THERMAL CONSTRAINTS ON THE LENGTHS OF TUBE-FED LAVA FLOWS ON THE EARTH, MOON, MARS, AND VENUS. Laszlo Keszthelyi (Hawaii Institute of Geophysics and Planetology, University of Hawaii, 2525 Correa Rd., Honolulu, HI 96822)

One of the outstanding questions in planetary geology is why lava flows many hundreds of kilometers long appear common on the Moon, Mars, and Venus, but are relatively rare on the Earth. The general consensus is that effusion rates much higher than observed for historical terrestrial eruptions could produce these long lava flows [e.g., 1, 2, 3, 4]. Lava tubes provide an alternative scenario for the formation of very long lava flows. It is generally acknowledged that the insulation of lava tubes allows tube-fed flows to be much longer than channel-fed or simple flows [e.g., 5,6]. Tube-fed flows are very common on the Earth and have been reported on the Moon and Mars [e.g., 7, 8, 9]. However, until recently there has been no published attempt to quantify the thermal budget of lava tubes [10, 11]. Without such a thermal budget, there is no way to compare the efficiency of lava tubes on the different planetary bodies.

I have examined the thermal budget of a mature lava tube that can be assumed to be in steady state with its surrounding. My thermal budget balances heat loss via (1) conduction, (2) convection of air in the rocks surrounding the tube, and (3) rain against (1) viscous dissipation, (2) latent heat of crystallization, and (3) cooling of the lava [11]. Other processes, including heat lost from skylights and thermal erosion, have negligible effect. Using this thermal model, I am able to reproduce the observed cooling inside active Kilauea lava tubes [10, 11, 12].

I now apply this thermal model to investigate hypothetical lava tubes on the Earth, Moon, Mars, and Venus. The slope is taken to be 0.1%, typical for flood lavas. The temperature, pressure, and compositional effects on the atmospheric properties, as well as changes in gravity and ambient temperature, are taken into account . Also, the viscosities of the lunar and the terrestrial flood basalt lavas have been adjusted to match known compositional effects. The Venera lander data and parental magma compositions of the SNC meteorites suggest that the viscosities of venusian and martian lavas were not too dissimilar to Hawaiian tholeiites [13, 14]. Also, all the dimensions of the model tube are scaled to the tube diameter. Finally, based on observations on Kilauea, the tubes are assumed to carry only 20% of their full volumetric flow capacity.

Figure 1 shows the result of applying my thermal budget to these model tubes. Cooling rates as low as 0.1 °C/km are reached in all cases with effusion rates less than 100 m^3/s. Assuming that the lava in the tube can travel until it cools ~50 °C (~25% crystallization), Figure 2 shows the cooling limits on the lengths of tube-fed lava flows. Lava flows hundreds of kilometers long are possible in all cases with lava tubes smaller than 20 m in diameter. The differences in thermal efficiency in each case can almost completely be explained by changes in rainfall and the changes in atmospheric convection around the lava tube (see Table 1).

I conclude that even the longest lava flows observed in our solar system could have been emplaced by long-lived, low-moderate effusion rate eruptions, if they were tube-fed. Furthermore, the atmosphere plays a critical role in the thermal budget of tube-fed lava flows.

References:

[1] Wilson L. and Head J. W. (1981) *J. Geophys. Res.*, 86: 2971-3001. [2] Wilson L. and Head J. W. (1983) *Nature*, 302: 663-669. [3] Wilson L. and Head J. W. (1994) *Rev. Geophys.*, 32: 221-263. [4] Head J. W. and Wilson L. (1986) *J. Geophys. Res.*, 91: 9407-9446. [5] Malin M. (1980) *Geology*, 8: 306-308. [6] Pieri D. C. and Baloga S. M. (1986) *J. Volcanol. Geotherm. Res.*, 30: 29-45. [7] Greeley R. (1971) *The Moon*, 3: 289-314. [8] Greeley R. and Spudis P. D. (1981) *Rev. Geophys. Space Phys.*, 19: 13-41. [9] Coombs C. R. and Hawke B. R. (1991) *NASA Conference Publication 3166*, 1: 219-229. [10] Keszthelyi L. (1992) *Eos*, 73: 648. [11] Keszthelyi L. (1994) *Thesis*. California Institute of Technology. 269 pp. [12] Helz R. et al. (1991) *Eos*, 72: 557. [13] McGill G. E. et al. (1983) Venus. Univ. Arizona Press, Tucson, pp. 69-130. [14] Harvey R. P. and McSween H. Y. (1992) *Earth Planet. Sci. Lett.*, 111: 467-482.

Table 1: Breakdown of the thermal budgets of the model lava tubes: Values for 10 m diameter tube with 2 m thick roof. All cases use 0.1% slope; appropriate values for ambient temperature, gravity, and atmospheric properties; and assume the tube is carrying 20% of its capacity. The Hawaii case is the baseline with 300 cm/yr of rain and 100 Pa s lava viscosity. Continental flood basalt case has 100 cm/yr of rain and 300 Pa s lava. The Venus and Mars cases have no rain and 100 Pa s lava. The lunar case uses 10 Pa s for lava viscosity. Note the effect of rain in the Hawaii and convection in the rocks surrounding the tube in the Venus case.

	Terms in the Thermal Budget (kW/m)						
Setting	Conduction	rain	atmospheric convection	viscous dissipation	latent heat	lava cooling	cooling rate
Hawaii	8.1	28.	12.	0.32	30.	17.	0.5 °C/km
CFB	8.1	9.3	12.	0.11	19.	11.	0.9 °C/km
Venus	4.9	0.	49.	0.26	35.	19.	0.6 °C/km
Mars	8.5	0.	0.9	0.05	6.1	3.3	0.2 °C/km
Moon	8.5	0.	0.	0.10	5.4	3.0	0.05 °C/km

Figures 1 and 2: Calculated cooling rates and maximal flow lengths for tube-fed flows. See caption of Table 1 for details on each case. Note in Figure 1 that the lava tubes on the Moon and Mars are the most efficient because of the lack of substantial atmospheres. The terrestrial and venusian cases are quite similar because the lack of rain on Venus is offset by the enhanced atmospheric convection. In Figure 2, the effect of rheology is also visible. The lunar tube-fed flows are longer than the martian case because of the lower viscosity used for lunar lavas. Also, the CFB flows are the shortest because they are the most viscous (and are under a thick atmosphere and rain). However in all cases, lava flows over 500 km long are possible with moderate effusion rates and moderate tube diameters.