CONSTRAINTS ON THE IMPACT PROCESS FROM OBSERVATIONS OF OBLIQUE IMPACTS ON THE TERRESTRIAL PLANETS. R. R. Herrick and K. Hessen (Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX 77058; Herrick@lpi.usra.edu).

Introduction: Recently there have been significant advances in both experimental and numerical modeling techniques that hold promise for providing details on how the cratering process is affected by impact at a nonvertical angle [1,2]. Anectdotal observations of craters on the terrestrial planets validated initial experimental efforts [3,4]. Recent and ongoing systematic characterizations of craters reslting from oblique impact on the Moon, Mars, and Venus provide important constraints for the detailed modeling efforts currently being conducted [5,6,7].

Observations: Pertinent observations from surveys conducted to date are:

- The general variation in ejecta pattern and crater shape with decreasing impact angle on the moon matches well with experimental work conducted in a vacuum. On the moon the following transitions occur with decreasing impact angle with respect to horizontal: < ~50 degrees, the ejecta blanket becomes asymmetric; < ~30 degrees, a forbidden zone develops in the uprange portion of the ejecta blanket, and the crater rim is depressed in that direction; < ~20 degrees, the rim topography becomes saddle-shaped, or depressed in both uprange and downrange directions; < ~15 degrees, the rim becomes elongated in the direction of impact and the ejecta forms a "butterfly" pattern in the crossrange direction [5].
- In agreement with experimental work, the presence of an atmosphere significantly increases the onset angle of oblique impact phenomena in the ejecta pattern [5]. No downrange forbidden zone occurs at low impact angles [4].
- Our preliminary work with Martian craters shows that the change in ejecta pattern with decreasing impact angle closely resembles that of the moon, with the development of uprange and then downrange forbidden zones with decreasing impact angle. While the transition angles to different ejecta patterns are generally similar on the moon and Mars, the development of a forbidden zone in the uprange direction occurs at a significantly higher impact angle on Mars than the moon.
- The transition to elliptical craters and a butterfly ejecta pattern occurs at a higher angle on the planets than in early experimental work [3,5,6].
- Adequate data on crater wall topography of oblique impacts currently only exist for the moon. Unlike in experimental work, there is no strong evidence of uprange steepening of the crater wall for oblique impacts [5]. Internal slopes for lunar craters appear largely independent of impact angle. However, interior crater wall slopes approach the angle of repose, and post-impact slumping to a uniform slope cannot be ruled out.
- There is minimal evidence that central structures are offset in any direction relative to the crater rim [7], nor could we find observations in imagery that were indicative of the point of impact.

Constraints on the Impact Process: The observations suggest the following constraints on modeling efforts of the impact process:

- That the ejecta pattern is more affected by oblique impact than the final crater shape suggests near-field versus far-field effects; material ejected from near the point of impact "sees" the impact angle the most.
- Modeling of ejecta emplacement in an atmosphere must consider the disturbance of the atmosphere by the incoming projectile.
- Whatever causes the higher onset angle for elliptical craters and butterfly ejecta on the planets relative to past experimental work, those causes are only important at the lowest impact angles.
- The lack of variation for interior shape and slope suggests that the cross-section of stream tubes for late-stage excavation does not vary with impact angle.
- Mars is clearly below the threshold for the atmospheric disturbance caused by the incoming projectile to have a significant effect on ejecta emplacement.
- While subsurface features may reflect the initial point of impact, observable surface features do not. In other words, while the shock level of the rocks can be modeled as strongly direction-dependent, final crater shape must not be (with exception of rim elevation).

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