SHAPE DISTRIBUTION & MODIFICATION SEQUENCE OF SIMPLE CRATERS IN LUNAR MARIA

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Introduction: The morphometry of simple lunar impact craters has been extensively studied to understand landscape evolution, impact cratering, and target properties [e.g., 1-5]. The goals of the present work are to (i) characterize the distribution of planform and profile shapes of well-preserved simple craters on the Moon ($1\text{ km} \leq D \leq 10\text{ km}$), and (ii) to characterize the morphological modification sequence and provide an additional test of linear diffusion models of lunar landscape evolution [e.g., 4,5].

Methods: A total of 210,046 impact craters were chosen for the study, mapped in [6] and sampled largely from the lunar maria to avoid highly complex surrounding topography. A 5*D* x 5*D* region was cropped around each crater (catalog diameter *D*) from a global 20m-resolution DEM assembled from SELENE/Kaguya terrain camera data [7]. The set of all radially-averaged profiles sampled from craters (whose positions were refined using a rim-finding algorithm) was 192,592, and the set of all planforms successfully sampled from cavity contours was 141,101. A battery of quality metrics were computed and combined to assess the accuracy of crater localization; a threshold was applied to generate two subsets: “high quality profiles” (51,271) and “high quality planforms” (81,967). Finally, a subset of craters labeled “deep + high quality” consisted of 313 craters for which the depth/diameter ratio fell in the range 0.2 to 0.3. This small subset was used to characterize the morphometric properties of impact crater DTMs exhibiting a high level of preservation and data quality.

The morphometry pipeline computes dozens of parameters; among these are: $\ell_{c:im}$: radius of curvature at the rim, where smaller values indicate sharper rims; λ_{rim}: steepening length scale at rim: the distance from the rim at which the slope reaches half of its maximum value in the cavity while moving centerward, where smaller values indicate sharper rims; λ_{cav}: steepening length scale in cavity: the distance from the crater center at which the slope reaches half of its maximum value in the cavity while moving outward, where smaller values indicate higher curvature; α_2: exponent of power law fit to the cavity profile (from center to $R/2$), where ~1 indicates a conical shape and ~2 a paraboloidal shape and >2 suggests a bowl shape with a flatter floor as values increase higher still; σ_R : the standard deviation of the crater radius (a measure of radial asymmetry of crater planforms).

Simulations: The LandLab landscape evolution modeling package [8] was used to simulate simple linear diffusion of impact craters in order to characterize the expected lunar crater modification sequence. Craters in the “deep + high quality” subset were used as the initial condition for these simulations. That is, their elevation profiles were sampled and used to generate symmetric 3-D elevation models which were then forward-evolved. The morphometry pipeline was used to extract key morphometric parameters from each time-step, for comparison with measurements.

Results (*profiles*): The measured crater modification sequence is represented as whisker plots of radius- and diameter-normalized morphometric quantities as a function of crater cavity aspect ratio (d/D), in this way illustrating how shape depends on diameter-normalized rim-to-floor depth. Plots of this kind are shown in Figures 1 and 2, filtered by profile quality. The results of the computer simulations are shown in red.

The trends in diameter-normalized rim height (h/D) vs diameter-normalized rim-to-floor depth (d/D) shows broad agreement with model results (see Figure 1A). That is, crater rims appear to erode and cavities infill by amounts consistent with highly local material transport via linear diffusion, as expected. By contrast, the median of rim steepening length (λ_{rim}/R) plots systematically below expectations (Figure 1B). This is consistent with results for rim curvature radius shown in Figure 1C. Both results suggest that crater rims remain sharper while the cavity fills than linear diffusion predicts; a nonlinear slope dependence may help to explain this [e.g., 5]. Linear diffusion drives the value of the exponent of lower cavity power-law fit to a value of ~1.7 (Figure 1D). This is despite a wide range of values for the initial crater. We find that the median of this quantity does in fact reach a value that is consistent with the expected result for $0.06 < d/D < 0.1$. On the other hand, the width of the distribution for smaller d/D remains very large, and does not narrow considerably as expected. This variation at small d/D in this and other plots is likely due to localization errors even in this high-quality profile population, deriving from preexisting complex topography, mass wasting, subsequent cratering, and the challenge of accurately measuring morphometric parameters from very shallow, heavily modified craters.

Results (*planforms*): The dependence of standard radial deviation (σ_R) on crater diameter (D) has been measured previously for a small population of well-preserved impact craters on Mars [9]. This previous work showed that the dependence is $\sigma_R \propto D^m$ for $m \sim 1$ for complex craters, whose final rim wall planform is largely determined by modification processes [9]. For simple craters, this was shown to be closer to $m \sim 0.5$ to 0.6 for well-preserved craters influenced by strength effects, and closer to $m \sim 1$ for heavily modified populations. It was unknown how or whether this relationship would hold for the lunar maria. We find that $m = 1.097 \pm 0.007$ for all planforms, and $m = 0.948 \pm 0.011$ for the high-quality subset, suggesting that poor localization has in many cases produced spurious measurements of highly irregular enclosed contours in intercrater topography. These results for the high-quality subpopulation measurements are consistent with the earlier martian crater results for a general population including mostly craters that have been heavily modified [9]. Results for the "deep + high quality" subset of well-preserved craters are also consistent with the earlier findings from the martian study, with $m = 0.502 \pm 0.076$ as expected from the influence of strength heterogeneities on the excavation flow [9]. In summary: the planform departure from radial symmetry is a far weaker function of size in small, simple craters whose shape was more likely to have been influenced by strength effects during excavation.

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References: [1] Soderblom, L.A. & L.A. Lebofsky (1972) *JGR*, 77:279–296; [2] Wu, B., etal (2022). *GRL, 49* (20), e2022GL100886. [3] Basilevsky, A. T. et al. (2018) *Planet. & Space Sci.*, 162, 31-40; [4] Fassett, C.I. and B.J. Thomson (2014) *JGR-Planets* 119, 2255–2271; [5] O'Brien, P. and S. Byrne (2022) *Planet. Sci. J.* 3, 235; [6] Robbins, S.J. (2019) JGR-Planets, 124 (4), 871–892; [7] Haruyama et al. (2012) LPSC 43, #1200; [8] Hobley, D.E.J et al. (2017) *Earth Surf. Dyn.*, 5 (1), 21–46; [9] Watters, W.A. et al. (2017) *Icarus 286,* pp.15-34.

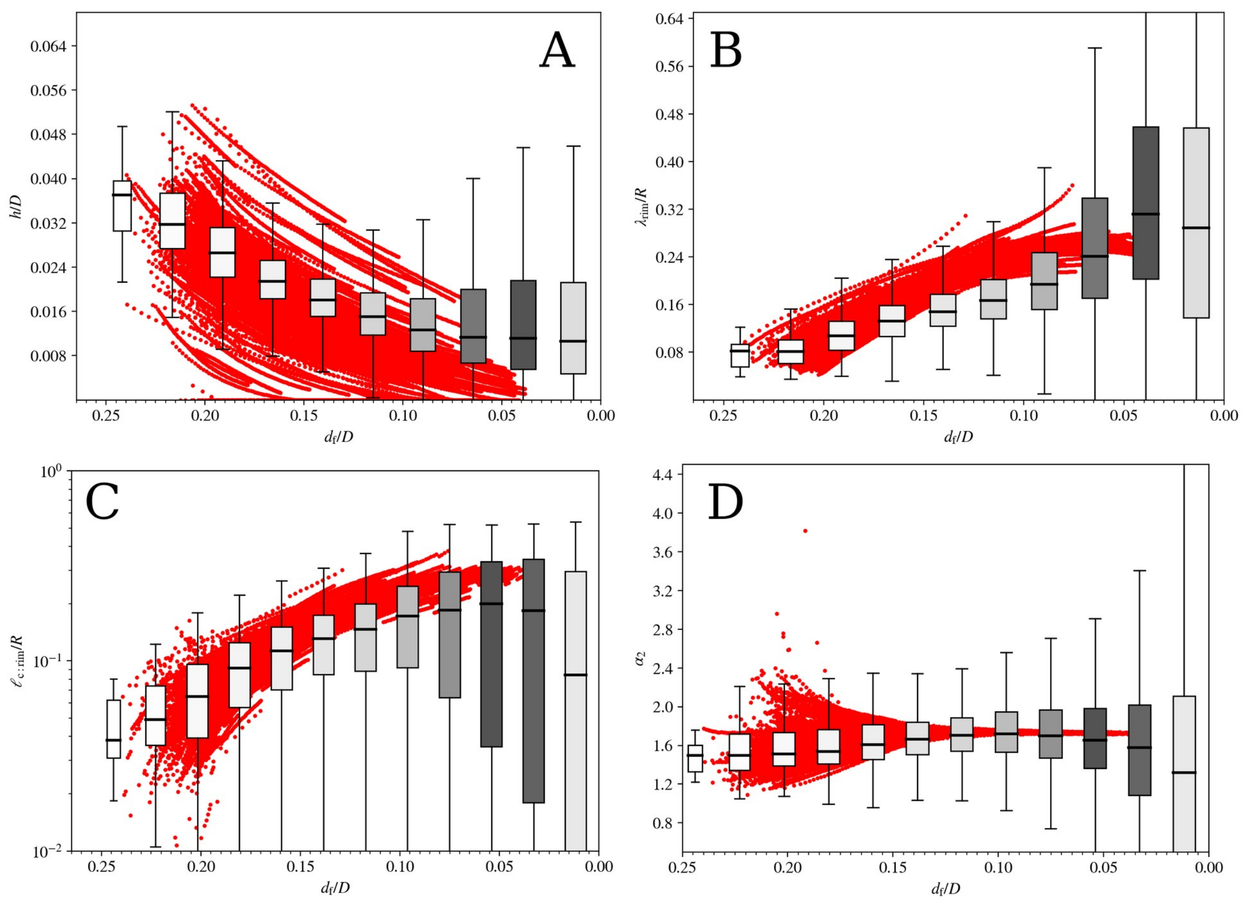

Figure 1: Crater modification sequence: plots of morphometric quantities vs. depth/diameter. The data set was filtered to find the ∼ 25% of profiles with the highest profile quality scores (N = 51, 271). (A) rim height/diameter (h/D) vs. d/D; (B) rim wall steepening length-scale (λ_{rim}/R) vs. d/D; (C) rim wall curvature radius ($\ell_{c:rim}/R$) vs. d/D; (D) power law exponent of basal cavity fit (α_2) vs. d/D.