**IMPACTS INTO POROUS VOLATILE-RICH SUBSTRATES ON MARS.** P. H. Schultz,. Brown University, Department of Geological Sciences, P. O. Box 1846, Providence, RI 02912, peter_schultz@brown.edu.

**Introduction:** The current mantra "follow the water" focuses research in order to understand fundamental aspects of Martian climate history and the possibility of past (or even present) life. The multi-lobed ejecta around craters is often used as evidence for water at depth (e.g., 1,2,3). However, this "evidence" is often an assumption used to draw a conclusion.

At issue are the underling processes that control the different styles of ejecta emplacement. Experiments (4,5) theory (6,7) and data (5,6,7) for Martian crater ejecta all indicate that the range of ejecta morphologies can be accommodated without the presence of water (or at least without water as the controlling parameter). The key parameter is the characteristic post-impact grain size that can be entrained in intense vortices created by the expanding ejecta curtain in the presence of an atmosphere, even at late times. This insight provides an alternative use for impact ejecta morphologies: a probe for assessing Martian lithologies. The presence of volatiles (including bound water or water/ice) may play a secondary role.

**Impacts into Sedimentary Materials:** Mars is covered with regional accumulations (or remnants) of thick, easily eroded sediments dating from the Noachian to today (8,9,10). The marked contrast in erodability is illustrated by pedestal craters perched on 0.1 km to 1.5 km outliers of sediments now missing in the surrounding terrains. The same degree of differential erosion rates (DER) is presently expressed at high latitudes but affect smaller craters (8). Consequently, volatile "cement" was proposed to account for the now-missing sequences, while the remainder was removed. Armouring by impact processes (ejecta, blast effects) preserved these materials within the platform comprising the pedestal crater. One plausible model for this material is dirty snow (mixtures of Martian loess and ice crystals). Natural snow on Earth has a density of around 0.4g/cm$^3$ and under load will reach equilibrium of about 0.5g/cm$^3$. Consequently, cratering in lower porosity sand targets may not even provide a reasonable model for certain regions on Mars. New laboratory impact experiments have been performed using perlite and frozen water-saturated perlite as a surrogate material. These experiments revealed unexpected changes in the excavation process that have direct applications for Mars.

The laboratory impact experiments were performed at the NASA Ames Vertical Gun Range. Quartz and pyrex spheres (0.159 to 0.653 cm diameter) were used as projectiles in order to simulate conditions of complete impactor disruption at the higher velocities on Mars. Impact angles were varied from 15˚ to 90˚ (from horizontal) with velocities ranging from 4 to 5.5. km/s. Impacts into sand (porosity of 23%, density of 1.7 g/cm$^3$) and fluffed pumice (porosity of about 50%, density of 1.1 g/cm$^3$) yielded similar evolution of the cratering flow field. This included the classical conical ejecta curtain and parabolic transient crater with a Diameter: depth (D:d) of 4:1 (referenced to the pre-impact surface). Pumice targets produced a distinctive floor pit lined with denser material as a result of deep penetration and compress target material (densification).

Highly porous perlite targets (porosity of 90% and density of 0.1 g/cm$^3$), however, produced a two-component ejecta curtain: both a vertical plume and a more tenuous inclined ejecta curtain. (Fig. 1).

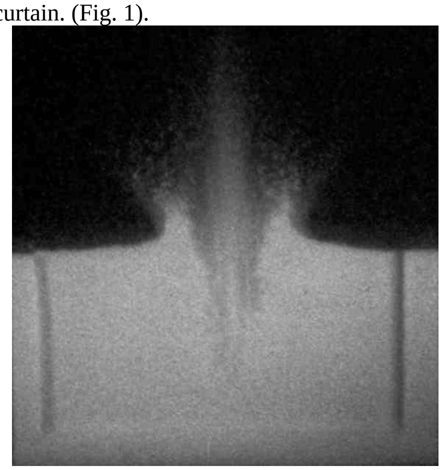

**Figure 1.** Quarter-space experiment demonstrating the deep initial penetration into a target composed of low-density perlite particles. The anomalously small D:d ratio persists up to the time of final crater growth, after which collapse destroys the transient crater. In addition, the vertical plume of ejecta continues to evolve and collapses back into the crater. Impactor was a 0.318 cm pyrex sphere launched at 6.1 km/s.

In addition, the crater cavity evolved with a D:d ratio of 1:2 to 1.5:1 before collapsing. The final crater (for vertical impacts) had little to do with the transient crater as ejecta from the high-angle plume returned to the crater interior and as the rim collapsed. A high-angle plume, however, also develops for lower angle impacts (Fig. 2). Its axis evolves with the growing cavity and is not just a reverse flow within the penetration tube.

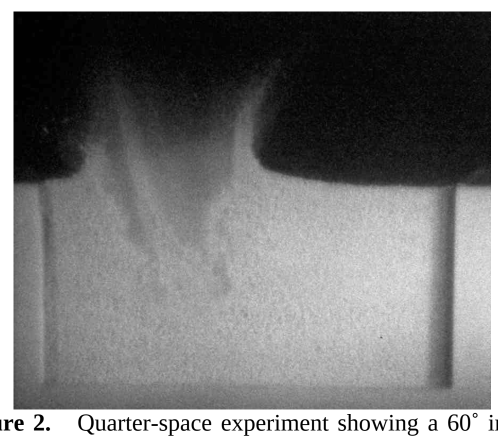

**Figure 2.** Quarter-space experiment showing a 60˚ impact (from horizontal) by a 0.318 cm pyrex sphere at 6.2 km/s. Deep penetration occurs prior to lateral crater growth. Total crater volume during excavation is enhanced relative to sand but collapses to appear much reduced.

The contrast between sand/pumice and perlite can be explained by differences in the effective depth of burst (EDOB). The low-density, high-porosity perlite results in deep penetration before complete transfer of energy and momentum. This results in containment and redirection of shocked/comminuted/vaporized material into a near-vertical plume containing lower velocity ejecta. Shock coupling near the surface also produces a weak surface-rarefaction wave responsible for the classic conical curtain. As impact angle decreases to about 30˚ (from the horizontal), the EDOB decreases and the crater becomes more stable.

**Implications for Mars:** These new experiments have several important implications for using craters as probes for near-surface lithology. First, small impacts (crater diameters <10 km) into highly porous substrates (e.g., polar layered terrains, circum-polar deposits, etc.) may be destroyed by self-collapse as well as by later gradational processes. If the target exhibits strength (e.g., indurated layers), deep penetration may produce a deep transient crater but collapse destroys the evidence (Fig. 3a).

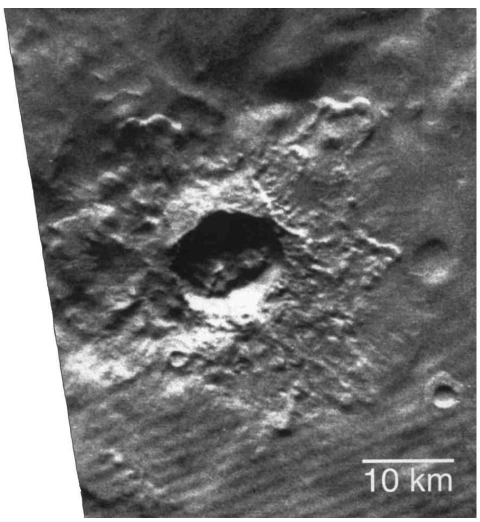


**Figure 3a.** Anomalously shallow 8 km-diameter crater at high latitudes (-59˚w, 344˚w). Raised rim is missing due to rim collapse. Viking Frame 573B58.

Second, large craters (> 15 km) should exhibit thick, near-rim ejecta due to a basal surge from gravity-collapse of vertical plume. Moreover, large secondary craters should form due to loose clumps of ejecta comprising the advancing curtain. The resulting crater resembles a lunar impact since the ejecta clusters accentuate secondary craters in the soft surface material (Fig. 3b).

Because the ejecta curtain is more permeable, atmospheric effects are reduced. Third, high-porosity sediments with indurated layers can result in anomalously small D:d ratios as diameter is attributed to deep penetration.

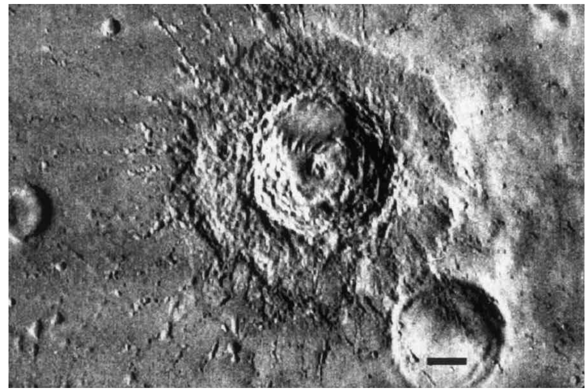

**Figure 3b.** Anomalously shallow 35 km-diameter complex crater located in the thick equatorial mantling deposit. Thick inner rim, excessive collapse, and large secondaries are consistent with being formed in highly porous materials. Viking frame 635A82.

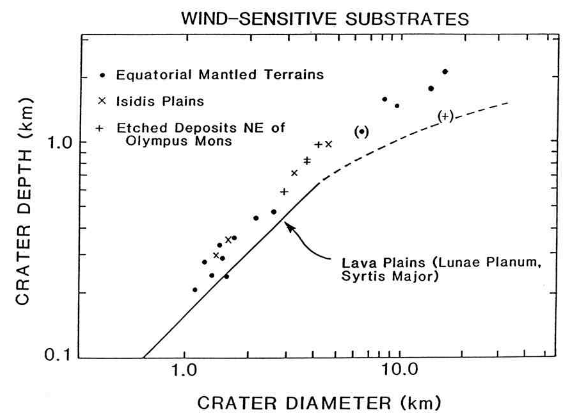


**Figure 4a.** Crater diameter and depth relations for impact craters produced in competent substrates, such as lava plains.

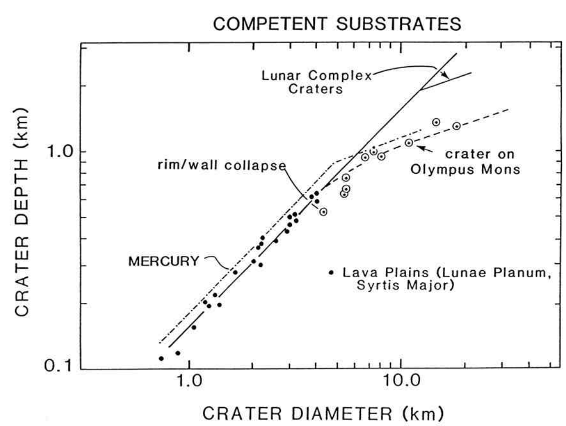


**Figure 4b.** Crater diameter and depth relations for impact craters produced in soft sediments inferred from sensitivity to wind erosion. The consistently greater depth for a given

Shadow measurements of crater depths in different lithol o-gies confirm this trend (Fig. 4). And fourth, compressed crater-floor materials become more resistant to erosion. This could account for high-standing saucer-shaped relicts within deeply eroded sediments, i.e., inverted topography where the relict crater floor stands in relief (Fig 5).

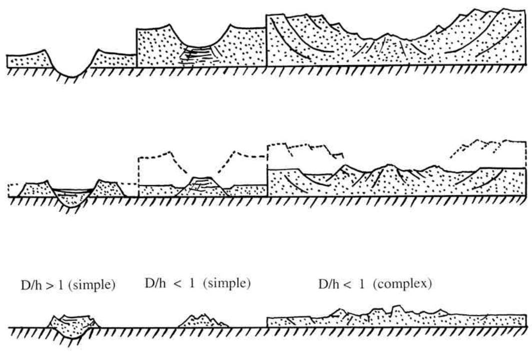


**Figure 5.** Diagram illustrating differential erosion of simple and complex craters produced within easily eroded target materials. Small, simple craters eventually exhibit inverted topography as more resistant, compressed floor material stands in relief. Larger, complex craters result in more complex crater relicts.

The effect of trapped volatiles may not play the role normally attributed to them. Heated volatiles should vaporize or atomize under the PT conditions of post-Noachian Mars. Near-surface volatiles heated by the blast or volatiles incorporated in the vortex-entrained ejecta flow may migrate vertically after emplacement. This process appears to have occurred within ejecta facies in Argentina. Precipitates (carbonates. manganese) commonly occur at the base of the ejecta deposits and form an indurated layer. This may provide an additional mechanism for creating pedestal craters.

**References:** [1] Barlow, N. (1994) *JGR, 99,* 10,927-10,935. [2] Head, J. W. et al. (1999) *Science286,* 2,134.[3] Garvin *et al.* (2000) *LPS XXXI*, Abstract #1619. [4] Schultz, P. H. (1992) *JGR 97,* 11,623-11662. [5]Barnouin-Jha, O. and Schultz, P. H. (1996) *JGR 101*, 21,099-21,115. [6] Barnouin-Jha, O. and Schultz, P. H. (1998) *JGR 103*, 25,739-25,756. [7] Barnouin-Jha, O. and Schultz, P. H. (1999) *Int. Jour. Impact Eng. 23,* 32-39.[8] Schultz, P. H. and Lutz, A. B. (1988) *Icarus 73*, 91-141. [9] Grant, J. and Schultz, P. (1990)*Icarus 84,* 166-195. [10] Tanaka, K. (2000) *Icarus144*, 254-260.