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 ($v\sin\theta$), 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).

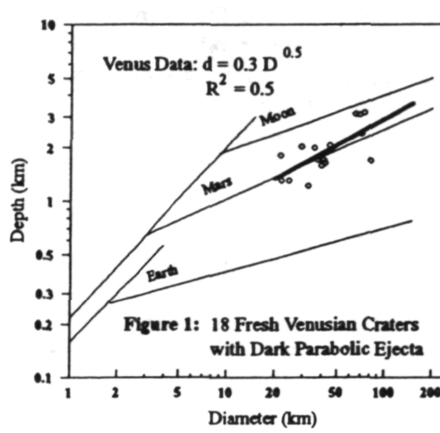

Fig. 1. Eighteen fresh venusian craters with dark parabolic ejecta.

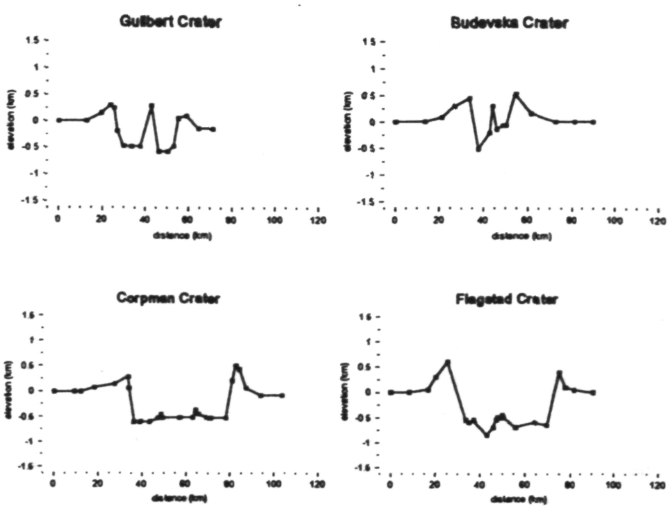

Fig. 2. Crater profiles constructed from Magellan image pairs.

Crater Profiles and Morphometry: The four crater profiles (~west-east, through the crater center) shown in Fig. 2 were produced using a nonstereo technique on Magellan cycle 1–cycle 2 image pairs. Guilbert and Budevska are central peak craters; Corpman and Flagstad are peak ring structures; Budevska is a fresh, bright-floored crater; the rest contain dark-floor deposits that may be indicative of volcanic or aeolian infilling. Corpman contains the most areally extensive dark floor deposits. The depth estimates of these craters support the single-image estimates presented above. Furthermore, because this technique does not hinge upon symmetrical topography, morphometric information can be extended beyond simple depth constraints.

The rim height (H_r) of these craters constitutes ~0.3–0.5 d and there are slight variations (<0.3 H_r) in the eastern and western H_r for all craters measured. Crater flanks, mantled by bright, blocky ejecta, are typically narrow, ranging from ~0.2–0.5 D. Assuming that ejecta constitutes ~0.5 H_r [5], the continuous ejecta blanket around Budevska Crater contains ~400 km^3 of ejecta, equivalent to ~300 km^3 of unfragmented target rock.

Central peak heights vary considerably from ~0.1 to 1.0 d. The lower extent of this range may be due in part to subsequent modification of Corpman by extensive dark floor deposits. The central peak of Guibert protrudes virtually to the level of the rim, and Budevska's central peak is only slightly shorter. Similar craters have been noted on other planets, e.g, the lunar farside crater, Icarus [7], and the terrestrial Marquez Dome crater [10]. Such craters, however, are relatively rare on other planets; having two such examples within a sample of four craters (Fig. 2) suggests that these anomalously tall central peaks might be more common on Venus. Crater floors are flat in all cases except Budevska, where the radar image shows a narrow ridge, coinciding with topographic profile, extending eastward from the central peak, thus resulting in the shallow depth on the profile's east side.

Fig. 3. Structure cross section of complex crater half-space. Crater center is on the right.

Implications and Conclusions: The unpredicted depth of fresh impact craters on Venus argues against a simple inverse relationship between surface gravity and crater depth. Factors that could contribute to deep craters on Venus include (1) more efficient excavation on Venus, possibly reflecting rheological effects of the hot venusian environment, (2) more melting and efficient removal of melt from the crater cavity, and (3) enhanced ejection of material out of the crater, possibly as a result of entrainment in an atmosphere set in motion by the passage of the projectile.

The broader issue raised by the venusian crater depths is whether surface gravity is the predominant influence on crater depths on any planet. There is an apparent d-g^{-1} trend in data from the Moon and Mercury, but these planets are all relatively small and, to the first order, of the same size. The surface properties and target characteristics of Mars are considerably different from those of the Moon and Mercury and could contribute to its somewhat lower d-D relationship. Although shallow depths, in accordance with g^{-1} scaling, are reported for terrestrial craters [6,2], there are no fresh complex craters on Earth from which to directly take these measurements. The Venus data in Fig. 2 indicate that H_r is a significant portion of d, and as all terrestrial complex structures are severely modified by erosion, d estimates may be up to a factor of 2 too low due to rim removal alone. In addition, when the crater rim and ejecta blanket have been removed, it becomes more difficult to determine the rim crest diameter. Reconstructions based on structural analysis may overestimate the true diameter if faulting extends beyond the rim as shown in Fig. 3. Thus while inverse gravity scaling of crater depths has been a useful paradigm in planetary cratering, the venusian data do not support this model and the terrestrial data are equivocal at best. The hypothesis that planetary gravity is the primary influence over crater depths and the paradigm that terrestrial craters are shallow should be reevaluated.

References: [1] Campbell D. B. et al. (1992) *JGR*, in press. [2] Grieve R. et al. (1981) *Multi-Ring Basins, Proc. LPS 12A* (P. Schultz and R. Merrill, eds.), 37, Pergamon, New York. [3] Ivanov M. N. et al. (1986) *JGR, 91*, 413. [4] Leberl F. et al. (1991) *Photogram. Engrg. Remote Sens., 57*, 1561. [5] Melosh H. J. (1990) *Impact Cratering: A Geologic Process*, Oxford, 245 pp. [6] Pike R. J. (1980) *Icarus, 43*, 1. [7] Schultz P. H. (1972) *Moon Morphology*, 626, Univ. of Texas. [8] Settle M. (1980) *Icarus, 42*, 1. [9] Sharpton V. L. and Edmunds M. S. (1992) *GRL*, in review. [10] Sharpton V. L. and Gibson J. W. (1990) *LPSC XIX*, 1136. [11] Solomon S. C. et al. (1982) *JGR, 87*, 7763.

K/T BOUNDARY STRATIGRAPHY: EVIDENCE FOR MULTIPLE IMPACTS AND A POSSIBLE COMET STREAM.

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A critical set of observations bearing on the K/T boundary events has been obtained from several dozen sites in western North America. Thin strata at and adjacent to the K/T boundary are locally preserved in association with coal beds at these sites. The strata were laid down in local shallow basins that were either intermittently flooded or occupied by very shallow ponds. Detailed examination by [1] of the stratigraphy at numerous sites led to their recognition