**THE INFLUENCE OF A GRANULAR TARGET'S PACKING DENSITY ON CRATER MORPHOMETRY AND EJECTA KINEMATICS: EXPLORATORY EXPERIMENTATION.** C. J. Cline II[1], M. J. Cintala[2], J. L. B. Anderson[3], R. A. Taitano[3], L. E. Dechant[3]. [1]Jacobs, NASA Johnson Space Center, Houston, TX 77058 (christopher.j.cline@nasa.gov), [2]Astromaterials Research and Exploration Science Division, NASA Johnson Space Center, Code XI3, Houston, TX, 77058, USA, [3]Winona State University, Geoscience Department, Winona, MN 55987.

**Introduction:** With current orbital cameras providing images of planetary surfaces at ever increasing fidelity, it is now possible to resolve meter-scale craters (e.g. [1]). As the morphology and morphometry of small craters have been demonstrated to be sensitive to the physical properties of the impactor and target in both laboratory-based [2,3] and modeling studies [4,5], these newly resolvable features offer an opportunity to probe the near-surface properties of impacted planetary surfaces. In order to robustly infer near-surface structure from craters formed on complex surfaces with poorly known physical properties, it is imperative to understand how small changes in target properties are manifested in the final morphometry of an impact crater. Here, we present early experimental results on the effects of changes in bulk density of granular targets (inclusive of porosity) on crater morphology and the cratering process.

**Methodology:** Impact cratering experiments were conducted using the vertical gun in the Experimental Impact Laboratory at NASA Johnson Space Center. Targets were cylindrical PVC buckets (interior diameter of 26.2 cm and depth of 12.2 cm) filled with dry, well-sorted quartz sand (grain size between 0.4 and 0.8 mm). The sand was either gently poured or sieved into the target container in order to produce a relatively low (1.46 g cm$^{-3}$) or high (1.64 g cm$^{-3}$) packing density, respectively. Aluminum projectiles, 4.76 mm in diameter, were accelerated to ~1.5 km s$^{-1}$ and impacted normal to the surface of the sand under a chamber pressure of ~1 torr.

Kinematic data were collected for ejecta using the Ejection-Velocity Measurement System (EVMS, [6]). A vertical sheet of strobed laser light illuminates a cross-section of the evolving ejecta curtain while a digital camera records a multiple-exposure image of ejected particles. Complete ballistic trajectories of the imaged particles can then be extracted, including parameters such as ejection speed, radial ejection position, and ejection angle.

Morphometric data were collected with a NextEngine 3D scanner affixed to the exterior of the impact chamber. Scans were collected immediately before and after an impact experiment, and were subsequently used to construct topographic maps (Fig. 1) and crater profiles (Fig. 2) from the impacted targets.

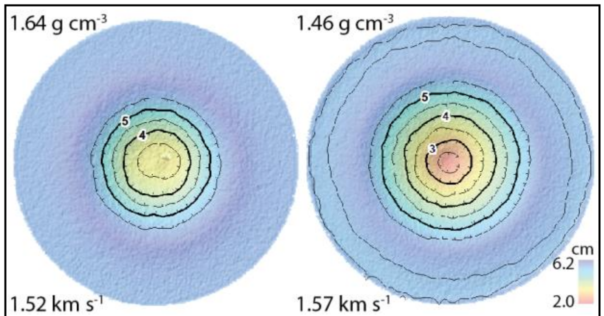


**Figure 1.** Topographic maps produced from post-impact 3D scans. The elevation scale is set relative to an external reference point on the target container, which is the same in both maps. The impact speed of each shot is given on the lower left of each map.

**Results:** The craters formed in both the high- and low-density sands are simple in morphology. The crater in the lower density target was conical in profile as is typical of such impacts into loose, dry sand (e.g. [6]). The crater formed in the denser target, however, was shallower and decidedly more bowl-shaped (see Fig. 2 for comparison). The depth-to-diameter (*d/D*) ratio of the crater formed in the denser target was 0.17, while the ratio of the less dense sand was 0.21, a value more typical of fresh, simple lunar craters (>0.4 km) formed in a gravity-dominated regime [8,9].

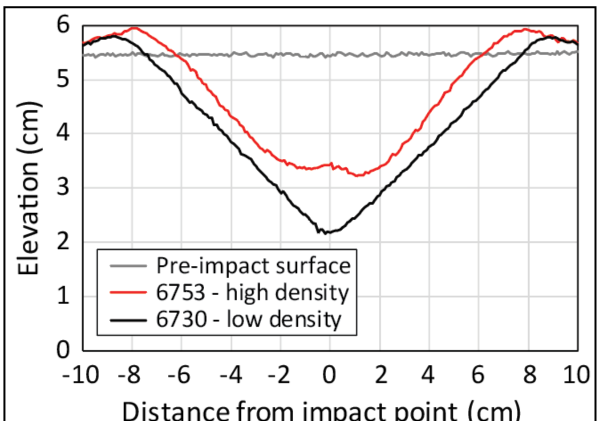


**Figure 2.** Crater cross-sections derived from 3D-scanner data. Profiles are shown with a nearly 2:1 vertical exaggeration. The small raised central portion of the 6753 crater is caused by the remnant projectile residing inside of the crater during the 3D scan.

The ejection speed of each particle is related to its radial ejection position relative to the impact point through a power-law relationship, similar to that originally described by [10]. The exponents for the fits from both experiments are in good agreement with the data collected by [6] from impacts into coarse, dry sand that was packed to a bulk density of 1.51 g $cm^{-3}$. Additionally, they are within the bounds of energy and momentum scaling [10]. Ejection angles in both shots decreased from a maximum of ~53° as fragments farther from the impact point were ejected.

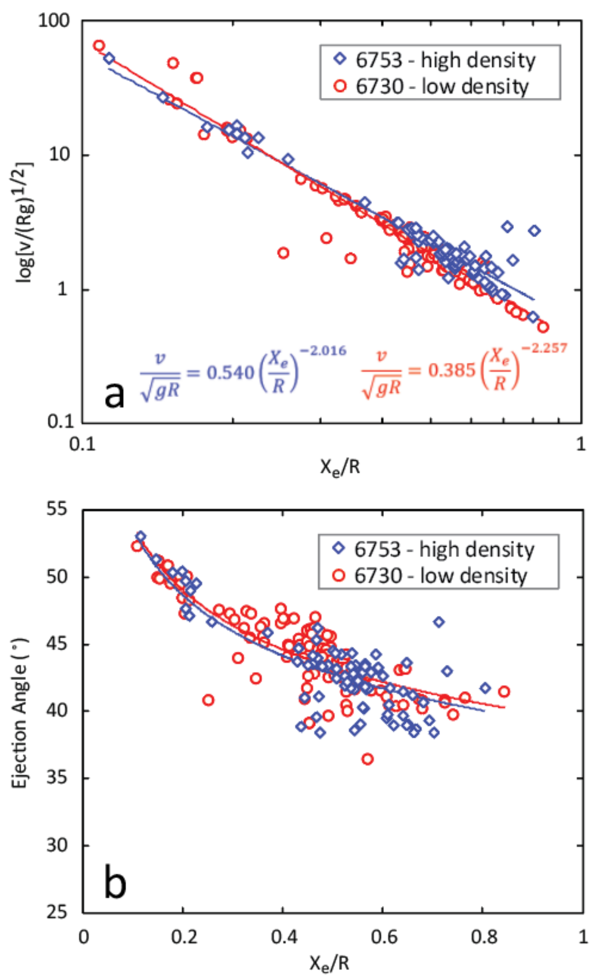


**Figure 3.** Ejecta data determined from reconstructed ballistic trajectories. a) Scaled ejection speed (described in [10]) plotted as a function of the scaled ejection position. b) Ejection angle of ejecta as measured from the horizontal, also as a function of the scaled ejection position.

**Discussion:** A difference of only ~11% in the packing density between two targets resulted in obvious differences in crater morphometry. Despite the dissimilar *d/D* ratios however, the speeds and ejection angles of the ejecta appear to be remarkably similar as functions of the scaled ejection position.

The work of [11] compared ejection-speed data from impacts into densely packed sand to those from the less-dense loose-sand targets of [12], and the even lower density sand+perlite mixtures of [13]. They noted a decrease in ejection speeds as target porosity was increased, associating this phenomenon with less efficient energy coupling in the more porous targets due to collapse of pore space very near the impact point, where coupling occurs. In contrast, we do not observe any statistically relevant decrease in either ejection speed or angle with an increase in porosity from 38 to 45%.

Identifying the governing mechanism responsible for these observations is difficult within the very limited set of exploratory experiments presented here. The two experiments investigate a change in packing density. Since each target is composed of the same granular material, a change in packing (bulk) density is concomitant with a change in porosity. Any analysis of the isolated effect of density or porosity is further complicated by consequential changes in other physical properties, such as material strength (*e.g.*, shear). Thus, given these experimental details, the crater- and ejecta-scaling relationships in light of the covariance among bulk target density, porosity, and frictional strength still remains elusive. While these exploratory experiments provide intriguing preliminary results, more work will be necessary to separate the effects of changing density on both the porosity of the target and its effective (frictional) strength, each of which can have important ramifications on the excavation, compression, and ejection of material during the cratering process.

**References** [1] Robinson et al. (2010) *SSR* 150:81-124. [2] Wünnemann K. *et al.* (2011) *Proceed. XI Hypervel. Imp. Sym.* [3] Prieur A. C. *et al.* (2017) *JGR:Planets*, *122*, 1704-1726. [4] Quaide and Oberbeck (1968) *JGR*, *73*, 5247-5270. [5] Schmidt R. M. and Housen K. R. (1987) *Int. J. Impact engine.*, *5*, 543-560. [6] Cintala M. J. *et al.* (1999) *Meteoritics and Planetary Sci.* 34, 605-623. [7] Love S. G. *et al.* (1993) *Icarus*, *105*, 216-224. [8] Pike R. J. (1977) *LPSC VIII*, 3427-3436. [9] Stopar J. D. *et al.* (2017) *Icarus*, *298*, 34-48. [10] Housen K. R. *et al.* (1983) *JGR*, *88*, *No. B3*, 2485-2499. [11] Housen K. R. and Holsapple K. A. (2011) *Icarus*, *211*, 856-875. [12] Anderson J. L. B. *et al.* (2003) *JGR*, *108*, 5094. [13] Housen K.R. and Holsapple K. A. (2003) *Icarus*, *163*, 102-119.