THERMAL EROSION BY LAVA: A COMPARISON OF THEORETICAL AND EXPERIMENTAL MODELING; D. Challis and R. Greeley, *Department of Geology, Arizona State University, Box 871404, Tempe, Arizona 85287-1404*

Summary: Lavas are hypothesized to carve channels by thermal erosion. This study models thermal erosion using Polyethylene Glycol (PEG) as an analog for lavas. PEG has been used in a variety of studies to model lava flows [1,2,3]. Two previously formulated melt rate equations [4,5] are compared to the measured erosion rates. Neither equation was found to match the experimental results eq. 1 was 2 orders of magnitude too low and eq. 2 was 80-90% too high. This is probably because the theoretical equations do not account for decreased heat transfer at the base of the flow.

Thermal erosion is a hypothesized mechanism enabling lava flows to enlarge their channels. On Earth, thermal erosion has been observed in carbonatite flows [6], documented in basaltic lava tubes [7] and suggested to occur during active basalt flow emplacement. Thermal erosion has been invoked for the formation of some sinuous rilles on the Moon [4] Mars [8,9] and Venus [10]. The great length of these channels suggest formation by a low viscosity lava, flowing so rapidly that it was turbulent [11].
Thermal erosion is controlled by the heat transfer rate into the ground. One-dimensional melting-rate equations were derived based on the ratio of energy available in the flow versus the energy needed to melt the ground. Gregg and Greeley[5] examined thermal erosion of turbulent lavas on venus and applied:

$$M = \frac{\dfrac{\kappa g\,(Tl - Ta)}{\sqrt{\pi\, Dg\, t}}}{\rho g\,[\,Cg\,(Tm - Ta) + Lg]} \qquad (1)$$

in which M = melt rate, κ = conductivity, D = diffusivity, T_l = lava temperature, T_a = ambient ground temperature, t = time, ρ = density, c = heat capacity, T_m = solidus temperature of the ground, L = latent heat. The suffix g refers to the substrate and l to the lava

Hulme adapted the equation below for lunar sinuous rilles from empirical relations in turbulent pipe flow[4,12]. Huppert and Sparks also used this equation to derive theoretical melting rates for the base of terrestrial komatiites [1].

$$M = \frac{h\,(T_l - T_m)}{\rho_g[C_g\,(T_m - T_a) + L_g]} \qquad (2)$$

in which h is a heat transfer coefficient:

$$h = 0.02\,\frac{\kappa_l}{H}\left(\frac{\nu}{D_l}\right)^{0.4} Re^{0.8} \qquad (3)$$

in which, ν = kinematic viscosity, H = flow height and Re is the Reynolds number. The Reynolds number is a dimensionless ratio between the inertial and viscous forces acting on the flow. When Re>2000 a lava flow is turbulent. Our experiments use Polyethylene Glycol (PEG) to model low viscosity lava flows, in order to investigate the factors controlling thermal erosion under laminar and turbulent conditions. The theoretical melting rates can also be tested against the experimental results.
The model lavas were extruded onto rectangular channels 3 cm deep, 6 cm wide and 170 cm long in a base of solid PEG. The slope temperature and viscosity of the fluid were varied to produce flows with Reynolds numbers ranging from 30 to 40,000. The depth of each eroded channel and run time were measured to produce a one-dimensional melting rate. Calculated melting rates were made using the properties of PEG in eq. 1 and 2 and compared to the experimental measurements.
Results: The measured erosion rates in the experiments were 2-4 orders of magnitude greater than eq. 1 predicted, but 81-91% smaller than the melt rates from eq. 2 (fig 1), suggesting that equation 2 is more accurate but that some process is as yet unaccounted. The channel geometry may have been a factor as eq. 2 was derived for circular pipe flow. However, adjusting the characteristic length only yielded a 5% change, not enough to account for the full melt discrepancy.
Discussion: Computer models of thermal erosion by Bussey et al. (1995) have also derived erosion rates that are considerably lower than would be calculated using eq. 2 [13].They suggest that this is due to both temperature losses into the substrate and the presence of a sub-laminar layer at the base of the flow [8]. Heat is transferred across the layer into the substrate by the less efficient method of conduction, hence insulating the ground (see figure 2). Our experiments support this finding. A better approximation of eq. 2. is being developed to incorporate the temperature drop across the sub-laminar layer. The consequences of these results is that the current hypothesized erosion rates of sinuous rilles

are at least 5 times too high. Hulme predicted emplacement of Hadley Rille, with a depth of 50m, would take 1 year based on an erosion rate of 1.6×10^{-6} m/s [1]. This study indicates formation by erosion would take at least 5 years. Formation of other sinuous rilles have been predicted to take 110-350 days [14]. This becomes at least 1.5-5 years. Thus, thermal erosion is a less efficient process than previously considered.

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Figure 1. Graph of Experimental Erosion Rates Versus Predicted Erosion Rates Based on Theoretical Equations

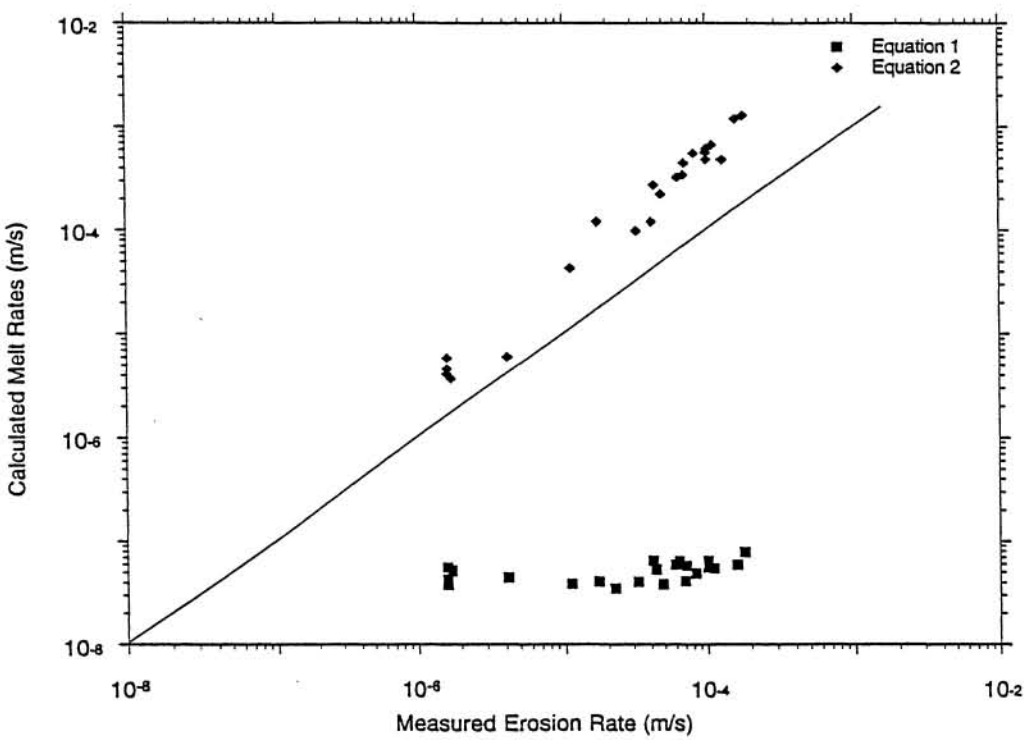

Figure 2. a) Thermal structure assumed by eq.2. b) Thermal structure postulated for experiments.