All these features lie within a broad region of Mesozoic marine sedimentary rocks, the Indosinias formation, primarily sandstones interbedded with shales and limestones, which covers much of central Indochina. The age and composition of these sediments are broadly consistent with Australasian tektite composition and age [2]. Field work to examine these structures and collect country rocks for specific comparisons would seem warranted.

References: [1] Schnetzler C. C. (1992) *Meteoritics*, June. [2] Blum J. D. et al. (1992) *GCA, 56*, 483–492.

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RECOGNIZING IMPACTOR SIGNATURES IN THE PLANETARY RECORD. Peter H. Schultz[1] and Donald E. Gault[2], [1]Department of Geological Sciences, Brown University, Providence RI, USA, [2]Murphys Center of Planetology, Murphys CA, USA.

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Crater size reflects the target response to the combined effects of impactor size, density, and velocity. Isolating the effect of each variable in the cratering record is generally considered masked, if not lost, during late stages of crater modification (e.g., floor uplift and rim collapse). Important clues, however, come from the distinctive signatures of the impactor created by oblique impacts.

In laboratory experiments, crater diameter exceeds impactor diameter by a factor of 40 for vertical impacts into gravity-controlled particulate targets and reduces to 25 for oblique impacts at 15° from the horizontal. Strength-controlled cratering in aluminum reduces these factors to 5 and 2 respectively. As scale increases, crater excavation is limited by gravity and cratering efficiency becomes progressively less efficient. A 100-km-diameter crater on Earth (rim-to-rim diameter with 25% enlargement due to slumping) is only a factor of 12 greater than the impactor diameter for a vertical impact and reduces to 6 for a 15° impact angle based on scaling relations given in [1]. The early compression stage [2] at planetary scales, therefore, comprises a significant fraction of the final crater size and approaches a value more typical of strength-controlled laboratory experiments, particularly for oblique impacts.

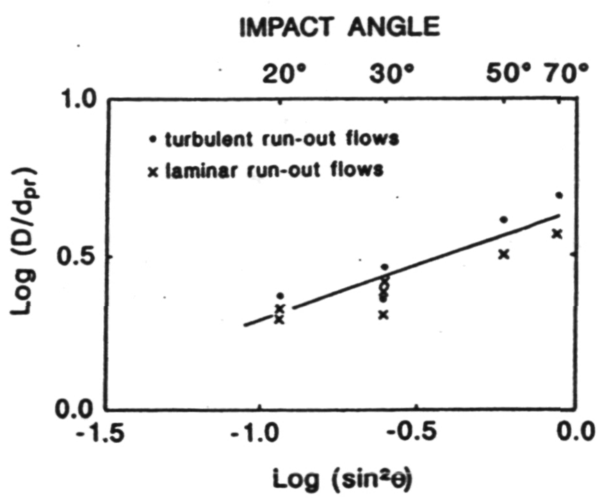

Fig. 1. Crater diameter (D) scaled to peak-ring diameter (d_{pr}) on Venus as a function of impact angle estimated from the degree of asymmetry in the ejecta deposits. If peak-ring diameter depends on impactor size (given velocity), D/d_{pr} should decrease as impact angle decreases, as is shown. Different symbols correspond to different styles of long run-out flows observed on Venus [6].

As a result, the distinctive signatures of early energy transfer may not be completely consumed by crater growth at planetary scales.

Two key diagnostic features of oblique impacts can be found in craters at both laboratory and planetary scales. First, oblique impacts create a distinctive asymmetric crater profile with the deepest penetration and steep inner wall uprange and a shallow, shelflike wall downrange [3]. Such a profile occurs for impact angles from 45° to 15° in strength-controlled craters (e.g., aluminum targets) but requires impact angles less than 5° for gravity-

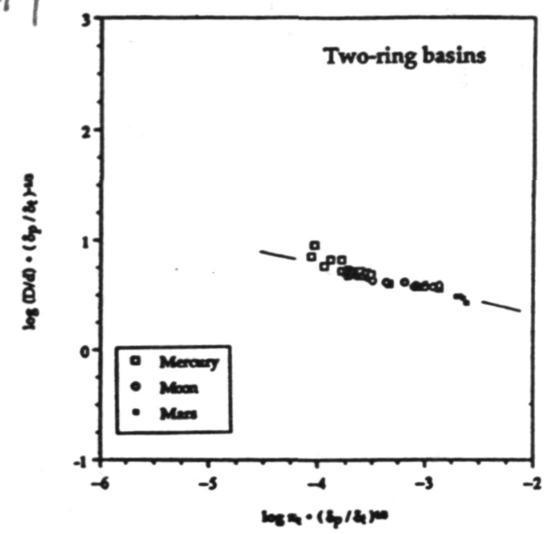

Fig. 2a. Crater diameter (D) scaled to impactor diameter (d) inferred from peak-ring diameter as a function of the dimensionless gravity-scaling parameter π_2 equal to $3.22\,gr/v^2$ with radius (r) again inferred from peak-ring diameter (g and v refer to gravity and impact velocity respectively; $\delta_p/\delta t$ represents projectile/target density ratio). Data for the Moon, Mercury, and Mars collapse onto a single relation for impact velocities 14, 16, and 32 km/s respectively.

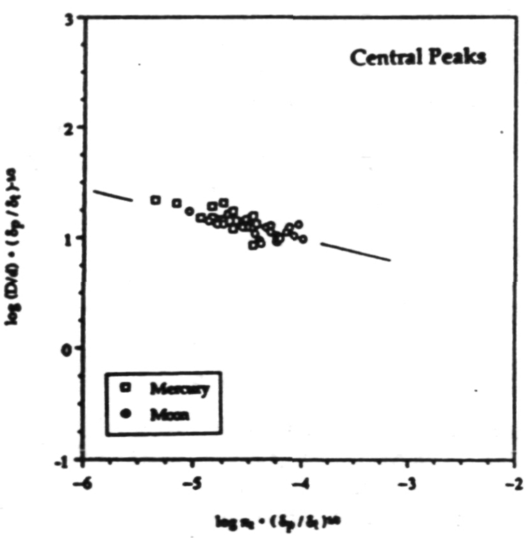

Fig. 2b. Crater diameter scaled to impactor diameter as in Fig. 2a but referenced to the diameter of the central peak. Assumed impact velocities for the Moon and Mercury in this case are 16 and 40 km/s respectively.

controlled targets (sand). Large simple craters on the Moon such as Messier exhibit the same profile. Larger complex craters, however, exhibit an indirect expression of this profile with more extensive rim/wall collapse uprange in response to the oversteeped inner wall and an uprange offset of the central peak complex in response to the deepest point of penetration (e.g., Tycho and King Craters). Two-ringed basins with other indications of an oblique trajectory also exhibit an uprange offset of the inner ring and enhanced uprange collapse (e.g., Moscoviense on the Moon and Bach on Mercury).

Second, interior pits created by hypervelocity impacts into strength-controlled targets become elongate and breached downrange as impact angle decreases from 45° to 15°. The diameter of the interior pit (χ_o) perpendicular to the trajectory is found to depend simply on the impactor diameter (2r), target/impactor density ratio (δ_t/δ_p), vertical component of impactor velocity (vsinθ), and target sound speed (c)

$$(\chi_o/2r)(\delta_t/\delta_p)^{1/3} \sim (v\sin\theta/c)^{\mu}$$

This relation can be directly derived from the pressure-decay law given in [4] where χ_o corresponds to a characteristic strength limit in the target.

Planet-scale craters also exhibit elongated and breached central peaks (e.g., King on the Moon) and peak rings (Bach on Mercury) as impact angle decreases [5,6]. If the central structures are large-scale analogs for the zones of maximum penetration in laboratory-scale hypervelocity impacts, then the diameter of the gravity-controlled crater diameter relative to the strength-controlled central structure should decrease with decreasing impact angle, as observed in craters on Venus (Fig. 1). In very-large-scale basins that undergo further enlargement by rim collapse or lithospheric failure, the distinctive impactor signature (e.g., breached downrange central ring) may persist even though its diameter relative to the diameter of the outer basin scarp no longer follows the same trend as smaller two-ringed basins (e.g., Orientale on the Moon).

If the central relief in impact structures simply corresponds to a zone of maximum compression during initial stages of penetration, then it may provide a measure of impactor size for a given impact velocity [6]. This hypothesis can be tested by referencing crater diameter to the central-ring diameter (in lieu of impactor size) and plotting this value against the dimensionless gravity-scaling parameter gr/v^2 where r again is replaced by the central ring dimension. The resulting power-law exponent (Fig. 2a) exhibits nearly the same value for different planets and can be brought into line by adopting reasonable average impact velocities for each planet. Central peaks may be similar manifestations of the impactor compression zone but it is uplifted during decompression due to higher peak shock pressures and smaller size. Figure 2b tests this hypothesis and reveals a very similar dependence.

In summary, oblique impacts allow identifying distinctive signatures of the impactor created during early penetration. Such signatures further may allow first-order testing of scaling relations for late crater excavation from the planetary surface record.

References: [1] Schmidt R. M. and Housen K. R. (1987) *Int. J. Impact Engng., 5,* 543–560. [2] Gault D. E. et al. (1968) In *Shock Metamorphism of Natural Materials* (B. M. French and N. M. Short, eds.), 87–100, Mono, Baltimore. [3] Gault D. E. and Wedekind J. A. (1978) *Proc. LPSC 9th,* 3843–3875. [4] Holsapple K. A. (1980) *Proc. LPSC 11th,* 2379–2401. [5] Schultz P. H. and Gault D. E. (1991) *Meteoritics, 26,* No. 4. [6] Schultz P. H. (1992) *LPSC XXIII,* 1231–1232. [7] Schultz P. H. (1988) In *Mercury* (F. Vilas et al., eds.), 274–335, Univ. of Arizona, Tucson.

PARADIGM LOST: VENUS CRATER DEPTHS AND THE ROLE OF GRAVITY IN CRATER MODIFICATION.

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Background: Previous to Magellan, a convincing case had been assembled that predicted that complex impact craters on Venus were considerably shallower that their counterparts on Mars, Mercury, the Moon, and perhaps even Earth. This was fueled primarily by the morphometric observation that, for a given diameter (D), crater depth (d) seems to scale inversely with surface gravity for the other planets in the inner solar system [e.g., 6]. Thus Venus, which is similar to Earth in its size and density, should yield a very low d-D trend, like that reconstructed from the terrestrial impact record (Fig. 1). In addition, deceleration of ejecta through the dense venusian atmosphere [8] and viscous relaxation of crater topography [11] due to Venus' high surface temperatures were expected to contribute to craters perhaps even shallower that those on Earth. Indeed, altimetric data from Pioneer Venus [6] and the Venera orbiters [3] indicated low relief for presumed impact craters on Venus, although the large footprint of radar altimeters grossly undersampled the true topography for all impact features measured, and many of the large circular structures thought to be impact basins were not. Even the enhanced resolution provided by the Magellan radar altimeter probably undersamples the relief of all but a few of the largest impact basins on Venus [4].

Depth Measurements: Useful crater topography can be extracted from Magellan radar images using the distortions in the cross track direction imparted by the interaction of radar incidence angle (θ) with surface slope. In the general case, two images of the same feature, taken at different θ, are required, but crater depths can be estimated by assuming the crater is symmetrical in the cross-track direction [4]. Using this technique, [9] have calculated crater depths for 73 craters out of a set of 102 large (18 km > D > 175 km) complex craters identified in Magellan data then available to them, indicating a power law fit $d = 0.28\,D^{0.46}$. The large dispersion in this dataset ($R^2 = 0.21$) probably reflects several effects including (1) errors associated with locating the rim crest and the outer boundary of the floor; (2) errors associated with asymmetries in the actual crater topography; (3) inclusion of relatively modified craters, as well as fresh craters; and (4) true variations in crater morphometry. Nonetheless, it is clear that venusian craters fall considerably above the terrestrial d-D trend, with the freshest craters (distinguished by parabolic deposits of distal ejecta [1]) virtually indistinguishable from the martian fresh crater trend (Fig. 1).

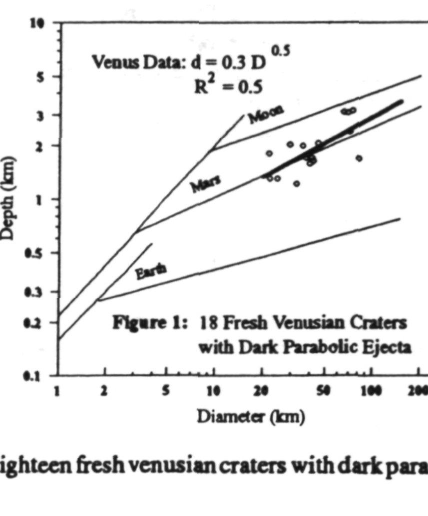

Fig. 1. Eighteen fresh venusian craters with dark parabolic ejecta.