FALL HEIGHT AND VOLUME CONTROL LANDSLIDE MOBILITY THROUGHOUT THE SOLAR SYSTEM. B. C. Johnson[1], C. S. Campbell[2] and M. M. Sori[3]. [1]Department of Earth, Environmental and Planetary Sciences, Brown University, 324 Brook Street, Providence, RI 02912, USA. (Brandon_Johnson@Brown.edu) [2]Department of Aerospace and Mechanical Engineering, University of Southern California, 3650 McClintock Ave, OHE430, Los Angeles, CA 90089, USA. [3]Lunar and Planetary Laboratory, University of Arizona, 1629 E University Blvd, Tucson, AZ 85721, USA.

Introduction: Long runout landslides are one of the most spectacular and mysterious geologic processes. These landslides extend much farther from their source than expected, and more voluminous slides tend to be more mobile. Observations of long runout slides on Venus [1], the Moon [2], Phobos [3], Ceres [4], Io [5], Callisto [6], and Iapetus [7] are inconsistent with friction reduction mechanisms that require lubricating fluids, except for possible frictional melts. Campbell et al. [8] modeled landslides as dry granular flow represented by multitudes of interacting disk shape particles using a soft-particle discrete element code. These simulations provided important insight into the rheology of long runout landslides and successfully reproduced terrestrial landslide observations of an increased mobility with increasing slide volume. A follow-up study using the same code by Johnson et al. [9] showed that the high mobility of voluminous slides was the result of sliding preferentially occurring when acoustic vibrations relieved overburden pressures, consistent with the acoustic fluidization model [10]. Here we discuss recent results of Johnson and Campbell [11], which suggest that drop height and volume are the major controls on landslide mobility. We show this dependence on drop height may explain observed distinct volume-mobility trends on the Earth, Mars, Iapetus, and Ceres.

Earth and Mars: For a given landslide volume, landslides on Earth tend to be more mobile than their Martian counterparts [12]. The average fall height of large terrestrial landslides is 1.2 km, while on Mars the average fall height is ~5.3 km. Figure 1 shows the result of soft particle simulations [11] exploring the effect of surface gravity, particle size, and fall height on landslide mobility. These simulations show that mobility has a weak dependence on surface gravity and particle size. More importantly, these simulations show that differences in fall height act as a natural explanation of the observed differences in volume mobility trends for Martian and terrestrial landslides. The reason for a decreasing mobility with increasing fall height is a rheology where shear stresses increase with increasing shear rate [8, 11]. Such a behavior is also expected for material fluidized by acoustic vibrations [10].

Iapetus: Singer et al. [7] mapped long runout landslides on Iapetus and found little to no dependence of mobility on slide length, which Singer et al. [7] used as a proxy for slide volume (Figure 2). This lack of a trend is contrary to the increasing mobility with increasing volume observed for the Earth and Mars (Fig 1). Singer et al. [7] attributed this lack of volume-mobility trend to frictional heating making ice surfaces slippery. But Singer et al. [7] divided their slides into "Blocky" if large blocks were visible on the slide's surface and "Lobate" if no blocks can be seen. If classified separately, (Figure 2), then the Lobate slides follow a Mars-like trend of mobility vs. volume, while the Blocky slides follow an Earth-like trend. Furthermore, Lobate slides tend to be from larger fall heights than Blocky, which may explain the finer breakage of the particles. In light of our simulation results showing that larger fall heights result in less mobile slides, the different mobility/volume trends can be explained by variations in fall height.

Ceres: Schmidt et al. [4] mapped landslides on Ceres, sorting them into three morphologic types. Schmidt et al. [4] argue that the least mobile type 1 slides were from higher latitudes compared to more mobile type 3 landslides (type 2 were between class 1 and 3 in latitude and mobility). These variations in mobility and morphology with latitude were attributed to variations in the temperature and depth of subsurface ice. All three slide types are present in figure 3 at runout lengths between 4 and 20 km, where L is again taken as a proxy for slide volume. For a given slide length in this region, type 1 slides tend to have the lowest mobility and largest fall heights while type 3 landslides are the most mobile and have the lowest fall heights. Type 2 slides fall between in mobility and fall height. Considering our simulation results indicating that larger fall heights lead to decreased mobility, we suggest that the observations of Schmidt et al. [4] may be the result of a dependence of slide fall height rather than ice temperature and depth. A dependence on latitude and fall height is supported by the observations showing that higher latitudes have more topographic power than equatorial terrains [13]. Moreover, 12 of 18 of type 1 landslides occur north of 30° N and northern latitudes have higher topographic power than equatorial or southern terrains [13]. This dependence is likely the result of latitude dependent viscous relaxation of topography [14]. Although our results do not rule out the presence of ground ice, there is no need to invoke the presence of ice based on landslide volume-mobility trends.

References: [1] Malin M. C. (1992) *JGR, 97*, 16337–16532. [2] Howard K. A. (1973) *Science, 180*, 1052–1055. [3] Shingareva T. V. and Kuzmin R. O. (2001) *Solar System Res., 35*, 431–443. [4] Schmidt B. E. et al. (2017) *Nature Geoscience, 10*, 338–343. [5] Schenk P. M. and Bulmer M. H. (1998) *Science, 279*, 1514–1517. [6] Chuang F. C. and Greely R. (2000) *JGR, 105*, 20227–20244. [7] Singer K. N. et al. (2012) *Nature Geoscience, 5*, 574–578. [8] Campbell C. S. et al. (1995) *JGR, 100*, 8267–8283. [9] Johnson B. C. et al. (2016) *JGR Earth Surf., 121*, 881–889. [10] Melosh H. J. (1979) *JGR, 84*, 7513–7520. [11] Johnson B. C. and Campbell C. S. (2017) GRL, doi: 10.1002/2017GL076113. [12] McEwen A. S. (1989) *Geology, 17*, 1111–1114. [13] Ermakov A. I. et al. (2017) *JGR Planets, 122*, 2267–2293. [14] Bland M. T. (2013) *Icarus, 226*, 510–521. [15] Legros F. (2002) *Engineering Geology, 63*, 301–331. [16] Quantin C. et al. (2004) *Planetary Space Science, 52*, 1011–1022. [17] Brunetti M. T. et al. (2014) *EPSL, 405*, 156–168. [18] Lucas A. A. et al. (2011) *JGR, 116*, E10001. [19] Lucas A. A. et al. (2014) *Nature Communications, 5*, 3417.

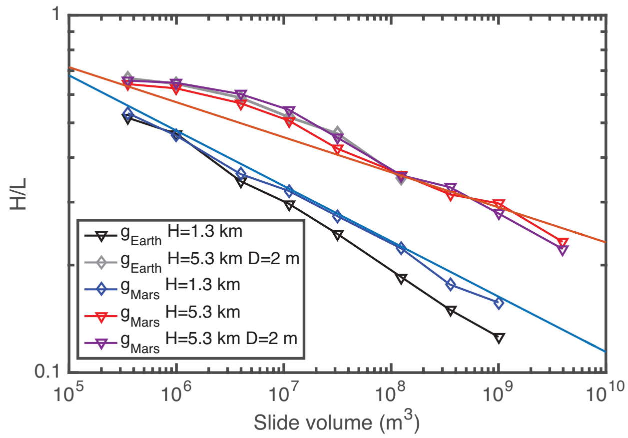

Figure 1: H/L versus slide volume of simulated terrestrial and martian landslides (after [11]). Simulations for different fall heights, surface gravities, and particle sizes as indicated in the legend. Each point represents the result of a single simulation. Trend lines for observed terrestrial (blue [15]) and martian slides (red [12, 16-19]).

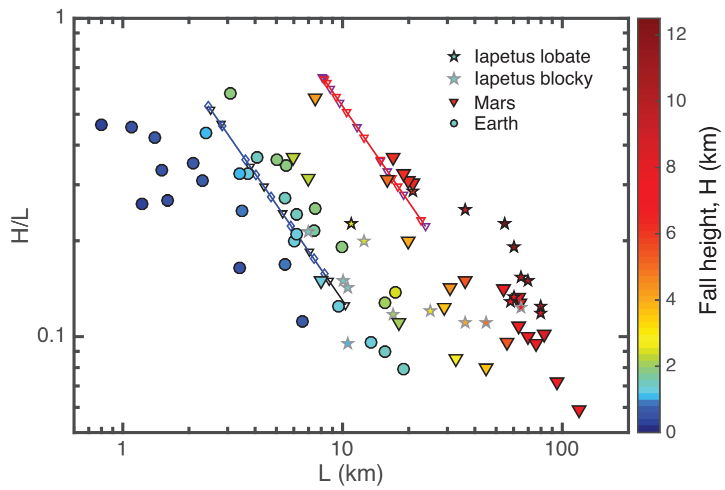

Figure 2: Comparison of H/L versus L (after [11]). Observed landslides on Earth (circles [15]), Mars (triangles [12]), and Iapetus (pentagrams [7]) colored by fall height H according to the color bar. The lines are simulation results reported in figure 1.

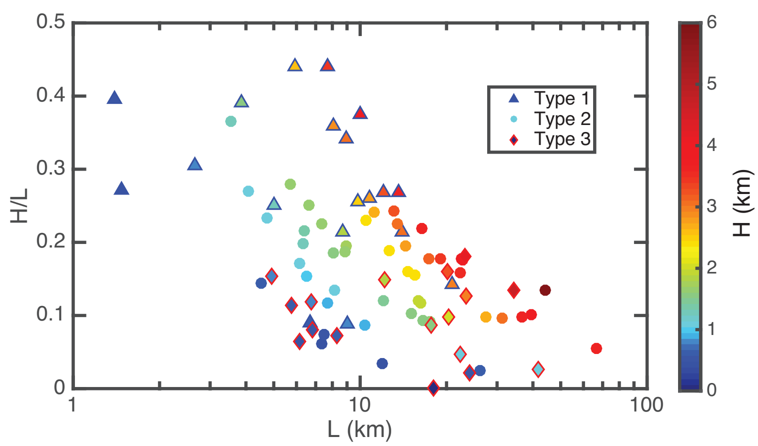

Figure 3: Comparison of H/L versus L. Observed landslides on Ceres [4] colored by fall height H according to the color bar. Morphologic types are indicated in the legend.