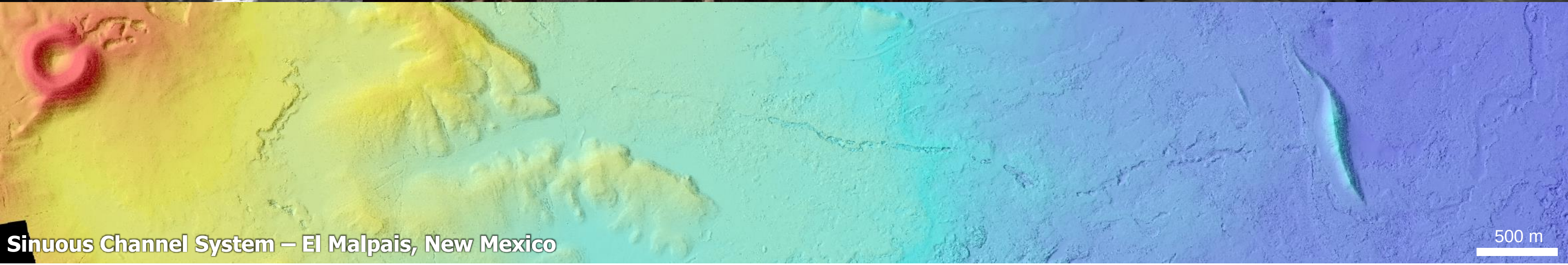
Moon Diver


Lava Tube – El Malpais, New Mexico

Sinuous Rill – Rima Bode, Moon



Sinuous Channel System – El Malpais, New Mexico

Virtual Research Presentation Conference

Pattern to Process: Flood Basalt Emplacement Parameters and their Cross-Sectional Morphologies

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Program: SURP

Assigned Presentation # RPC-077

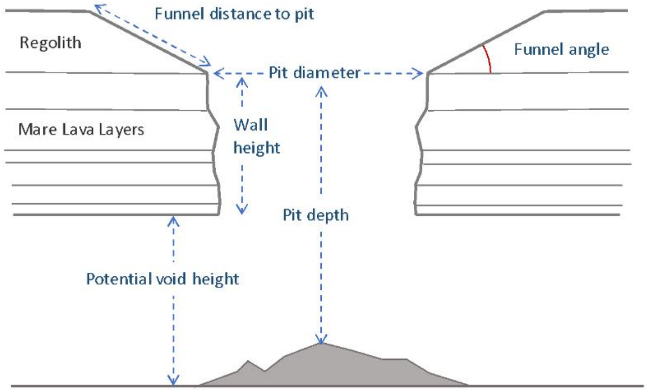
Jet Propulsion Laboratory
California Institute of Technology

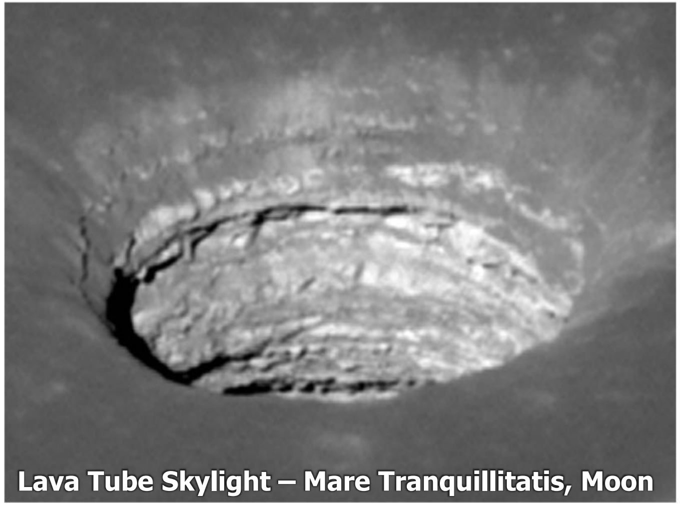
Tutorial Introduction


Axel Rover

Abstract

Moon Diver is a Discovery mission concept developed by JPL Research Scientist, Laura Kerber. The mission would send a tethered robotic system—the *Axel Rover*—into a lava tube skylight in Mare Tranquillitatis to examine a cross-section through both the lunar regolith and underlying lava layers. The mission would collect information on the chemistry, mineralogy, and morphology of these intact layers to investigate the origin of lunar crustal materials, including their relationship to interior processes (i.e., magma production and eruption dynamics) and external processes (i.e., impact-induced regolith formation). *Moon Diver* would also characterize subsurface voids associated with drained lava tubes to determine their utility for future human exploration and habitation. The mission concept was submitted to the Discovery program in 2019, and although it was not selected, it will be re-competed at the next opportunity. The objective of this SURP project is to obtain 'ground-truth' observations of terrestrial lava flows to quantify the processes that form lava tubes, and lava tube skylights, as well as relationships between lava emplacement processes, morphologies, and chemistry to refine JPL's *Moon Diver* mission concept for the next round of Discovery.




Lava Tube Skylight – Mare Tranquillitatis, Moon

Problem Description

a) Context (Why this problem and why now)

Field-observations are required to better characterize lava tube structures, lava stratigraphies, and related volcanic landforms to improve the design of the *Axel Rover* and *Moon Diver* mission architecture to make it more competitive for the next round of Discovery.

b) SOA (Comparison or advancement over current state-of-the-art)

Lava tubes and lava stratigraphies have generally not been examined on Earth from the perspective of analogs for robotic exploration of similar structures on other planetary surfaces. The data collected within this study will be instrumental for advancing engineering concepts and our scientific understanding of lava tube formation in extraterrestrial environments. Furthermore, coupling chemical variations within a lava lobe with physical processes of flow emplacement has not been previously implemented and would represent a state-of-the-art approach to understanding effusive volcanism.

c) Relevance to NASA and JPL (Impact on current or future programs)

The key objective of this SURP project is to advance our understanding of lunar-relevant volcanic terrains that will enable improved mission design for *Moon Diver* to make it more competitive for funding through the next Discovery opportunity.

Methodology

Lava flows within the Zuni–Bandera Volcanic Field are seven times larger than the products of the recent 2014–2015 Holuhraun eruption, which was the largest effusive eruption in Iceland during the past 235 years

a) Formulation, theory or experiment description

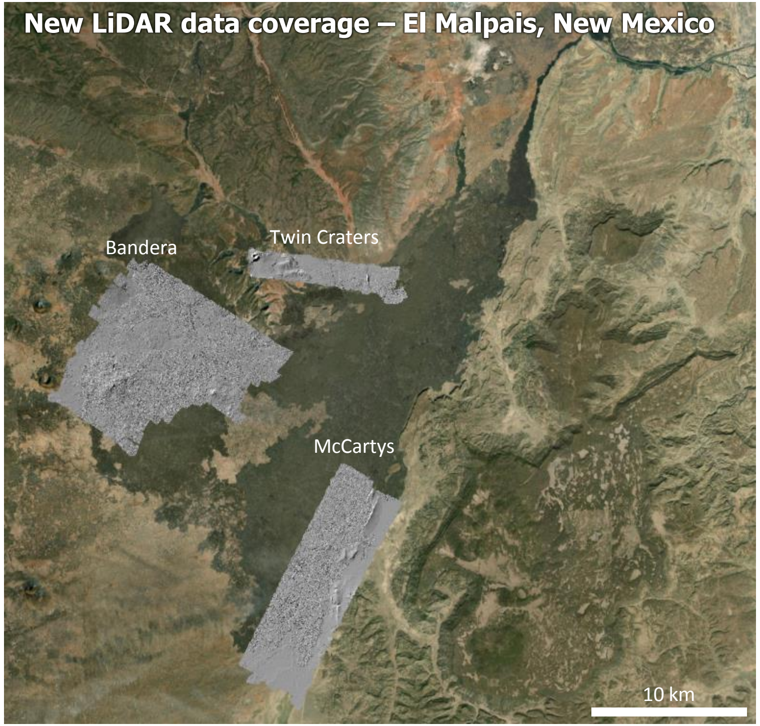
Basaltic flood lavas are among the most widespread geologic units on the surface terrestrial planets and moons (Self et al., 1998), and can determine what kind of atmosphere forms around a planetary body (Needham et al., 2017; Alienov et al., 2019). Flood basalts were once thought to only be emplaced for short durations at high effusion rates, but new research suggests that large lava flows can be composed of complex inflated flow-fields that are extruded over long periods of time at much lower flow rates (Self et al., 1998; Vye-Brown et al., 2013; Hamilton et al., 2020). However, uncertainties in the lava flux creates uncertainties in thermal models of lava emplacement, eruption parameters, and gas flux into the atmosphere. While well-preserved flood basalts are rare on Earth, the Zuni–Bandera Volcanic Field, the focus of this study, includes large and exceptionally recent (3000-year-old) lava flows, similar to older flood basalts on the Moon.

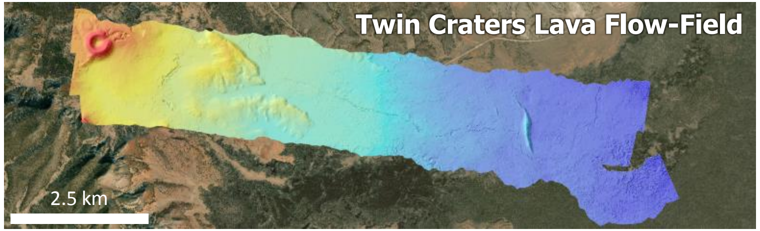
b) Innovation, advancement

The innovation of this project is to explore the variability of morphology, textures, and chemistry in well-preserved lava flows to develop a finite element model that connects these measurable properties to the actual process of lava emplacement. Relatively little work has been done previously to determine relationships between the surface expression of lava flows and their interior structures, which we will do using airborne and ground-based LiDAR systems. Additionally, few studies have considered the local chemical variability within thick lava flows due to in-situ fractional crystallization, and previous numerical models have not considered multi-layer rheologies.

Results

New airborne LiDAR surveys conduct over three lava-flow fields within the Zuni–Bandera Volcanic Field in New Mexico. LiDAR hillshades (grey) are overlain over visible-wavelength image mosaic.





a) Accomplishments versus goals

Year 2 goals centered on the examination of the Zuni–Bandera Volcanic Field, in the El Malpais National Monument, to characterize the morphology of lunar like lava tubes and sinuous channels using LiDAR, and obtain samples of lava units in cross-section for geochemical analysis. In February 2020, we collected three new high-resolution (0.3 to 2.0 m/pixel) airborne LiDAR datasets over portions of the Zuni–Bandera Volcanic Field, including: lava tubes and skylights in the Bandera lava flow-field; inflation features in the McCartys lava flow-field; and sinuous channels in the Twin Craters flow-field. The aim was then to ground-truth these observations using differential GPS and use ground-based simultaneous localization and mapping (SLAM) LiDAR to image lava tube interiors and link them with their surface expressions. However, due to COVID-19 travel restrictions, field work was not possible. So, instead, we focused on remote sensing analysis of the airborne LiDAR and modeling of lava flow emplacement processes.

Hamilton et al. (2020) was published in the *Journal of Geophysical Research—Planets* (https://doi.org/10.1029/2019JE005975). The paper focuses on lava inflation processes in the McCartys lava flow-field.

Results

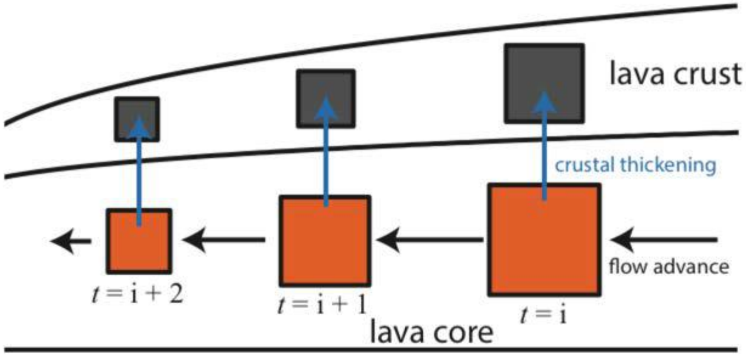
b) Significance

Results will be incorporated into the *Moon Diver* data collection strategy to improve its mission design for the next Discovery mission solicitation. The partnership therefore reinforces JPL's already strong reputation in the field of volcanology and increase JPL's stake in future lunar missions.

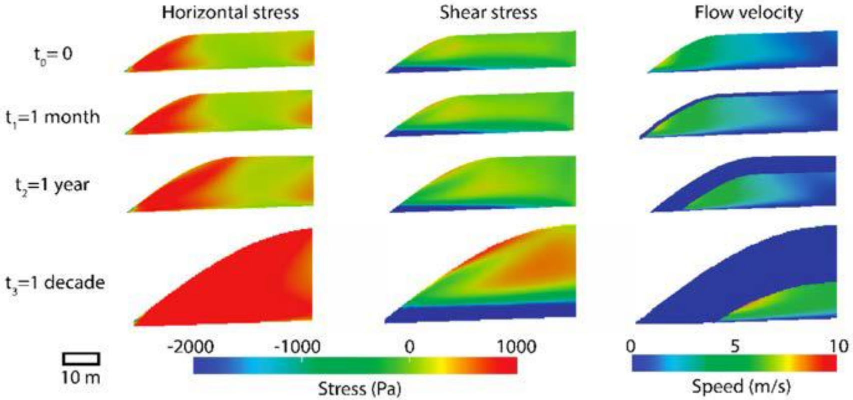
c) Next steps

In Year 3, postponed field-work in the Zuni–Bandera Volcanic Field will be completed to finish papers about lava tube morphology and sinuous channel formation. A preliminary multi-layer thermo-rheological model, initially implemented in ELMER, will also be converted over to COMSOL Multiphysics to model lava emplacement process on Earth and the Moon, using observations from Years 1 and 2 as model constraints.

Schematic cross-section of a lava lobe developing over three time-steps *t*. At each time step, some portion of a tracked parcel of liquid cools into a solid, thickening the crust at that location. Remaining molten lava advances according to a velocity assigned by our flow models. The process repeats until no molten lava remains.



Deviatoric stresses and flow velocities for inflating lavas on Mars based on a preliminary finite element model implemented in ELMER. Rows show the development of the flow over time, and columns show horizontal stresses (positive values tensile), shear stress, and flow velocity.



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