EJECTA THICKNESS AND TARGET UPLIFT MEASUREMENTS FROM LUNAR CRATER RIMS.

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Introduction: The elevated rims of impact craters consist of fragmental ejecta ballistically emplaced onto target rock that has been structurally uplifted from its pre-impact level. Reliable constraints on the proportions of each of these components, therefore, are essential to understanding how craters grow and distribute their ejecta.

McGetchin et al. [1] proposed a semi-empirical model of ejecta distribution, $t(r,R) = T(r/R)^{-3}$, where t is ejecta thickness at any range, r, from the crater center; T is the ejecta thickness at the crater rim; and R is the crater radius. This model was developed specifically to understand large lunar craters and basins as well as their influence on specific localities around the Moon and has been used widely and with far-reaching conclusions. Until recently, however, the only available estimates of T came from laboratory-scale impact experiments, high-explosion craters, and the terrestrial Barringer Crater. These results are generally reported [e.g. 2] to indicate that ejecta thickness makes up 50-75% of the total rim relief, h, measured from the pre-impact surface, i.e., T/h=0.5-0.75.

High-resolution LRO/NAC images recently revealed layered outcrops along the walls of many craters formed on mare surfaces. Such images along with elevation data (i.e., GLD100 [3] and NAC-stereo DTMs [4]) provide new constraints on the relative proportions of rim ejecta and wall uplift at lunar craters.

Craters formed on mare surfaces offer several important advantages for accurately constraining T: they are among the youngest lunar craters and thererfore retain characteristics of their original morphology; they form on a flat-lying, readily constrainable surface allowing rim heights to be accurately measured; and outcrops of their stratified volcanic target rock assemblage are readily apparent in the walls of many mare craters (e.g. Fig. 1).

Here I report measurements of maximum ejecta thickness (T_{max}) and minimum target uplift (WU_{min}) for 5 lunar mare craters, ranging in diameter from 2.2km to 30km and address the implications for understanding the nature of material flow during the crater excavation stage.

Approach: Pre-impact surface elevations were determined by fitting a 2nd order polynomial to a subset of the the best available elevation data surrounding each crater beyond its continuous ejecta deposit; these elevations were then subtracted from the original DTM to derive elevations referenced to the pre-impact surface. Layered parautochthonous outcrops were identified relying on lateral continuity and thickness; in the case of crater Linné, >35° slopes on the upper crater walls provide additional support for these layers being coherent rock units and not fragmental ejecta. The top of the uppermost outcrop layer is assumed to define the local *minimum* amount of wall uplift, WU_{min}. Rim height (h) and WU_{min} were measured along a radial traverse. The local *maximum* eject thickness on the rim, T_{max} was derived by subtracting WU_{min} from h.

Results: Table 1 summarizes the average values (with standard deviations) of n measurements taken around each of the five craters studied so far. These results indicate that only the upper 10-28% of the crater rim represents ejecta – *a significant deviation from the 50-75% previously suspected* [e.g., 1,2]. This holds for both simple and complex craters. The values reported here are conservative: only laterally extensive outcrops were considered and it is likely that covered target rocks could exist above those exposed as outcrops in the walls of these craters.

Table 1: Maximum ejecta thickness (T_{max}) and minimum wall uplift (WU_{min}) measurements from 5 lunar craters

Crater	h	n	WU_{min}	T_{max}	T_{max}/h
Linné* ***(R=1,089)***	105 ±5	8	80 *±4.8*	25 *±4*	0.24 *±0.04*
Lichtenberg B* ***(R = 2,441)***	199 ±37	14	178 *±36*	20 *±9*	0.10 *±0.04*
Marius A ***(R = 7,657)***	673 ±30	14	541 *±70*	132 *±75*	0.19 *±0.11*
Dawes ***(R = 8,511)***	658 ±116	28	502 *±87*	157 *±81*	0.23 *±0.09*
Kepler* ***(R = 14,947)***	578 ±142	17	404 *±65*	175 *±111*	0.28 *±0.13*

All dimensional values in meters referenced to the estimated pre-impact surface. *Used in calculating WU* and h*

Analysis: The data in Table 1 demostrate that crater rim elevation is constructed principally through structural uplift of the target assemblage rather than ejecta emplacement as has long been held. The target outcrop assemblage on the eastern wall of Marius A (Fig. 1) appears to have been uplifted *en masse* at least 600m from its pre-impact level and is covered by no more than 110m of ballistically emplaced ejecta. This suggests that outward expansion of the excavation cavity, at least during the latest part of the excavation stage, is dominated by *injection* into the surrounding target rather than *ejection*.

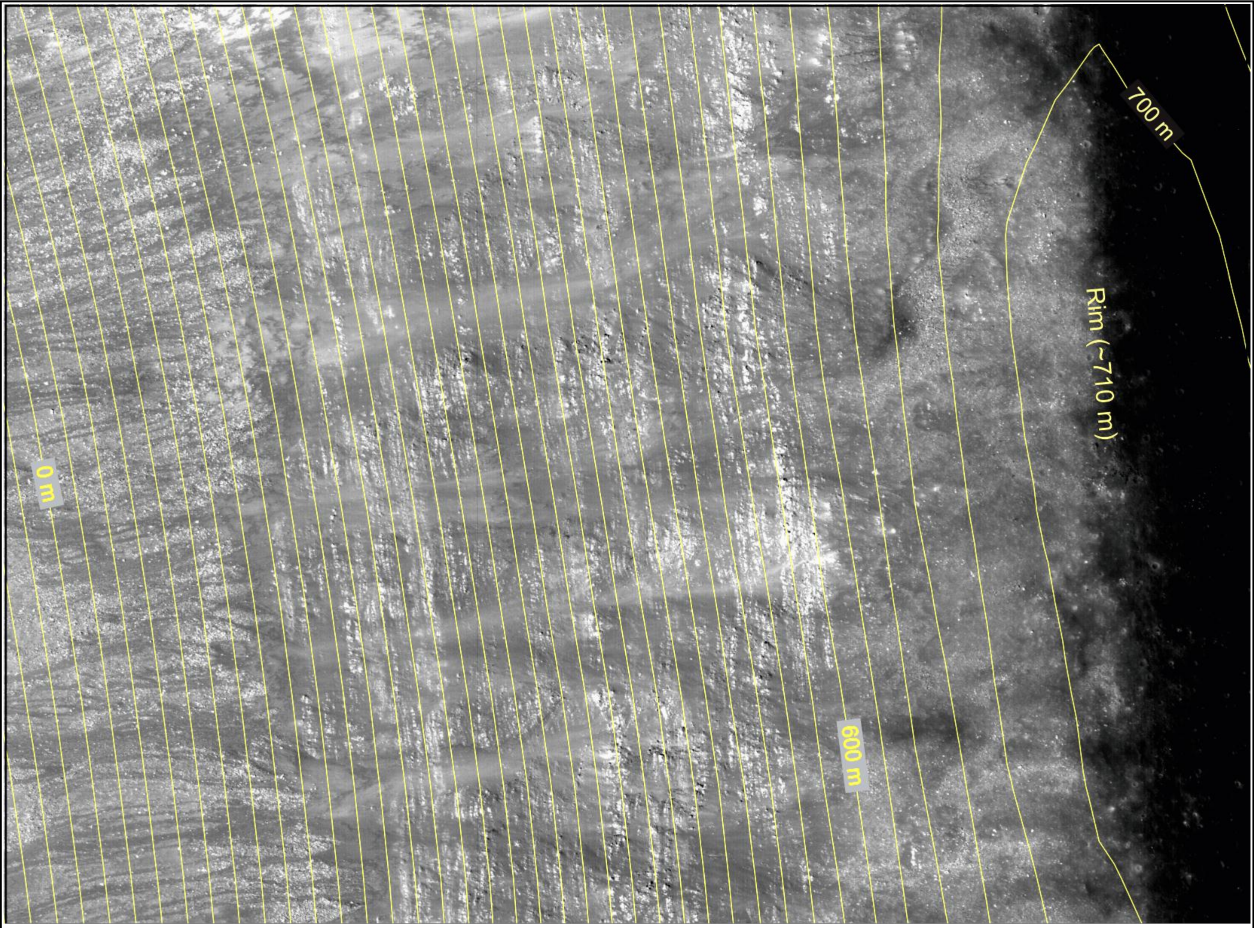

Fig. 1: Portion of NAC 137848463R over eastern the wall of Marius A crater showing ~450m-thick exposed layered target-rock sequence extending to within ~100m of the rim. Yellow lines indicate 20 m elevation contours from the GLD100 DTM referenced to the pre-impact surface (0m contour). Image is 1,350m by 1,000m.

Complex craters such as the ~30km Kepler (Table 1) are widely believed to have undergone a late-stage modification that enlarges their final crater diameters by a factor of 1.5-2 [e.g., 2]. The degree of wall uplift displayed in Kepler, therefore, indicates that uplift does not simply reflect a narrow zone of deformation limited to near the excavation crater wall but may follow a radial decay law similar to that of the ejecta deposit.

Normalizing WU_{min} for Linné, Lichtenberg B, and Kepler (Table 1) to the excavation cavity radius (R_e) using conventional scaling laws (i.e., Re=.85R and Re=.65R for simple and complex craters, respectively [5]) yields a best-fit function: $WU^* \geq 0.13(r/R_e)^{-2.7}$. Using the same approach for h, yields $h^*=0.15(r/R_e)^{-2.1}$.

This assessment ignores the role of ballistic sedimentation [6] which would erode the underlying, uplifted target surface at the final crater rim. As the importance of this effect increases with increasing R_e and, due to late-stage modification, is greatest for complex craters, the WU* decay rate reported here is steeper than the actual value.

Even so, comparison of WU*and h* indicates that the volume of material injected into the target surrounding the excavation crater, rivals and *perhaps exceeds* that which is ballistically ejected during the excavation stage of these relatively large lunar craters.

Measurements from other mare craters are underway to gain more insights into crater rim development. The values reported here, however, appear sufficient to demonstrate that analytical models of excavation flow [e.g. 7] primarily based on experimental and explosion craters may be providing misleading results.

References: [1] McGetchin T. R. (1973) *EPSL, 20,* 226–236. [2] Melosh H. J. (1989) *Impact Cratering: A Geologic Process, Oxford Univ. Press, 245 pp.* [3] Scholten F. et al. (2012) *JGR, 117,* DOI: 10.1029/2011JE003926. [4] Tran T. et al. (2011) *Proc. ISPRS, Tech. Commission IV. ASPRS/CAGIS 2010 Fall Specialty Conference*. [5] Grieve R. A. F. et al. (1981) *Proc. LPSC 39A*, 37–57. [6] Oberbeck V. R. (1975) *Rev. Geophys, 13*, 337-362. [7] Croft S. K. (1980) *Proc. LPSC 11*, 2347–2378.