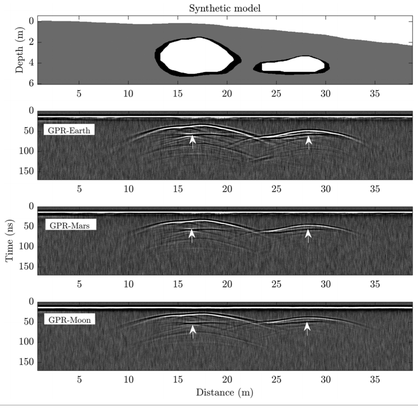

Figure 9. Top: Model of cross section of tubes based on geometry measured with LiDAR at GPR profile 29-1 over Valentine Cave. Bottom: Simulated data on Earth, Mars and Moon.

Acknowledgements

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References

[1] Esmaeili, S., Kruse, S., Jazayeri, S., Whelley, P., Bell, E., Richardson, J., et al. (2020). Resolution of Lava Tubes with ground penetrating radar: The TubeX project. Journal of Geophysical Research: Planets, 125, e2019JE006138. https://doi.org/10.1029/2019JE006138

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