A MODEL FOR VARIABLE LEVEE FORMATION RATES IN AN ACTIVE LAVA FLOW. L.S. Glaze[1], S.M. Baloga[1], P. Mouginis-Mark[2], and J. Crisp[3], [1]Proxemy Research (14300 Gallant Fox Lane, Suite 225, Bowie, MD 20715; lori@proxemy.com), [2]University of Hawaii (1680 East-West Road, POST 504, Honolulu, HI 96822). [3]Jet Propulsion Laboratory, California Institute of Technology (4800 Oak Grove Drive, Pasadena, CA 91109).

Introduction: Channelized lava flows on Mars and the Earth often feature levees and collateral margins that change in volume along the path of the flow. Consistent with field observations of terrestrial flows, this suggests that the rate of levee formation varies with distance and other factors. Previous models [1,2] have assumed a constant rate of levee growth, specified by a single parameter, λ. The rate of levee formation for lava flows is a good indicator of the mass eruption rate and rheology of the flow. Insight into levee formation will help us better understand whether or not the effusion rate was constant during an eruption, and once local topography is considered, allows us to look at cooling and/or rheology changes downslope.

Here we present a more realistic extension of the levee formation model that treats the rate of levee growth as a function of distance along the flow path. We show how this model can be used with a terrestrial flow and a long lava flow on Mars. The key statement of the new formulation is the rate of transfer from the active component to the levees (or other passive components) through an element dx along the path of the flow. This volumetric transfer is expressed as,

$$dV_{levee}(x,t) = \lambda(x) w_o h_o \big(t(x_f) - t(x)\big) dx \quad \textbf{(1)}$$

where $t(x_f)$ is the total time of emplacement, and t(x) is the time it takes the flow front to travel the distance, x. The only assumption appearing in (1) is that the time rate of loss, λ, is only a function of x. The right hand side of (1) indicates that the levee can only begin growing when the flow front reaches x, and will continue to grow until the flow stops at x_f. The primary constraints on the model are the flow thickness and width as functions of distance along the flow.

There is presently no detailed quantitative information in the literature on how the rate of levee formation changes along the flow path. However, $\lambda(x)$ can be determined by knowing how the final levee volume changes with distance, the total volume of the lava flow (active plus passive), and the total duration of emplacement. We are primarily interested in determining the absolute values of $\lambda(x)$ and the way this function changes for flows in different settings on Mars and the Earth. Specifically, we will assess whether these functions are the same or different on Mars and the Earth and whether they are sensitive to factors such as the size of the flow, the slope of the underlying flowbed and so forth.

Our model does not presently predict the shape of the levee. It requires only knowledge of the total volume in the levee as a function of distance. However, one natural and instructive assumption is that the levees are symmetric on both sides of the flow, are wedge-shaped with height h(x) at the channel, and extend to L_w on each side (Figure 1). Thus, knowing $L_w(x)$, we can then determine the planform shape of the levees for varying forms of $\lambda(x)$ and h(x). Because the formulation predicts only the total volume in the levees, any levee shape can be used. We use the wedge-shaped model for illustrative purposes here.

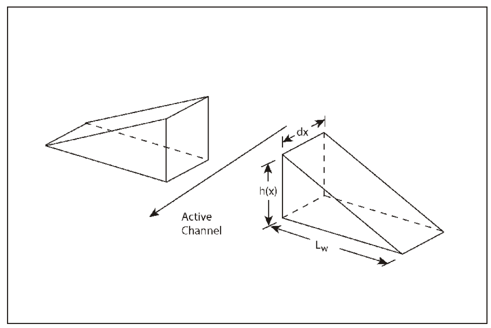

Figure 1: Hypothetical Levee Shape

Mauna Loa 1984 1A Flow: We have compiled detailed information on the widths of the active channel and levees for the 1984 1A lava flow from Mauna Loa, Hawaii. The raw flow width data along the flow path show significant variability. However, the cumulative volumes contained in the active channel, and in the levees as a function of distance along the flow, are both well described by second-order polynomials (Figure 2).

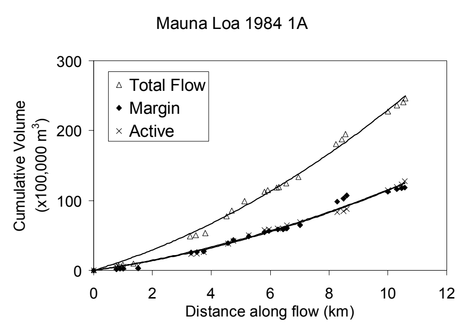

Figure 2: Cumulative volumes.

To compare with theory, we use the cumulative volume of material in the margins to estimate the planform shape of the levees. From the fitted curves, we can determine the volume of material contained in the levees at each point, x, along the flow, $V_m(x)$. Field data [3] for the Mauna Loa 1984 1 and 1A flows indicate that a wedge-shaped levee is a reasonable approximation.

Levee width, $L_w(x)$, is a function of $dV_{levee}(x)$ and h(x). The 1A flow thickens approximately linearly from about 5 m near the breakout source of the flow to about 15 m near the flow front.

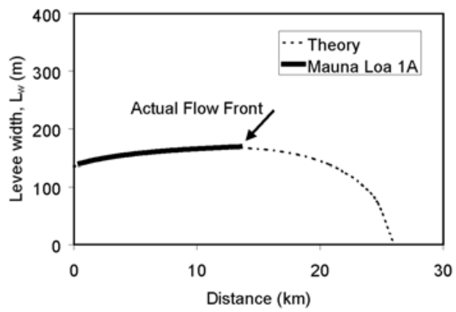

Figure 3

Figure 3 shows the levee width, L_w, for the Mauna Loa 1984 1A lava flow (based on the cumulative volumes in Figure 2). Also shown are theoretical levee widths for a flow with linearly increasing rate of transfer to the levees.

To match the levee widths at Mauna Loa in Figure 3, we have used a length scale for the rate of levee formation of 26.7 km. This length scale can be interpreted as the hypothetical length of the lava flow if it were to cease advancing due solely to the loss of flow rate (i.e., there is no lava left in the active channel after the last transfer to the levees in the final time step). In actual flows, other factors come into play, such as the formation of crust with mechanical strength, the deposition of rubbly layers at the front, shallowing of the slope at the terminus, upstream breakouts, and similar factors. A second length scale of 15 km allows some material to go into margin building in the very first step. Both length scales affect the initial value of the rate loss variable, λ_o.

The model can readily accommodate any type of flow thickness behavior with distance, but at this point assumes a constant channel width. We anticipate extension of the model to account for an increasing channel width, such as happens with the 1984 1A flow and many channelized planetary lava flows.

Although some refinements have yet to be made (e.g., incorporation of a spatially varying active channel width), we now have a means for characterizing and intercomparing the levee formation processes for different lava flows. Moreover, our formulation requires no presupposed functional form of the rheology of the lava, but it does require detailed spatial knowledge of the lava volume in the final margins and stagnant zones. This provides us with a new tool for investigating differences and similarities in emplacement of large lava flows on the Earth and Mars and different volcanoes and settings on Mars.

For example, the volumetric rate loss functions for the 1984 1A lava flow and a recently investigated channelized lava flow on the plains north of Pavonis Mons [2] are shown in Figure 4. Although the lengths, thicknesses, and underlying slopes differ by about an order of magnitude, and rheologic changes during emplacement were dramatically different [2, 4], the nature of the levee formation process was very similar.

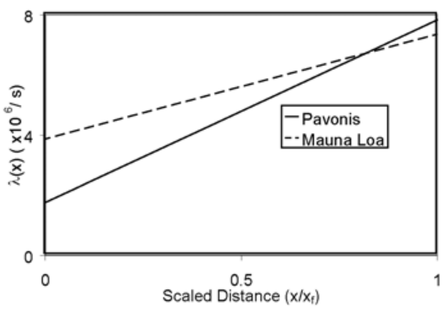

Figure 4

Because we can constrain the form of the rate loss function, $\lambda(x)$, we can also use flow dimensions to constrain the lava rheology. As stated by [1], the loss of material can result in a lava flow thickness profile that is "flatter" than one would expect when no levees are formed. This means that any increase in viscosity could be significantly "masked".

For the Pavonis lava flow referenced above, we have found that even when accounting for a density increase in the lava, and a constant loss of material to levees, the flow still shows an almost constant viscosity over many tens of km. This in turn suggests a balance between the levee formation process and the rate of cooling and crust formation during advance [2]. Accounting for the detailed nature of the levee building process for such large flows on Mars by using the new model will provide further insight about the viability of this style of emplacement that is apparently prevalent on Mars.

References: [1] Baloga, SM, et al. (1998) *JGR, 103,* 5133-5142. [2] Baloga, SM et al. (2003) *JGR doi:10.1029/2002JE001981*. [3] Lipman, PW and NG Banks (1987) *USGS PP 1350,* 1527-1567. [4] Crisp, J et al. (1994) *JGR, 99,* 7177-7198.