ASTEROIDS WITHOUT EJECTA.
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Introduction: Recent observations have made it clear that many small bodies in the solar system contain significant pore space. This may have resulted from primordial accretion processes or repeated collisional recycling into rubble-pile structures. Observations have also shown that impacts on highly porous bodies, such as Mathilde [1] or Hyperion [2] produce craters unlike those typically observed in laboratory experiments in moderately porous soils. Craters on porous objects form in close proximity without significant degradation of extant craters and appear to generate very little if any ejecta. Therefore, it is important to understand how porosity affects the mechanics of crater and ejecta formation.

Housen and Holsapple [3] conducted impact experiments in porous silicates on a geotechnic centrifuge [3]. The craters replicated the basic characteristics of craters on Mathilde, i.e. formation in close proximity without mutual degradation, and a surprising lack of ejecta. They posited that craters in porous materials form primarily by compaction of pore space, rather than by shearing and ejection. If ejection velocities were lower than in less porous materials, as one would expect because of energy dissipation during compaction, then most of the ejected material would fall back into the crater. The crater would not be filled up because of the volume created by compaction, and very little material would be observed around the crater. That argument relies on the assumption that ejection velocities in highly porous materials are lower than in a more consolidated material such as sand. In this abstract we report on ejection velocity measurements and crater formation mechanisms in highly porous materials to examine that assumption.

Experiments: As in the earlier study, the present experiments used a material composed of a mixture of dry quartz sand (55% by mass), perlite (13%) and water (32%). Perlite is a highly porous silicate manufactured from volcanic rock. The water is used to allow the sand and perlite to be mixed without separating. In the two experiments reported here, one target was dried in an oven at 90C for several days to remove essentially all of the water. The resulting bulk density and porosity were ρ=440 kg/m^3 and 83%. The material was extremely weak as evidenced by the difficulty is forming a vertical cliff in the specimen.

The other target was not dried prior to testing and therefore contained roughly 32% water by mass. Its bulk density and porosity were ρ=630 kg/m^3 and 63%. The texture of the material was similar to damp potting soil. The water content resulted in greater strength. The crater in this target had very steep, nearly vertical walls with a height, h, of ~0.1m. A rough lower bound on the cohesion is therefore ρgh=600 Pa.

Both targets were impacted by cylindrical polyethylene projectiles with diameter and height = 12.2 mm, and mass=1.33 gm. The impact speed for the dry target was 1770 m/s and 1610 m/s for the wet target. Both impacts occurred normal to the target surface in a vacuum chamber.

The impacts were performed in a quarter-space fixture, i.e. an aluminum box with an open top and a thick Plexiglas window on the front. The impact occurred at the interface between the window and the target material. The events were recorded with two high speed digital video cameras aimed perpendicular to the front window. One camera ran at 120,000 pictures/s to record the projectile speed, and one ran at 15,000 pictures/s to record crater and ejecta formation.

Results: Figure 1 shows the ejection velocity, v, versus launch position, x, for particles originally located near the surface of the target. The data are shown in the form consistent with point-source scaling [4], where U is the impact speed, a is the projectile radius, δ is the projectile density and the scaling exponent ν is 0.4. The results of the two experiments reported here are shown as the red and blue circles. Data are also shown from previous quarter-space experiments by one of the authors (KRH) for impacts into dry sand (porosity ~35%) and targets with porosities of 55% and 67% [5]. The ejection velocities for the 55% and 67% targets are a factor of 1.5 to 2 below those for sand. The present data for a porosity of 63% agrees relatively well with those earlier results, although some differences could be expected because of the significant water conent for the present case. The ejection velocities for the 83% porous target are a factor of 4 to 5 below those for sand.

The quarter-space technique also provides information on the mechanics of crater formation through direct visualization of the material flow. Figure 2 shows a snapshot roughly 33 ms after the impact into the target with 83% porosity. The trajectories of several particles were digitized and are shown in the figure. The green lines indicate particles that were ejected. The black lines indicate material that was compressed downward or radially outward into the crater wall. As indicatd in the figure, only a thin layer of the near-surface material was ejected. The majority of the crater volume was formed by permanent compaction with the material being compressed into a transient crater with very steep walls (indicated by the red line in the figure). Given the very low cohesion of the material, this shape was unstable and collapsed to form the final crater whose profile is shown by the blue curve.

Discussion: These results support the crater formation and ejection proceses described in [3]. That is, increased porosity of the target material results in lower ejection velocities. Furthermore, the quarter-space experiments clearly show that crater formation in highly porosus targets occurs mainly by compaction, rather than the shearing and excavation mechanisms typically observed in soils with moderate porosity.

The question of whether an ejecta blanket forms depends on the mass of material that is ejected beyond the crater rim. This in turn depends on the magnitude of the ejecta velocities and the size of the crater. Figure 3 shows the results of a preliminary model that is based on current data for ejection velocities and crater scaling laws [4]. For a given size of body, ejecta blankets are extinguished above a threshold crater size. Below this size, a significant mass of material is ejected beyond the crater rim. Lines are shown for target porosities of 45% and 70%. Craters above the line for a given porosity should exhibit minimal ejecta. The model results are consistent with observations of the four small bodies shown in the figure. Additional experiments are being planned to explore crater formation in highly porous materials and to reveal the conditions under which ejecta blankets are expected to form around craters on porous bodies.

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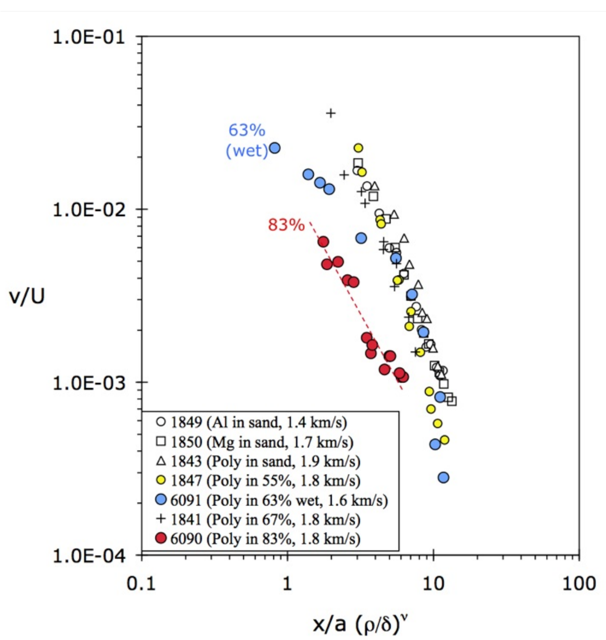

Figure 1. Ejection velocity vs launch position for sand and porous materials.

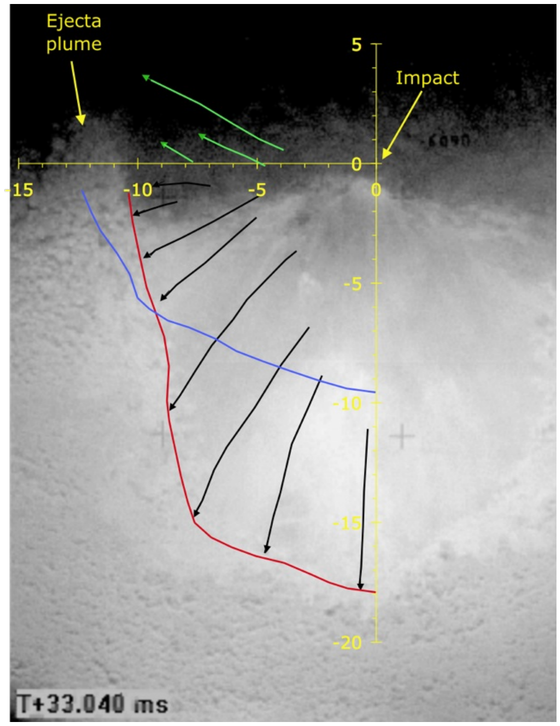

Figure 2. Material trajectories for an impact into a target with 83% porosity.

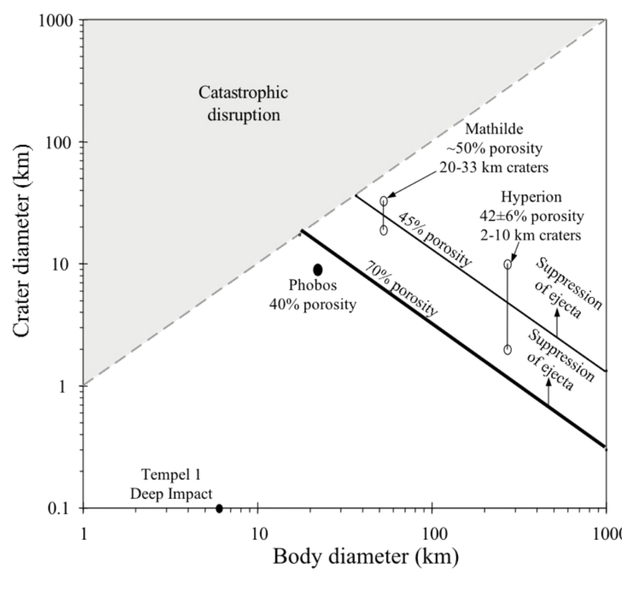

Figure 3. Thresholds for ejecta blanket formation.

References: [1] Veverka J. *et al*. (1999). ICARUS 140, 3-16. [2] Thomas P.C. *et al*. (2007) *Nature*, 448, 50-53. [3] Housen K.R. and K.A. Holsapple (2003) ICARUS 163, 102-119. [4] Housen K.R. and K.A. Holsapple (2010) Submitted to ICARUS. [5] Housen K.R. (2003) LPSC XXXIV, #1300.