**MARTIAN LANDSLIDES IN VALLES MARINERIS: WET OR DRY?** Veronika Soukhovitskaya[1] and Michael Manga[2], [1]Department of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138, vsoukhov@fas.harvard.edu, [2]Department of Earth and Planetary Science, UC Berkeley, 307 McCone Hall, Berkeley, CA 94720, manga@seismo.berkeley.edu.

**Introduction:** Evidence for the presence or absence of liquid water on Mars's surface provides important constraints on the climatic and dynamic evolution of the Martian surface and interior. Here we analyze the geometric properties of landslides on Earth and compare these with landslides in Valles Marineris [17] to learn about the dynamics of Martian landslides. The goal is to determine whether liquid water played a significant role in forming Martian landslides in Valles Marineris.

**Landslide models**: An analytical model of sturzstroms – giant landslides that travel long runout distances at high velocities – can be derived from the geometric characteristics of a landslide, mechanical energy dissipation, frictional stress, and fragmentation of particles within the flow [14]. The results yield $L \sim V^{1/3}$ and $L \sim g$ for whole-body flow, where L is the runout distance of the landslide, V is the volume of the landslide, and g is gravitational acceleration. For basal boundary layer flow, in which the bulk of the energy dissipation occurs within a thin layer at the base of the flow, results are $L \sim V^{1/2}$ and $L \sim g^{5/6}$ [14].

L may also depend on drop height (H), slope, material properties, and other parameters of the landslide; however these are assumed hereafter to be constant in the relationships L-V and L-g.

An analytical model of turbulent, suspension-driven pyroclastic gravity currents, called low-aspect ratio ignimbrites, produces $L \sim g^{1/8}$ and $L \sim V^{3/8}$ [7]. The aspect-ratio of a flow is the ratio of its average thickness to the radius of a circle over which it spreads.

**Observations:** Figure 1 shows data for Martian and Earth's landslides [2, 9, 11, 12, 15, 16, 18, 23, 24]. Table 1 summarizes the least square equations for each trend.

Comparing the equations for observed trends for terrestrial and Martian landslides suggests that Martian landslides are more similar to volcanic or dry landslides than wet landslides on Earth. Comparing observations to analytical models shows that Martian data most closely resemble whole-body flow model [14]: $L \sim V^{1/3}$. Model for dilute flows [7] ($L \sim V^{3/8}$) is significantly different from the trend of Martian data ($L \sim V^{0.29}$). We thus argue that Martian flows were largely dry and not water-saturated flows, and that their dynamics were governed by whole-body flow.

*Runout distance-gravity relationship:* The empirical relationships between runout distance and volume of Earth's volcanic flows and Martian flows can be used to learn about the role of gravity in the flow movement. Wet landslides are excluded from this comparison because the observed trends show that Martian landslides behave more similar to volcanic or dry landslides. Since $R^2_{volcanic} > R^2_{dry}$ (Table 1), we adopt the power law for volcanic landslides for our comparison.

**Table 1.** Least square approximated trends and their uncertainties for the data of Martian and terrestrial landslides.

| Name | L vs. V trend |
|---|---|
| Martian Landslides (Valles Marineris), combined data from MOLA and non-MOLA sources | $L \sim 7.2(\pm 0.8)V^{0.29\pm0.02}$ <br> $R^2 = 0.8527$ |
| Volcanic Landslides on Earth | $L \sim 16(\pm 1)V^{0.31\pm0.02}$ <br> $R^2 = 0.7641$ |
| Dry Landslides on Earth | $L \sim 8(\pm 1)V^{0.26\pm0.04}$ <br> $R^2 = 0.594$ |
| Wet Landslides on Earth | $L \sim 316(\pm 70)V^{0.52\pm0.05}$ <br> $R^2 = 0.884$ |

The empirical power laws for Earth's volcanic and Martian landslides are (Table 1):

$$L_{Earth} \sim 16(\pm 1)\, V^{0.31} \quad (1)$$

$$L_{Mars} \sim 7.2(\pm 0.8)\, V^{0.29} \quad (2)$$

After rescaling (2) so that V is taken to the same power as in (1) and assuming a power law relationship $L \sim g^z$ we obtain:

$$\frac{C_{Earth}}{C_{Mars}} = \left(\frac{g_{Earth}}{g_{Mars}}\right)^z \quad (3)$$

where $C_{Earth} = 16\pm1$ and $C_{Mars} = 6.2\pm0.7$ are proportionality constants in the power laws (1) and (2), $g_{Earth} = 9.78$ m/s$^2$, and $g_M = 3.69$ m/s$^2$. From (3) $z = 1.0\pm0.2$ and the empirical power law becomes $L \sim g^{1.0} V^{0.31}$. This power law shows that runout distance depends approximately linearly on gravity.

The result of $L \sim g$ supports the hypothesis that Martian flows are best modeled as dry or volcanic whole-body flows. In contrast, analytical model of dilute flows predicts $L \sim g^{1/8}$ [7].

**Melting of surface ice:** It is possible that massive landslides in Valles Marineris melted frozen water in pore spaces as the potential energy (PE) of falling landslides was converted into the thermal energy and energy of fusion. We assume that dissipated potential

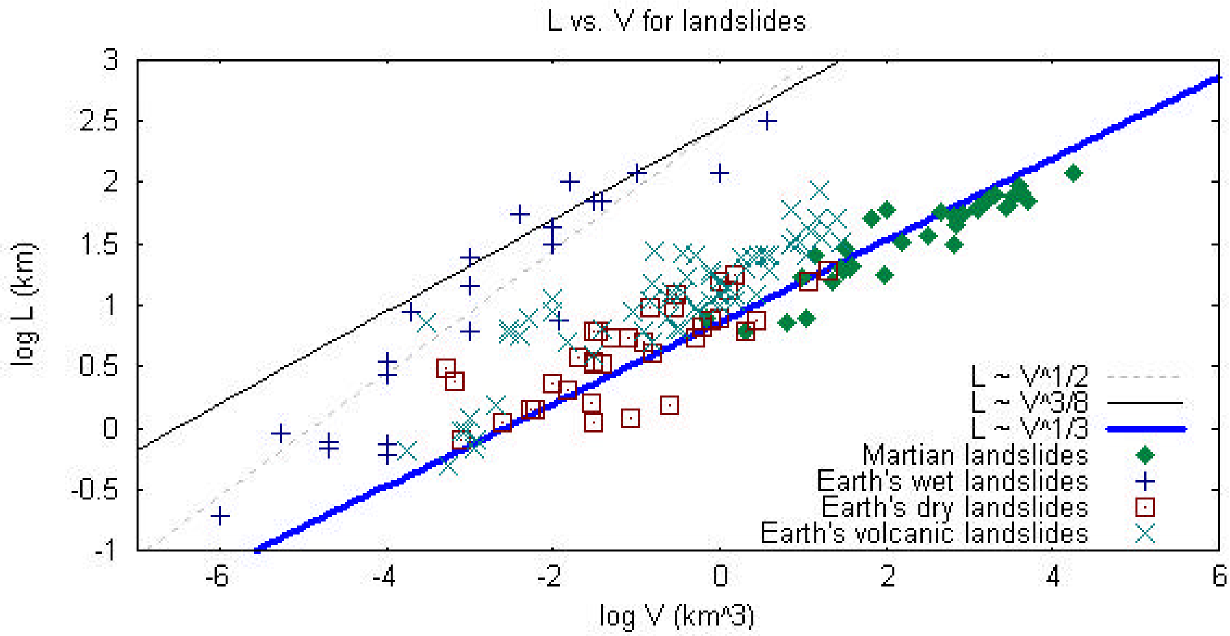


**Figure 1.** L-V plot for terrestrial and Martian landslides. Table 1 summarizes the least square equations and uncertainties for each trend. Lines $L \sim V^{1/2}$, $L \sim V^{1/3}$, and $L \sim V^{3/8}$ are predictions of analytical models [14, 7] respectively.

energy primarily goes into the latent heat of fusion and neglect the energy contribution to warming the rock, ice, or liquid water. Thus PE$\longrightarrow$Q, where PE = $\rho_{landslide}$gVH, $\rho_{landslide}$ is the average density of landslide (~ 2000 kg/m$^3$), H ~ 6000 m [9], Q = $V_{melt}\,\rho_{ice}\,L_f$ is the heat of fusion of ice, $V_{melt}$ is the volume of melted ice, $\rho_{ice}$ is the density of ice (~ 900 kg/m$^3$), and $L_f$ = 334 x 10$^3$ J/kg is the latent heat of fusion of ice at normal atmospheric pressure, gives:

$$\frac{V_{melt}}{V} \approx \frac{H\rho_{landslide}g_{Mars}}{L_f\,\rho_{ice}} \approx \frac{(6\times10^3 m)(2000kg/m^3)(3.7m/s^2)}{(900kg/m^3)(334\times10^3 J/kg)} \approx 0.1 \quad (4)$$

Thus, on average Martian landslides could melt a volume of ice about 10% of their total volume, a large fraction of the pore space (~ 30%) that could be filled with liquid water or ice.

**Conclusion**: Based on this study we conclude that Martian landslides in Valles Marineris are more similar to dry or volcanic landslides on Earth and dynamics of Martian landslides are governed by whole-body flow. Thus, liquid water probably was not a significant part of Martian landslides. This is consistent with the chronology estimate that Valles Marineris landslides occurred between 1.2 Ga and 8 My [21], suggesting that Martian landslides are younger than possible episodes of liquid water on Mars. Possible triggering-mechanism for landsliding may be volcanic activity or Marsquakes, but probably not rainfall or melting of subsurface ice.

**References:** [1] Barnouin-Jha O. S. and Baloga S. (2003) *LPS XXXIV*, 1599. [2] Bulmer M. H. et. al. (2002) *JGR*, *107*, 10.1029/2001JE001531. [3] Bulmer M. H. et. al. (2003) *LPS XXXIV*, 1225. [4] Campbell C. S. (1990) *Annu. Rev. Fluid Mech.*, *22*, 57-92. [5] Cleary R. W. and Campbell C. S (1993) *JGR*, *98*, 21911-21924. [6] Collins G. S. and Melosh H. J. (2003) *JGR*, *108*, doi:10.1029/2003JB002465. [7] Dade W. B. (2003) *JGR*, *108*, doi:10.1029/2001JB001010. [8] Grunewald U. (2000) *J. Geol.*, *28*, 827-830. [9] Harrison K. P. and Grimm R. E. (2003) *Icarus*, *163*, 347-362. [10] Hayashi J. N. and Mouginis-Mark P. (1992) *Eos, AGU Trans.*, 323. [11] Hayashi J. N. and Self S. (1992) *JGR*, *97*, 9063-9071. [12] Iverson R. M. (1997*) Rev. Geophys.*, *35*, 245-296. [13] Iverson R. M. and Vallance J. W. (2001) *Geol.*, *29*, 115-118. [14] Kilburn C. and Sorensen S.-A. (1998) *JGR*, *103*, 17,877-17,884. [15] Legros F. (2002) *Engineering Geol.*, *63*, 301-331. [16] Lucchitta B. (1978) *Geol. Soc. Am. Bulletin*, *89*, 1601-1609. [17] Lucchitta B. (1979) *JGR*, *84*, B14. [18] McEwen A. (1989) *Geol.*, *17*, 1111-1114. [19] Peulvast J.-P. et. al. (2001) *Geomorph.*, *37*, 329-352. [20] Savage S. B. and Hutter K. (1989) *J. Fluid Mech.*, *199*, 177-215. [21] Quantin C. et. al. (2003) *EGS-AGU-EUG Joint Assembly*, Abstract #338. [22] Shaller P. J. (1991) *Ph.D. Thesis*, *Caltech*. [23] Geol. Soc. Am. (2002) *Rev. Eng. Geol.*, *15*. [24] Wieczorek G. F. and Naeser N. D. (eds.) (2000) *proceedings of the Second International Conference on Debris-Flow Hazards Mitigation*.