BOULDER DISTRIBUTIONS AROUND YOUNG, SMALL LUNAR IMPACT CRATERS.

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Introduction: Boulders on the Moon degrade over time, primarily as a result of micrometeorite bombardment [1,2], so their residence time at the surface can inform the rate at which rocks become regolith. Boulder distributions around craters of varying ages are needed to understand regolith production rates, and Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) images [3] provide one of the best tools for conducting these studies. Here we present initial work using NAC images to analyze boulder distributions around craters of different sizes and ages, and to compare these boulder distributions with crater properties (*e.g.,* age, diameter, regolith thickness, terrain type, depth-to-diameter ratios). These comparisons inform how various properties affect the distance to which boulders are ejected and the size and density of boulders produced by an impact event.

We count boulders around craters at legacy landing sites because there is extensive NAC coverage of these craters at high resolutions, and because we have age estimates for many of these craters. We have completed counts around the following craters: Cone (26 Ma [4], 340 m diameter), North Ray (50 Ma [4], 950 m), South Ray (2 Ma [4], 700 m), Surveyor (200 Ma [4], 200 m), and Zi Wei (at the Chang'e-3 site; 100 Ma [5], 450 m).

Methods: We use CraterTools [6] and Crater Helper Tools in ArcMap to identify and estimate the size of boulders. Detailed methods can be found in a companion abstract [7]. Using NAC images with 0.5-1.0 m/pixel resolutions, the smallest boulders that can be identified with confidence are ~1-2 m. We determine boulder size and frequency distributions at increasing distances (in units of crater radii) to find how the frequency of ejected boulders varies as a function of distance from the crater rim, as discussed in [7,8].

Results: We investigate boulder distributions and sizes as a function of crater age, crater diameter, regolith thickness, and depth-to-diameter ratio, and a few correlations have begun to emerge.

Size-Frequency Distributions: Because of the gradual degradation of exposed boulders, boulder population densities should decrease as craters age. Comparing the size-frequency distributions (SFDs) at our count areas (**Fig. 1**), we find that this relationship holds true. North Ray, however, has more boulders than the younger South Ray and Cone craters, and we attribute this to North Ray's large size. These SFDs are fit with power-law functions, consistent with other studies [9-13]. Resolution limitations may be responsible for smaller power law curve slopes [12], as seen for Zi Wei (1.5 mpp image), because smaller boulders are not captured in the count.

Large craters generally excavate more boulders than small craters, and the size of the largest boulder ejected is related to the size of the crater [12-16]. Our analyses indicate there is a linear correlation between increasing crater diameter and maximum boulder size (**Fig. 2a**), and larger craters generally eject boulders to greater distances (**Fig. 2b**). Deviations from this trend can be explained in part by impact conditions. For example, South Ray distributed boulders much farther than North Ray, even though North Ray is larger. This discrepancy could be explained if South Ray was formed by a higher velocity impact than North Ray, which would result in the production of more small boulders that were ejected at higher velocities and therefore traveled farther from the crater rim [17]. Similarily, lower velocity impacts favor larger boulder sizes [17], which could explain why NR has a greater population of large boulders than the younger South Ray and Cone craters (**Fig. 1**).

When normalizing for crater size, we also see a relationship between age and maximum boulder distance; younger craters have boulders out to greater distances than older craters (**Fig. 2c**). This trend likely occurs because fewer boulders have degraded at young craters, so the smaller boulders that were ejected far-

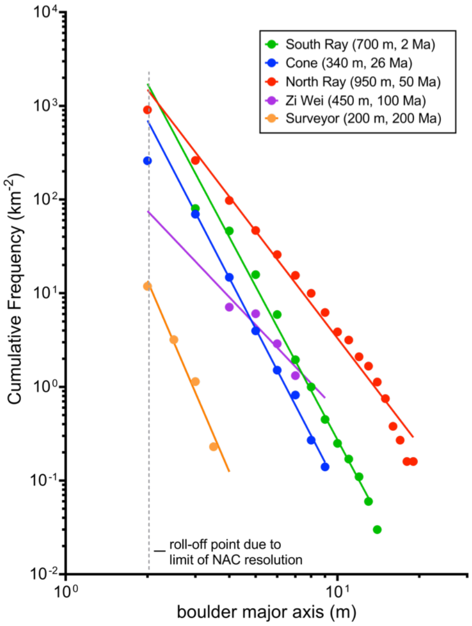

Fig. 1: Size-frequency distributions show that young craters have higher boulder populations. Each distribution is fit with a power-law function.

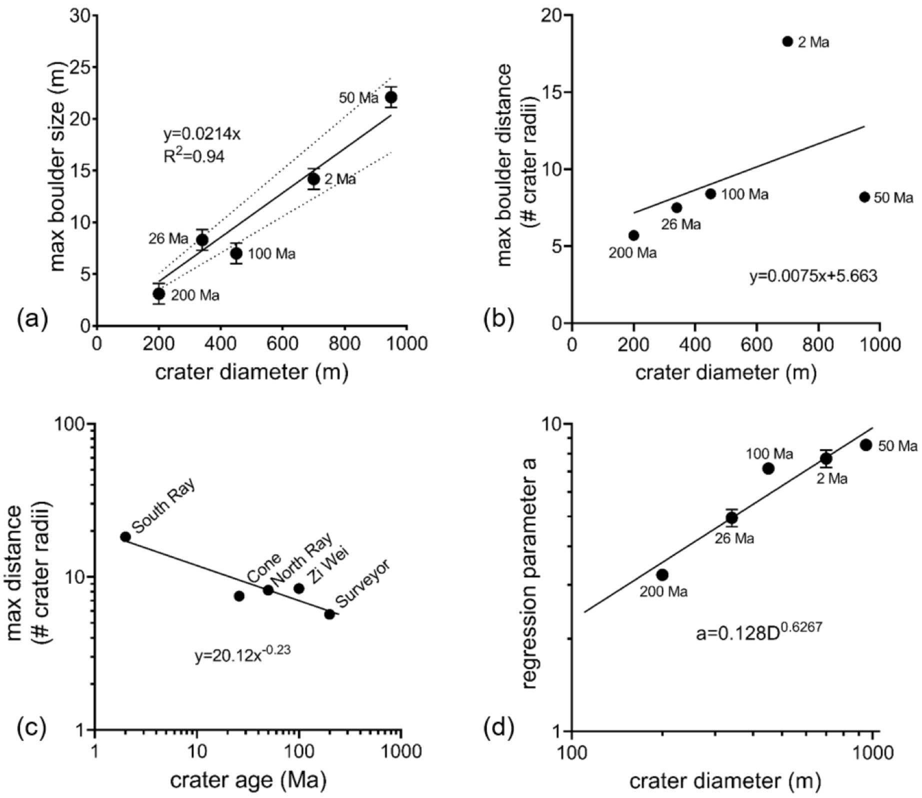

Fig. 2: Comparison of a) max boulder size as a function of crater diameter (dashed lines are 95% confidence interval), b) max distance boulders were ejected as a function of crater diameter, c) max distance boulders were ejected as a function of crater age, and d) quantile regression parameter "a" as a function of crater diameter for each count area.

ther out are still visible in NAC images.

Size-Range Distributions: Size-range distributions (SRDs) show that the largest boulders occur close to the crater rim and small boulders occur at all distances [8,13,16]. Large boulders are scarce at the older craters (Zi Wei and Surveyor), supporting the idea that large boulders degrade more quickly [18,19]. SRDs can be used to predict the maximum boulder size at any radial distance from the crater using quantile regression fits of the form $d_{max}=aR^{-b}$, where d_{max} is the maximum boulder diameter at a distance R from the rim [7]. Fitting the 99th quantile to each SRD, we find a correlation between a and crater diameter (**Fig. 2d**, [13]) and a weak correlation (not shown) between increasing crater diameter and decreasing b. Quantile regressions at additional study areas will provide enough values for a and b to allow us to derive equations to predict these values as a function of crater size.

Other Correlations and Future Work: Cone, North Ray, and South Ray craters are young relative to the estimated time required to break down boulders [9,16], so many of their boulders are still present. However, we have not yet seen a quantitative relationship between crater age and boulder areal density because of complicating factors such as crater size, regolith thickness, and impact conditions (target strength, impactor speed, size, and impact angle). Following the model set forth by [18] that establishes a relationship between Diviner rock abundance (DRA) and crater age, we can use DRA as a proxy to test for a relationship between crater age and boulder areal density using NAC boulder counts. Areas of thinner regolith should have higher block densities associated with craters [12] since the craters have penetrated to bedrock, but we have insufficient data to test for a relationship between regolith thickness and boulder populations. There are many variables that affect boulder distributions, and our ongoing work will include more counts of boulder populations around craters with similar properties. These counts will allow us to better assess how boulder distributions change as a function of time, and of varying crater and terrain properties, thereby informing the median survival time of boulders and the Moon's regolith production rates.

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