THERMAL CONTROLS ON TUBE-FED PLANETARY LAVA FLOW LENGTHS;
S.E.H. Sakimoto[1], *and S.M. Baloga*[2] [1]Department of Earth and Planetary Sciences, The Johns Hopkins University, Baltimore, MD 21218-2681. [2]Proxemy Research Inc., 20528 Farcroft Lane, Laytonsville, MD 20882.

Lava flow lengths often reach tens of kilometers on Earth, hundreds of kilometers on Mars, and thousands of kilometers on Venus. Since tube flow is the most thermally efficient method for transporting large volumes of lava over large distances, many long planetary flows have been postulated to be tube-fed. To date, however, little quantitative analysis has been directed toward tube-fed systems in planetary volcanism, even though tube flow is a significant contributor to the volcanic record on both Venus and Mars. This study investigates tube flow thermal processes and their control of planetary lava flow lengths. Radiative, convective and conductive cooling losses under ambient conditions for Earth, Venus, and Mars are considered during the formative, pre-tube phase of flow emplacement, where thermal and mechanical crustal boundary layers develop. This boundary layer growth governs the transition into tube flow, where only conductive losses are important. We investigate the effects of the pre-tube versus tube phase thermal losses on the non-Newtonian coupled fluid and thermal dynamics in order to explain the persistence of tube flows and the enormous flow lengths that often occur in planetary settings.

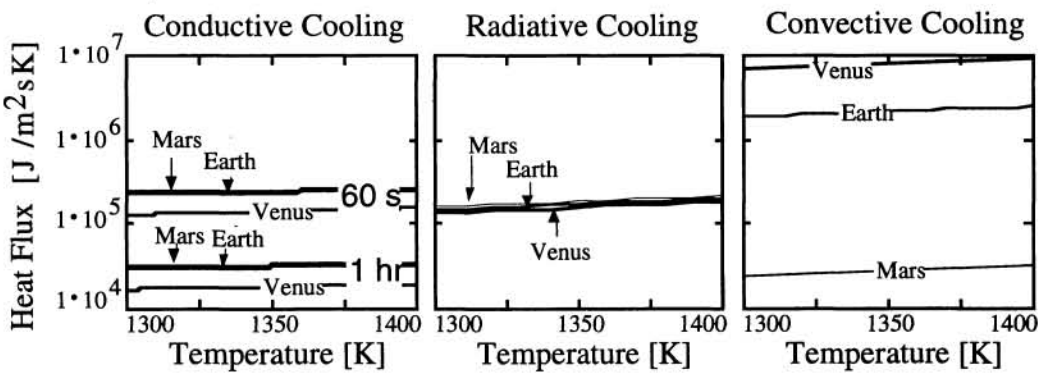
During the early pre-tube phase of flow emplacement, convective and radiative losses from the flow surface are larger than the conductive losses after the tube has formed and are thus an important factor in controlling the flow length. The atmospheric and thermal conditions for the surfaces of Venus, Earth, and Mars (650-750 K and 4-10 MPa on Venus [1]; 140-300 K and 560 Pa on Mars [2]) result in different cooling rates for the pre-tube flow regime that are a function of the thermal cooling efficiency of the atmosphere as well as a function of planetary surface temperature. This study will consider the pre-tube phase thermal losses and conductive losses from the tube and input them as initial and boundary conditions to a basic tube flow model and compare the results for Earth, Venus and Mars ambient conditions.

Venus lava channels (canali) up to 6800 kilometers long were discovered during the Magellan mission to Venus [3,4]. Analysis of the channel flow physics [5] suggests that venusian lavas rapidly form crusts, and that the canali were essentially tube-fed. On Mars, tube-fed flows two orders of magnitude larger than common terrestrial analogs were identified almost two decades ago. Enormous tube-fed flows are readily apparent in Viking images of the northwestern and southeastern flanks of Alba Patera [6] and in the plains of the Elysium province [7]. These flows are typically 5-10 km in width, several tens of meters in thickness, and may extend as discernible units for several hundred km. In many cases, they are distinguished from neighboring lava flows by a central construction ridge, often with evidence of roof collapse. At Alba Patera and in the Elysium plains, large scale tube-fed flows form a significant part of the volcanic record. Smaller scale tube-fed flows are more difficult to discern, but such morphologies are evident on the Tharsis shields and in the older volcanic features such as Tyrrhena Patera.

It has long been thought [8] that lava tubes provide efficient conduits for magma transport and result in significantly longer flow lengths than other types of emplacement modes with comparable eruption rates. Traditionally, the qualitative explanation given for this behavior is that heat, and perhaps some volatiles, are retained by tube fed systems causing the lava to remain fluid for significantly longer periods of time. Recent models of non-Newtonian tube flow with viscous heating indicate that, with only conductive cooling and without convective and radiative cooling, lava in a tube is capable of flowing extremely long distances with very little drop in temperature [9,10] for even low eruption rates. To date, little quantitative analysis has been devoted to tube fed systems in planetary volcanism, even though tube flow is a significant contributor to the volcanic record on both Venus and Mars. Additionally, the mechanics of tube-fed lava flows could drastically alter our notions of the eruption rates and durations necessary to produce large scale flows. Recent work on terrestrial tube flow [11] suggests that large variations in eruption (and thus flow) rates discourage tube roof formation and preservation. Once a tube is established, minor flow variations are accommodated in flow level fluctuations, and thermal erosion of the substrate is common [11].

The longest lava flows ought to be produced when the bulk of the flow's travel is via lava tube. Rapid tube formation is favored in conditions that enable rapid initial convective or radiative cooling, so that the crust and tube form quickly and the flow may use the bulk of its heat budget on relatively slow conductive heat transfer. Venus is proposed to have a convectively efficient atmosphere for lava flow cooling [3], and thus tube flows ought to be more common there than on Earth. In order to get a first-order idea of the initial cooling rates and mechanisms for lava flow on the Venus, Earth and Mars, we can compare initial thermal loss rates from convective, conductive, and radiative cooling for a flow before crust formation, shown in Figure 1 for each planet's ambient environment. We can see that radiative cooling dominates on Mars, and convective cooling on Earth and Venus for the early thermal history. These cooling rate estimates are only valid prior to the growth of an insulating crust. Therefore, knowledge of the growth of the thermal and mechanical boundary layers is needed to determine the subsequent cooling rates. For the boundary layer model, the flow initially has the largest thermal and velocity gradients in the z direction, and is thus assumed to be two-dimensional. The evolution of the thermal and velocity fields of the flow is calculated, with thermal losses to the atmosphere by convection and radiation, and to the ground by conduction. The thermal and velocity fields are coupled by empirically determined rheologies that are a function of both temperature and strain rate[8,9]. This allows a more accurate assessment of the effects of the boundary layer on the heat and momentum transfer within the flow. The rheology is essentially Newtonian for temperatures above the liquidus, non-Newtonian between the liquidus and 55% crystallinity, and rigid below 55% crystallinity. The effects of the growing boundary layer on the heat loss rates are evaluated for ambient conditions on Venus, Mars, and Earth, and the results used to determine initial and entry conditions for the tube flow model. The planetary surface temperature governs the conductive losses from the tube. Results and their implications for planetary flow lengths are compared for Earth, Venus and Mars.

Figure 1. Thermal loss rates from a lava flow surface prior to crust formation for ambient conditions on Earth, Venus and Mars.



References:

[1] Kieffer, H.H et al., in Mars, ed. by Keiffer et al., 1-33, U. of Arizona Press, 1992. [2] Seiff, A., in Venus, ed. by D.M. Hunten et al., 215-279, U. of Arizona Press, 1983. [3] Parker, T. J. and G. Komatsu, *Geol. Soc. Am. Abstr. Programs,* **23**, A277, 1991 [4] Baker, V.R. et al., *J. Geophys. Res.*, **97**, 13421-13443, 1992. [5] Gregg, T. K. P. and R. Greeley, *J. Geophys. Res.*, **98**, 10873-10882, 1993. [6] Cattermole, P., Proc. Lunar Sci. Conf. 17th, *J. Geophys. Res.*, **92**, E553-E560, 1987. [7] Carr, M. H. et al., *J. Geophys. Res.*, **82**, 3985-4015, 1977. [8] Greeley , R., Proc. Lunar Sci. Conf. 7th, 2747-2759, 1976. [9] Sakimoto, S. E. H. and M. T. Zuber, in preparation. [10] Sakimoto, S. E. H. and M. T. Zuber, *EOS Trans. AGU,* **75**, 728, 1994. [11] Peterson, D. W., et al., *Bull. Volcanol.*, **56**, 343-360, 1994.