SINUOUS RIDGES AND PLATEAUS AS EVIDENCE FOR LAVA FLOW INFLATION IN THE THARSIS PLAINS OF MARS: INSIGHTS FROM ANALOGOUS FEATURES ON THE COASTAL PLAIN OF KILAUEA VOLCANO, HI. J.E. Bleacher[1], T. Orr[2], W.B. Garry[1], C.W. Hamilton[1,3], J.R. Zimbelman[4], A. de Wet[5]. [1]Planetary Geodynamics Laboratory, NASA GSFC, Greenbelt, MD, 20771, Jacob.E.Bleacher@nasa.gov, [2] USGS Hawaiian Volcano Observatory, Volcano, HI, [3]CRESST at GSFC, [4] Center for Earth and Planetary Studies, Smithsonian Institution, Washington, DC, [5] Earth and Environment Department, Franklin & Marshall College, Lancaster, PA.

Introduction: The main flanks of the Tharsis Montes developed from summit eruptions, followed by rifting to the SW and NE to form rift zone deposits that are now known as the Tharsis Montes rift aprons [1,2]. Formation of the rift aprons involved lava emplacement from the chasmata [1,2] and rift zone-aligned groups of low shields [3,4,5]. However, it is also proposed that the rift aprons were modified by the release of large volumes of water, fluvial erosion, and possibly the emplacement of mud deposits [6,7].

The debate surrounding the role of volcanic and fluvial processes centers on differing interpretations of channel formation mechanisms within these units. These channels are typically composed of single stem non-leveed rilles that can also exhibit branching channel sections with terraced walls and islands. However, these features rarely display an obvious distal margin, which prompts questions regarding their origin. For instance, "Why are there no observable distal fans or deltas associated with these channels even though there is a significant slope break between the 1–3°steep rift aprons and the <1° slope of the Tharsis plains"? Here we focus on the volcanic development of the coastal plain south of Kīlauea Volcano, Hawai'i, as a possible volcanic analog for Tharsis rift apron flows that lack deltaic deposits.

Tharsis Observations: Sinuous ridges have formed across the Tharsis plains that are as long as 100 km. These wall-like features are tens to hundreds of meters across and typically <10 m in height. In some instances only a wall-like structure is present within an otherwise featureless plain, but some walls are located along the axis of a broad rise that can extend up to several kilometers across (Fig. 1a). Together a wall and rise might reach 100 m above the adjacent plains. A wall and, where present, a rise are hereafter referred to as "ridge". Ridges tend to follow the regional slope and often weave between older topographic highs such as shields or thick flow features.

The ridges appear to vary in height and width, sometimes disappearing from view but reappearing short distances away. A ridge can be a source for small (hundreds of meters, up to kilometers) surface lobes. Where these lobes are stacked they compose the broad rise as previously described here. Although ridges are often identified in the low slope plains where the sources are generally unrecognized, some are seen in association with the plains volcanoes. Figure 1b shows a low shield vent from which a typical lava channel becomes a ridge where the slope changes from ~1° (likely higher) to <0.5°.

Sinuous ridges sometimes terminate as broad, flat-topped plateaus (Fig. 2). These plateaus often include numerous irregularly shaped depressions. The margins of the plateaus are often irregular and scalloped in map view, sometimes transitioning to a number of lower topography lobes or terraces that are similar to the lobes associated with ridges. Often the plateaus form in locations where the ridges trend into a topographic obstacle, such as a low shield. Ridges and plateaus are not always found in association with one another. However, their fairly common association suggests that the two features, even when found separate from one another, share a common developmental history.

Kīlauea Observations: Lava flow emplacement associated with Kīlauea's East Rift Zone generally follows a common pattern. After advancing down the ~6º Pūlama scarp (which marks the eastern end of the Hilina fault system that cuts across Kīlauea's SE flank) a flow's active front encounters the gently sloping (<2º) coastal plain. Upon reaching the coastal plain, a flow generally spreads out laterally and advances by the progressive extension of pāhoehoe lobes along the margin of a broad sheet with a liquid core (e.g. [8,9,10]). Continued seaward progress is slow, often taking weeks for the leading margin to reach the ~5–15 m-high, nearly vertical, seacliff that bounds Kīlauea's SE coastline. As the flow moves across the coastal plain, thickening (or endogenous inflation) can occur across the entire sheet. However, once flow begins to descend the sea cliff, lava within the fluid core of the sheet is preferentially focused into efficient pathways between the base of the scarp and the ocean outlet through the sheet. The development of a central pathway reduces the flow of new lava into the lateral margins of the sheet, which in turn reduces the rate of lateral spreading and leads to stagnation of lateral advance and inflation. At this point a flow will be characterized by a well-developed tube within a broad, inflated plateau and unless rootless vents feed new breakouts form the tube, lava will be delivered through the sheet to the ocean with little change to the plateau.

Observations of flows emplaced during an episode in late 2010 have also shown that flow inflation can be focused along the tube itself when a low discharge rate enables the flow to be confined laterally by local, small-scale topography (Orr et al., manuscript in prep.). In this case, the flow field remains narrow and only the tube roof experiences inflation-related uplift. This process is accompanied by periodic breakouts along the tube wall during periods of increased lava flux through the system. As the tube roof continues to be uplifted it is synchronously partly buried by its own outbreaks, thereby producing a narrow ridge surrounded by broader breakout lobes. The resulting morphology includes sinuous ridges, or elongate tumuli, which are generally located between and confined by broad plateaus, or inflated sheet lobes.

Discussion: Lava flows encountering a steep-to-shallow slope break do not always produce deltaic landforms. Depending on the emplacement rate the active flow front can spread laterally and produce a variety of inflation-related features, such as ridges and plateaus. The morphologies produced as flows from Kīlauea's East Rift Zone transition from the Pūlama scarp onto the flat coastal plain display many similarities with features observed where flows from the Pavonis Mons southwest rift zone transitioned onto the flat eastern Tharsis plains. Thus, a lack of deltaic deposits at the boundary between the Tharsis Montes rift apron and Tharsis plains would be consistent with slowly emplaced rift apron lavas that spread across the low slope plains and inflated.

Other martian sinuous ridges are interpreted as inverted fluvial channels [11, and references therein], eskers [12–14], or eroded remnants of dikes [15]. Inverted fluvial channels and eskers require flowing water, and all three processes require significant erosion of sediments or ice. The interpretation of sinuous ridges on Mars as elongate tumuli over lava tubes is an alternative hypothesis that does not require regional deflation or fluvial processes, and is an ideal explanation for volcanic regions and/or where additional evidence of regional erosion is not observed.

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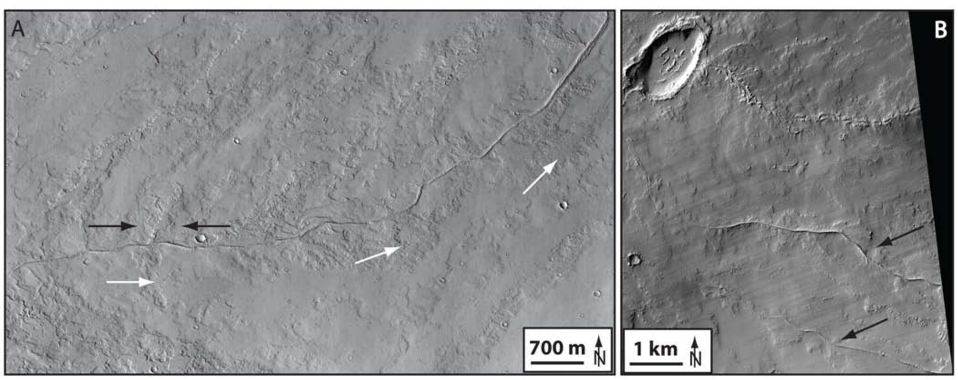

Figure 1. Images of sinuous ridges within the Tharsis volcanic province of Mars. (a) CTX image P07_003673_1774 showing ridge. Black arrows point to one a small. White arrows point in flow direction. (b) HiRISE image ESP_027289_1790 showing a low shield volcano in the Tharsis plains with caldera at upper left. The arrows point to two sinuous ridges.

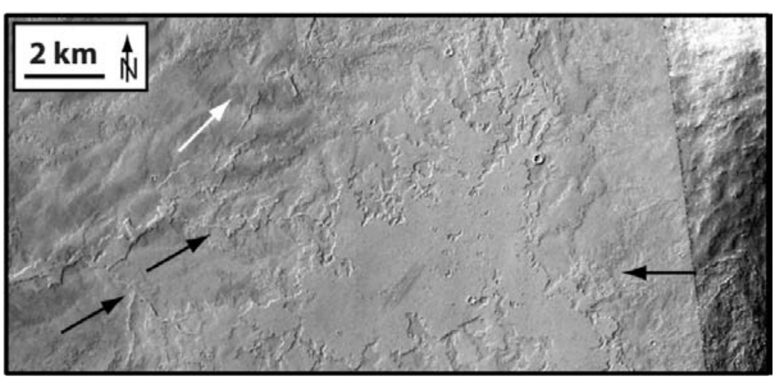

Figure 2. CTX image B01_009870_1788 showing a ridged flow (white arrow) with two smaller ridged low lobes (right pointing black arrows) that transition into a plateau. Left pointing arrow indicates boundary between plateau and a low shield to the east.