LAVA-RISE PLATEAUS AND INFLATION PITS WITHIN THE MCCARTYS FLOW, NEW MEXICO, USA.

S. P. Scheidt[1], C. W. Hamilton[2], J. R. Zimbelman[1], J. E. Bleacher[3], W. B. Garry[3], A. P. de Wet[4], and L. S. Crumpler[5], [1]Center for Earth and Planetary Studies, Smithsonian Institution (scheidts@si.edu), [2]Lunar and Planetary Laboratory, University of Arizona, [3]Planetary Geodynamics Laboratory, NASA Goddard Space Flight Center, [4]Department of Earth and Environment, Franklin and Marshall College, and [5]New Mexico Museum of Natural History and Science.

Introduction: Pāhoehoe lava flows on Earth and other planetary surfaces comprise recurring elements analogous to the tiles that compose an intricate mosaic. From smallest to largest, these recurring elements include toes, lobes, and flows, which combine to produce flow fields and volcanic plains [1]. The scale of these features depends largely on local effusion rate, lava rheology, and eruption duration, with the total thickness of a lobe including contributions from both the molten core and thickness of the surrounding crust. This observation is particularly important in the context of planetary geology, where remote sensing observations of lava flow dimensions provide a vital constraint on eruption conditions. However, if a flow's total thickness is incorrectly attributed to its dimensions in a molten state, then associated effusion rates will tend to be excessively high, and calculated emplacement durations erroneously short.

This study explores the architecture of a lava-rise plateau (i.e., a network of inflated pāhoehoe lobes) within the McCartys flow in New Mexico to establish morphological criteria that can provide evidence of significant crustal thickening due to a prolonged duration of lava supply. These criteria are important because they can be applied to remotely sensed observations of pāhoehoe-like flows on other planetary surfaces to assess if the related eruptions were short-lived high-effusion rate events, or if the flows were emplaced more gradually at lower rates of effusion.

Geologic context and approach: The McCartys flow is located in the Zuni–Bandera volcanic field and was erupted 3160–3200 years ago [2]. The flow is composed of porphyritic basalt with a total volume of ~7 km^3, area of ~308 km^2, and maximum length of ~65 km [3]. This study focuses on the morphological and structural characteristics of lava-rise margins and inflation pits located within the southernmost portion of the flow, which were examined using a combination of remotely sensed visible images, U.S.G.S. topographic maps, Differential Global Positioning System measurements, and multiview stereo photogrammetry [4].

Inflation processes: The process of lava inflation includes two parts: molten core thickening and crustal thickening. During the initial stages of lava emplacement, the proportion of a lobe's total thickness will be dominated by the thickness of the molten core, which for low-discharge basaltic pāhoehoe flows in Hawai'i tend to inflate to their equilibrium core thickness over the course of approximately one week [5]. However, as the emplacement duration continues, the crustal thickness will continue to grow as it cools and thickens according to a square root of time dependence [5]. As the flow thickness grows, the molten core becomes proportionally thinner than the flow's total thickness. Local environmental effects can affect rates of crustal growth (e.g., [6]), but overall it is clear that the total thickness of long-lived pāhoehoe flows dominantly reflects a gradual process of crustal thickening, rather than the flow's initial thickness.

When the fluid pressure within the molten core exceeds the combined lithostatic pressure and mechanical strength of the upper brittle crust and viscoelastic layer, the crust may be lifted to produce inflation structures such as tumuli and lava-rise plateaus. Tumuli have a dome-shape and tend to develop circumferential fractures at their base with deep clefts located along their long axis [7,8]. In contrast, larger lava-rise plateaus tend to be flat-topped with fractures developing primarily in a zone along the outer flow margins, which can enable their interior surface to be uplifted with little or no disruption [9]. Nonetheless, the interior surface of a lava-rise plateau may exhibit highly fractured zones in the vicinity of circular to elliptical pits. Pits of this type have been identified within the McCartys flow and interpreted as subsidence or collapse features [3]. However, these pits do not exhibit any evidence of connection with lava tubes, either up-flow or down-flow of the depressions [10] and have since been explained as the products of inflation around places where the lava failed to inflate [7,11]—for instance, above topographic highs that were surrounded by lava or at the sutures between lobes. These features have been termed "lava-rise pits" [7,11], but are herein referred to as "inflation pits".

Results: Geological mapping and field observations of the southern portion of the McCartys flow reveals that extensional fractures concentrate near the steeply inclined exterior margins of flat-topped plateaus and in the vicinity of large (tens of meters wide) circular to elliptical depressions within it. These inclined margins also tend to exhibit arcuate folds with axes that are oblique relative to the dip of the surface. The fractures, ranging up to 2 m in width and 15 m in depth, exhibit systematic patterns that divide into three classes: Linear (Fig. 1a), Concentric (Fig. 1b), and Polygonal (Fig. 1c).

Linear factures occur along straight (zero curvature) segments of the plateau margin and tend to concentrate extension along one, or a few, large parallel fractures located near the top of a rotated slab of crust. Parallel linear fractures also occur at the base of the tilted slabs, but are commonly obscured by small breakouts issuing from the lower part of the plateau.

Concentric fractures occur along convex (negative curvature) segments of the plateau margin and around circular to elliptical depressions. These curvilinear fractures tend to be regularly spaced along the sloping margins, with individual crack widths and depths being smaller than the linear fractures described above.

Polygonal fractures occur along concave (positive curvature) segments of the plateau margin. These fractures networks resemble those on the surface of tumuli [8] and tend to include a wider and deeper fracture running along the long-axis of the dome-shaped lobe. Widths and depths of the polygonal fractures tend to be intermediate between the linear and concentric types.

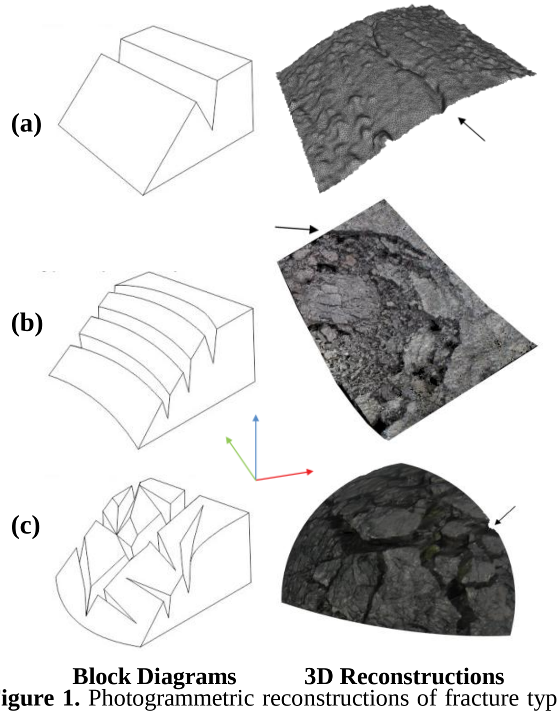

Figure 1. Photogrammetric reconstructions of fracture types along plateau margins: **(a)** Linear fractures with zero curvature. **(b)** Concentric fractures with negative curvature. **(c)** Polygonal fractures with positive curvature. Black arrows indicate examples of fault traces. Colored arrows show 3D orientation axes.

Interpretation: The overall geometry of the plateau is consistent with a lava-rise origin in which a network of lobes coalesced to form a broad sheet-like molten core that supplied new material to the interior surfaces of the confining crust. The upper crust was then uplifted through a gradual process of crustal accretion and pressurization of the molten core. This inflation process also caused the peripheral parts of the plateau to tilt outwards, thereby creating steeply inclined margins as the interior of the flow thickened. Rotation of the outer surfaces of the plateau is evidenced by the orientation of the “ropes” relative to the current dip direction because these arcuate features typically form as the cooling lava surface deforms such that the nose of the fold points in the local flow direction (i.e., down-slope) at the time of formation. The inflation process also lead to the formation and growth of extensional factures along the exterior margins of the lava-rise, and in the vicinity of lava-rise pits within the plateau. The observed fracture patterns may therefore reflect the state of stress that developed in three distinct regions of surface curvature (defined in plan view) as the inflating lobe was subjected to internal pressurization. The maximum depth of the extensional fractures, expressed in the monoclinal clefts that developed in the upper hinge zone of the plateau margins with zero curvature was 15 m, which implies that there was sustained lava flux through the core of the lava-rise plateau for a minimum of 4.2 years (Eq. 2 in [5]).

Discussion and conclusions: Based on the above observations, we expect that the margins of inflated lava-rise plateaus should exhibit linear, concentric, and polygonal fracture patterns in regions with near-zero, negative, and positive curvature, respectively. Furthermore, zero curvature regions should exhibit the widest and deepest extensional cracks and the presence of these monoclinal clefts should be interpreted as evidence for sustained flow through the molten core, with the final thickness of a lobe depending largely on the time available for crustal thickening. Consequently, lava-rise plateaus that exhibit the systematic fracture patterns shown in Fig. 1 may have a total thickness that is dominantly attributable to the gradual accretion of the crust above an active molten core. Therefore, the thicknesses of long-lived flows do not necessarily provide a direct measure of initial flow thicknesses and emplacement conditions unless the equilibrium thickness of the molten core can be calculated and subtracted from the total.

References: [1] Hamilton et al. (2013) *Bull. Volcanol.*, *75*(756), 1–16. [2] Laughlin et al. (1993) *Geology*, *22*, 135–138. [3] Nichols (1946) *Geol. Soc. Am. Bull.*, *57*, 1049–1086. [4] Scheidt et al. (2014), *LPSC XLV*, Abstract #1446. [6] Hon et al. (1994) *Geol. Soc. Am. Bull.*, *106*, 351–370. [7] Keszthelyi (2012) *LPSC 43*, Abtract #2547. [8] Walker (1991) *Bull. Volcanol.*, *53*, 546–558. [9] Rossi and Gudmundsson (1996) *J. Volcanol. Geotherm. Res.*, *72*, 291–305. [10] Hobblit et al. (2012), *Geosphere*, *8*(5), 179–195. [11] Champion and Greeley (1977) *NASA CR 154621*, 133–151. [12] Walker (2009) *IAVCEI 2 Geol. Soc. Lond.*, 17–32.