PREDICTING EXTRA-TERRESTRIAL LAVA FLOW MORPHOLOGY

Jonathan Fink and Nathan Bridges, Geology Dept., Arizona State Univ., Tempe, AZ 85287

The morphology of lavas is controlled in large part by relative rates of crust growth and surface deformation within the flows. Laboratory and theoretical studies show that a progression of common lava flow features can be formed by varying either the cooling rate or the local flow rate (or both)[1,2]. If cooling rates are relatively high, surface crust growth inhibits the radial or lateral spreading of flows, and the resulting morphology consists of short bulbous lobes like those found in submarine pillow basalts and subaerial "toey" pahoehoe flows. Persistence of these conditions over an extended period of basaltic extrusion can lead to large-scale delta-like constructs such as those seen on the north flank of Mauna Loa Volcano [3] and on submarine portions of Kilauea Volcano [4]. Slower crust growth rates in basalts favor the formation of surface folds and levees, and produce longer, narrower flows and lower volcanic constructs. For silicic compositions, more efficient cooling results in the formation of endogenic domes in which new lava is added to the dome interior without substantial fracturing of the crust. Slower cooling of silicic extrusions yields exogenous domes and flows in which the crust cracks frequently, allowing hot interior lava to cool faster.

In the laboratory, transitions from one morphologic type to another correspond to specific ranges of two dimensionless parameters, Π and τ_s, where Π is a modified Peclet Number relating effusion rate to cooling rate, and τ_s is the time required for the surface to solidify, which combines ambient, eruption, and solidification temperatures. As shown in Fig. 1, the transitions occur at discrete values of a third parameter, Ψ, which describes the dimensionless distance from the vent at which surface crust first appears. For lavas erupted at or near solidus temperatures or in very cold environments, crust appears relatively close to the vent. In contrast, super-liquidus flows or those emplaced in a hot environment will not develop crust until the lava has travelled a greater distance. The morphology of larger-scale volcanic constructs should also reflect these conditions.

In laboratory simulations of lava flows in which polyethylene glycol is injected into a cold sucrose solution, four principal transitions can be noted: (1) flows without crust first develop levees when $\Psi=55$, (2) folds appear on leveed flows when $\Psi=30$, (3) rift-like fractures disrupt folded flows if $\Psi=13$, and (4) rifted flows become pillow-like when $\Psi=3$. Calculations of comparable parameters for a submarine basalt flow [4] yield a point near the border of the rifting and pillow regimes ($\Psi=6$). Similar calculations for growth of the Mount St. Helens dome also indicate conditions within the rifting regime. We are currently collecting eruption data to allow us to plot conditions for a large enough number of eruptions to test the applicability of Figure 1 to natural terrestrial flows.

There are three main differences between terrestrial and extra-terrestrial conditions which must be considered before these results can be used to interpret flows on other planets: gravity, ambient temperature (T_a), and cooling mechanism. Considering a basalt flow erupted under water on earth [2,4] yields a Π of 8.8×10^6, τ_s of 3.6×10^{-2}, and Ψ of about 5. If we calculate these groups for Venus by substituting $g=8.8$ m-s^{-2} and $T_a=457°C$, and assuming that cooling in the dense, hot venusian atmosphere is primarily by convection, we obtain $\Pi=2.3 \times 10^7$, $\tau_s=2.4 \times 10^{-2}$, and Ψ of about 9. These values indicate that solidification of a basaltic crust is about two times slower on Venus than on earth so that for comparable effusion rates and compositions, volcanic constructs on Venus should be broader and lower with proportionally more structures like folds and levees, and should exhibit fewer pillow-like or rift-like forms. Comparable calculations for Mars using $g=3.7$ and $T_a=-73°C$ show that sub-aerial crust growth may under certain circumstances be slower on Mars than on earth, depending on the heat transfer mechanism assumed for the thin martian atmosphere. Thus lava flows on Venus and Mars may look more like each other than they do flows on earth.

LAVA FLOW MORPHOLOGY
Fink, J. and Bridges, N.

Ongoing laboratory simulations and calculations for a variety of eruption scenarios should allow our model of morphologic dependence on crust growth and effusion rates to first be calibrated and then used to interpret the appearance of extra-terrestrial lava flows and volcanic constructs.

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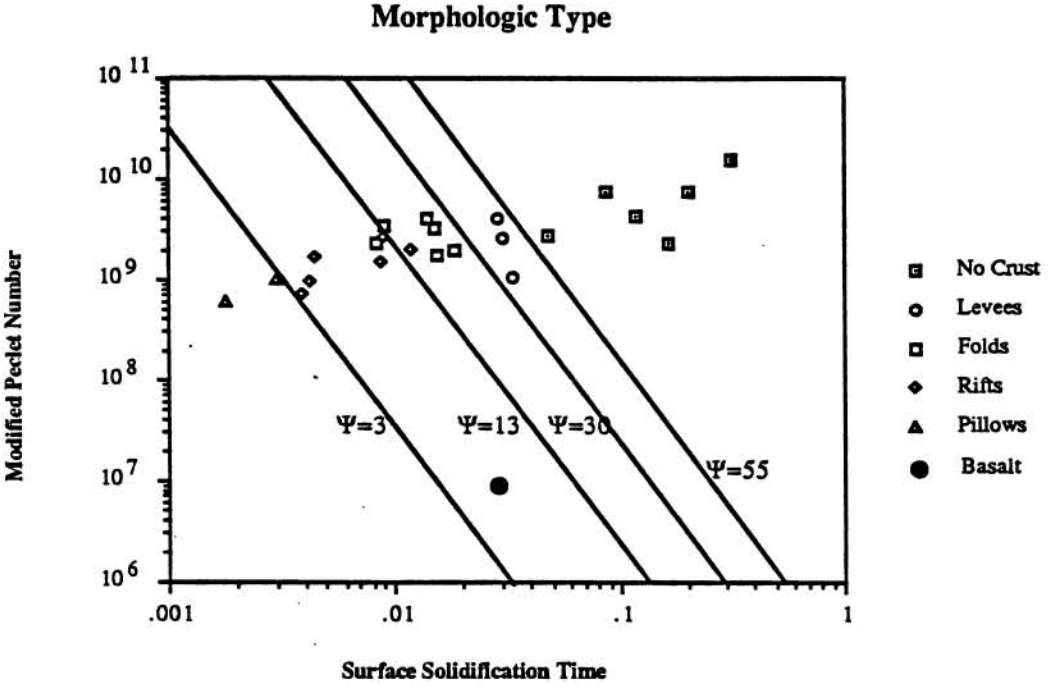

FIGURE 1. Plot showing extrusion type and experimental conditions for 21 laboratory simulations of lava effusion. Data expressed in terms of a modified Peclet Number, Π, and a dimensionless time to solidification, τ_s. Lines representing constant Ψ separate the different morphologic fields. Large circle represents calculated values for terrestrial basalt flow emplaced under water by a combination of rifting and pillow formation.