

THE EFFECTS OF COOLING ON LAVA DOME MORPHOLOGY Nathan Bridges and Jonathan Fink, Geology Department, Arizona State University, Tempe, AZ and Ross Griffiths, Research School of Earth Sciences, Australian National University, Canberra

The most widely used method of estimating the rheology of extra-terrestrial lava flows has been to relate the height (h) of marginal levees to their yield strength (τ_0): $\tau_0 = \rho g h \sin \theta$, where ρ = lava density, g = gravity and θ = underlying or surface slope (1, 2). A recently published model (3) has shown that the height (H) and radius (R) of sub-circular lava domes similarly can be related to the yield strength of the lava: $\tau_0 = 0.32 H^2 \rho g / R$. Both of these models were derived by balancing the gravitational stresses driving a flow forward with the yield strength holding it back, and both assume that the yield strength is a material constant of the magma, independent of its temperature. Here we argue that the way a lava flow cools plays a crucial role in establishing its morphology.

Attempts to uniquely relate the yield strengths of lavas (estimated using the above equations) to composition have been unsuccessful (1-3). We suggest that it is the thickness of a lava flow's cooled carapace, rather than flow composition, that determines the *effective* yield strength. This solidified crust that forms at the flow surface and cascades off the flow front to create a talus pile provides the resistance to advance commonly attributed to the lava yield strength. Thus the more rapidly crust forms, the greater the resistance to buoyant stresses, and the sooner a flow will come to rest. For a fixed eruptive volume, more rapid crust growth will lead to shorter, thicker flows and domes. Similarly, decreased gravitational stresses (as on planetary bodies with smaller mass) will also lead to relatively stubby extrusions.

Intuitively one might assume that planetary surface temperature would play a major role in determining how rapidly a flow cools and thus what morphology will result. However, calculated cooling rates for lavas experiencing a combination of convection and radiation for likely surface conditions on all of the terrestrial planets reveal that the time scale for the flow surface to begin to solidify will be negligible relative to total emplacement times for all but the smallest extrusions. As a consequence, variations in surface temperature should not lead to significantly different dome shapes as long as the temperature does not approach the magmatic solidus.

Although ambient temperature does not strongly influence the shape of domes, the *rate of extrusion* does play an important role. For a given eruptive volume, a higher extrusion rate will allow lava to flow further before surface solidification is able to stop its advance. Slower extrusion rates will result in shorter, steeper domes. Cooling is even more effective if the erupted volume comes out in a series of pulses separated by repose intervals, rather than as a single episode. The larger the number of eruptive pulses and the longer the intervening repose periods, the more effective cooling will be and the thicker the resulting extrusion.

We have conducted two series of laboratory experiments designed to quantify the effect of cooling and extrusion rate on the aspect ratios of domes that experience surface solidification during advance. In the first series, fixed volumes of polyethylene glycol were extruded at progressively lower rates into tanks of cold sucrose solution (4). In the second set, the control volume was sub-divided and eruption of individual portions was alternated with various repose intervals. The results show that the aspect ratio of a dome of a given volume is dependent upon the eruptive rate and whether or not that volume is emplaced continuously or episodically. The more rapidly crust forms, the thicker the extrusion will be, all other conditions being equal. The results further indicate that whether new magma is added to the surface (exogenous growth) or interior (endogenous growth) of a dome depends on the length of the repose period, confirming a conclusion obtained from topographic measurements of the Mount St. Helens lava dome (5).

Our results thus suggest that variations in lava dome morphology on different planets will depend much more critically on local gravity and the style of eruption than on the magma composition, ambient temperature, or the relative roles of convective and radiative cooling. Eruption style in turn reflects differences in tectonic conditions and the ability of magma to exsolve volatiles. Observed crude correlations between silica content and calculated yield strengths for terrestrial lava flows and domes (1, 2) probably are due to differences in extrusion rate and volatile solubility, rather than intrinsic rheological properties. Thus, even after taking the known effect of gravity into account, observed differences in gross dome morphology on different planets cannot by themselves be directly related to composition. Additional information such as the distribution of surface textures and structures, or spectroscopic data will be needed to conclusively establish dome compositions.

REFERENCES

- (1) Moore H. J., Arthur D. W. and Schaber, G.G. (1978) *Proc Lun. Planet.Sci. Conf.* 9, 3351-3378. (2) Hulme G. (1974) *Geophys. J. Roy. Astr. Soc.* 39, 361-383. (3) Blake S. (1990) *IAVCEI Proc. in Volcanology* 2, 88-126. (4) Fink J. H. and Griffiths R. W. (1990) *Journal of Fluid Mechanics* 221, 485-509. (5) Fink J.H., Malin M.C. and Anderson S.W. (1990) *Nature* 348: 435-437.