RIM CHARACTERISTICS IN FRESH LUNAR CRATERS INDICATE DIRECTIONAL VARIATIONS IN EXCAVATION FLOW.

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Introduction: Theorists [**e.g., 1**] assert that the initial product of impact excavation is a symmetrical cavity and that any departures from perfect circularity in the final crater's rim crest are solely due to subsequent, inward collapse of the transient crater's flanks [**1**]. Previously, we reported evidence derived from azimuthal variations in rim heights that contradict this belief [**2**]. In response, Melosh [**3**] argued that this "rim scalloping" is produced by ejecta ray formation. This suggests he believes that azimuthal variations in a crater's final rim height are not indicative of the relative volumes of excavated material deposited on a crater's flanks. Here we briefly review the morphological requirements of an ideally symmetrical excavation cavity and present additional data that support our original thesis.

Symmetry Requirements: Assuming a vertical impact onto a horizontal surface, perfectly symmetrical excavation flow must result in four morphological characteristics: The transient rim must be (**1**) *perfectly circular* and (**2**) *perfectly even* in elevation. Furthermore, the volume of ejected (and otherwise displaced [**4**]) material surrounding the excavation cavity must also (**3**) *decrease systematically* with increasing range from the impact point and (**4**) be *invariant with respect to azimuth*. Consequently, while inward, late-stage collapse destroys the crater's transient rim, it is possible to derive key information about its nature from the spatial characteristics of its final rim and flank topography as shown in **Fig. 1**.

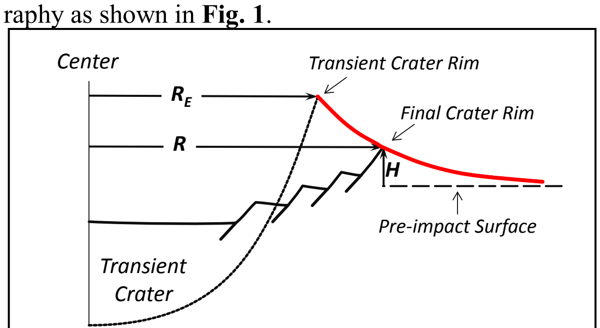

Fig. 1: Ideal symmetrical transient crater. Red line shows the trend of flank topography used to test symmetry.

Analytical Model: Any crater's flank topography is constrained by the relationship first described by [**5**], namely $h/H = r/R^B$, (**equation 1**) where h is the height of any point beyond the rim crest; H is the rim-crest height; r is the range to any point beyond the rim crest; R is the rim radius; and, B is the radial decay function controlling how rapidly flank topography diminishes with increasing range.

To test symmetrical excavation, we set H equal to the average of the set of h(θ) values representing individual height measurements taken along the final crater's rim crest, where θ denotes azimuth from the crater center. We similarly set R to the average range from center of this set of rim-crest measurements, r(θ).

If late-stage modification is solely responsible for plan-form and rim height variations within a crater, then those variations should correlate according to **equation 1** so that relatively high-standing rim segments are located at relatively short distances from the center in accordance with this equation. We use B=-3 to assess this correlation but its value is irrelevant as long as B is azimuthally invariant as requirement 4 ensures.

For those rim crest points that are higher than predicted, the surplus in elevation is assigned a positive value, i.e. +Δh; likewise, for any h(θ) value that is lower than equation 1 predicts, the deficient in elevation is assigned a negative value, i.e. -Δh.

We [2] applied this technique to 26 fresh craters formed on flat-lying mare surfaces by first referencing subsets of the GLD100 DEM to the local pre-impact surface and measuring the apparent heights and ranges of local rim crest points as a function of azimuth (θ).

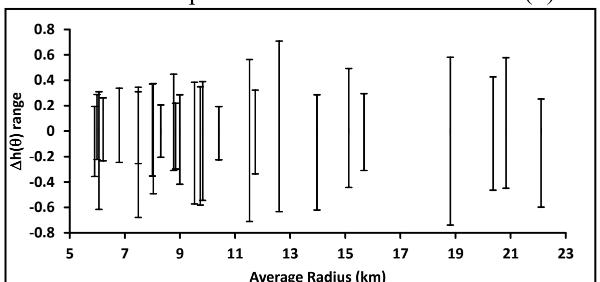

Fig. 2: Range of Δh(θ), i.e., measured h/H minus that predicted by equation 1. A perfectly symmetrical transient crater would plot as a point at Δh(θ) = 0.

Results: As previously reported, all analyzed craters showed significant inconsistencies with the symmetry requirements as shown in **Fig. 2**.

To assess whether local Δh values are reliable indicators of excavation asymmetries, we constructed radial topographic profiles at azimuths corresponding to the maximum and minimum Δh values for craters

Name	R(km)	+Δh	-Δh	Span
Sulpicius Gallus	6.0	0.288	-0.224	0.512
Cauchy	6.1	0.310	-0.616	0.926
Euclides	6.8	0.337	-0.246	0.583
Bessel	8.0	0.370	-0.353	0.723
Peirce	9.5	0.384	-0.572	0.956

Table 1: Craters selected for radial flank profile analysis taken at Δh maxima and minima. The first three are simple craters, the remainder are complex crater forms. All were formed on smooth, well characterized surfaces.

shown in **Table 1**. We then calculated the area under each profile beginning at a distance corresponding to the maximum range to each crater's rim crest and extending to equivalent distances for each crater's pair of profiles. **Fig. 3** and **Table 2** show the results of this effort.

Analysis and Conclusions: In all cases, profiles at azimuths corresponding to Δh maxima are associated with considerably thicker flank deposits compared to those taken at Δh minima locations; with flanks in the direction of Δh minima having only approximately half as much apparent topography as those associated with Δh maxima. As this flank topography is created during the excavation process through ejecta deposition and target uplift [**4**], this relationship verifies our original conclusion that Δh values are indicative of the relative proportions of material that have been excavated in those directions. Consequently, we conclude that these values are reliable indicators of asymmetric excavation flow.

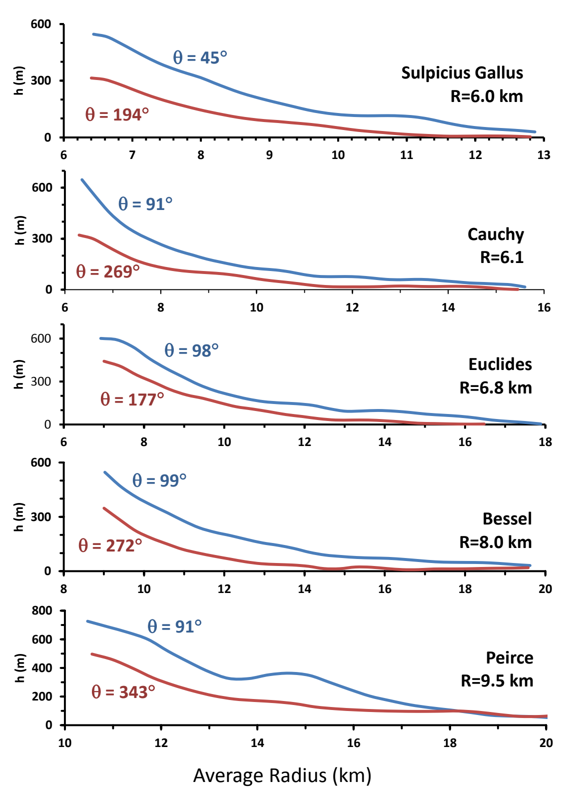

Fig. 3: Radial profiles show azimuths (θ) associated with Δh maxima (blue profiles) are consistently associated with higher flank topography – indicative of thicker deposits of excavated material – than are Δh minima (red profiles).

Name	Blue Profile	Red Profile	Red profile/ Blue profile
Sulpicius Gallus	1.36	0.63	0.46
Cauchy	1.52	0.75	0.49
Euclides	2.11	1.2	0.57
Bessel	1.79	0.77	0.43
Peirce	3.21	2.08	0.65

Table 2: Areas under each profile (in km^2) show clear correspondence between locations of Δh extrema and meaningful differences in the implied volumes of excavated material in those directions.

Azimuthal variations in excavation flow may indicate lateral variations in target properties within the excavation zone. Alternatively, they may result from non-vertical impact trajectories. If the latter, then Δh values may be a more sensitive indicator of impact angle than those previously reported [**e.g. 6**].

We are currently evaluating patterns in Δh(θ) data [**2**] to gain additional insights into their geological significance.

References: [**1**] Melosh H. J. and Ivanov B. A. (1999) *Ann. Rev. Earth Planet. Sci. 27*, 385-415. [**2**] Sharpton V. L. et al. (2016) *LPSC LXVII*, Abstract 1115. [**3**] Melosh, H. J. (2016) Oral Comment at *LPSC LXVII*. [**4**] Sharpton V. L. (2014) *JGR 119*, 154-168, doi:10.1002/2013JE004523. [**5**] McGetchin T. R. et al. (1973 *EPSL 20*, 226-236. [**6**] Schultz P. H. and Anderson R. R. (1996) *Geol. Soc. Am. Spec. Pap. 302*, 397-417.