**Introduction:** Understanding boulder size-frequency distributions on the lunar surface is important in understanding small-scale erosion processes and the rate at which rocks become regolith [1, 2]. The dominant process by which boulders degrade over time is a result of bombardment by small meteoroids [3, 4, 5]. Rock distributions also contain geological information related to the planet’s origin and evolution [6].

Lunar Reconnaissance Orbiter Camera (LROC) Narrow Angle Camera (NAC) images are one of the best tools for boulder population counting. Past studies on boulder counting present results in the form of cumulative size frequency distribution (SFD) as a function of boulder size (diameter). The slope of that distribution is the parameter of interest, and it varies for rock populations that have experienced differing levels of comminution [7]. An error range is necessary to quantitatively determine whether two different slope values are in fact statistically distinct. The error on the number of boulders is commonly taken to be the square root of the number of boulder in a particular size bin [e.g., 8]. However, past studies have not conducted an error analysis for the boulder size. In this work, we report on our analysis of these errors. We have two main goals: 1) to determine the smallest boulder size that can be mapped with confidence, and the quantitative error associated with rocks of that size; and 2) to quantify the effect of size uncertainties for all boulder diameters. Previous studies suggest that the smallest boulders that can be identified with confidence are ~1-2 m in diameter (> 3 pixels), if the NAC images have a resolution of ~0.5 m/pixel [9]. However, smaller boulders contribute to the observed roll-off in the cumulative SFD plot (Fig.1), indicating that some of these small boulders are being missed; moreover, those small sizes are uncertain by a previously unknown margin. Our results provide new insight into this issue. In addition, a rigorous error analysis for the size of boulders will help in quantitatively analyzing the SFD slopes for different distributions.

**Methods:** In the NAC images, we identify boulders as bright, sun-facing pixels adjacent to dark, shadowed pixels [10]. We use LROC NAC images with ~0.5 m/pixel resolution and ~60°-80° incidence angle. We map boulders using the ellipse fitting tool in ArcMap CraterTools. Using the long and short axes of the ellipse, we calculate the volume of an ellipsoid (with the third dimension (height), being equivalent to the short axis). We know that in most cases a rock ejected would lie with its short axis upward (i.e. long axis lies on the surface). So we see the long and short dimensions when looking at observed rocks [e.g., 11, 6]. We therefore estimate the unknown third (vertical) axis to be equal to the short horizontal axis. We then take the diameter of a sphere with equivalent volume to the ellipsoid thus formed as the boulder diameter, for plotting against boulder size frequency. In order to determine the error on this value, we use a rectangle fitting inside an ellipse (Fig. 2), to calculate volume of that rectangular prism, again taking the third side to be equal to the short axis. As mentioned above, we identify boulders as bright pixels (which are square in shape in the LROC NAC images) and we map these using ellipses. The volume of the ellipsoid we assume is larger than the volume of the rectangular prism that square pixels would represent, leading us to overestimate boulder sizes (Fig. 2). We estimate this volume discrepancy by examining a series of rectangles fitting inside ellipses, representing different pixel arrangements. As shown in Figure 2, we map such that edges of the bright pixels representing boulders are always enclosed in the ellipses we draw. For this reason, a given ellipse is always larger than the rectangular arrangement of pixels, and our boulder sizes are therefore

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**Fig.1:** Cumulative size-frequency distributions of boulders around different craters.
always overestimated. However, this represents an idealized case. In practice, it is very difficult using the ArcMap tool (CraterTools) to draw the ellipses with the precision implied in Figure 2; most of the ellipses actually “cut off” one or more corners of the pixel arrangement that represents a given boulder (Fig.3). The result is still an overestimate of the boulder size, but the error is usually smaller than what we calculate here. Therefore, our results give an upper bound on the boulder size error.

Finally, we assume that a worker using this tool will draw the most reasonable ellipse for a given boulder pixel arrangement (i.e., those shown in Fig. 2, and not ellipses drawn, e.g., perpendicular to these). Our error estimates below are based on this assumption; relaxation of this assumption would lead to much larger error estimates.

Fig.2: Rectangle fitted inside an ellipse for different pixel arrangements, for a boulder defined by 6 pixels.

Fig.3: Examples of boulder mapping using ellipses in ArcMap. The ellipses “cuts off” one or more edges of the boulders.

Results: Our calculations show an error range of 14-36% on boulder sizes (Fig.4). A given boulder diameter has a range of errors as a result of different pixel arrangements. In the case where all the edges of the bright pixels exactly touch the outline of the ellipse, the error is 13%. As the number of edges that lie on the ellipse decreases, the error increases. We perform error calculations for boulders with diameter of ~2-5 m (2-10 pixels). However, we can extend these results to larger boulders because the uncertainty is determined by the rectangle-to-ellipse ratio, which is independent of boulder size.

Fig.4: Range of error for boulder sizes in range of 1.0-5.0 m. Different error values for a given boulder diameter is a result of different pixel arrangements.

Future Work: We will continue boulder counting around craters of varying ages, sizes, and terrain type (mare vs. highlands). This is important in understanding how boulder distributions change over time. Having multiple people mapping the same area can also help better constrain the error range in boulder sizes.