IMPLICATIONS OF INFLATED SHEET-LIKE FLOW EMPLACEMENT ON PLANETARY SURFACES

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Introduction: Basaltic rocks are the dominant crust forming material in the inner Solar System. Earth Science studies of basaltic eruptions tend to focus on forward modeling to aid in hazard assessment, whereas studies of lava flows in Planetary Sciences are primarily concerned with inverse modeling eruption parameters based on the characteristics of previously emplaced flows. In both cases, lava flows are typically classified as either pāhoehoe or ʻaʻā, but there exist a range of alternative flow emplacement processes and related morphological structures that defy such basic categorizations. Determining the characteristics and emplacement conditions associated with a wider range of flow types therefore represents the next big step in modeling lava emplacement processes on Earth and other terrestrial planets and moons [1–3].

Here we discuss some implications of basaltic sheet-like flow emplacement with respect to interpreting planetary volcanic terrains. Our field site is the McCartys lava flow field, New Mexico, and we focus on the southern distal margin where the flow advanced over nearly zero degree slopes and displays no evidence for lava tube or channel formation.

McCartys Flow Field: The McCartys lava flow field is among the youngest (~3 ka) [4] basaltic lava flows in the Continental United States and is located within the Zuni–Bandera Volcanic Field (ZBVF). The ZBVF is located within an arid environment, which combined with the McCartys flow field's youthful age results in observable pristine textures and relationships. The southern sections of the flow display smooth, flat-topped plateaus with irregularly shaped pits and hummocky, lower topography, inter-plateau surfaces.

Plateaus are typically elongate in map view, up to 20 m high and display lineations within the glassy crust. Lineations are generally straight and parallel, sometimes for many 10s to over 100 meters. Lineated morphologies are occasionally replaced by crust that is composed of lava balls, which are roughly the size of basketballs. Plateau and depression margins can be tilted to angles sometimes approaching vertical, and preserve the lineated and lava ball textures. Margin-parallel cracks, sometimes containing squeeze-ups, mark the boundary between tilted crust and plateau. Topographic data show that plateaus across the southern portion of the flow are of equal elevation (within 1–2 m) showing less than 10 cm of variation within a plateau. However, at least one additional plateau level is encountered closer to the vent that rises an additional ~10 m above the lower plateau.

Plateaus also display textures/features that are formed during early stages of emplacement. Lineated surfaces can display small <1 m diameter lava coils, indicative of sheer stresses within a flowing lava surface. Plateaus also display small orange-reddish clay-like chips that cover areas of 1–2 m^2. Chips are found within the lineations, sometimes loose and sometimes welded to the crust, extending for several meters in one direction. Also identified on plateaus are small circular holes that are several 10s cm across and less than 1 m deep, often preserving the imprinted texture of tree bark on the lining of the holes. In some places, the surface crust has been disrupted, forming tilted slabs of material, which are on the scale of a meter or less across and up to 7–10 cm thick. The slabs often preserve the lineated textures of the undisturbed crust.

Some topographic depressions within the plateau display level floors with hummocky surfaces, while some are bowl shaped with floors covered in broken lava slabs. Infrequently, pit floors display the upper portion of high topography from an older flow.

Interpretations: We interpret the southern portion of the McCartys flow to have experienced sheet-like inflation. The lineated texture is consistent with early emplacement of a sheet-like flow lobe. Lineations record shear zones within the sheet [5], occasionally forming coils [6]. Slabs indicate disruption of the original crust [7]. Unlike platy-ridge flows [8], these slabby units are confined to several meter diameter patches across the plateaus. As such, they did not involve extensive lateral transport as is observed during the development of ʻaʻā lava flows. We suggest that disruption occurs as advance of a sheet-like lobe stagnates along the lateral margins and inflation begins. It seems likely that inflation across broad areas involves localized differences in response to the inflation, possibly related to variations in pre-flow topography. Inflated flows are known to invert the pre-flow topography [9]. For instance, some irregular depressions include exposures of pre-flow terrain on their floors. These locations are likely the highest points in the pre-flow terrain, which may have resulted in initially thinner flows and the suppression of inflation at these localities.

Once the McCartys flow crust reached a thickness of 7–10 cm, or 75 to 120 minutes of cooling time and crust formation (calculated using equations from [5, 8]), the surface was generally capable of supporting sheet-wide inflation without crustal disruption. We interpret the orange chips and circular holes to represent early stage emplacement features formed at the same time as lineations and coils. Orange chips likely represent baked clay-rich soils that developed into ceramic chips as they were heated by the overlying lava. The chips may then have been erupted onto the flow's surface at an early stage by local steam explosions and incorporated into the advancing sheet-like flow along with the lineations. The circular holes likely represent tree molds that form as lava surrounds tree trunks. Common in basaltic terrains, these features form when lava flows are relatively thin (<1–2 m). Their presence on the top of the highest plateaus (likely 20–30 m above the pre-flow terrain) suggests that they formed in the initial stages of flow advance when the lava sheet thickness was on the order of a few meters. Much like the orange chips, these features were then transported upward as the flow inflated later on.

Implications: The McCartys flow is ~40 km long and dominantly flowed to the north. Although the regional slope is to the north-northwest, a significant volume of lava flowed south and southeast. Thus, it appears that the McCartys flow field advanced up a gentle slope. Although a simple assumption involves lavas within a flow field advancing radially away from the eruption site, the southern, inflated sections of the McCartys flow field suggest a different process.

We interpret each plateau as a separately emplaced flow lobe that was formed after the previous lobe stagnated and inflated to a common level, possibly reaching a hydrostatic (or 'lava-static') level. At this point the active lobe would experience breakouts providing a local source for the next lobe. Multiple lobes could be active as lava passed through the previously emplaced lobes to the advancing flow front. As each new lobe spread across the surface to establish a new inflating sheet it encountered topographic constraints imposed by the pre-flow terrain and the previously emplaced McCartys lobes. Each inflated lobe to the south of the vent was inflated against the regional slope and created a topographic trough into which the next breakout could flow, thereby advancing the flow to the south-southeast. As pre-flow slopes increased to the east and south, the topographic troughs and lobes that formed over them narrowed to be <100 m across, while remaining quite long (several kilometers). In this way, the McCartys flow field locally advanced up-slope.

Another important implication of inflated sheet flow emplacement is the development of disrupted crust. Disrupted pāhoehoe creates a rough texture that might be misinterpreted as ʻaʻā lava. However, the process described above is fundamentally different from the formation of an ʻaʻā flow, or even a platy ridged surface that involves lateral transport of crustal materials. Typically, the brecciation of an ʻaʻā flow crust results from higher emplacement rates than are characteristic of inflated flows, which can display disrupted pāhoehoe. As such, it is critical to conduct facies-style mapping of lava flow textures, particularly in planetary data, if those textures are used to constrain emplacement conditions.

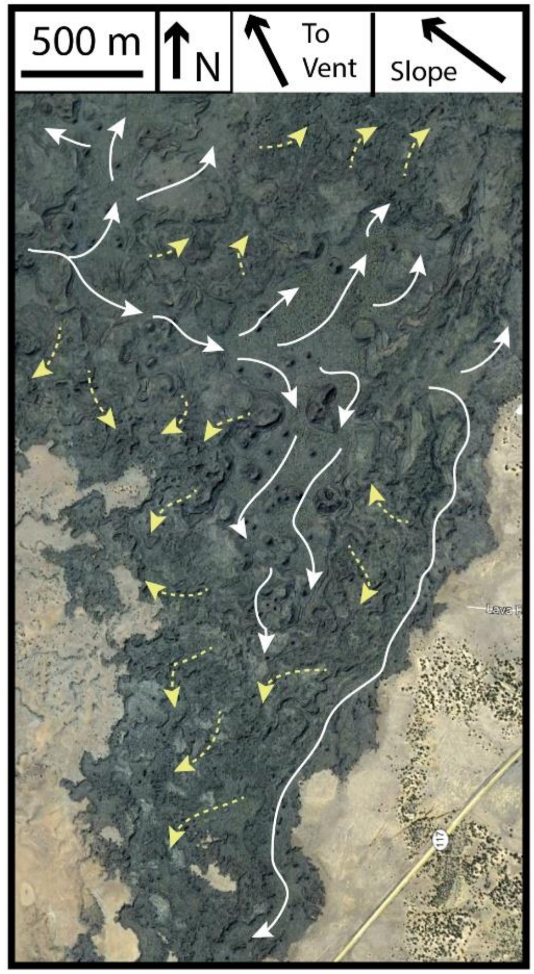

Fig. 1. Southern portion of the McCartys flow. White lines show inferred pathway of lava advance associated with inflated plateaus. Dotted yellow lines are presumed advance of inter-plateau flow directions.

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