

IMPACT CRATERING EXPERIMENTS USING LUNAR HIGHLAND SIMULANT AS TARGET MATERIAL. C. J. Cline II¹, M. J. Cintala², ¹NASA Johnson Space Center, Astromaterials Research and Exploration Science, Mail code X15 (christopher.j.cline@nasa.gov), ²NASA Johnson Space Center, Astromaterials Research and Exploration Science, Mail code X13.

Introduction: The properties of a target material have long been known to influence the cratering process for relatively small impact events, where the material “strength” is more dominant than the local gravitational force [1]. Strength in granular materials, however, is dependent on the interactions among packing fraction, grain size, and cohesion [2], and can thus vary for the same bulk material at different porosities. Experimentally, this relationship has been demonstrated for the most commonly used target material in impact cratering studies, unconsolidated sand, where [3] observed a notable decrease in depth-diameter ratios (d/D) for more densely packed (higher packing fraction, or lower porosity) targets. In order to extend the applicability, or properly scale, those findings to relatively small lunar craters, for example, a more realistic analog material (in terms of physical properties) should be interrogated for use as a target medium. To this end, we have conducted a series of impact cratering experiments using a lunar-highlands regolith simulant to investigate the relationship between packing fraction and crater morphology/morphometry.

Methods: In total, 10 impact experiments were conducted using the vertical gun located in the Experimental Impact Laboratory at NASA Johnson Space Center. The target material was a lunar highlands simulant from the Colorado School of Mines (CSM-LHT-1). The simulant is primarily made of GreenSpar anorthosite and basaltic cinder, with a final mean grain-size of 122 μm and a grain-size distribution similar to that of actual lunar regolith [4]. An independent physical assessment found that this material has a co-

hesion of ~ 10 kPa [5], while the values for lunar regolith between 0.1 and 2.1 kPa [2].

To make the targets, a set amount of regolith simulant was initially poured into a cylindrical Al bucket (26.0 cm interior diameter, 10.2 cm depth) and the surface was leveled off with a straight edge. Targets of differing packing fraction were then produced by placing a lid (that just fits inside the bucket) on top of the simulant surface and tapping the bottom of the container with a rubber mallet. The lid prevented material from escaping during tapping, while simultaneously ensuring that the surface would be flat and as close to normal to the projectile trajectory as practical. Varying the number of taps equated to different degrees of settling in the simulant, thus producing control over the packing fraction. The minimum and maximum packing fractions achievable with this combination of target material and settling technique yielded targets between 48 and 36% porosity, respectively. Due to the necessary slack in the fit of the lid, minor tilt from perfectly horizontal was allowed. This produced targets where the impact surface was not perfectly normal to the trajectory of the projectile, or gravitational vector, but these deviations were kept relatively small, with the largest being ~ 3 mm of elevation change over the diameter of the bucket (0.8° slope at the impact point).

After target construction, the simulant-filled buckets were placed under a vacuum of ~ 1 torr and held for a minimum of 2 hours, and up to 4.5 hours. The exposure to reduced atmosphere was found to be a necessary step to completely degas the targets, as the trapped atmosphere would cause easily identifiable

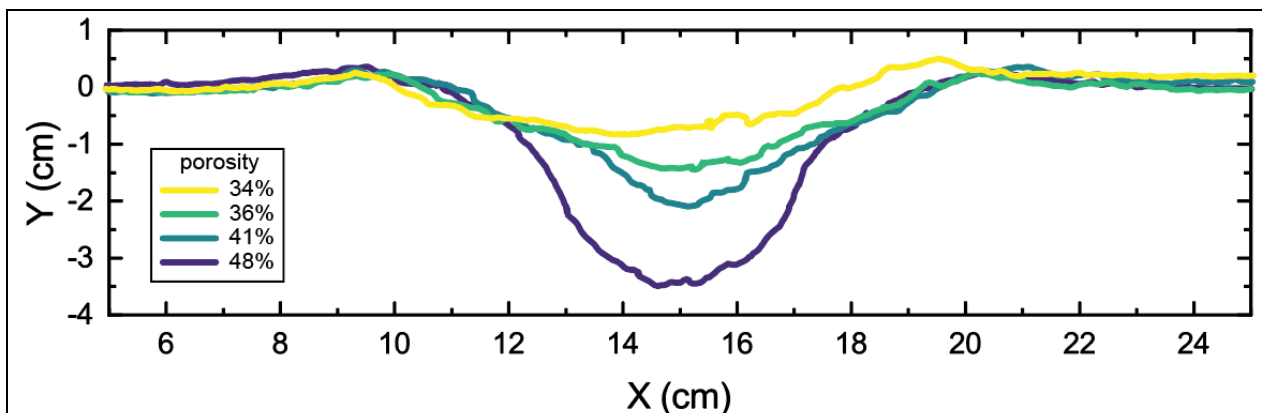


Figure 1. Crater cross-sections from four representative impact experiments into CSM-LHT-1 simulant that span the range of tested porosities (*i.e.*, packing fractions). These cross-section also illustrate the three crater morphologies identified throughout the experimental series – flat-floor (34 and 36%), central pit (41%), and pit (48%).

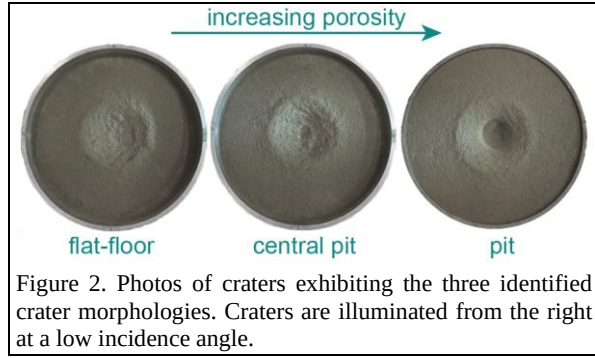


Figure 2. Photos of craters exhibiting the three identified crater morphologies. Craters are illuminated from the right at a low incidence angle.

collapse features in the final craters. After degassing, the targets were impacted with 3.18-mm (1/8") spherical Al projectiles at either 1.1 or 2.5 km s⁻¹. The resulting crater topography was recorded using a Peel 2 high-resolution 3D-scanner and those data were processed to yield crater cross-sections and morphometric values.

Results: Morphology. A variety of crater morphologies were identified as a function of target packing fraction (porosity). Targets with the highest porosity produced deep pit craters with long, steep, and straight walls (Figures 1 and 2). Decreasing the porosity The portion of the crater floor closest to the crater rim flattened out with decreasing porosity, but still maintained a smaller central pit below the impact point. These craters exhibited two different, distinctive slopes on their walls, similar to those observed in strength-layered targets [6]. Further decreasing the porosity eventually yielded craters that are characteristically flat-floored. The crater surfaces in these experiments are neither smooth nor homogenous, but instead are markedly hummocky compared to those in the higher porosity targets. The rugged interiors are particularly notable when compared to those from experiments using target materials with lower friction and cohesion, such as sand.

Morphometry. Substantial morphometric changes were observed as a function of packing fraction (porosity). Depth-diameter ratios (d/D , rim-crest relative) varied between 0.11 and 0.35 and were predominantly driven by the changes in crater depth as a function of target porosity, rather than crater diameter (Figure 3). A linear trend is observed between d/D and porosity within the tested parameter space. For the experiments conducted at an impact speed of 2.5 km s⁻¹, the transition between flat-floor and central-pit craters occurs near a porosity value of 37.5%, and the next transition to a pit morphology is estimated to occur between 44 and 47%.

Discussion: Lunar regolith is known to have a sharp increase in packing fraction as a function of depth, reaching near full packing density within 35 cm

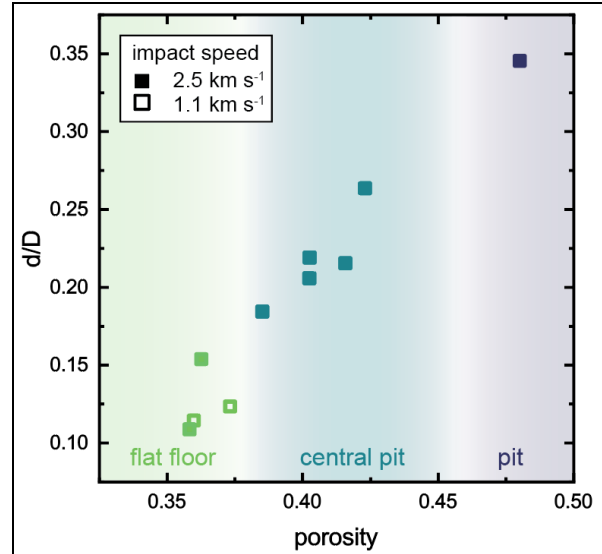


Figure 3. Target porosity plotted as function of final crater depth-diameter ratio for all 10 impact experiments. Vertical coloring indicates regimes of identified crater morphologies. Boundaries between colors are blurred to indicate the unknown nature of these morphological transitions.

of the surface [4]. This high packing fraction, in combination with a fine grain-size and high cohesion, leads to a higher effective shear strength for lunar regolith compared to those of the sand-like target materials often used in impact-cratering experiments. Previous experiments using quartz sand demonstrated a dependence of d/D ratio on packing fraction [3] and densely packed sand targets were able to produce craters with d/D ratios of ~ 0.17 . Although that study was able to approach the low d/D ratios (0.11-0.17) that are observed for small (<400 m diameter), fresh, lunar craters [7], the current experiments not only duplicate the observed range of d/D ratios for small lunar craters, but the craters themselves are also more similar morphologically as well. These results suggest that using a target material with more realistic values of friction and cohesion may be a more appropriate when conducting impact experiments for the purposes of constructing crater scaling relationships[8]. Future experiments will be conducted to define the scaling relations of this particular, and other relevant, simulant materials.

References: [1] Schmidt R. M. and Housen K. R. (1987) *Int. J. Impact engine.*, 5, 543-560. [2] Mitchell, J. et al. (1972) *LPSC III*, 3235. [3] Cline II, C.J., and Cintala, M.J. (2022) *MAPS*, 57, 1441-1459. [4] Carrier III, W.D. (1973) *The Moon*, 6(3-4), 250-263. [5] Martin, A., Wagoner, C. (2022) *Lunar Surface Science Cons.* [6] Quaide and Oberbeck (1968) *JGR*, 73, 5247-5270. [7] Stopar J. D. et al. (2017) *Icarus*, 298, 34-48. [8] Schultz and Gault (1985) *JGR:SE*, 90(B5).