ANALYTICAL MODELING OF THERMAL EROSION BY LOW-VISCOSITY LAVA FLOWS AND IMPLICATIONS FOR PLANETOLOGY;

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The discovery of long, sinuous channels on Venus [1] has renewed the interest in thermal erosion by lava flows. Previous studies suggested that thermal erosion could have produced some lunar sinuous rilles [2] and some channels on Mars [3] and Venus [4,5,6]. However, these models did not evaluate the full range of thermal, rheological, and environmental parameters involved in thermal erosion. Hence, a new analytical model to evaluate thermal erosion potential on the terrestrial planets is required which takes into account all relevant parameters. Figure 1 shows a preliminary model for one-dimensional thermal erosion applied to turbulently-flowing, submarine Archean komatiite flows in Western Australia [7,8]. This model separates a lava flow into surface crust and thermally-mixed inner core [9], and yields estimates of the heat available for thermal erosion by calculating total heat flux (energy per time·area) subtracting heat losses due to radiation, seawater convection, crust formation, thermal convection of the turbulent core, latent heat of crystallization, and viscous dissipation. Requirements for constraining these models and adaptations for applying these models to other planets are discussed.

Thermal erosion potential is dependent on the eruption temperature of the lava, the thermal and rheological properties of the lava and substrate, and the environment in which eruption occurs. Some of the thermal and rheological properties have been measured in the field for terrestrial basalt and carbonatite flows [10,11], but for other lavas (e.g. komatiites, lunar basalts) these properties were determined from laboratory and experimental studies or extrapolated from those values obtained for basalt [8,12-18], and hence are uncertain. Application of a useful analytical model requires good input parameters, and reevaluation of existing values may be in order. Likewise, a good thermal erosion model needs to be calibrated by predicting quantities of erosion determined from field evidence. Unfortunately, good evidence of thermal erosion is not observed in modern basalt flows, and field evidence for thermal erosion by komatiites in Western Australia is equivocal [19]. For example, some of the features observed at or near komatiite/substrate contacts in the field (truncation of underlying stratigraphy, channel-like embayments, presence of interspinifex ore, entrained and partially melted substrate fragments, and geochemical anomalies) offer a good but far from unequivocal case for thermal erosion. These constraints need to be addressed as the development of a new thermal erosion model proceeds. Application of such a model can provide a better understanding of lava flow dynamics on other planets.

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Figure 1. Schematic diagram of analytical model developed in this study.

$$\boxed{\text{Steady-state Melting Rate} = \frac{H}{\rho_g\left[c_g(T_m - T_a) + L_g\right]}}$$

$$H = Q - F_r - F_{cv} - F_{cg} - F_{cc} - F_{xc} - F_{vd}$$ **Heat transfer rate to ground**

$$Q = \rho_l c_l T v (1-f)$$ **Heat flux of flow**

$$F_r = \varepsilon\sigma\left\{(1-f)(T^4 - T_a^4) + f(T_{sc}^4 - T_a^4)\right\}$$ **Radiative heat loss from top surface**

$$F_{cv} = \rho_w c_w \gamma\left(\frac{\alpha_w g D_w^2}{\nu_w}\right)^{1/3}\left\{(1-f)(T - T_a)^{4/3} + f(T_{sc} - T_a)^{4/3}\right\}$$ **Convective heat loss by seawater from top surface**

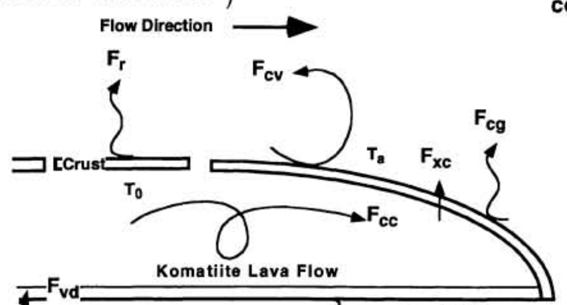
$$F_{cg} = \rho_l c_l T \frac{x}{t} f$$ **Conductive heat loss through surface crust**

$$F_{cc} = \lim_{T \to \theta_{bl}}\left[\rho_l c_l \gamma\left(\frac{\alpha_l g D_l^2}{\nu_l}\right)^{1/3} T^{4/3}\right]$$ **Turbulent flow - thermal convection of inner core**

$$F_{xc} = \rho_l\left[c_l(T - T_m) + L_l\right]\frac{x}{t} f$$ **Conductive heat loss of latent heat of crystallization**

$$F_{vd} = \frac{k_l}{h}\left(T - T_a + \frac{\mu_l v^2}{2k_l}\right)$$ **Heat loss by viscous dissipation**

$$\mu_l = \exp(34.551 - 0.0226T)$$ **Viscosity changes with temperature and crystal content**



$$h \approx 10\,\frac{\mu_l}{\rho_l}\sqrt{\frac{\rho_l}{\tau}}$$ **Thickness of Laminar sub-layer**

$$F_{cd} = \frac{k_g(T - T_m)}{\sqrt{\pi D_g t}}$$ **Conductive heat loss into flow bed**

Table 1. Thermal and rheological parameters for analytical model of Figure 1.
Subscripts: l - lava; g - ground; w - seawater; m - melting; a - ambient; sc - surface crust; bl - boundary layer.

Symbol	Meaning	Symbol	Meaning
H	Heat transfer rate to ground	ρ	density
c	specific heat at constant pressure	T	temperature
L	heat of fusion	v	flow velocity
f	fraction of surface covered by crust	ε	emissivity
σ	Stefan-Boltzmann constant	γ	convection parameter
α	coefficient of thermal expansion	g	gravity
D	thermal diffusivity	ν	kinematic viscosity
x/t	crustal growth rate	θ_{bl}	mechanical solidus of lava
μ	dynamic viscosity	k	thermal conductivity
h	thickness of laminar sub-layer	σ_w	shear stress