RHEOLOGY COMPARISONS FOR SEVERAL MARTIAN AND TERRESTRIAL LAVA FLOWS.

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Introduction: Mars Orbiter Laser Altimeter (MOLA) data provide a level of detail equivalent to that available for unobserved lava flows on Earth. For lava flows on Mars, we have used MOLA data to derive longitudinal thickness profiles and underlying slope information [1]. Here we report on a study to compare lava flows in different volcanic provinces and settings on Mars. We present some examples of the types of analyses and comparisons that can be done for typical flows at Ascraeus, Alba (Flow F6 in [2]), Pavonis [3], Elysium ([1], and Flow 46 in [4]), and Mauna Loa [5]. These flows span a range of lengths, underlying slopes and rheologies. Some flows show channels and others do not. Through this comparative study, we are looking for correlations e.g., between underlying slope and rheologic changes, and systematic differences among volcanic provinces. Identification of such correlations enable us to isolate and refine models of lava flow emplacement.

Flow Characteristics: Inferences from theoretical models depend critically upon thickness and slope data. For lava flows at Ascraeus, Elysium and Alba, we have used the methodology described by [1] to extract longitudinal thickness and underlying slope information directly from MOLA transects. Direct use of the transects, as opposed to a gridded digital elevation model (DEM) is necessary for the flows at Ascraeus and Elysium because the vertical relief of the flows is comparable to the relief of the ambient terrain. For Pavonis, we have used data collected by [3] from the gridded MOLA dataset. For Mauna Loa, we have used data collected by [6].

Width changes in response to slope breaks, and the existence, or lack, of well developed channels, can be of use in trying to better untangle the role and magnitude of rheologic changes during lava flow emplacement. The shape of the upper surface of a lava flow (concave up or concave down) also provides information regarding the nature of rheologic change along the flow path. For example, flows with a concave up flow surface are consistent with an exponential viscosity increase.

Table 1 summarizes these important dimensional and morphologic characteristics for the selected lava flows identified above. We can then determine the suite of appropriate models that can be used to describe emplacement [5, 7-12]. Here we discuss the details of each flow.

Mauna Loa. The main lava flow of the 1984 eruption, the “1 Flow”, is ~26 km long and was emplaced on a slope of ~ 4.0 degrees. If we assume a simple viscous fluid on a constant slope, we estimate that the viscosity must have increased about 100 times over the length of the flow. However, we know that the density of the 1 Flow increased due to degassing as a function of distance along the flow [13]. Assuming the case of maximum degassing, [5] show that a viscosity increase of over 400 times produces a thickness profile that is consistent with the 1 Flow.

Elysium. The flow at Elysium examined here is a 35 km breakout from a much larger flow (#46) described by [4]. While the length of this breakout is similar to the Mauna Loa 1 Flow, the underlying slope NW of Elysium is about an order of magnitude less than the flanks of Mauna Loa. Detailed analysis of MOLA data [1] seems to imply that this breakout may be comprised of 2 discrete segments. Using the degassing model [5], and an assumption of moderate degassing, [1] predict changes of 10x and 50x over the lengths of these final flow segments.

Alba. At Alba, we examined the final 95 km of Flow F6, as identified by [2]. While the slopes at Alba are similar to those for the Elysium flow described above, the flow itself is dramatically different. The flows at Alba are relatively unusual on Mars in that they show significant thickening toward the flow front. The Alba flow examined here has a maximum thickness near the distal end of ~130 m. There is no evidence for a channel and the top surface of the flow appears very flat. Although this flow has exceptionally high relief, we again infer that only modest viscosity change occurred during emplacement. This may be due to an emplacement time that is relatively short (on the order of days to a few weeks) so that significant heat loss and crystallization was inhibited.

Ascraeus. The example flow NE of Ascraeus is at least 145 km long with a well defined channel visible in both Viking images and MOLA transects. The underlying slope is on the same order as the Elysium and Alba flows. However, unlike Elysium and Alba, the Ascraeus flow shows no evidence whatsoever of thickening over the 145 km extent. Even using a model that allows a proportion of lava flow volume to be lost to stationary levees [10], we estimate a negligible increase in viscosity over the length of the flow. Again, this argues for a flow that is well insulated.

Pavonis. Baloga et al. [3] have examined the distal 175 km of a very long lava flow originating in the saddle between Pavonis and Ascraeus, that flowed onto the plains north of Pavonis. The flow also seems somewhat enigmatic in that it appears to have flowed extreme distances as a coherent unit on slopes an order of magnitude less than those at Elysium, Alba and Ascraeus. Although the entire flow is quite thick, there is little evidence for a significant increase in flow thickness as a function of distance (~ 20 m over 175 km). The flow shows evidence of a channel over much of the extent examined by [3]. Incorporating the loss of volume to stationary margins [10], Baloga et al. [3] have estimated a viscosity increase of only about an order of magnitude over 175 km. Inclusion of degassing does not change the overall estimate of viscosity by a significant amount. The small viscosity increase, combined with the extreme length of this flow, have led to the interpretation that this flow was emplaced as a huge, thick, single coherent unit, retaining its integrity over the last 175 km. This implies a rate of crustal growth approximately equal to the rate of volume loss to stationary margins [3].

Interpretation: All of the Mars lava flows studied here feature only modest viscosity increases during emplacement compared to our expectations from terrestrial basaltic volcanism. This tentative conclusion holds on extremely shallow slopes less than 0.1 degree to those of a few degrees. Whether or not a channel formed does not influence this conclusion.

It is interesting that only the flow at Elysium provides a hint of the longitudinal flow surface shape. All other flows are either too flat to discriminate (e.g., Ascraeus) or too modified by post-emplacement processes to distinguish thickness variations due to viscosity changes from the noise (e.g., Alba).

It is also worth noting that the Mars flows are significantly thicker (by a factor of ~ 2 – 10) than terrestrial basaltic flows emplaced as solitary lobes, including those with sequential breakouts. It may be that the greater thickness of the Mars flows causes a significant increase in flow velocity (proportional to the thickness squared for Newtonian fluids) over the length of the flow path. The greater velocity would then reduce the time required for viscosity changing processes to operate. In addition, there is evidence that the thickness of the Mars flows minimizes flow mixing and exposure of the inner core due to variations in the underlying topography. The extremely flat topography in many of the Mars plains would also act to minimize mixing.

Why we find such thick lava flows on Mars still remains a mystery. Possible explanations include higher viscosity lavas, larger vents, higher effusion rates, or post-emplacement inflation. There is little evidence for any lava types other than basalt, and the paucity of visible source locations argue against the first two options. However, higher effusion rates are consistent with the more rapid emplacement times required by these flows. It is also plausible that post-emplacement inflation, such as that observed at Mt. Etna [14], could be responsible for increasing flow thicknesses in the proximal and medial portions of the flows, eliminating evidence of the style and magnitude of viscosity changes during initial emplacement.

References: [1] Glaze L. S., Baloga S. M. and Stofan E. R. (2003) *Icarus* in review. [2] Schneeberger D. and Pieri D. C. (1991) *JGR, 96,* 1907–1930. [3] Baloga S. M., Mouginis-Mark P. J. and Glaze L. S. (2003) *JGR* in press. [4] Mouginis-Mark P. and Yoshioka M. T. (1998) *JGR, 103,* 19,389 – 19, 400. [5] Baloga S. M. et al. (2001) *JGR, 106,* 13,395 – 13,405. [6] Crisp J. A. *pers comm*. [7] Baloga S. M. (1987) *JGR, 92,* 9,271 – 9,279. [8] Pinkerton H. and Wilson L. (1994) *Bull Volcanol, 56,* 108-120. [9] Bruno B. C., Baloga S. M. and Taylor G. J. (1996) *JGR, 101,* 11,565 – 11,577. [10] Baloga S. M. et al. (1998) *JGR, 103,* 5,133 – 5,142. [11] Williams D. A., Fagents S. A. and Greeley R. (2000) *JGR, 105,* 20,189 – 20,205. [12] Fagents S. A. and Greeley R. (2001) *Bull Volcanol, 62,* 519-532. [13] Moore H. J. (1987) *USGS PP, 1350,* 1,569 – 1,588. [14] Guest J. et al. (1987) *Bull Volcanol, 49,* 527-540.

Lava Flow	Length Analyzed (km)	Initial Thickness (m)	Front Thickness (m)	Variable Width ?	Upper Surface Shape	Channel?	Slope (deg)	Viscosity Change
Mauna Loa	26	4	19	Y	?	Y	4.0	100 - 400x
Elysium	35	15	37	N	concave up	N	0.6	50x
Alba	95	40	130	N	?	N	0.4	30 – 60x
Ascraeus	145	20	30	Y	?	Y	0.3	< 10x
Pavonis	175	30	55	Y	?	Y	0.05	10x

Table 1. Summary of morphologic and dimensional flow characteristics.