ASSESSING IMPACT TRAJECTORY IN THE GEOLOGIC RECORD. P. H. Schultz , Brown University, Geological Sciences, Providence, RI, 12912 (peter_schultz@brown.edu)

A paradigm exists that impact craters must be largely circular due to the overall symmetry of the intense, expanding shock at large distances from the point of impact. This paradigm is reinforced by cursory examination of impact craters on other planets, on terrestrial field experience, and on laboratory impact experiments in particulate targets. With this paradigm, most observed asymmetries are typically attributed to either differential erosion or overprinting by regional structure. Only the lowest angle impacts producing obviously elongate shapes, therefore, are easily recognized (1, 2). Here it is proposed that impact angles as high as 50_ from the horizontal can produce diagnostic asymmetries in primary patterns of deformation and modification that hold clues for impact trajectory.

Trajectory Indicators: Most terrestrial impacts are heavily eroded; hence, correlations between asymmetries in ejecta deposits and crater structure are rarely possible. Consequently, the planetary impact record and laboratory experiments provide the best clues for recognizing trajectory effects. These clues include the following features for complex craters and basins: uprange offset of the central uplift (peak, peak ring, or gravity anomaly) related to the maximum transient depth; breached or elongate central peak or ring reflecting the compression stage; greater central peak diameter ring relative to crater diameter (for a given diameter); pear-shaped crater outline; deep rim faults uprange (shallow downrange); maximum structural rim uplift perpendicular to the trajectory; maximum shock effects at depth perpendicular to the trajectory; minimal shock effects uprange; reduced shock at depth downrange; faults and fractures at depth parallel to trajectory downrange; enhanced shear deformation at depth downrange; and enhanced impactor signature in downrange melts. These general signatures of trajectory apply for impact angles between 15_ and 30_ but some elements persist to higher angles. They also become more evident with increasing crater size due to reduced cratering efficiency at large scales (3). All signatures, however, can be clearly documented for craters from 15 km to over 1000 km in diameter on the Moon, Mars, and Venus where the preserved distribution of ejecta allows corroborating evidence (4, 5). Moreover, all can be documented in much smaller scale hypervelocity laboratory experiments under controlled conditions that trace the distribution of peak pressures.

Because many terrestrial impact structures have been extensively eroded below the crater rim and well into the central peak, asymmetries in crater outline comparable to preserved analogs on planetary surfaces are lost. The outer limits of impact-induced failure near the surface are not the same as at depth. Near-surface failure is controlled by tensile strength following passage of the shock. Tensile strength is not only weaker than compressive strength but also depends on strain rate. Consequently, near-surface failure should extend well beyond the excavation rim and should increase with crater size beyond expectations for constant strength versus gravity scaling (5). This strain-rate dependence complicates derivation of impactor size from crater diameter and contributes to the apparent shallowing of craters with scale. Because the central uplift reflects the conditions of impactor penetration, it provides a more reliable indicator of impactor size (4, 6). Such processes contribute to the overall symmetry of the outer boundary of most craters, but asymmetry of the central structure preserves the fingerprint of the trajectory.

Possible Terrestrial Examples: The Chicxulub impact is believed to exhibit evidence for an impact trajectory from the southeast at 20_ to 30_ (7). It is suggested, however, that the Sierra Madera, Clear Water EW Lakes, and the Vredefort impact structures also exhibit evidence for impact angles less than 45_. The Sierra Madera (Texas) structure is a heavily eroded structure about 13 km in diameter (8) exhibiting four key signatures: an elongate central uplift indicative of a NW-SE impact; maximum shock effects perpendicular to the elongate uplift (expressed by the outer limit of shatter cones); offset placement of the uplift to the northwest in this zone; and breccia dikes parallel to the uplift trend.

The Vredefort structure also exhibits strucural, gravity, and magnetic asymmetries (9, 10) which often are attributed pre-existing or post-impact faulting. Nevertheless, the striking similarity with other even larger oblique impact structures on the Moon should at least raise the possibility that its pear-shaped outline could also be an expression of trajectory. Such a proposal may help explain its enigmatic shock record (11).

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