NON-PROPORTIONAL CRATER GROWTH IN EXPERIMENTAL IMPACT CRATERS. P. H. Schultz[1] and B. Hermalyn[2], [1]Dept. Geological Sciences, Brown University, peter_schultz@brown.edu, [2]NASA Astrobiology Institute/Institute for Astronomy, University of Hawaii, Honolulu, HI.

Introduction: It is often implicitly assumed that craters grow proportionally: crater diameter and depth grow at the same rate. Hypervelocity impact experiments, however, demonstrate that craters actually grow non-proportionally in gravity-controlled particulate targets. We highlight and examine this process by artificially truncating the excavation flow field by using a layer of sand on top of a competent substrate.

Background and Approach: Dimensional scaling relations assume similarity in all dimensions [1, 2]. Such an assumption allows derivation of fundamental relations between independent (impactor and target properties) and dependent (crater diameter, depth, volume, ejecta velocities). Nevertheless, numerous studies conclude that the final crater depth is achieved prior to the final crater diameter [e.g., 3, 4]. Moreover, the maximum depth of penetration in strength-controlled targets follows a different scaling relation than does crater diameter. The present study explores two experimental approaches at the NASA Ames Vertical Gun Range (AVGR) to underscore this process. First, quarter-space experiments (using both air-fall pumice dust and sand) allow tracking crater growth. Second, sand layers of varying thicknesses over competent substrates reveals the effect of a fixed depth on the final crater diameter and ejecta velocity flow field.

In quarter-space experiments, the launched projectile just misses a vertical acrylic window, typically less than a projectile diameter. This strategy allows tracing crater evolution [5,6]. While some concerns have been raised about energy partitioning in such experiments, high-speed imaging reveals that the initial shock decouples during the initial contact. The resulting shock wave cannot be transmitted across the opened space around the projectile, away from the window. Moreover, shocks transmitted along (parallel to) the window do not significantly disturb the flow field. Comparison of the expanding ejecta curtain diameter between half space (e.g., into a full bucket) and ¼ space experiments exhibit little difference, except at very early times.

For the ¼ space experiments, we examined both #20-30 sieved sand and air-fall pumice. The properties of air-fall pumice are very different from ground-up (commercial) pumice dust. The former is composed of loose elongate fragments; the latter, frothy grains. Impacts into ground-up pumice results in significant crater collapse after formation. Impacts into air-fall pumice retain their profile, but exhibit a zone of extension (bulking) delineating an inverted sombrero hat when excavated. Impacts into layered targets result in a nested crater: (a) excavation of the sand layer; (b) a central pit in the substrate (thin layer). The effect of the substrate on crater diameter in the sand layer was assessed with two strategies. First, crater diameters for different sand depths can be compared with craters produced in half-space targets (i.e., a nominal target). Second, the projectile can be allowed to pass through a hole in the competent substrate covered by a thin (0.5 mil Mylar sheet), which decouples the shock in the substrate.

Results: Crater diameter for impacts into pumice and sand targets evolves in two stages. The vertical acrlyic sheet affects measurements during the earliest stages of growth, but not the late stages. Before the crater in sand has achieves ~2% of its final diameter (in time), its diameter grows rapidly with a power-law exponent of 0.35. After about 30% of growth for sand (15% for pumice), the exponent reduces to 0.28, which is close to expectations for gravity-controlled growth [6]. Most of the ejecta are launched during this stage. The diameter-to-depth ratio reflects this growth pattern. The transition to gravity-controlled growth (rather than penetration) occurs when the crater achieves its final depth; nevertheless, the crater diameter continues to grow outward (Fig. 1). In other words, the crater grows non-proportionally during the final stages when most of the mass is ejected. Impacts into sand result in a transient crater shallower ($D_F/d_F = 2.3$) than pumice ($D_F/d_F = 2.9$).

Impacts into layered targets (Fig. 2) reveal that the final crater diameter is unaffected by the underlying substrate until the depth of the sand layer (h) is less than 4 times the projectile diameter (a) for vertical impacts, but 2a for a 30° impact [7]. In other words, artificial truncation of crater depth does not affect lateral crater growth (i.e., crater diameter). This observation demonstrates that crater diameter is controlled by the initial shock reflecting off the free surface, not the overall flow field. Laser sheets through the ejecta curtain reveal that the width of the ejecta curtain (i.e., the ballistic equivalence of emplaced ejecta thickness) is thinner than the width of a typical (½ space) impact experiment. This thinning indicates that the ejecta curtain is not receiving contributions from depth.

Particle Tracking Velocimetry (PTV), described in [8], further reveals that ejecta velocities are unaffected by truncating crater excavation (Fig. 3). Nevertheless, ejection angles for shallow sand layers (h=2a) become shallower (from 45° to 35°) relative ejection angles for a nominal impact or a layer with h = 4a.

Implications: Laboratory experiments demonstrate that craters grow laterally after achieving their maximum depth. Moreover, scaling relations for the final crater diameter are not the same for depth. Lateral crater growth reflects the consequences of the shock created at first contact as it interacts with the free surface, whereas depth depends on penetration. Our experiments also indicate that scaling relations for the outer rim diameter of nested craters (typical of small craters in the lunar regolith [9]) do not change until the h/a becomes very small, e.g., the melt pond of King crater [12,13].

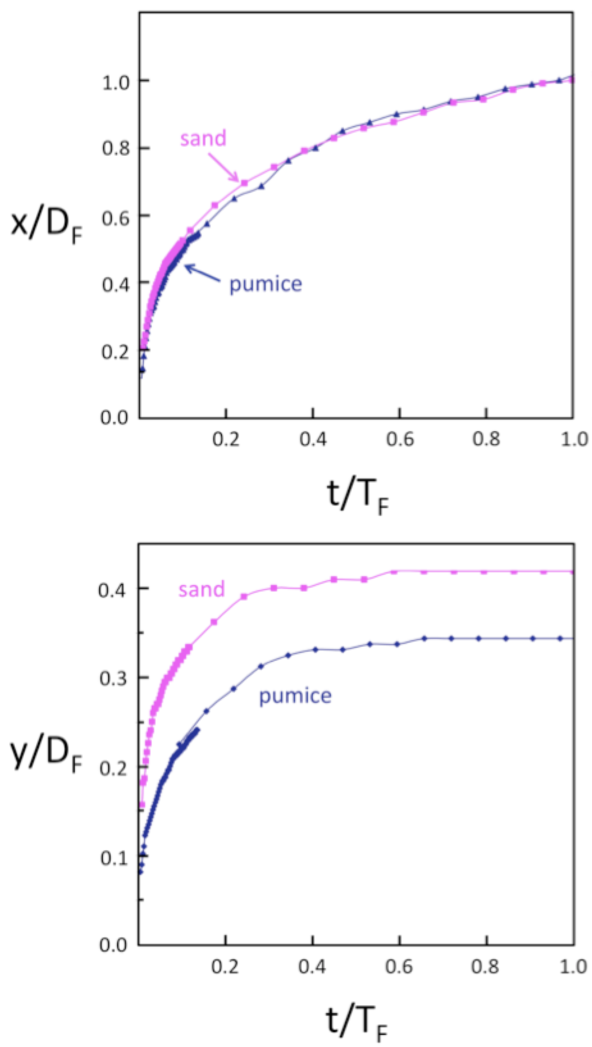

Figure 1: Evolution of the transient crater diameter (x, above) and depth (y, below) scaled to the final crater diameter (D_F) from quarter-space experiments for pumice and sand targets at a given time (t) scaled to the final formation time (T_F). Crater diameter continues to grow while depth effectively ceases by the time the crater has achieved about 30% of crater growth.

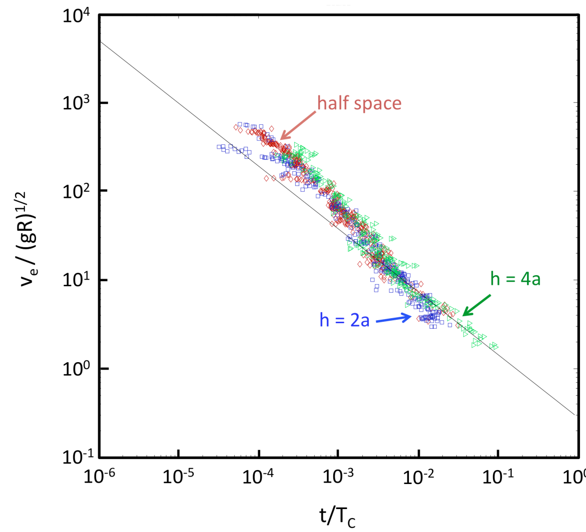

Figure 2: Dimensionless ejection velocities (scaled to gravity, g, and final crater radius, R) as a function of scaled time for sand target layers of thickness, h, over an aluminum plate relative to projectile diameter, a.

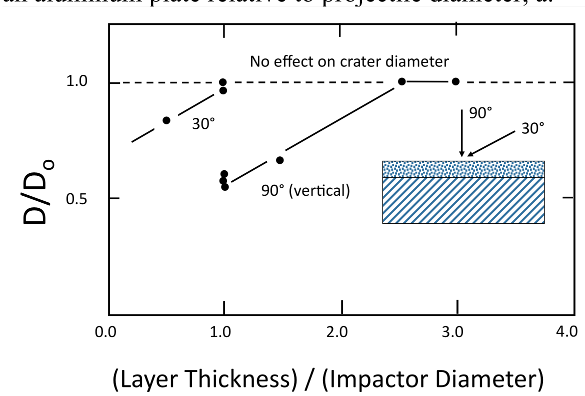

Figure 3: Effect of layer thickness on final crater depth (D) relative to half-space experiments for vertical and oblique impacts (from [7]).

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