**MARTIAN IMPACT CRATER EJECTA RUN-OUT EFFICIENCY: ITS IMPLICATIONS FOR WATER IN THE SUBSURFACE.** Joseph M. Boyce, and Peter Mouginis-Mark, University of Hawaii, Honolulu HI 96822; jboyce@higp.hawaii.edu

**Introduction**: There has been considerable debate about whether water in the crust of Mars is required for ejecta flow on that planet. We suggest that among the lines of evidence supporting the importance of water in Martian target materials on ejecta flow is run-out efficiency. We contend that contrary to previous study [1], water appears to be essential for explaining the large run-out distance of Martian ejecta.

To fully appreciate run-out efficiency of a flowing granular mass such as fluidized impact ejecta and terrestrial mass flows (i.e., gravity-driven granular flows such as rock avalanches, landslides and debris flows), it is necessary to consider the kinetic energy distributions of particles within in each of their masses as movement is initiated and proceeds. For example, particles in primary impact ejecta have nearly the opposite energy distribution as those in a mass flow originating from slope failure [2, 3]. This difference can dictate whether materials will flow or not.

**Terrestrial Mass Movements and Their Flow**: Commonly, mobilization of terrestrial mass flows results from slope failure as the mass fails (nearly *en mass*), and there is sufficient conversion of gravitational potential energy to bulk translational kinetic energy and grain vibrational kinetic energy to change the style of motion from sliding on a local failure surface to flow. The gravitational potential energy, and hence, internal kinetic energy of each grain is a function of the height that it descends during its movement, and is $MgH$, where $M$ is flow mass, $g$ is the magnitude of gravitational acceleration, and $H$ is the height which the mass descends. Consequently, grains that start at greater heights have the greatest energy and as a result transfer of momentum is from them toward the direction of the propagating flow front (i.e., downhill) [e.g., 2, 3] through solid-contact phenomena (e.g., collisions, friction, adhesion). If the mass is water saturated, then solid-liquid interactions (such as viscous drag, buoyancy and turbulence) may also be important [e.g., 3].

**Ballistic Primary Ejecta and Their Lack of Flow**: In contrast, ballistically transported primary impact crater ejecta has nearly the opposite mass/momentum/kinetic energy geometry, with the velocity of impacting ejecta particles increasing continuously outward from the crater [4, 5]. This means that, even though their granular temperature may be high, particles of primary ejecta have little opportunity to transfer momentum through solid-contact phenomena (or solid-liquid interactions, if water saturated) that facilitate the flow in granular materials because their relative velocities result in their physical separation. We suggest that this is most likely the reason that ejecta on the Moon show little evidence of flow.

But, some limited viscous-like flow of lunar ejecta does occur as evidenced by dune-like features are found in the ejecta of large impact craters on the Moon. We suggest that this limited flow is the result of the interaction of secondary crater debris. This debris is sprayed radially and downrange from the myriad of individual secondary craters with a great range in velocities and directions [6, 7, 8, 9]. The interactions of particles in this pray of secondary ejecta have a substantially greater opportunity to interact through solid-contact phenomena. But because secondary ejecta are of relatively low-velocity (i.e., kinetic energy) they quickly halt as their modest energy is dissipated through grain-contact friction and inelastic collisions, hence, typically only producing dune-like features.

**Ejecta Flow (Wet and Dry)**: However, it is possible to produce significant flow even in dry ejecta under the right circumstances [e.*g*., 2, 10] if the velocity distribution of primary ejecta is altered as to substantially increase the number of grain interactions, substantially increase the velocity of secondary ejecta (or weaken the surface materials), increase the proportions of fine-grain materials, and/or increase the overall vibrational kinetic energy (granular temperature) of the ejecta as it moves across the surface. In addition, the saturation of the debris with water has been shown to promote flow through reducing intergranular friction and influencing grain collisions associated with high granular temperature [2]. All other characteristic being equal, except for saturation with water, the run-out efficiency [L/H] of debris flows are typically about twice that of dry rock avalanches.

**Run-out Efficiency**: The run-out efficiency of a granular flow describes conversion of gravitational potential energy to work done during flow translation, and the more efficiently this conversion occurs, the less energy degrades to irrecoverable forms such as heat, the further the flow runs out before stopping. Heim [11] pointed out that net efficiency can be calculated by equating the total energy lost during motion (*MgH*) to the total energy degraded to irrecoverable forms by resisting forces, *MgR*, that work throughout the horizontal distance L to make the flow stop after having descended from the height *H* (i.e., *MgH* = *MgR*, where *R* is a dimensionless net resistance coefficient). Although it is difficult to determine or quantify R, dividing each side of *MgH* = *MgR* by *MgHR* shows the net efficiency is

$$1/R = L/H$$

which shows that the net efficiency (1/R) increases as the run-out distance increases for a fixed descent height.

Barnouin-Jha [1] derived the governing equation for the run-out efficiency of Martian fluidized ejecta as

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

where $R_c$ is the transient crater radius; $R_b$ is the crater radius that defines ejecta mass in continuous ballistically emplaced ejecta; and c, μ are empirically derived crater scaling parameters. He used this equation to calculate the run-out efficiency of sample Martian craters in Lunae Planum and compared the results with terrestrial mass movements. In his calculations he adopted L as the distance between the outer edge of the fluidized ejecta and that of the outer edge of the continuous ejecta deposit (estimated from craters on Mercury of the same size), and found that ejecta behaved similar to dry, rock avalanches instead of volatile-rich terrestrial mass movements.

**New Estimate of Martian Ejecta Run-out Efficiency**: We suggest that the assumption of [1] is invalid because there is considerable evidence that ejecta flow begins near/at the rim. Hence, L should be measured from near the rim to the outer edge of the continuous fluidized ejecta deposit instead of starting at the boundary of the theoretical edge of the continuous ballistic ejecta. When this is done, and the new value of L plugged into the equation above the run-out efficiency increases by greater than a factor of 2; consistent with the run-out of water saturated debris flow.

**References**: [1] Barnouin-Jha, O. S., 2005 *in The Role of Volatiles and Atmospheres on Martian Impact Craters*, 21-22; [2] Savage S. B., and K. Hutter, 1989 *J. Fluid Mech.,* 199, 177-215; [3] Iverson, R.M., 1997, *Rev. of Geophys., 35, 245-296;* [4] Gault, D. E., et al , 1968, in *Shock Metamorphism of natural Material,* eds., B French and N. M. Short, Mono, Baltimore MD., 87-100*;* [5] Oberbeck, V. R. 1975, *Rev. Geophys. Space Phys*, 13:337-337; [6] Oberbeck, V. R.,et al, 1975, *Earth, Moon, and Planets*, 13, 1-3, 9-26; [7] O'Keefe J. D., and T. J. Ahrens, 1985, *Icarus*, 62, 2, 328-338; [8] Melosh, H. J., 1989, *Oxford Univ. Press*, New York, 245; [9] Cintala, M. J., et al, 1999, *Met. & Planet. Sci.*, 34, 605-623; [10] Wada, K., Barnouin-Jha O. S., 2006, *Met. & Planet. Sci.,* 41, Nr 10, 1551-1569; [11] Heim, A., 1932, Fretz und Wasmuth, Zurich, Switzerland, 218.