COMPARING RUN-OUT EFFICIENCY OF FLUIDIZED EJECTA ON MARS WITH TERRESTRIAL AND MARTIAN MASS MOVEMENTS.

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Introduction: We broadly characterize the rheology of fluidized ejecta on Mars as it flows during its final stages of emplacement by using the concept of run-out efficiency. Run-out efficiency for ejecta can be obtained through an energy balance between the kinetic energy of the excavated ejecta, and the total work lost during its deposition. Such an efficiency is directly comparable to run-out efficiency (i.e., *L/H* analyzes where *L* is the run-out distance and *H* is onset height) of terrestrial and extraterrestrial mass movements. Determination of the *L/H* ratio is commonly used in terrestrial geology to broadly determine the type and rheology of mass movements [e.g., 1 and references therein].

Background: The use of *L/H* to characterize mass movements has derived naturally by balancing the initial potential energy of a mass movement with the total energy or work lost during its emplacement. Typically, initial potential energy of a landslide is given by *MgH*, where, in this form, *M* is the point mass of the flow, *H* is strictly speaking the height to the center of mass of the source area, and *g* is the acceleration due to gravity. As the flow progresses downslope, the work lost is defined as *MgRL* where *L* is the run-out length to the center of mass, and *R* is the resistance coefficient. In practice, *H* is measured from the top of the source area, and *L* to the distal edge of the deposit. There are multiple mechanical factors that influence *R* that are complicated to determine. However, the net run-out efficiency (i.e., 1/*R*) is given by:

$$1/R = L/H$$

The factors influencing run-out efficiency of different types of mass movements are broadly well-known [1, 2] and include water content, overall volume *V* of the movement, path geometry and surface boundary conditions. Comparison of this run-out efficiency between different flows generally provides a broad first order understanding of the type of mass movement that produce a given deposit, including whether or not the flow contained significant water.

Table 1: Symbols

Symbol	Definitions
$dM_e(x)$	Incremental ejecta mass excavated at x
M_e	Total mass of ejecta
x	Distance from crater center to point of ejecta excavation
V_e	Ejecta excavation velocity at x
R_c	Transient crater radius
R_b	Crater radius that defines ejecta mass in continuous ballistically emplaced ejecta
c	Empirically derived crater scaling parameter [3, 4]
e	Empirically derived crater scaling parameter

In order to compare fluidized ejecta with other mass movements, a similar analysis must be undertaken, whereby the kinetic energy injected into the flowing ejecta is balanced with the work lost by friction while flowing. The total kinetic energy of the ejecta is computed using gravity controlled crater scaling rules [2, 3, 4] as:

$$KE_e = \frac{1}{2}\int_0^{R_c} V_e(x)^2\, dMe(x) = \frac{1}{2}\int_0^{R_c}\left[c\sqrt{R_c g}\left(\frac{x}{R_c}\right)^{-1/\mu}\right]^2 \frac{3Me}{R_c^3}x^2\,dx$$

where the symbols are defined in Table 1. This integral is undefined for certain values of μ. We, therefore, introduce the radius R_b by tracing ballistic paths back into the transient crater from the edge of the continuous ejecta deposits seen on Mercury. We chose continuous ejecta deposits on Mercury as representative of the extent of the continuous ejecta blanket at Mars craters which have not flowed because of the similarity in *g* between these two planets, and the fact that the ejecta on Mercury possesses no evidence for flow. Remember that ejecta velocity, which is partly responsible for defining the edge of the continuous ejecta when no fluidizing agents are present, varies with local *g*. Thus, KE_e of the ejecta becomes

$$KE_e = \frac{3}{2}\frac{c^2 M_e R_c g}{(3-2/\mu)}\left[1-\left(\frac{R_b}{R_c}\right)^{3-2/\mu}\right]$$

The initial kinetic energy injected into the flowing ejecta, Ke_f will be somewhat less than KE_e because of some losses that occur prior to flow. These losses result either from sedimentation processes that occur once ballistic first strikes the target surfaces or atmospheric entrainment processes. The variable *e* parameterizes these losses so that $KE_f = e\, Ke_e$ and can be estimated from laboratory experiments [7, 8, 9, 10, 11].

Because the energy analysis treats the ejecta as a point mass, the work lost W_l as the ejecta flows is given by RM_egL in the same form as for landslides regardless of the geometric differences between these flows. In keeping with the *L/H* approach for mass movement, the variable *L* defines the radial distance that the ejecta flowed after being injected into a continuum flow. A reasonable estimate of *L* is given by the distance separating the edge of fluidized ejecta with that of continuous ballistic ejecta deposit. As for R_b, the extent of the continuous ejecta when no subsequent flow occurs is provided by Mercurian craters.

The resulting ejecta run-out efficiency 1/*R* (equivalent to *L/H* for planar debris flows) is thus given by

$$\frac{1}{R} = \frac{2}{3}\frac{(3-2/\mu)L}{c^2 e R_c}\left[1-\left(\frac{R_b}{R_c}\right)^{3-2/\mu}\right]^{-1}$$

Approach: Several measurements are required to compare the run-out efficiency of fluidized ejecta with that of landslides. These include run-out distance, rim-to-rim diameter, and volume of the ejecta flows. In the case of landslides, *H* is also needed. We obtain this data from several fresh craters in Lunae Planum - primarily a volcanic plain - and also for a few landslides in Coprates and Ganges Chasm. This data is obtained from the 1/128th degree digital topographic maps (DTM) of the Mars Orbiter Laser Altimeter (MOLA), and imagery data from the Mars Observing Camera (MOC) and Viking orbiters.

These images and DTM are used to identify the boundaries of the ejecta or landslide, the onset location of the landslides, and the crater center. Once the flows are outlined, a least squares best-fit ellipse is used to measure crater rim-to-rim diameter as well as flow run-out from either the crater center or the onset location of the landslide. The flow volumes are computed by determining a polynomial fit to the surface beyond the distal edges of the ejecta or landslide. This surface is then subtracted from the DTM within the boundaries of the ejecta or landslide. The resulting heights are then summed appropriately over the surface area of the deposit in question to determine its volume.

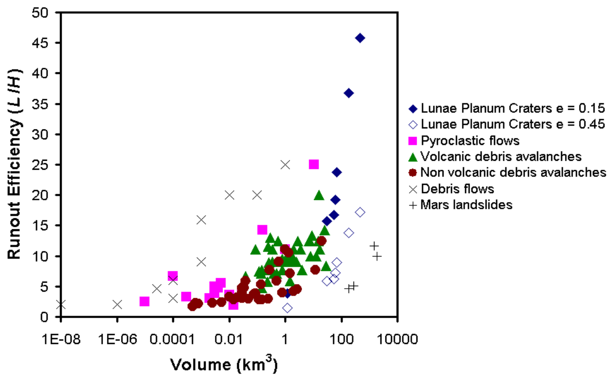

Figure 1. Run-out efficiency versus flow volume for Martian fluidized ejecta and landslides, and a few terrestrial mass movements. Terrestrial data from [1, 2].

Results and Discussion: Preliminary run-out efficiency results for Mars craters and landslides are shown in Figure 1. Also shown are terrestrial data for pyroclastic flows, volcanic debris avalanches, non-volcanic debris avalanches and debris flows. The debris flows generally possess a greater volatile content than the other flows shown.

Two sets of results are shown for the fluidized martian ejecta. The first set (closed blue diamonds) is for the case where 15% of the kinetic energy of the excavated ejecta is injected into its forward flow. This corresponds approximately to the amount of energy imparted to ejecta of a secondary crater formed by the impact of a single projectile within the primary ejecta curtain [7, 8, 9]. This energy probably represents the minimum amount of energy that would be injected into the flowing ejecta since generally ejecta falls as an amalgam of particles rather than as individual particles.

The second set assumes (open blue diamonds) the more realistic situation where primary ejecta strikes the target surface as such an amalgam or cluster of particles. Experiments indicate that while overall impact cratering efficiency (ratio of displaced mass to projectile mass) for such clustered impacts is reduced relative to a single impactor, the total kinetic energy of the ejecta is increased significantly [10, 11]. We assume in this study, therefore, that 40% of the kinetic energy of impacting primary ejecta is injected into the flowing ejecta.

Keeping these two cases in mind, it appears that Mars ejecta in Lunae Planum generally flows less efficiently than volatile-rich terrestrial mass movements. They are more comparable in behavior to the drier volcanic and non-volcanic rock avalanches. Such a result is consistent with analyzes of individual MOLA profiles along fluidized ejecta, which indicate that ejecta flows primarily along a basal layer much like Blackhawk on Earth, or some of the more massive landslides on Mars.

The run-out efficiency for some of the Mars landslides observed by [6] are confirmed here. The run-out efficiency of these landslides are low relative to the data presented in Fig. 1 even when their volumes are reduced by a factor of 4 to account for the multiple flows observed on them However, they do fall within a broader cloud of data for mass movements on Earth and elsewhere, indicating that gravity is not the primary cause for the differences in run-out observed in Fig. 1. More likely these martian landslides formed in an even drier environment than the ejecta seen Lunae Planum.

References: [1] Iverson, R.M., *Rev. of Geophys. 35*, 245-296, 1997. [2] Hayashi, J.N. and S. Self, *J. Geophys. Res. 97*, 9063-9071, 1992. [3] Schultz, P.H. and D.E. Gault, *J. Geophys. Res., 84*, 7669-7687, 1979. [4] Housen,K.R., R.M. Schmidt, and K.A. Holsapple, *J. Geophys. Rev. 88*, 2465-2499, 1983. [5] Barnouin-Jha, O.S., A.F. Cheng, and U.I. von Mehlem, Track 2.204, 1999. [6] McEwen, A.S., *Geology, 17*, 1111-1114, 1989. [7] Gault and Heitowit, *Proc. Sixth Hypervelocity Impact Symp*. 2:419-256, 1963. [8] Braslau, D., *J. Geophys Res., 75*, 3987-3999, 1970. [9] Ahrens and O'Keefe, *Geo. Soc. Amer., Special Papers 190*, 103-120, 1982. [10] Schultz and Gault, *J. Geophys. Res., 90*, 3701-3732, 1985. [11] Barnouin-Jha and Schlutz, *J. Geophys. Res., 101,* 21,099-21,115 1996. Weitz et al., *J. Geophys. Res., MER special issue,* in press, 2003.

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