QUANTIFICATION OF EXTRATERRESTRIAL LAVA FLOWS THROUGH ANALOG EXPERIMENTS; Tracy K.P. Gregg and Jonathan H. Fink, Department of Geology, Arizona State University, Box 871404, Tempe, Arizona 85287-1404; e-mail: ahkat@acvax.inre.asu.edu

Because active extraterrestrial lava flows have not yet been observed, eruption conditions--such as effusion rate and lava composition--must be estimated based on lava flow morphology. We have conducted a series of 224 laboratory simulations of mafic lava flows, in which polyethylene glycol wax is extruded at a constant rate and temperature into a tank filled with cold sucrose solution. By systematically varying cooling rate, effusion rate and underlying slope, we can produce a repeatable sequence of flow morphologies; these morphologies are identified by the ratio of solid to liquid wax exposed on the flow surface. At the lowest effusion rates and slopes, and highest cooling rates, pillowed flows form. As effusion rate and slope increase, and cooling rate decreases, pillowed flows transition into rifted flows (solid plates of crust separated by zones of liquid wax along which spreading occurs), folded flows (channelized flows in which the surface crust buckles into a series of parabolic folds with axes perpendicular to the flow direction), and finally to leveed flows (channelized flows in which solid wax forms only at the flow margins, leaving the channel interior completely liquid). These morphologies can be characterized by a single dimensionless parameter, Ψ, which is the ratio of a time scale for surface solidification to a time scale for heat advection within the flow [1]. Because Ψ contains all the key physical properties of both the extrusion and its environment, we have been able to successfully correlate laboratory-derived morphologies and associated Ψ values with submarine basalt flow types [2], enabling effusion rates to be estimated based on lava flow morphology.

There are two inherent difficulties in applying this model to extraterrestrial flows. First, classification of laboratory (and submarine) flow types is based on relatively fine-scale surface features which may not be resolved on planetary images. In correlating laboratory and extraterrestrial lava flow morphologies, it was occasionally necessary to first relate laboratory morphologies to terrestrial subaerial flow types, and then relate these flow morphologies to extraterrestrial flows. For example, it has been quantitatively shown [1] that terrestrial lava domes, such as the Mount St. Helens dacite dome, correlate with the laboratory "pillowed" regime, for which $\Psi \leq 3$. Thus, we can tentatively assign extraterrestrial lava domes the same range of Ψ values. Second, the parameter Ψ incorporates physical properties of the extrusion, such as viscosity, eruption temperature, and thermal diffusivity. Because samples for extraterrestrial lavas exist only for a few samples on the Moon, these properties must be estimated for other lunar flows and for lavas on other planets.

Analogs for all the laboratory-derived flow regimes can be found among Venusian lava flow types, perhaps because the primary mode of cooling (convection) is the same in the laboratory and on the surface of Venus [3]. If the "pancake" domes were composed of tholeiitic basalt, they would require an effusion rate (Q) of $\leq 10^{-7} m^3/s$. Alternatively, if the domes were composed of rhyolite with ~0.2wt% H_2O, then $Q \leq 10^7 m^3/s$. The relatively low effusion rate required to produce the pancake domes from basaltic lava suggests that either the domes were emplaced episodically or that they are not composed of basalt. Flows resembling the "rifted" regime in the laboratory are rare on Venus, but appear where lava has apparently ponded, resulting in radar-bright plates of crust separated by radar-dark material. These morphologies would require $10^{-7} \leq Q \leq 10^{-5}$ m^3/s if produced by basaltic lava. Only 3 large festooned flows have been observed on Venus; these morphologies would form from basalt if $10^{-5} \leq Q \leq 10^{-3} m^3/s$. Leveed flows are common on Venus, and the canali are probably an end-member of this flow type [3]. Effusion rates as low as 10^{-1} m^3/s could produce small basaltic channels on Venus; the canali would require higher, steady rates of effusion.

There are few lunar mare basalt flows which still retain primary surface morphology, making identification of lava flow types difficult. The ~1200km-long Imbrium flows display central channels [4], probably placing them in the "leveed" flow regime, with $\Psi \geq 25$. Assuming a flow viscosity of 10 Pa-s and an eruption temperature of 1225°C [5], this range of Ψ values requires $Q \leq 10^{-6} m^3/s$. This relatively low minimum effusion rate is capable of producing channelized flows on the Moon primarily because of the low viscosity of the lunar basalts. Lunar impact melts within and around Tycho and Copernicus display surface folding, corresponding to $13 \leq \Psi \leq 25$. The fold wavelength suggests that these impact melts are considerably more viscous than the mare basalts [5]. Assuming a viscosity of 10^5Pa-s and an emplacement temperature of 1000°C, this range of Ψ values corresponds to $100m^3/s \leq Q \leq 10^4m^3/s$. The Gruithuisen Domes may have been formed by mare basalts erupting at extremely low effusion rates ($< 10^{-10}m^3/s$). Such low rates suggest that the domes are not formed by "typical" mare basalts; instead, they may be composed of a more crystal-rich lava, a more silicic lava, or lava with a relatively low eruption temperature. Alternatively, the domes may have been emplaced episodically, leading to very low long term average effusion rates [6]. We have thus far been unable to identify lunar flows which have morphologies analogous to the rifted flows produced in the laboratory.

The morphology of Martian lavas suggests that they are mafic or ultramafic [7]. Most flows observed on the flanks of the Tharsis volcanoes are leveed channels, implying $\Psi \geq 25$. Assuming reasonable eruption viscosities and temperatures for Hawaiian tholeiites [4], this corresponds to $Q \geq 10^{-5}m^3/s$. Analyses of surface folds on some Martian flows suggest that they may be composed of basaltic andesite [8]. Again, assuming reasonable eruption parameters, these flows would require $10m^3/s \leq Q \leq 100m^3/s$. Domes on Mars, such as those observed east of Hellas, would require $Q \leq 10^{-10}m^3/s$ if composed of basaltic lava. Such a low value suggests that Martian domes, like the lunar domes, were either emplaced episodically, or are not composed of typical basaltic lava. We have thus far been unable to identify "rifted" Martian flows, although it is possible that this flow regime existed temporarily within some of the large shield volcano calderas.

Estimated eruption rates for the various planets depend upon the cooling rate and efficiency of lava flows. Cooling of mafic or ultramafic lavas is most efficient on Venus, because the thick atmosphere cools lavas convectively. Similar lavas cool least efficiently on Mars, because the thin atmosphere is not sufficient to provide convective cooling, but is sufficient to raise the ambient temperature above the temperature of space. Lunar flows cool at an intermediate rate, because there is no atmosphere on the Moon to provide convective cooling, and the heat from the flows radiates directly into space. Thus, lavas with a given composition would form the same flow morphologies from relatively high-effusion rate eruptions on Venus, intermediate effusion-rate eruptions on Mars, and relatively low-effusion rate eruptions on the Moon. However, the effusion rates estimated here for flows on Mars and the Moon are similar because samples of lunar lavas reveal that they are more fluid than terrestrial basalts, whereas we lack similar information for Martian lavas.

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