EXPERIMENTAL EVIDENCE FOR NON-PROPORTIONAL GROWTH OF LARGE CRATERS P.H. Schultz, Dept. of Geological Sciences, Brown University, Box 1846, Providence, RI 02912 and D.E. Gault, Murphys Center of Planetology, Box 833, Murphys, CA 95247.

INTRODUCTION: The role of gravity in modifying the excavation cavity of large craters can be documented in the terrestrial geologic record (1,2) and observations of lunar craters (3,4). The terrestrial record also exhibits craters with flattened profiles and geologic cross-sections (5,6) that have prompted hypotheses for low-density impactors (7) or unusual impact conditions, e.g. atmospheric break-up or a shallow-sea environment (8,9). Others have proposed shallow basin excavation due to lunar internal structure (10). Evidence from laboratory impact experiments is indicating, however, that increasing crater aspect ratios (diameter:depth) also can result from increasing both velocity and projectile size without invoking unusual impactor conditions. If this trend continues to planetary-scale dimensions, then the shallowness of 100km-diameter craters may result not only from post-formation collapse but also from a modification of the cratering flow field during excavation.

EXPERIMENTAL RESULTS: An extensive data base of experimental impact cratering has been analyzed for a variety of impactors (aluminum, pyrex, lexan, lead, iron, clustered pyrex, etc.) and impact velocities (0.05 - 8km/s) for low strength targets (sand and compacted pumice). These data indicate a change in cratering efficiency that appears to be related to the onset of projectile deformation or rupture (11,12). For constant projectile size, this transition is accompanied by an increase in crater diameter relative to undeformed projectiles and net increase in diameter/depth (D/d). The aspect ratio for low-velocity impact ($v < 1.3$km/s) decreases slightly with increasing velocity but increases markedly for high-velocity impacts ($v > 2$kms). For constant impact velocity, D/d increases with projectile radius (r) for 0.159-0.635cm radii aluminum spheres. Smaller projectiles ($r < 0.2$cm), however, exhibit a reversal in this relationship for velocities greater than 3km/s: craters become deeper with increasing size. Combining these results, we find that $D/d \propto \alpha \log(r) - \beta \log(v)$ for larger projectiles larger projectiles (>.2cm) undergoing deformation at impact where $\alpha \approx \beta \approx 0.05$. The same relationship is found for aluminum wafers where the characteristic projectile dimension is the thickness (/2) rather than the radius. Small, high-velocity impactors, however, have $\alpha \approx -0.04$ to -0.1 and $\beta \approx -0.09$.

When all projectile types and sizes are considered, we find two contrasting relationships between crater aspect ratio and impactor parameters (r,v and density, δ_p). The transition occurs at a critical value of $\eta_c = (\delta_t/\delta_p)(r/v)$, which depends on target material: for sand, $\log \eta_c = -4$; for compacted pumice, it is -6. If $\eta < \eta_c$, we find that $\log D/d \propto \lambda \log (\delta_t/\delta_p)(v^2/r)$ where $\lambda \approx +0.1$. The gravity-scaled scaling parameter described in (13) can be used in place of r/v^2, but subsequent analyses suggest that gravity does not alter the cratering flow field, only the limiting diameter. The physical significance of the observed relationship may be related to the energy transfer rate to the target, which to first order can be expressed as v/t or v(v/r) if v/r is proportional to the time for projectile penetration. Higher rates of energy transfer result in proportionally shallower craters. For $\log \eta > \log \eta_c$, the aspect ratio depends simply on the time (r/v) for projectile penetration and target/projectile density contrast provided that projectile deformation occurs upon impact. Undeformed projectiles result in small aspect ratios. Long penetration times, whether the result of large hypervelocity or small low velocity impacts produce shallow craters. This point can be illustrated (Figure 1) by hypervelocity impacts by debris clusters with large radii or low velocity impacts by easily deformed projectiles (plastic or lexan). It should be remembered that these results apply to low-strength targets where gravity-dominated scaling relations apply. Both sand and compacted pumice targets indicate $\log D/d \propto 0.28 \log (\delta_t/\delta_p)\cdot(r/v)$. At extremely low impact velocities

(<0.1km/s) and no projectile deformation, a different relationship between aspect ratio and impactor/target parameters appears to be present.

MPLICATIONS: Most laboratory experiments permit a wide range in impact velocities (.05-7km/s) but only a narrow range in projectile sizes (0.159-0.318cm) over the same velocity range. Consequently subtle but important effects of projectile size at planetary scales are easily masked. On the Moon, the situation is reversed: projectile sizes can range over many orders of magnitude with the most probable impact velocities confined to less than an order of magnitude. If a typical lunar impact velocity of 15km/s is assumed, then η_c indicates a corresponding projectile diameter of 3m. The requirement that gravity-controlled scaling exists requires that either the crater is formed completely in low strength material (regolith) or at large enough scales (>2km) where gravity controls crater growth. At small scales, the Ranger and SIV-B impacts of the lunar surface have values of $\eta > \eta_c$ and were formed largely within the regolith. If the relation between crater aspect ratio and impactor parameters for small but high-velocity impacts were adopted, a small deep crater would be predicted. The alternative relation for predicts a shallow crater with a central mound, as is observed (15). If D/d = 5 for a 5km-diameter crater, then the gravity-limited transient cavity aspect ratio for a 100km-diameter crater is predicted to be about 12. The importance of post-cratering rim collapse (plastic flow and slumping), however, may be lessened but cannot be ignored.

References: (1) Dence, M.R., Grieve, R.A.F., and Robertson, P.B. (1977) in *Impact and Explosion Cratering*, p. 247-275, Pergamon, NY (2) Grieve, R.A.F., Robertson, P.B., and Dence, M.R., (1981) in *Multi-Ring Basins*, p. 37-57, Pergamon, NY. (3) Quaide, W.L., Gault, D.E., and Schmidt, R.A. (1965) in *New York Acad. Sci. Ann.*, *123*, p. 563-572. (4) Pike, R.J. (1980) *U.S. Geol. Survey Prof. Paper 1046-C* 77 p. (5) Roddy, D.J. (1968) in *Shock Metamorphism of Natural Materials*, p. 31-32, Mono Book Corp., Baltimore, MD. (6) Wilshire, H.G., Offield, T.W., Howard, K.A., and Cummings, D. (1972), *U.S. Geol. Survey Prof. Paper* 599-H, 42 p. (7) Roddy, D.J. (1977) in *Impact and Explosion Cratering*, p. 277-308, Pergamon, NY. (8) Melosh, H.J. (1981) in *Multi-ring Basins*, p. 29-35, Pergamon, NY (9) Gault, D.E. and Sonnett, C. P. (1982) *Geol. Soc. Spec. Paper 190*, p. 69-92. (10) Wilhelms, D. *et al.* (1977) in *Impact and Explosion Cratering*, p. 539-562, Pergamon, NY (11) Gault, D.E. and Wedekind, J. (1977) in *Imapct and Explosion Cratering*, p. 1231-1244, Pergamon, NY (12) Schultz, P.H. and Gault, D.E. (1985), *J. Geophys. Res.*, *90*, p. 3701-3732. (13) Schmidt, R.M. and Holsapple, K.A. (1980), *J. Geophys. Res*, *85*, 235-252. (14) Whitaker, E.A. (1972) *Apollo 16 Prelim. Sci. Revort. NASA SP-315*, 29.39-29.45.

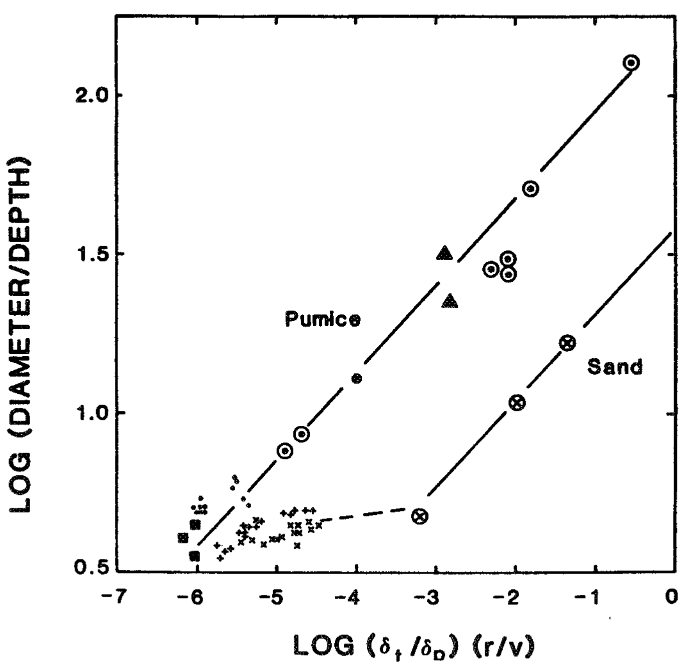

Figure 1. Data indicating the increase in D/d for increasing penetration times and δ_t/δ_D. Symbols for sand targets are: ⊗ clustered impacts; + 1.27cm diameter aluminum spheres; and x 2cm diameter lexan cylinders. Symbols for pumice targets are: ⊙ clustered impact; ▲ hollow nylon; • easily deformed plastic; ■ 0.635cm aluminum spheres. Dots indicate data for aluminum spheres impacting lead and glass shot targets.