N92-10789

CRYSTALLIZATION DURING EMPLACEMENT OF LAVA FLOWS

J. Crisp, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

Thermal models of lava flows provide a way of estimating emplacement durations and eruption rates of planetary lava flows, which can help constrain magma ascent, rheology and composition. Most of the models that have been developed consider only the effects of cooling by radiation. However, heating due to crystallization can be a large component of the overall heat budget of a flow[1].

Little is known about the amount of crystallization and latent heating during flow advance. We have these examples and constraints: {1} The Yakima flood basalt experienced almost no crystallization during flow advance[2]. {2} The 1947-48 Hekla flows were erupted undercooled (1000°C), which did not allow the inner core to crystallize during flow advance.[3] Shearing action in the crust, margins, and flow front triggered crystallization and raised the temperature to 1150°C in these outer zones[3]. {3} An upper bound for the maximum amount of crystals in any flow is about 50-60%, based on studies of Marsh[4], which indicate that at higher crystal contents, the bulk viscosity does not allow a flow to move. {4} Half-way downstream (11 km), the Mauna Loa 1984 1A flow had 15% more crystals than at the vent. For typical Hawaiian and Etna lava flows, the amount of crystallization during advance is probably between 15 and 50%. A more in-depth discussion of example {4} is given below.

Crystal size distribution (CSD) measurements were made to quantify and study the effects of crystallization in the well-documented 1984 Mauna Loa flow. Plots of frequency versus crystal size reveal two crystal populations (Fig. 1). The smaller crystals (microlites) nucleated and grew during emplacement, whereas the larger ones nucleated in the rift zone before eruption. The theory of CSD analysis has been developed for the study of crystallization rates in rocks[5,6]. A sample CSD plot for microlites in quenched-dip samples of the Mauna Loa flow is shown in Figure 2. For most igneous rocks, this type of plot is linear with a slope equal to $-1/\tau G$ and an intercept (crystal size = 0) of J/G, where τ is the time for crystal growth (time spent travelling in channel), G is growth rate, and J is nucleation rate[5,6]. Crystal growth and nucleation rates for the microlites in the Mauna Loa flow were found to be 10^{-9} - 10^{-7} cm s^{-1} and 10^{4} - 10^{5} cm^{-3} s^{-1}.

The volume fraction Φ of crystals expected at time (t) can be approximated as a function of growth (G) and nucleation rate (J) and nucleation time (t'), by the formula[7]:

$$\Phi = 1 - \exp\left[\frac{-4\pi}{3} \int_{t'=0}^{t'=t} J \left(\int_{t'}^{t} G\, dt \right)^3 dt' \right] \qquad (1)$$

Assuming that the values of J and G calculated for microlites during the first 11 km of travel remained constant throughout flow advance, equation (1) would predict that the Mauna Loa flow would have solidified several kilometers short of its 26 km extent (based on measured flow velocities[8]). Thus, the rate of microlite crystallization must have decreased downstream, most likely as a result of increased undercooling. If this can be determined for other flows, then equation (1) should be evaluated by integrating appropriate estimates of G and J as functions of time and/or temperature. Note that Φ is a key parameter required in thermal models of lava flows.

For 15% crystallization during the first 11 km travel on April 6, 1984, the latent heat effect in the Mauna Loa flow was about 0.016 J per gram of magma per second ($\tau \approx 1$

hour). Assuming a maximum crystallinity of 50% during flow advance[4], latent heating during the last 16 km of travel would have been less than 10^{-3} J g^{-1} s^{-1} ($\tau > 1.5$ days). Integrated over time, the latent heating (J g^{-1}) for this lower 16 km stretch could have equalled that of the first 11 km.

These crystallinity measurements provide us with a rough guide to the amount of crystallization and latent heating likely in other flows, as a function of emplacement duration. Using the nucleation and growth rates for the microlites in the Mauna Loa flow and integrating over emplacement duration, crystallization is estimated to have contributed a 2-75° increase in temperature for the Puu Oo flows and 20-50° for the Etna flows listed in Crisp and Baloga[1] (the *net* effect of radiation, convection, conduction, and latent heating was a temperature decrease[1]). It would be preferable to have actual measurements of crystallization in these flows, but without this, we must use the rates for the Mauna Loa flow to make estimates for other flows.

Thermal models used to estimate eruption rates of planetary lava flows should include latent heating. Measurements of crystallization during flow advance are needed because they provide the only independent way to validate theoretical cooling models, by constraining temperatures and latent heating. For flows on Mars, we must assume that the amount of crystallization is similar to that in terrestrial flows and place minimum and maximum bounds on the latent heat effect. Unfortunately, as examples {1}-{4} show, there can be anywhere from 0 to 60% crystallization during flow advance. To improve our constraints for martian flows, we need to search for correlations in terrestrial flows between flow morphology and the amount of crystallization during emplacement.

REFERENCES: [1]Crisp and Baloga (1991) *Lunar Planet. Sci. Conf.* XXII 257-258. [2]Shaw and Swanson (1970). *Proc. 2nd Columbia River Basalts Symp.*, 271-299. [3]Einarsson et al. (1949) *The eruption of Hekla 1947-1948*. Visindafelg Islendinga, Reykjavik, Iceland. [4]Marsh (1981) *Contrib. Mineral. Petrol.*, 78:85-98. [5]Marsh (1988) *Contrib. Mineral. Petrol.*, 99:277-291. [6]Cashman and Marsh (1988) *Contrib. Mineral. Petrol.*, 99:292-305. [7]Kirkpatrick (1981) *Rev. in Mineral.*, 8:321-398. [8]Lipman and Banks (1987) *USGS Prof. Paper* 1350:1527-1567.

Figure 1. Number of crystals per μm^2, as a function of size, for a sample of the 1984 Mauna Loa flow

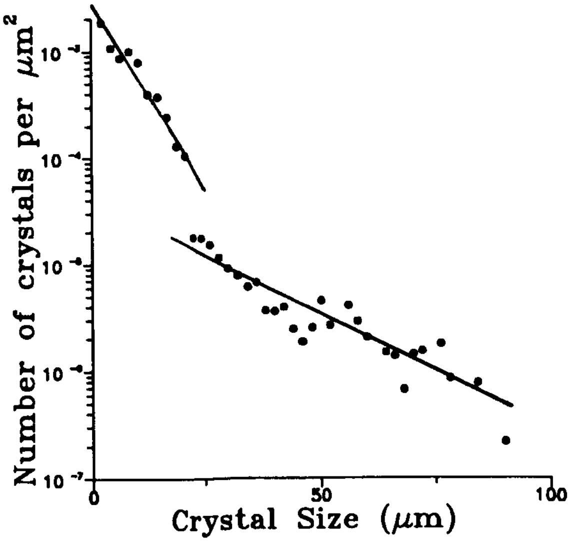

Figure 2. Plagioclase microlite size distribution plot for the Mauna Loa 1984 flow