CHANNELIZED LAVA FLOWS WITH DENSITY CHANGES DURING EMPLACEMENT. S.M. Baloga[1], L.S. Glaze[1] and J.A. Crisp[2], [1]Proxemy Research (20528 Farcroft Lane, Laytonsville, MD 20882, steve@proxemy.com), [2]California Institute of Technology Jet Propulsion Laboratory (4800 Oak Grove Dr., Pasadena, CA).

Introduction: Three processes that are important for understanding the emplacement of large basaltic lava flows are 1) changes in viscosity or other specifications of internal resistance to flow, 2) the formation of channels, levees, or stationary margins that divide the flow into active and inactive components, and 3) the loss of volatiles that causes a change in the density of the lava. The loss of lava volume from an active flow, with concurrent changes in flow resistance, was treated in [1]. Applications to planetary flows appears in [2]. Density changes with different flow rates and rheologic changes are treated in [3]. Here we present a model that includes all three processes.

Even with the recently released MOLA data, there remains very little evidence of significant thickening along the path of Mars flows. The fact that these planetary flows do not appear to thicken significantly is puzzling. It has often been conjectured that planetary eruptions were more deeply seated and more persistent than their terrestrial analogs. To erupt flows from deeper levels, correspondingly more volatiles are required. To generate flows that persist for longer durations, again more volatiles are needed.

The loss of volatiles from a moving lava flow can have a significant impact on the dynamics of the flow. As a lava degasses, its density will increase, effectively counteracting the thickening tendency of a viscosity increase [3]. Terrestrial experience suggests that the density of lava in large Hawaiian basalt flows can change over the course of an eruption and change with distance from the vent [4-6]. These and other studies [7-8] suggest that differences between erupted and emplaced volumes of lava are quite common in terrestrial basaltic and basaltic andesite flows.

Channelized lava flows are common on both Earth and Mars. When levee building occurs concurrently with significant degassing, it inhibits the thickening of a lava flow with distance, as shown by the results below. These effects thus mask increases in viscosity with distance and may explain the tendency of Mars flows to exhibit only modest thickness increases with distance.

The Governing Equations: To describe the thickness of a lava flow that has a changing viscosity, loses mass to stationary margins or levees, and loses volatiles, we must address both the conservation of mass and volume. For mass conservation [See Table for definitions of symbols], we have obtained:

$$\frac{\partial}{\partial t}(\rho h)+\frac{\partial}{\partial x}(\rho q)=-\lambda_m h_o \Phi_m \rho$$

where Φ_m is a dimensionless function that describes how mass is lost to the stationary part of the flow and λ_m is a conventional rate constant. This equation assumes that the loss of volatiles that causes a density change has a negligible effect on mass conservation. Volume conservation is given by

$$\frac{\partial}{\partial t}(h)+\frac{\partial}{\partial x}(q)=-h_o\left(\lambda_\rho \Phi_\rho+\lambda_m \Phi_m\right)$$

where Φ_ρ is a dimensionless function that describes how volatiles are lost and λ_ρ is a rate constant. It should be noted that the volume loss that causes a density change is not negligible. Combining Equations (1) and (2) results in a partial differential equation for density that can be solved simultaneously with (2) to obtain solutions for the density profile along the flow and the longitudinal thickness profile.

Solutions for the thickness and density profiles using a Newtonian flow rate for q, the assumption of steady state, and a constant rate of volatile and mass loss (i.e., $\Phi_m = \Phi_\rho = 1$) are,

$$\rho(x) = \rho_o \left(1 - \frac{L_m + L_\rho}{L_m L_\rho} x\right)^{-\left(1 - \frac{L_\rho}{L_m}\right)^{-1}}$$

and

$$h(x) = h_o \left(\frac{\nu(x)}{\nu_o}\right)^{1/3} \left(1 - \frac{L_m + L_\rho}{L_m L_\rho} x\right)^{1/3}$$

where length scales (e.g., $L_\rho = q_o/\lambda_\rho h_o$) for mass and volatile losses are used for convenience and zero subscripts refer to the vent location. The Figure shows the lava thickness profile (using (4)) with a relative exponential viscosity increase of 1000 in 25 km. Three values of density change with distance were used and the flow rate was set to produce a thickness of 25 m at the vent. The upper curve has no density change with distance, nor are stationary margins formed by depletion from the active component. The flow thickens to approximately 200 m at the front. The two lower curves show the effect of a loss of volatiles comparable to that found in the Mauna Loa 1984 1 flow (L_ρ =50 km). Two different rates of margin formation are used in the lower curves. In the lowest curve with L_m=50 km, the cumulative losses to the margins along the length of the flow cause cessation of flow advance. In this case, the maximum thickness of the flow is less than 4 times the thickness at the vent. It is noteworthy that the processes of volatile loss and margin formation almost completely mask the 1000-fold increase in viscosity. The intermediate case, L_m=60 km, would continue to advance and also has a flow thickness of slightly more than 100 m at 25km.

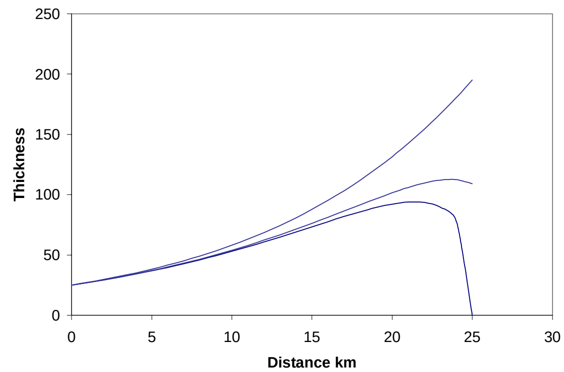

Figure: Flow thickness for exponential viscosity increase for different mass and volatile losses.

Table: Notation

	Definition
ρ	Density of lava
h	Flow thickness
L_ρ	Length scale for volatile loss
L_m	Length scale for mass loss
q	Volume flow rate/width
t	Time
x	Distance
λ_m	Mass loss rate constant
λ_ρ	Volatile loss rate constant
Φ_m	Mass loss function
Φ_ρ	Volatile loss function

References: [1] Baloga, S, LS Glaze, JA Crisp, and SA Stockman, 1998, JGR 103, 5133-5142; [2] Glaze, LS and SM Baloga, 1998, JGR 103, 13,659-13,666; [3] SM Baloga, LS Glaze, MN Peitersen, and JA Crisp, 2001, JGR, 106, 13,395-13,405. [4] Moore, HJ, 1982, USGS Open File Report 82-314, 17 pp. [5] 1987, USGS PP 1350, 1569-1588. [6] Lipman, PW and NG Banks, 1987, USGS PP 1350, 1527-1567. [7] Einarsson, T, 1949, Soc Sci Islandica, Reykjavik. [8] Cashman, K, MT Mangan and S Newman, 1994, JVGR, 61, 45-68.