MEASURING LATE AMAZONIAN FLEXURAL DEFORMATION OF DAEDALIA PLANUM WITH PALEO-SLOPE INDICATORS.

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Introduction: Arsia Mons is the southernmost of the three enormous Tharsis Montes volcanoes on Mars, with a height over 12 km and a basal diameter of about 350 km. Arsia has distinctive morphological features, notably a single large (115 km wide) caldera paved with flows as young as 150 Ma, and prominent flow aprons (Figure 1) that emanate from the northeast and southwest flanks, which postdate and partially surround the main edifice [1-6]. The southwest apron fans into the wide expanse of Daedalia Planum to the south of Arsia Mons. Daedalia is an elevated plains region comprised of numerous overlapping, long, thin lava flows emplaced during the Hesperian and Amazonian Periods, including some areas with estimated ages of just a few 100 Ma [7-9].

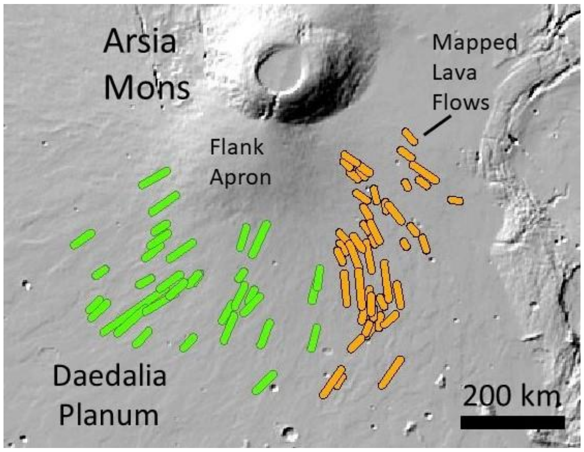

Figure 1. Daedalia Planum study area. Long, relatively straight lava flows are mapped as vectors to represent the downhill azimuthal direction at the time of their eruption. Each flow vector is compared with the corresponding modern local topographic slope direction to identify areas of topographic deformation. Orange vectors were mapped in an area of generally higher crater densities that show evidence for subsidence toward the west. Green vectors are flows that have undergone minimal apparent post-eruptive deformation.

These young eruptive ages reveal that Arsia Mons and Daedalia Planum were witness to some of the most recent volcanic activity on Mars. The volume of magma produced and hence importance of this relatively recent activity, however, is not clear, as estimates of the extrusive/intrusive ratio and magmatic flux (rate of total magma production, both extrusive and intrusive) for Mars and the Tharsis Montes are not well constrained. The young surface lavas observed could be just a thin carapace emplaced during the waning stages of activity in the region, or they could be part of a relatively voluminous late surge of activity.

Large volume magmatic activity can have a profound influence on local and regional topography, as both intrusive and extrusive products act as flexural loads on the lithosphere, producing downward-subsided moats around volcanoes on Earth (e.g. Hawaii) and at Olympus Mons on Mars [10]. The loading causes topographic slopes to change over time, and lava flows that flowed “downhill” when they were emplaced can become re-oriented. These flows are thus indicators of “paleo-slopes” and their orientations relative to modern-day topography can be used to identify and measure flexural loading due to magmatic activity.

Mapping Methods: In this study, we measured the azimuthal orientations of 77 relatively long (>20 km) and straight lava flows on Daedalia Planum to the south and southeast of Arsia Mons (Figure 1) on a Mars Reconnaissance Orbiter Context Camera (CTX) image mosaic. Each flow records the downhill topographic direction at the time it was erupted, and these relict flow orientations, when compared with current downhill directions derived from Mars Orbiter Laser Altimeter (MOLA) topographic data collected from buffer regions around each flow, can yield evidence of post-flow slope reorientation. The magnitude and direction of the slope change is then used to model and infer the cause of the deformation, while crater counts on the deformed plains are used to constrain the deformation timing.

Modelling Methods: Following [10], we calculate the vertical deflections of the lithospheric response to computed loads and subtract them from the current topography to restore the original topography and slopes at the time of flow emplacement. We perform a bootstrap statistical inversion [11] to constrain the range of values of the load dimensions (radius r and height h of a conical volcanic construct) and lithosphere thickness T_e that best restore the slopes to those indicated by the measured flow orientations.

Preliminary Mapping Results: Our mapping thus far shows that modern slope azimuths for a region of older (~330 Ma) terrain to the southeast of Arsia have been rotated clockwise >10° for 14 of 44 flows (orange in Figure 1) mapped there (ranging from 10.2° to 41.9°), and none were rotated >10° counterclockwise. This deformation is consistent with subsidence to the west of the flows or uplift to the east. For the younger (~160 Ma) plains to the south and southwest of Arsia, the flows show less evidence of deformation, with 31 of 33 mapped flows (green in Figure 1) showing less than 10 degrees of azimuth difference from modern local slopes in that area. These observations suggest significant deformation of the older southeastern part of Daedalia Planum, perhaps related to magmatism at Arsia Mons or emplacement of the flank apron, took place in the interval between these two dates.

Preliminary Modelling Results: We use a load centered at 238.8° E, 13.0° S to simulate the Arsia Mons southwest flank apron (Figure 1). Our inversion considered flows with clockwise rotations of downhill direction > 5°. Unlike at Olympus Mons [10] we do not find strong constraints on individual model parameters for the Arsia region paleo-load. However, the overall volume of the volcanic load is well constrained (Figure 2), with 95% confidence bounds in the range 0.49-1.64 x 10^6 km^3. If the tilt-inducing load of the Arsia Mons southwest flow apron was emplaced between 330 and 160 Ma, as implied by the cratering ages, lower bounds on magma supply rates of 2.9 to 9.6 x 10^{-3} km^3/yr are obtained. Significantly, these findings overlap the volume and mean magma supply rate findings for late-stage Olympus Mons [10], suggesting a similarly vigorous magmatic activity for the two settings at the same late epoch of Martian history. This rate is also comparable to the 80 Ma emplacement rate average for the Hawaiian-Emperor chain on Earth [10].

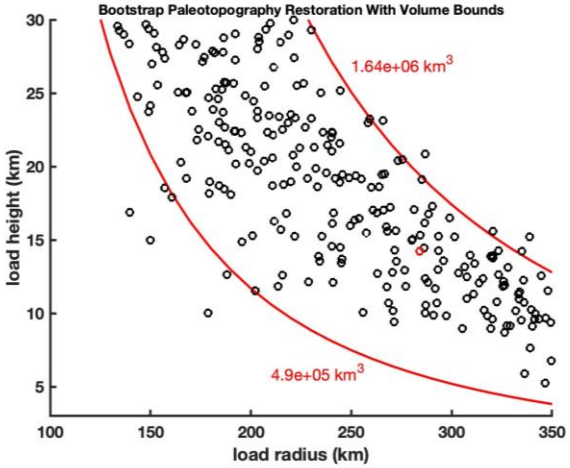

Figure 2. Best-fit values of load dimension parameters (radius *r* and height *h* of a conical load) for 250 resamplings of a bootstrap statistical analysis [11] of paleo-loading south of Arsia Mons. 95% confidence bound contours on load volume are shown as red lines.

References: [1] Crumpler et al., *Geol. Soc. Lond. Spec. Pub.*, 1996; [2] Plescia, *Jour. Geophys. Res. Planets*, 2004; [3] Richardson et al., *Earth Planet. Sci. Lett.* 2017; [4] Mouginis-Mark and Christensen, *Jour. Geophys. Res. Planets*, 2005; [5] Bleacher et al., *Jour. Geophys. Res. Planets,* 2007; [6] Scott and Zimbelman, Geologic Map of Arsia Mons volcano, Mars, 1995; [7] Berman and Crown, LPSC abstracts 2019; [8] Tanaka et al., *Planet. And Space Sci.*, 2014; [9] Crown et al., LPSC abstracts, 2015; [10] Chadwick et al., *Jour. Geophys. Res. Planets*, 2015. [11] Menke, *Geophysical Data Analysis: Discrete Inverse Theory*, Academic Press, London, UK, 2018.