Exploring the Effects of Pre-eruptive Topography on Lava Flow Morphology and Flow Interior Structure Using Wax Analogs. Tessa Krueger Jones[1] and Steve Anderson.[2,3], [1]Dept. of Geology, 876 Natural Sciences Complex, University at Buffalo, Buffalo, NY 14260, [2]Black Hills State University, Spearfish, SD, 57783 [3]Planetary Science Institute, Tucson, AZ

Introduction: One of the goals of volcanology is to answer the basic question: “Can we observe the surface of an active or solidified lava flow and infer how the volcano is or was behaving during eruption?”. High-resolution image and topographic data sets from MRO, Mars Express, and MGS now permit imaging of small-scale features (e.g. tumuli, crease structures, blocks, levees and compressional ridges) providing an avenue for answering this fundamental question for Mars.

One of the key variables known to affect lava flow surface morphology is the nature of the pre-eruption topography. The term “topography” is a general term that includes elements such as slope, obstacles, and RMS deviation of adjacent points [1]. Some investigators have inferred a clear relationship between pre-flow topography and surface form. For example, Self et al. [2] suggested that flows forming over hummocky pre-flow surfaces will “invert” the topography: low pre-flow areas will become high post-flow areas because lava will pool in low spots and provide foci for inflation of the flow and the growth of tumuli.

Because of the ambiguity associated with determining pre-flow topography in nearly all other terrestrial sites, several investigators have turned to laboratory experiments involving analog fluids such as polyethylene glycol (PEG). Fink and Griffiths [3-8] extended some of the pioneering modeling work of Hulme [9] and Blake [10] and related surface morphology (pillowed, rifted, folded and leveed) to a dimensionless parameter ψ, which is the ratio of the advection timescale to the cooling time scale. On flat slopes, ψ values of <3 produced pillowed flows, $\psi = 3\text{-}10$ formed rifted flows, $\psi = 10\text{-}30$ were ropy, and $\psi > 30$ were leveed.

Gregg and Fink [11,12]) found planetary lava flow surface morphology could be used to infer eruption conditions by using the ψ value modeling technique. They also discovered that flow down progressively steeper slopes had the same effect as increasing extrusion rate: it increased the advection rate of the flow. Experiments that examine the effect of other topographic elements, such as obstacles, are not yet published.

Hummocky topography is the focus of the work discussed here because of the tendency for terrestrial mafic flows to display this dominant late-stage surface morphology [13,2]. Because lava flow simulations have been a successful approach to questions relating to surface morphology, we have employed wax analogs to investigate the affect of hummocky topography.

Procedure: We conducted 17 simulations in a 50x50 cm Plexiglas tank. Four different sized inverted watch glasses were placed along the bottom of the tank, sorted by size. PEG was pumped into the middle of the tank, through a round hole. A 10 cm area around the vent was left without watch glasses. By allowing the flow to begin development prior to contact with pre-eruptive topography, we could determine if initial contact with hummocky topography stimulates immediate changes in surface morphology. The flows were color-coded with respect to time by the addition of dye to the PEG at three timed intervals, allowing us to accurately observe the evolution of the simulated flow.

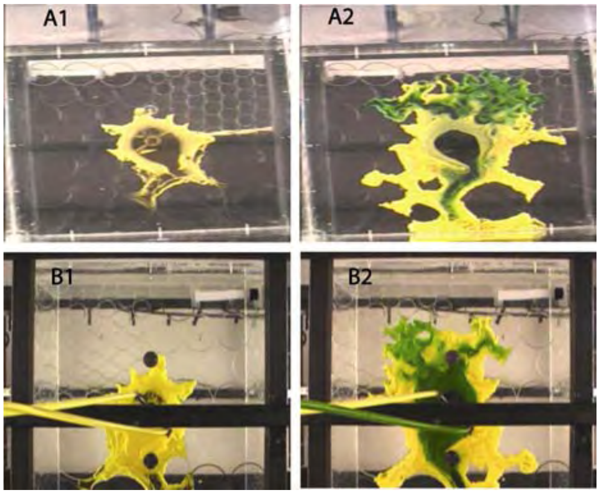

Figure 1 Images of a progressing wax flow from below (B) and above (A) at time 1 and 2.

Results: Flows without pre-eruptive hummocky topography generally followed the Ψ value/surface morphology relationships discovered by Fink and Griffiths [3-8], although some experienced brief periods of transition into other surface morphologies as the flows progressed. These transitions were discussed by Anderson et al. [14], who suggested that they represent lower strain rate environments due to the effect of a steady effusion rate on a continually-enlarging flow.

Pillowed Flows: The presence of hummocky topography aids in the formation of pillowed surfaces. During the simulated flows with hummocky pre-eruptive topography, pillowed morphologies were observed at much higher Ψ values compared to flows with flat pre-eruptive topography. Twelve of the flows with hummocky pre-eruptive topography had pillowed morphologies, with a Ψ value range from 9.15 to 37.3. Eleven flows were recorded with flat pre-eruptive topography containing pillowed features, and have a Ψ value range from 1.27 to 15.95.

Simulations with hummocky topography developed pillowed features much sooner than simulations with flat topography given a similar Ψ value. If a simulation were allowed to run long enough or if started at a low Ψ value (define low Ψ value), internal solidification began, creating patches of solidified material within the flow along the bottom of the tank. Pillow surface morphologies became prominent once this solidification began, regardless of the presence of hummocky topography. This solidification, referred to here as subsurface solidification margins (SSMs) proved to have profound effects on morphology. SSMs and pre-eruptive hummocks acted as a catalyst to pillow morphology formation. As more material solidified under the crusted surface, the movement of the fluid became restricted, enhancing solidification and promoting breakouts. The interplay between surface breakouts, observed in proximity to SSMs within the flow, were clearly related to the formation of pillowed surface morphology.

Folded Flows: In the presence of pre-eruptive hummocky topography, folded surface morphology becomes less abundant. Our observations indicate that the main component contributing to the development of folded surface features was a fluid subsurface that pushed the solidified surface away from the vent. Underlying topography created a barrier to movement, and initiated solidification of the fluid subsurface, hindering the free movement of fluid below the surface. The surface of the flow no longer moved out in a continuous fashion and the folded features become less abundant.

Rifted Flows: We found that when flows encountered pre-eruptive topography, all rifted flow surface structures were disrupted. Of the simulated flows with hummocky topography, six produced short lived rifting surface morphology. Among the flows with flat pre-eruptive topography, eleven had long lived rifting morphologies and fit the evolutionary profile previously outlined for the surface morphologies of flat pre-eruptive topography simulations. The rifting features began to diminish once solidification took place at the base of the tank.

Rifted surface morphologies contained a steady stream of fluid flowing under a solidified crust, one which diverged into separate flow fronts. Rifted surface morphologies were accompanied by folds and/or pillows. As solidification progressed at the base of the tank, the rifting subsided and pillowed features predominated. The hummocky pre-eruptive topography had the same effect on surface flow development. This in turn eliminated the development of rifting features.

For rifting to occur, different flow fronts must be free to move away from each other and the subsurface of the flow must be fluid. Two things happen in the presence of topography and/or SSMs: 1) The pre-eruptive topographic obstacles and fluid cannot move freely through them. Therefore, the divergence of the flow front becomes unlikely; and 2) SSMs and/or the presence of topography makes the subsurface initiate more solidification increasing viscosity. Therefore pre-eruptive topography inhibits the development of rifting surface morphologies.

Leveed Flows: The presence of hummocky topography reduced the length of time a particular flow expressed leveed morphologies. During a simulation with pre-eruptive topography, leveed morphologies stopped developing sooner compared to a flow without topography given a similar Ψ value. At some point the Ψ value became high enough that the leveed morphology existed throughout the entire flow.

Conclusions: Our investigation suggests that pre-flow topography strongly influences final flow morphology. The presence of hummocks promotes solidification within the developing flow. As a result, pillowed morphologies are favored over folded, rifted, or leveed surface morphologies.

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