National Aeronautics and Space Administration

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

Principal Investigator (PI): Laura Kerber, Planetary Science Section (322)
Co-I: Christopher Hamilton, Lunar and Planetary Laboratory, University of Arizona
Program: SURP

Project Objective:

Moon Diver is a planetary mission concept proposed to the 2019 NASA Discovery program by PI Keber. The mission architecture includes a lander and tethered rover, Axel, which would land within Mare Tranquillitatis—a volcanic plain on the Moon where there is a large collapse pit thought to be evidence of a subsurface lava tube. Advancing over the regolith and descending into the cavity on a tether (Fig. 1), Axel would examine layers in the walls of the pit to provide critical information about the creation of secondary crusts, as well as determine if the pit is connected to a lava tube that could shelter future human explorers.

Fig. 1. The NASA Discovery mission concept Moon Diver would send the Axel rover into pit in Mare Tranquillitatis to investigate lava layering to learn about the Moon's volcanic history. Inset: Moon Diver's target: a 100-m-deep lunar pit (8.33° N, 33.22° E); actual image from LRO.

The objective of this work was to document the morphological characteristics and geochemical stratigraphy of lunar-like terrestrial lava flows in cross-section to: (1) assess trade-offs between data resolution and scientific reconstruction of lava emplacement processes based on lava flow structures; and (2) describe features that are expressed near lava flow boundaries to develop science operational strategies that would be employed Moon Diver. The project improves the framework for interpreting lavas in cross-section in general, and directly benefits a potential mission.

In Year 1 of the project (FY18/19), our team focused on two examples of lava flow stratigraphy: field-based observations of the ~3000 year old McCartys lava flow-field in New Mexico; and drill core through the 200 million year old Orange Mountain Basalt (OMB) sequence within the Newark Basin in New Jersey. These two examples provide end-member examples of flood lava (>1 km^3) and flood basalt (>1000 km^3) eruptions on Earth as analogs for small to large eruptions within Mare Tranquillitatis.

Results of the McCartys lava flow-field investigation are described by Hamilton et al. (in review), whereas results of the OMB analysis are primarily digital and are available through an online archive to facilitate use by JPL engineers and scientists.

FY18/19 Results:

McCartys lava flow-field: Hamilton et al. (in review) present criteria for distinguishing between lava tube skylights and lava-rise pits, which are another type of topographic depression formed within inflating lava flows. Distinguishing between these landforms is important because lava-rise pits are not connected to lava tube segments and therefore would not provide cave-like shelters from harmful solar radiation. Hamilton et al. (in review) also demonstrate how lava-cooling equations can be used to model lava emplacement durations based on the thicknesses of the lava crust exposed within fractures. In the case, 7.8-m-deep fractures (Fig. 2) imply 1.2–2.5 years of continuous lava supply, depending on the rate of precipitation during the emplacement.

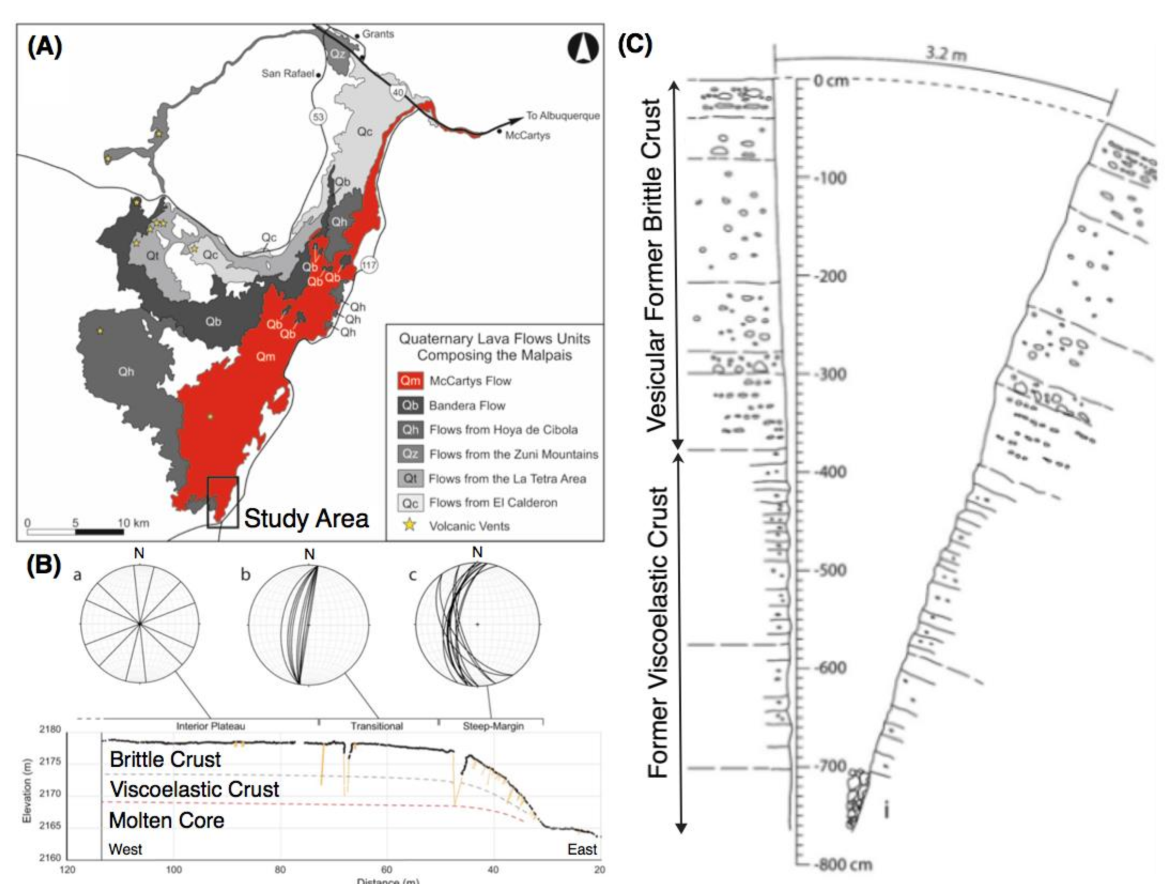

Fig. 2. (A) Study location in the southern portion of the McCartys lava flow-field, New Mexico. (B) Cross-sectional profile showing stereo net projections of fracture orientations in: (a) interior plateau; (b) transitional; and (c) steep-sided regions. (C) Layering structures within the large fracture in the steep-sided region shows a change in vesiculation at 375 cm depth, marking the transition from the former brittle upper crust and underlying viscoelastic layer. The total crack depth (780 cm) indicates the total thickness of the upper crust above the once molten core.

Orange Mountain Basalt (OMB): The Martinsville #1 drill core through the OMB (Fig. 3), includes three lava flow units, which from bottom to top, include: OMB 1 (85.5-m-thick), OMB 2 (65.5-m-thick) and OMB 3 (13.8-m-thick). No sedimentary deposits (i.e., paleosols) are present between these three flows, which implies that they were emplaced in short succession. Using an ITRAX scanner at Columbia University's Core Lab, the ~180-m-long core was examined to obtain: (1) 10-mm-wide 8-bit color images; (2) 10-mm-wide 16-bit color images; (3) 100-mm-wide 8-bit images; (4) 100-mm-wide 16-bit images; (5) DSLR images of key features of interest; (5) tabular core logs for the complete section; (6) accompanying annotated sketches; (6) XRF data for the first 6 m (i.e., 21 feet) of core; and (7) detailed descriptions and sketches of the complete core, with additional focus near flow unit boundaries. All data are archived online at: https://drive.google.com/open?id=1gt8lUUcDR1GnX3DSDNtLTG-mndnj52lY. The online documentation also details all data resolutions.

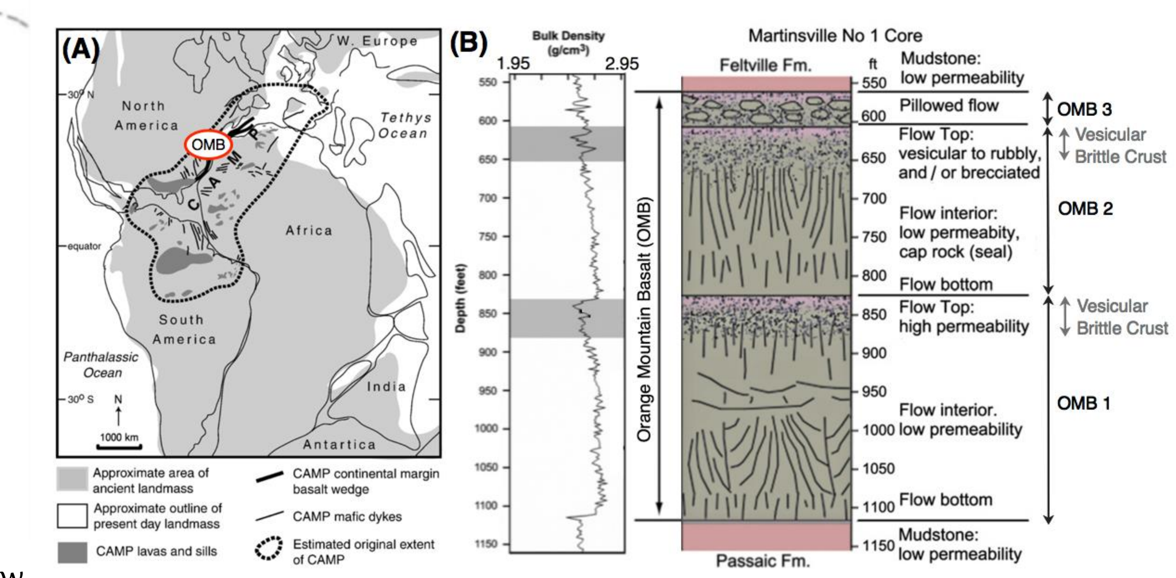

Fig. 3. (A) Location of the Orange Mountain Basalt (OMB) within the Central Atlantic Magmatic Provence (CAMP) during the early stages of the breakup of Pangaea, 200 Ma (adapted from Cohen and Coe, 2017). (B) Density and stratigraphy (adapted from Goldberg et al., 2010). OMB 1 and 2 include a vesicular upper brittle crust and increase in density toward their bases. However, unlike the McCartys flows, divisions between brittle crustal zones and the underlying viscoelastic and once molten layers are not clearly defined.

Benefits to NASA and JPL:

Prior to conducting a planetary science mission, it is imperative to assess methods of evaluating testable hypotheses under different conditions to discover potential complications and establish contingency plans. For instance, in examining the OMB core, it proved challenging to identify internal boundaries and evaluate the thickness of the three thermo-rheological divisions (i.e., former brittle crust, viscoelastic layer, and molten core). Internal contacts were commonly gradiational or indistinct within a narrow (10-cm-wide) core, unscoring the need for Moon Diver's wide field-of-view cameras. Additionally, erosion of the upper parts of OMB 1 and 2 prevent accurate reconstuctions of total flow thickness and upper crustal thickness. This means that the cooling models (e.g., Hon et al., 1994; Keszthelyi, 2007) will underestimate emplacement times. Flow velocities calculated using well-established models (e.g., Jeffreys equation) would also be underestimated because velocity is nonlinearly proportional to lava thickness. On the Moon, lava flows would be eroded mostly in place via impact bombardment. Long periods of hiatus would be required for a regolith layer to form (more than 7.5 million years per centimeter).

Publications:

Hamilton CW, SP Scheidt, MM Sori, AP de Wet, JE Bleacher, WB Garry, PL Whelley, PJ Mouginis-Mark, S Self, JR Zimbelman, and LS Crumpler (in revision) Lava-rise plateaus and inflation pits in the McCartys lava flow-field, New Mexico: An analog for pāhoehoe-like lava flows on planetary surfaces. *Journal of Geophysical Research: Planets.*

PI Contact Information:

Phone: (818) 354-5967 ***Email:*** Kerber, Laura A (US 3223) <laura.a.kerber@jpl.nasa.gov>

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

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