TRANSIENT CRATER GROWTH IN LOW DENSITY TARGETS  P. H. Schultz, Brown University, P. O. Box 1846, Providence, RI 02912, peter_schultz@brown.edu

Introduction: Recent studies suggest that impacts into highly porous target materials require a new cratering regime controlled by compressional effects (1). Such research is important for interpreting the geologic history of small bodies and for the upcoming Deep Impact mission in 2005. An alternative view (2) suggests that even highly porous targets (density of 0.2g/cc) undergo gravity controlled growth and that previous studies underestimated the effects of an ambient atmosphere as previously documented (3,4). The present study re-examines these conflicting views.

Approach: Hypervelocity impact experiments were performed at the NASA Ames Vertical Gun range. Target materials included low-density perlite (and perlite mixes), microspheres, pumice, and sand. Impactor materials included aluminum and copper but primarily pyrex in order to ensure complete failure, as would be the case for much higher velocity impacts. High-speed imaging (500 and 6000 frames per second) captured the excavation process using both half-space and quarter-space target configurations. Quarter-space experiments previously documented atmospheric effects on crater excavation and demonstrated that the final crater measured was significantly different from the pre-collapse excavation crater (3,4).

Results: Vertical impacts into half-space (normal) targets at 1-g using sieved perlite targets revealed significant reduction in the cratering efficiency consistent with previous reports (1). In contrast with these studies, however, significant material was ejected from the crater. High-speed imaging revealed two ejecta regime. The first is a long-lived, pillar-like plume above the crater containing high-angle ejecta (80-90°). The second is the classic outward-advancing conical ejecta curtain with higher ejection angles (50-60°) than ejecta produced by impacts into less porous materials (pumice or sand). As the outward-moving curtain leaves the transient crater interior, the high-angle ejecta pillar returns to the crater and the crater collapses returning rim material to the interior.

Quarter-space experiments reveal that three material displacement regimes occur at hypervelocity. A penetration tube characterizes the first regime at early-times as target material is compressed in front of the fragmenting projectile. This tube expands cylindrically similar to the mach tube creating during hypervelocity atmospheric entry. The second stage of displacement is represented by the high-angle ejecta. Such high angles develop as the result of an expanding cavity at depth analogous deeply buried explosive charge. A pillar-like plume characterizes the third stage and lasts throughout crater formation. This stage represents the combined effects of cavitation and rebound.

Because most impacts are oblique, a series of experiments were performed at 60° and 30° (from horizontal). The 60° impact experiments demonstrated that the pillar-like plume is not directed back up the trajectory but evolves with time as the buried transient cavity expands. The reverse plume does not return to the cavity opening downrange with a shallower excavation cavity.

Crater growth for both vertical and oblique impacts into sieved perlite is distinctly non-proportional (Figs. 1 and 2). The diameter-to-depth ratio (D/d) evolves from 0.5 within the first 4 milliseconds to 1.5 at the end of excavation in the quarter-space experiments. In contrast the final D/d value for nominal (half-space) experiments with perlite is almost 3.

While final crater dimensions result in cratering efficiencies significantly below those for cratering in sand, the transient craters captured in the quarter-space experiments display values comparable to the sand experiments. Because of the deep penetration and delayed energy/momentum deposition, the transient crater is unstable with transient crater wall slopes approaching 60°. Crater collapse (combined with return of high-angle and rim ejecta) produce a final crater that has little to do with standard crater-scaling relations (see Fig.1a). As impact angle decreases, however, cratering efficiency based on final crater dimensions (half-space experiments) increases as the effective source depth decreases and ejecta permanently leave the cavity downrange. This result contrasts with impacts into less compressible and higher density sand and pumice impacts. Figure 4 illustrates the final transient profiles for various angles. Nevertheless, transient crater cratering efficiencies do follow the expected impact-angle effects (reflecting the vertical velocity component down to 60 degrees but depart at low angles.

Introduction of an ambient atmosphere (30 millibars) dramatically shuts-downs crater growth in perlite as previously shown (4,5). Experiments using the 30 millibars of He also reduced entering efficiency but to a lesser degree, consistent with the combined role of static pressure and dynamic pressure acting against the advancing wall of ejecta (see Fig. 3).

Concluding Remarks: The experiments suggest that highly porous targets primarily affect cratering efficiencies by producing deep transient cavities resembling deeply buried explosions. The transient
craters follow gravity-controlled excavation even though the final craters do not. Our experiments used sieved perlite targets. The addition of fine powders to the perlite changes the excavation process by introducing frictional drag between constituent perlite grains. In contrast with cratering in sand and pumice powder, reduced impact angles (30 to 15 degs) using fine-grained perlite result in a significant increase in crater size and greater stability in the final crater profile.

Figure 1. Transient crater evolution obtained from quarter-space impact experiments revealing non-proportional growth. Figure 1a shows the time evolution for a vertical impact at 6 km/sec (0.318 cm pyrex) into sieved perlite. The transient crater is completely unlike the final crater (dashed line) due to rim collapse and significant fallback of high-angle ejecta. Figure 1b shows a hypervelocity 60 deg impact at 5.6 km/sec and reveals the opening (blooming) of the transient cavity with time.

Figure 2. Effect of projectile/target density on the crater aspect ratio (diameter/depth). Data are for hypervelocity (6 km/sec) experiments at 60 degs.

Figure 3. Transient crater profiles for 60 and 90 deg impacts yield cratering efficiencies similar to impacts into sand. Lower angle impacts (30 degs), however, produce much larger craters due to energy/momentum deposition at shallower depths, analogous to the optimum depth of burst for explosion craters. The introduction of an atmosphere (30 millibars) has a significant effect on both the transient and final crater profile.