

THERMAL PROCESSES IN LAVA FLOWS; J.A. Crisp and S.M. Baloga, Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109

**Introduction.** Different viewpoints have been asserted in the literature concerning the importance of various processes that can affect the thermal budget of lava flows during emplacement. Several models are based on the assumption that radiative losses are the dominant consideration [1,2,3]. Radiative losses were considered to be the governing factor in changing the bulk rheology of the flow and, consequently, in determining the final dimensions. Although these models dismissed the importance of conductive losses to the underlying flowbed, viscous dissipation, atmospheric convection, and thermal effects associated with phase changes (vesiculation and crystallization), others have suggested that they could be important under certain conditions [4,5,6,7].

Field observations of active flows and recent theoretical studies [8,9] take account of the formation of a cooler plastic or solid crust that shields the interior of the flow. For most basaltic flows, the average area fraction,  $f$ , of the core of the flow that is exposed and radiating at eruptive temperatures is less than  $10^{-1}$ . Current best estimates show that  $10^{-2}$  to  $10^{-3}$  is more typical. For more silicic lavas, the area fraction may be even smaller.

The formation of a crust is important to the overall heat budget of a lava flow because the shielding of the core from extreme radiative losses brings the previously neglected thermal processes back into consideration. In this abstract, we estimate the contributions of various processes to the thermal budgets of lava flows. The effect of each thermal process was estimated separately from the other, sometimes competing, processes. Table 1 shows the contribution (positive or negative) to the budget of some actual lava flows. Rather than show the absolute losses or gains during emplacement in Joules, a more convenient measure is the number of degrees that would be gained or lost by the entire flow. Depending on conditions, a temperature change of just  $10^\circ$  can have a strong influence on the rheology [10].

**Thermal Losses.** Two types of radiative losses are considered in the tabulation below. One is the loss from the incandescent interior and another is the loss from the cooler skin, rubble, and debris. The influence of this thermal loss mechanism is sensitive to the parameter  $f$ , the average fraction of exposed core during emplacement. The table shows values associated with minimum and maximum (and best) estimates of  $f$  [8]. We also show the radiative loss from the cooler crust. The thermal loss into the underlying flowbed was estimated by averaging the Fourier flux over the emplacement duration. Convective losses from the crust were calculated using the standard  $T^{5/4}$  dependence. The table shows that each of the processes could produce significant decreases in the bulk temperature of most of the flows. Not shown in Table 1 is the effect of cooling due to vesiculation during flow in the channel, which would be  $< 1^\circ$  for most Hawaiian flows, but could be as high as  $30^\circ$  for a gas-rich ( $\approx 1$  wt%  $H_2O$ ) eruption [11,12].

**Thermal Gains.** The processes of crystallization and viscous dissipation are thermal sources in the overall heat budget. For all but one of the flows in Table 1, the heat gained by viscous dissipation is rather small when averaged over the entire duration. The values in Table 1 are for viscous heating along the flowbed and do not include viscous shear along the sides of the channel. Although it may not impact the overall heat budget of most flows, viscous heating could be important for the maintenance of fluidity during late stages of emplacement for narrow-channel or tube-fed flows.

Thin-section study of the crystallization of the Mauna Loa 1984 flow indicates that about 15 volume% of the mobile core crystallized after travel

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downstream of 6-11 km. The extent of microlite crystallization could have been higher (by a factor of 2-3) in the more distal sluggish zones of the flow.

Table 1 shows the effect of latent heat on various flows, assuming that 55% total crystallinity is a maximum amount [13]. Latent heating can have a substantial effect on the temperature. Measurements of crystallization during emplacement are thus critical for understanding the heat budget of lava flows.

**Mars Applications.** We can calculate the ratio of radiative losses to the total energy of the eruption, as a function of  $f$ , initial eruption temperature, and emplacement duration [8]. Without knowledge of these parameters for Mars flows, at this point we can only conjecture that the importance of radiation and convection is similar to that for the terrestrial basalts in Table 1. We might also assume that the Martian flows have similar magnitudes of latent heating. The effect of viscous heating on the lava flow budget for Mars flows would be lower by a factor of 2.6 (surface gravity difference), for flows of similar length and flowbed slope. For the flows at Ascraeus Mons, Alba, and Olympus Mons described in [14], [15], [16], and [17], the estimated influence of viscous heating along the flowbed is less than that for the Mauna Loa 1984-1 flow.

**Conclusions.** Due to shielding of the core of a lava flow, several other thermal processes have an important effect on the total thermal budget. Viscous heating would only be important for long flows on steep slopes or perhaps tube-fed flows. Vesiculation would only have a significant impact for very gas-rich eruptions. Crystallization of microlites could be a major contributor to the heat budget of lava flows, but more studies are needed to study the importance of this in terrestrial flows. An understanding of how thermal dynamics influence the bulk dimensions and morphologies of lava flows will require a detailed analysis that combines the interactions and feedbacks between these processes.

TABLE 1. Degrees Cooling Or Heating of Bulk Lava Flow During Emplacement

Overall Δ Temp.	-----Radiation-----						Convection from crust	Conduction to ground	+++++	
	-----core-----			crust	Viscous Dissipation	Latent Heat				
	BEST									
	MIN	ESTIMATE	MAX							
PuuOO-1	-8		-60	-13	-4	-13	1	0-151		
PuuOO-2	-8		-59	-29	-14	-25	2	0-150		
PuuOO-3/2	-8		-59	-40	-19	-23	0	0-149		
PuuOO-3/5	-8		-67	-10	-3	-10	0	0-149		
PuuOO-4	-8	-11	-65	-30	-14	-26	2	0-146		
PuuOO-13/1	-8		-74	-31	-12	-28	1	0-161		
PuuOO-18/2	-8	-8	-69	-28	-12	-24	3	0-160		
PuuOO-18/3	-8		-84	-22	-8	-20	1	0-160		
Mauna Loa 1984-1	-34	-8	-66	-34	-16	-28	8	44+		
Mauna Loa 1984-1A	-56	-15	-61	-38	-18	-32	3	44+		
Etna 1981		-8	-58	-19	-8	-17	3	0-73		
Etna 1983 < May1		-9	-51	-33	-12	-25	1	0-73		

\*\*These flows are described further in [8]. Radiation and convection are estimated from the conductive crust model (Appendix in [8]), using parameters discussed in text of [8] and shown in Table 1 and Fig. 6 in [8]. Values used for Etna crystallinity at vent  $\approx$  30%, Puu Oo vent crystallinity from [18].

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