REGIONAL SIMILARITY OF LEVEED LAVA FLOWS ON THE MARS PLAINS. S. M. Baloga[1], L. S. Glaze[2]; [1]Proxemy Research (20528 Farcroft Lane, Laytonsville, MD 20882 steve@proxemy.com) [2]NASA Goddard Space Flight Center (Code 698, Greenbelt, MD 20771), Lori.S.Glaze@nasa.com)

Introduction: The dynamics of lava flow movement are controlled by the fluid interior. Crust, solids, and nondeformable material can only retard the advance or spreading of a lava flow. Figure 1 shows a typical large, channelized lava flow found on the Mars plains. It has been suggested in [1] that such large leveed flows on the Mars plains were emplaced by a balance between the formation and shedding of crust as the flow advances. For the prototypical flow north of Pavonis Mons (Fig. 1), such a balance leads to a flow morphology that approximately self-replicates at all locations along the flow path [2,3]. Moreover, most quantitative characteristics of emplacement (e.g., viscosity, volumetric flow rate) of the prototype flow at Pavonis Mons resembled those of large channelized lava flows on Earth. The exception was the relatively long, sustained supply of lava, on the order of a year as opposed to hours or days for terrestrial analogs.

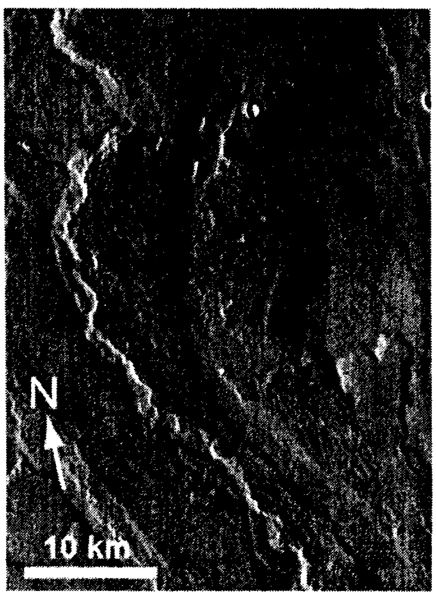

Fig 1. A LEVEED LAVA FLOW NORTH OF PAVONIS MONS.

Here we analyze and compare the quantitative emplacement characteristics of 5 additional large leveed lava flows north of Elysium Planitia, the plains north of Pavonis Mons, and near Arsia Mons. The issues investigated here are: 1) Are there significant regional differences in the viscosities, eruption durations, and volumetric flow rates of the large leveed lava flows? 2) Are the emplacement mechanisms reasonable extrapolations of terrestrial experience? 3) Can averaging dimensional data provide an efficient method for regional comparisons of emplacement conditions?

Approach: Figure 2 is a cartoon of the flow model in [3]. This model assumes steady-state upstream conditions in the proximal zone and time-dependent levee-building only in the distal zone [2,3]. The essential inputs to the model are the channel width (w_c), levee width (w_l), flow thickness (h_l), the length of the flow (L), and the underlying slope (θ). The outputs of the model are the thickness of the fluid interior (h_c), the thickness (h_{crust}) of the "crust" (interpreted as all nondeformable lava overriding the core), the time (T) required to form the crust (interpreted as the emplacement time), the average flow velocity, the viscosity (μ) of the molten core, and the volumetric flow rate (Q).

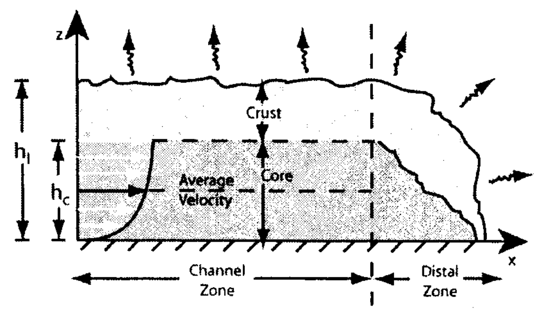

Fig 2. LEVEED FLOW CARTOON (FROM [3])

To continuously construct triangular shaped levees in the distal zone, the upstream core thickness must be

$$h_c = \left(\frac{1}{2} - \frac{1}{3\sqrt{3}}\right)^{-1} \left(\frac{1}{2} - \frac{w_l}{w_c}\right) h_l \qquad (1)$$

This criterion provides an immediate test of the validity of steady-state upstream flow conditions for actual flows. Core thickness cannot be negative, nor can it exceed the overall thickness of the flow. These requirements give the validity condition

$$0.19 w_c \le w_l \le 0.5 w_c \qquad (2)$$

When either of these limits is grossly violated for a particular flow, nonsteady upstream conditions must have prevailed to produce the observed deposit dimensions. Too much volume in the levee (according to eq 2) indicates a time-dependent transient upstream condition such as a major overspill, a breakout, or a channel surge due to either a significant upstream collapse or a spike in the effusion rate.

Once the core thickness is known, the time required to construct the crust can be determined by the empirical data analysis of [4] or other theoretical methods that account for exposures of the hot core due to cracking of the flow surface, stretching, shearing at the channel margins, etc. Using results from [4] for crustal thickening by conduction alone, the flow viscosity is estimated by

$$\mu = \frac{\rho g \sin\theta h_c^2}{3u} = \frac{\rho g \sin\theta h_c^2}{12L\kappa}\left(\frac{h_{crust}}{\lambda}\right)^2 \qquad (3)$$

where κ and λ are empirical constants given in [4].

Applications: Five additional long leveed flows with continuous channels over the length of the flow were identified in three, low slope plains settings. All flows have been studied in previous investigations [2,3,5,6]. However, viscosity and flow rate estimates of past studies have been constrained only by 3 - 4 orders of magnitude or more.

The dimensions of the five flows all satisfy the validity requirement in (2). It is noteworthy that several dozen candidate channelized flows [7] were investigated on the steeper slopes of Ascraeus Mons. However, none satisfied the validity requirement shown in (2) suggesting that time-dependent effects induced by variable eruptions rates or topographic slope changes were significant factors.

Baloga and Glaze [2,3] applied the levee model to multiple topographic profiles from MOLA gridded data for the prototype PavE flow (Fig. 1), then performed a somewhat complex statistical analysis to extract the systematic behavior of the levee construction and flow dynamics. Here, the procedure is reversed, i.e., average dimensions were obtained first and the levee model was applied subsequently. The averages used in the computations for PavE and the five additional flows are shown in Table 1.

Table 1.

Flow	h m	w_c km	w_l km	L km	θ deg
PavE	47	14	12	173	0.05
PavW	32	23	9.0	307	0.09
Ely13	66	2.7	1.0	43	1.08
Ely12	54	3.7	1.2	107	1.08
Ely9	58	5.3	1.4	107	1.08
Arsia	22	1.9	0.8	75	0.7

Quantitative inferences for the emplacement conditions are shown in Table 2. Processes such as overspills, surficial cracking, internal flow circulations and shearing at the margins, and responses to small-scale topography typically change results by factors of 2 to 4. Therefore, the results for Table 2 have been rounded to reflect these uncertainties in the actual emplacement conditions. Results for PavE were taken from the profile-by-profile analyses in [2,3] for comparison.

Table 2.

Flow	T d	Q m3/s	μ Pa-s
PavE*	600	10^3	10^6
PavW	700	10^3	10^4
Ely13	2700	10^1	10^7
Ely12	1000	10^2	10^6
Ely9	300	10^3	10^6
Arsia	400	10^2	10^5

Although flow lengths and thicknesses vary by factors of 3-4, slopes a factor of 20, and widths a factor of 10, there are a number of off-setting factors in the dynamics of this model. This was noted in [3] as a potential explanation why channelized lava flows over many scales of dimensions appear similar on different planets and in dramatically different volcanologic settings.

The long channelized plains flows have somewhat remarkable similarities in the emplacement dynamics. The volumetric flow rates are at the high end range of terrestrial experience for large basaltic eruptions. The viscosities of the fluid cores similarly are comparable to terrestrial estimates of basalt flows in distal segments. The notable difference, however, is the duration of the supply, persisting for approximately 1-10 yrs as opposed to hours or days on terrestrial shields.

Conclusions: This levee flow model provides a means for isolating the viscosity and volumetric flow rate instead of the product of the two. Emplacement times can be significantly longer than results by other models because the dynamics are controlled only by the inner fluid core, which may be significantly less than the total flow thickness. It appears that cautiously applying the model to averaged dimensional data is an efficient method for establishing regional differences or similarities of emplacement conditions.

Large channelized flows on the Mars plains have relatively high volume flow rates and core viscosities by terrestrial standard, but the values are not at all unreasonable. The key difference in all regions investigate to date is the duration of supply. This has significant implications for subsurface conditions and processes that can sustain such conditions.

References:

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