N92-10858

IMPACT DECAPITATION FROM LABORATORY TO BASIN SCALES; P.H. Schultz, Geological Sciences, Brown University, Providence, RI 02912 and D.E. Gault, Murphys Center of Planetology, Murphys, CA 95247.

Although vertical hypervelocity impacts result in the annihilation (melting/vaporization) of the projectile, oblique impacts (<15°) fundamentally change the partitioning of energy with fragments as large as 10% of the original projectile surviving (1, 2, 3). Laboratory experiments reveal that both ductile and brittle projectiles produce very similar results where limiting disruption depends on stresses (σ_θ) proportional to the vertical velocity component, i.e., $v^2\sin^2\theta$. The failure process occurs in two ways. First, shock pressures generated at first contact spall the top of the projectile. The resulting decapitated projectile fragments impact downrange due to the added upward velocity component. The size of the largest fragment depends on the rise time of the shock wave, which depends on both depth of penetration before the shock reaches the back surface (related to impact velocity and material properties) and a dimensionless penetration time, τ, expressed as projectile diameter (2r) divided by the horizontal impact velocity component ($v\cos\theta$). As previously reported (3), the impactor fragments form craters downrange that are distinct from secondaries (defined as impacting target debris); hence, they have been termed "sibling" impacts. The distance from the uprange crater rim, x, is approximately given as $2r/v\tan\theta'$ where θ' reflects the altered trajectory (from horizontal) due to the upward spall velocity component. Experiments reveal that θ' can be significantly modified by entrainment in impact-generated vapor. Specifically, vapor produced during impacts into water, plasticene, and carbonate targets disperse the sibling fragments and extend the impact distance.

The second failure mode is expressed by pits overlapping the downrange rim of the oblong primary craters formed in strength-controlled aluminum at (15°). This mode may reflect simple shear as the projectile penetrates farther into the target with time and as strain rates decrease. This layer-cake failure style is most suggestive for ductile aluminum projectiles at lower impact velocities (3 km/s) or low angles and for projectiles with low yield strengths (e.g., pure aluminum). Downrange witness plates in such cases record a vertical chain of sibling impacts with reduced lateral dispersion. Paired downrange pits to either side of the trajectory axis commonly occur for hard (2024) aluminum spheres impacting aluminum and may indicate conjugate shear sets.

For strength-controlled cratering, the resulting profile of the primary crater along the trajectory exhibits deepest penetration uprange (reflecting energy partitioned at first contact) and a distinctive shelf-like region downrange (sibling impacts by the sheared projectile) at relatively modest impact angles (15°). As impact velocity or projectile-target density ratio decreases, however, the primary crater takes on a distinctive arrowhead shape with deeper penetration downrange. Clustered impacts provide an extreme example of this morphology (4). For gravity-controlled craters, such profiles also occur, but require much lower impact angles (<5°). Even though the profile and outline for craters in loose particulates are not dramatically changed at 15°, impacts by sibling fragments nevertheless emerge downrange from beneath the ejecta.

Failure of the projectile at laboratory impact velocities (6 km/s) is largely controlled by stresses established before the projectile has penetrated a significant distance into the target. This can be demonstrated by comparing the ricochet pattern and size distribution for an oblique (15°) impact into a thick plasticene block with an impact into a thin plasticene layer (equal to r) coating an aluminum block. The resulting siblings impacted downrange at identical distances; hence, the spall velocity was established by the plasticene, not the aluminum. Moreover, the underlying aluminum block showed only a subtle dent. Use of a thin water layer over aluminum gave the same results.

The planetary surface record exhibits numerous examples of oblique impacts with evidence for projectile failure and downrange sibling collisions. Selected examples were present previously (3) but a further survey has allowed quantifying the results. Figure 1 presents data for Mars where the downrange distance to the smaller sibling scaled to primary crater width is compared with the primary crater shape in plan. If crater width is controlled by strength scaling while crater length is controlled by the work expended during penetration, then crater length/width should be proportional to $\cot\theta$. Similarly, the downrange sibling impact distance scaled to crater width should scale as $\cot\theta/v^{2/3}$ for $\theta' \sim \theta$. The assumption of strength control in Figure 1 on the extreme reduction in peak stress expected for extremely low-angle impacts (0.8% vertical). Oblique impacts without downrange companions could indicate ejection off the planet. The crater Hale can be linked with downrange oblique sibling craters with arrowhead shapes extending completely around the planet.

The Crisium Basin on the Moon provides a specific example that bears remarkable similarities to strength-controlled craters in the laboratory. Figure 2 shows a sketch map identifying the basin massifs, mare units, and outer scarp. In addition to its oblong shape the western end exhibits the characteristic pinched morphology, whereas the eastern end exhibits a shelf and breach in the massif ring. Both elements are consistent with an east-west impact direction. The interior ring is more circular and offset to the west, analogous to the deeper penetration uprange observed in the laboratory. The striking similarity between the laboratory impacts and Crisium raises several intriguing questions. First, could Mare Marginis indicate downrange sibling collisions? If created by simple shear and allowing for surface curvature, such a scenario would lead to a projectile 360 km in diameter with an impact angle of 25°. If, instead, the eastern shelf marks impacts by this failure mode, then the projectile approaches 120 km in diameter with an impact angle of 15°. Mare Marginis would then represent decapitated sibling impacts. Second, could Mare Angus and Mare Undarum also indicate sibling fragments created by conjugate shear failure of the middle portion of the projectile? And third, what other impactor signatures exist on the planets and can the different modes of failure (e.g., Orcus Patera *vs* Crisium) provide new clues about basin-scale collisional processes and scaling?

References: (1) Gault, D.E. and Wedekind, J.A. (1978). *Proc. Lunar Planet. Sci. Conf. 9th*, 3843-3875. (2) Schultz, P.H. and Gault, D.E. (1990). *Global Catastrophes in Earth History: An Interdisciplinary Conference on Impacts, Volcanism, and Mass Mortality*, Geological Society of America Special Paper 247 (in press). (3) Schultz, P.H. and Gault, D.E. (1990). *Lunar and Planetary Sci. XXI*, LPI, Houston, TX, 1101-1102. (4) Schultz, P.H. and Gault, D.E. (1985). *J. Geophys. Res. 90*, 3701-3732.

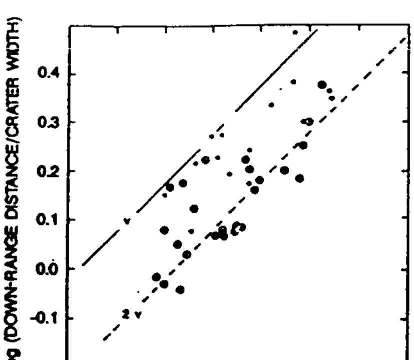

Figure 1. Distance from uprange crater rim (first contact) to downrange decapitation impact separated from crater (dots) or overlapping the crater (open circle) as a function of crater shape in plan. Lines correspond to two different relative velocities (v) predicted from strength scaling.

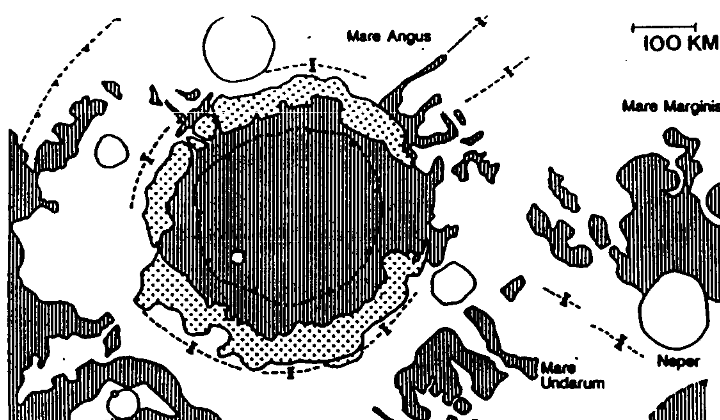

Figure 2. Terrain map of the Crisium Basin showing massifs (stipple) and mare regions. Eastern mare shelf may indicate consequence of projectile shear failure while Mare Marginis may indicate decapitation impacts.

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