INVESTIGATION OF TERRESTRIAL LAVA TUBES USING ACTIVE SOURCE SEISMIC DATA AND ADVANCED PROCESSING TECHNIQUES IN ANTICIPATION OF FUTURE EXPLORATION MISSIONS. N. McCall1 (naoma.t.mccall@nasa.gov), N. Schmerr2, J.A. Richardson3, J. Wang2, J. Giles2, L. Wike2, E. Bell2,3, P. Whelley1,2, Maria E. Banks1, N. Deykes4, J. West5, M. Zanetti5 NASA Goddard Space Flight Center, 8800 Greenbelt Rd, Greenbelt, MD 20771, 2University of Maryland College Park, Department of Geology, College Park, MD 20742, 3Now at Blue Origin, Reston, VA, 4Northern Arizona University, School of Earth Sciences and Environmental Sustainability, Flagstaff, AZ, 5Arizona State University, School of Earth and Space Exploration, Tempe, Arizona, 6Marshall Space Flight Center, Huntsville, AL

Introduction: Extraterrestrial lava tubes are subsurface void spaces that are protected from solar radiation and are areas of importance for future Lunar and Martian exploration missions [1]. Lava tubes across the Solar System have pristine outcrops protected from common weathering surface processes, may preserve water ice [2] and volatiles, can provide shelter for crew on future exploration missions [3], and may preserve habitable environments. Analog studies of terrestrial lava tubes are a crucial step in understanding lava tube formation and refining the process of tube detection and characterization. Seismic reflection can provide information on subsurface structure from a few meters below the surface to hundreds of meters into the subsurface, making it a useful tool for resolving tubes and structure at various depths.

Methods: We present high resolution seismic reflection data from three basaltic lava tubes with varying overburden depths: Skull Cave at Lava Beds National Monument, California, USA, Lava River Cave in Arizona, USA, and La Corona Lava Tube, Lanzarote, Spain.

Field Sites. Skull Cave is an accessible, shallow lava tube with ~5m of overburden and a diameter 10-20m. It is well studied with many co-located geophysical data sets such as Ground Penetrating Radar (GPR), magnetometry, LiDAR topography, and LiDAR of the tube interior [4,5]. Lava River Cave is ~15m wide and has approximately 10m of overburden at the survey location. The tube was initially mapped in a 1984 survey and more recently the tube was scanned with high resolution LiDAR [6]. The La Corona Tube is ~8 km long and up to 25m wide in parts [7]. It is deeper than Skull Cave and Lava River Cave, the depth to the cave ceiling is over 30m deep in some locations. Unlike Skull Cave and Lava River Cave, which formed by over crusting of a lava flow, La Corona Tube formed via deep inflation [7], which may be how Lunar lava tubes commonly form [8,9]. Like Skull Cave and Lava River Cave, the morphology and position of La Corona Tube is constrained from a recent LiDAR survey [10,11].

Seismic Surveys. At the three field sites we used the same survey geometry and seismic source (10 and 12 lb hammers). To maximize near surface resolution our surveys have a densely spaced geometry, with receiver spacing at 0.5 meters and sources every 0.5 to 1 m. Surveys were composed of overlapping seismic transects composed of 48 channels which resulted in common midpoint coverage of nominal 12-fold to 24-fold. We processed the data using the CREWES MATLAB seismic processing toolkit [12].

Results: We found that shallow overburden depths and strong near-surface scattering made resolution of the tube ceiling challenging when using a traditional seismic processing workflow based on common midpoint stacking and Kirchhoff migration. On our profiles, both reflections and diffractions are present at the position of the tube, sometimes with higher amplitudes at the position of the cave walls. Implementation of a Radon transform helped eliminate linear arrivals without degradation to near surface reflectors.

At Skull Cave, we applied reverse time migration (RTM) [13], a wave equation-based migration approach, to the shot records (unstacked data). The migration results show that RTM effectively resolves the lava tube ceiling and geometry, with the caveat that this approach is dependent on the velocity model used; in this study, we used refraction analysis from our survey to build a velocity model [14].

Our data and analysis allow for refined survey parameters during deployment and showcase processing steps for improved characterization of subsurface voids that can be used for protection on exploration missions, in-situ resource utilization, which could provide a better understanding of lava tube formation mechanisms and potentially habitable areas on planets with volcanic terranes.

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