COMPARING THE RUNOUT OF FLUIDIZED EJECTA ON MARS WITH MASS MOVEMENTS ON EARTH.

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Introduction:

New data from several Mars missions continue to indicate that both volatiles and an atmosphere may play a role in the formation of fluidized ejecta seen at many Martian craters [e.g., 1], sometimes in ways that are unexpected. For example, there is mounting evidence that often the morphology of fluidized ejecta are well explained by dry granular flow mechanics that are probably also responsible for many of the long runout landslides on Earth [2, 3]. The role of volatiles or an atmosphere during the actual process of ejecta deposition could be minor. Instead, both volatiles and an atmosphere could have generated suitable surface conditions on Mars (e.g., smooth plains, or low cohesion and easily erodable soils) that allow for flow after ballistic ejection and emplacement, conditions which are not present on the Moon and Mercury.

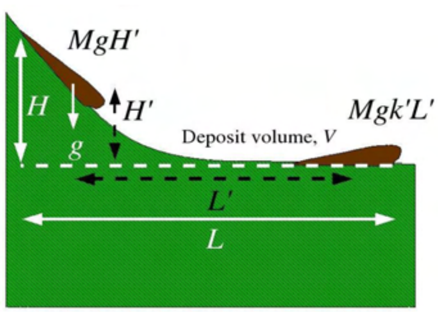

Fig. 1: Schematic illustrating how runout efficiency is measured at terrestrial landslides.

One way to assess how important volatiles might be during the actual fluidized ejecta emplacement is to compare ejecta run-out on Mars with mass movements on Earth. The ratio L/H of the run-out distance to onset height with the mass M of mass movements on Earth (Fig. 1) are frequently used to broadly characterize the rheology of landslides on Earth [e.g., 4, 5], where other empirical field evidence for these rheologies are available. In this study, we build on a new technique to compare ejecta run-out with data for terrestrial landslide [6, 7], extending our analysis beyond the Lunae Planum region investigated in those study to gain additional insights on whether or not volatiles and an atmosphere are required.

How do we compare ejecta and landslide runout?

The use of L/H to characterize mass movements derives naturally from 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 runout length to the center of mass, and k' is the resistance coefficient. Traditionally, authors use the onset height H and the runout distance L (Fig. 1) to obtain the runout efficiency

$$1/k=L/H$$

Table 1: Symbols

Symbol	Definitions
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, μ	Empirically derived crater scaling parameter [8, 9]
e	Empirically derived secondary cratering parameter

In order to obtain runout efficiency for ejecta, a similar energy balance must be undertaken. In the case of ejecta, the component of its kinetic energy that is injected into along surface flow must be balanced with the work lost by friction during flow. Since most fluidized martian craters are fairly large, the total kinetic energy of the ejecta is computed using gravity controlled crater scaling rules [8, 9] as:

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

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 [11]. 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. To first order, a variable e can parameterize these losses so that $KE_f = eKe_e$ and can be estimated from laboratory experiments and numerics [8, 9, 10, 12, 13, 14].

Because the energy analysis treats the ejecta as a point mass, the work lost W_l as the ejecta flows is given by kM_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 [11].

The resulting ejecta runout efficiency $1/k$ (equivalent to L/H for planar debris flows) is thus given by

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

This efficiency allows to broadly characterize the rheology of landslides on Earth [e.g., 3, 4 and references therein] and the planets [e.g., 5, 6]. It varies mostly with the volume of a landslide, but is also influenced by other factors including the presence of water [e.g., 3, 4 and references therein]. In the case of very large landslides ($V>10^7 m^3$), L depends primarily on the flow volume [7], although differences in rheology remain important.

We compare results of L/H and L as a function of flow volume obtained for several Martian fluidized craters with terrestrial debris flow and rock avalanches to broadly characterize the rheology of these ejecta, once they have begun to flow. However, before such characterization are made, we must first define L and H of ejecta in a way that is meaningful for comparisons with data from terrestrial mass movements.

Results and Discussion:

To date we have measured runout distances, rim-to-rim diameter, and ejecta flow volume for ~80 fresh craters in Lunae Planum and Chryse by combining topography from (MOLA), and imagery data from THEMIS and Viking. By the time of this presentation, we expect to extend our investigation to over 150 craters.

Preliminary runout efficiency results for Mars craters are shown in Fig 3. Also shown are terrestrial data for pyroclastic flows, volcanic debris avalanches, non-volcanic debris avalanches, debris flows, and martian landslides. 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 (triangles) is for the case where 1% of the kinetic energy of the excavated ejecta is injected into its forward flow. This is a very conservative estimate of the amount of energy imparted to ejecta by a secondary crater formed by the impact of a single projectile [8,9].

The second set assumes (squares) the more realistic situation where primary ejecta strikes the target surface as such an amalgam or cluster of particles. Experiments [3] and numerics [13] indicate for such clustered impacts the total kinetic energy of the ejecta approximates 30% of the kinetic energy of impacting primary ejecta is injected into subsequent primary and secondary ejecta that flows.

Keeping these two cases in mind, it appears that Mars ejecta on Mars 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, as well as the Martain landslides.

References: [1] Barlow, N.G., S. Stewart, and O.S. Barnouin-Jha 2006, Meteoritics and Planetary Science 41, 1423-1424.[2] Barnouin-Jha, O.S., S. Baloga and L. Glaze, 2005. JGR(Planets) 110,4010. [3]Wada, K. and O.S. Barnouin-Jha, 2006. Meteoritics and Planetary Science 41, 1551-1569.[3] Iverson, R.M., 1997. *Rev. of Geophys. 35*, 245-296. [4] Hayashi, J.N. and S. Self 1992. *JGR 97*, 9063-9071. [5] Barnouin-Jha, O.S. and S. Baloga, 2003.LPSC, 34, 1599. [6] Barnouin-Jha, O.S., 2005. LPI Contributions 1273, 21-22. [7] Housen, K.R., R.M. Schmidt, and K.A. Holsapple, *JGR 88*, 2465-2499, 1983., [8] Holsapple, K.A., 1993, Ann. Rev. Earth and Planet.Sci. 21, 333-373. [9] Gault et al., *JGR* 80, 2444-2460, 1975. [10] Gault and Heitowit, *Proc. Sixth Hypervelocity Impact Symp*. 2:419-256, 1963. [11] Braslau, D., *JGR 75*, 3987-3999, 1970. [12] Ahrens and O'Keefe, *Geo. Soc. Amer., Special Papers 190*, 103-120, 1982. [13] Schultz and Gault, *JGR, 90*, 3701-3732, 1985. [14] Barnouin-Jha and Schlutz, *JGR 101,* 21,099-21,115 1996.

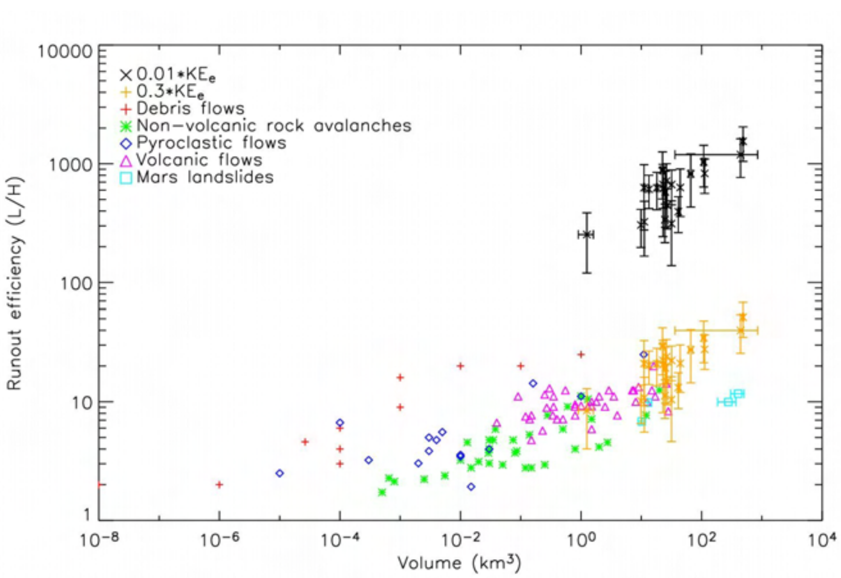

Fig 2: Runout efficiency (L/H) versus flow volume. Martian fluidized ejecta and landslides, and a few terrestrial mass movements. Terrestrial data from [3, 4]