LABORATORY SIMULATIONS OF LAVA FLOWS WITH SOLID CRUSTS.

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Planetary volcanology relies on the interpretation of flow morphology to constrain the compositions of remotely observed lavas. One of the tools available to assist in this task is laboratory simulation of flow processes. Properly scaled experiments can be used to replicate the overall geometry and structural details of features observed on natural flows. The appearance of a lava flow is controlled in large part by the presence of a cooled skin or crust at its surface, whereas overall dimensions are strongly influenced by rheology. Most previous laboratory simulations have not been able to generate surface crusts and, as a result, they have failed to produce realistic flow morphology. In addition, natural lavas have a temperature-dependent rheology that is only roughly approximated by the commonly used Newtonian and Bingham models. Here we report on a method of laboratory simulation which allows surface structures on lava flows and domes to be more accurately modeled using materials with temperature-dependent rheology.

We have performed a series of 23 experiments in which liquid carbowax, maintained at a temperature (T_l) 1-3° above its freezing point (T_s) of 18°C, was pumped at a constant flow rate (Q) through a hole in the horizontal base of a 30 x 30 x 30 cm tank of sucrose solution held at a constant temperature (T_w) between -3° and +16°C. When the fluid in the tank was sufficiently cold and the flow rate sufficiently low, a solid crust formed on the wax as it spread away from the central inlet. The extent of crust formation could be gauged using a dimensionless temperature, $\theta=(T_s-T_w)/(T_l-T_w)$, and a Peclet Number, $Pe = (Q^{.75}\, g'^{.25})/(\kappa\, \nu^{.25})$, where g' is the reduced gravity, κ is the thermal diffusivity, and ν is the kinematic viscosity of the wax. Crust growth was favored in those experiments having relatively high θ and low Pe.

Digitization and analysis of sequential vertical photographs allowed radial growth rates to be determined, along with average radial velocities ($v = \Delta r/\Delta t$) and radial strain rates ($\varepsilon_r=\Delta v/\Delta r$). For low θ, crust did not form and radial growth rates were identical to those determined theoretically and in the laboratory for Newtonian viscous fluids [1]:

$$r = (g'\, Q^3 / 3\nu)^{0.125}\, t^{0.5}$$

(t = time). At higher θ values, crust appeared, imparting an effective yield strength (τ) to the flow. Growth was then better explained by a Bingham plastic model [2]:

$$r = (\rho\, g'\, Q^2 / \tau)^{0.2}\, t^{0.4}$$

A transition from viscous to Bingham behavior, marked by a change in slope of the radial growth curve (Fig. 1), was found to occur at the theoretically predicted time [2]:

$$T = [(g')^{0.75}\, (\nu)^{1.25}\, (\rho)^2\, (Q)^{0.25}] / [\, (\tau)^{0.5}\,].$$

Strain rates were combined with laboratory-determined viscosities to compute stresses. In cases where the radial compression was high relative to gravity, regularly spaced transverse surface folds formed with wavelengths on the order of 1-3 mm and amplitudes of about 1 mm (Fig. 2). As predicted by theory and seen in lava flows [3], wavelengths increased as the crust thickened, in some cases resulting in more than one generation of super-imposed folds. Under circumferential tension, radial crust-free zones developed over the vent which evolved into multi-armed rift-like structures. As the crust thickened, the width and number of clear zones decreased, eventually leading to a single elongate rift or a three-pronged structure. Spreading took place along circumferential strike-slip faults, analogous to transform structures seen on mid-ocean ridges and active lava lakes. For the coldest experiments (highest θ), pillow-like structures developed, rather than rifts or folds. In these runs, discrete narrow lobes of wax would advance a fixed distance and then stop, allowing the pressure to build up until a new break-out occurred, either along the same or a different lobe. The overall flow grew through this incremental process, producing a morphology analogous to submarine pillow basalt complexes and subaerial pahoehoe fields formed on shallow slopes.

By plotting Pe versus θ, we were able to map out conditions under which folds, rifts, pillows, or no crust were favored. Transitions from one set of conditions to another correlated with the speed of crust growth. Crust growth rates were calculated analytically [4], so that transitions could be quantitatively related to eruptive conditions. We are currently calibrating the analytical model to our experiments and to natural flows in order to devise empirical expressions for effective viscosity and yield strength as functions of crust thickness. Such expressions will allow further quantitative interpretation of flow morphology.

REFERENCES: [1] Huppert HE (1982) The propagation of two-dimensional and axisymmetric viscous gravity currents over a rigid horizontal surface. *J. Fluid Mech.* **121**:43-58. [2] Blake S (1989) Viscoplastic models of lava domes, *in* Fink JH (ed.) The mechanics of lava flow and dome growth. *IAVCEI Proc. in Volcanol.* **2** (in press). [3] Fink JH, Fletcher RC (1978) Ropy pahoehoe: surface folding of a viscous fluid. *Jour. Volcanol. Geotherm. Res.* **4**: 151-170. [4] Turcotte D, Schubert G (1982) *Geodynamics*. New York: Wiley, 450 p.

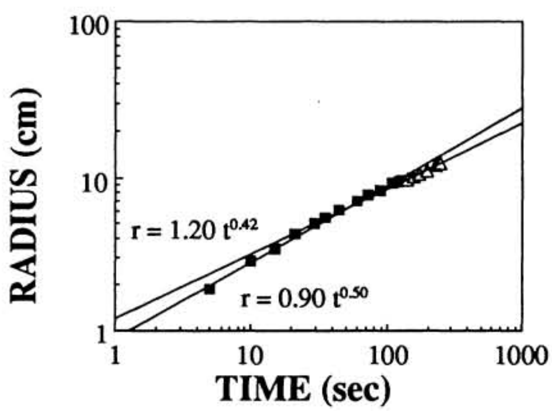

FIG. 1. Plot of average dome radius versus time for experiment with Pe=523 and θ=0.91. At times less than T=102 sec, influence of the crust is negligible and spreading rate is Newtonian [1]. After T, yield strength effects slow the growth to the Bingham rate [2]. r^2 for both lines = 0.99.

FIG. 2. Vertical view of carbowax dome formed with Pe=782 and θ=0.73, conditions which favor the production of surface folds. Field of view is approximately 30 cm across.