THE SHAPES OF SIMPLE IMPACT CRATERS ON MARE SERENITATIS.

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Introduction: In previous work [1,2] I showed that the vast majority of simple impact craters can be very well-represented by general conic sections (not just parabolas), and that under this assumption the shadowfronts they contain must consist of arcs of ellipses. These can be measured directly from spacecraft imagery and used to calculate accurate crater depths *and shape profiles*, independent of whether the shadowfront crosses the crater center. The resulting crater shape is then fully specified in terms of the depth (d), the diameter (D), and the eccentricity (e) of the approximating conic section of revolution.

In [1,2] I also showed that this "Free Shadowfront Method" (FSM) compares very favorably with some of the best laser altimetry (LOLA) and stereo-derived DEMs available for simple craters. I also found that the existing paradigm for simple craters (i.e. $d/D \sim 0.20$, $e \sim 1.00$) is not very accurate. Here I apply the FSM to over 100 more small (0.4 km < D < 6 km) simple craters on Mare Serenitatis (MS) in order to support and quantify these conclusions using a considerably larger sample size. In the process I find a striking correlation between the *quantified* shapes of these craters and their *subjective* 'degradation states'.

Methods: I used the latest version of my computer implementation of the FSM to measure 124 simple craters in 20 suitable LRO_NAC images of MS. This version uses least-squares routines to compute best-fits to the crater rim circles and shadowfront ellipses from sets of user-selected data points. The solar incidence angle for each crater was calculated from the sub-solar latitude and longitude and those of the individual target crater. The crater shape results were plotted on e vs. d/D axes (Fig. 1). Except for the 7 members of a small cluster of secondaries, the resulting crater profiles were then normalized to $D = 1$, resampled at 100 points, and 'stacked' point by point to obtain a mean shape for these craters (plotted on Fig. 1). Clips of all of these craters (minus the cluster craters) were then sorted according to their positions along a best-fit straight line fit through the e vs. d/D data, organized into a "line-up", and examined for any systematic, qualitative variations.

Results: The most obvious result of all this is that none of the non-clustered simple craters is very close to the current parabolic ideal (marked as a large white circle, Fig. 1). All but one (a distinct outlier) have eccentricity values, e, considerably greater than unity, and a large majority (90 of 117) have d/D less than 0.20. Thus, as a whole, these craters are generally shallower and all significantly more cone-shaped than the existing model. The mean, $d/D = 0.174$, $e = 2.09$, is marked on Fig. 1.

All 7 bright halo craters are deep ($d/D > 0.23$) and relatively "bowl shaped" ($e \leq \sim 2$). One third (7 of 21) of the craters with $d/D > 0.22$ are of this type including Linne (marked "L", Fig.1), and all 21 feature sharp rims, and well-defined ejecta features (see also ref. [3]). Most of them contain few or no later, smaller impact craters in their interiors or on their ejecta, and they also are deeper and more "bowl-shaped" than the remainder of the sample craters.

On the other end of the distribution ($d/D < 0.15$, n = 23 craters) the craters are shallower, have little or no evidence of visible ejecta, have generally rounded rims and ubiquitous subsequent cratering. None of these craters features a bright ejecta halo or interior. Between these extremes lies a region ($0.15 < d/D < 0.22$; $n = 73$) of transition. In this region craters become increasingly space-weathered, cratered, and shape-modified (bottom of Fig. 1).

Nineteen of the 124 craters are also crossed near-center by LOLA altimetry tracks. These were used to obtain 19 more comparisons between the direct measurements (LOLA) and shadow measurement (FSM) results, in addition to those given in [2]. The results are shown in Fig. 2, and reconfirm the excellent agreement of the FSM results with such direct measurements.

Conclusions: Although 124 craters may not represent a statistically large sample, certain observations may be made from this dataset:

- The current paradigm for simple impact craters does not well-approximate my sample of simple craters on Mare Serenitatis, which are all more hyperbolic, and mostly shallower, than the existing model. A better shape, *for this sample*, is given herein.
- Inspection of Figs. 1 shows that plotting the results of my crater measurements on e vs. d/D axes has essentially sorted the craters by degradation state. This implies that crater shape, as embodied in d, D and e correlates closely with crater degradation state: shallower depths and more cone-like shapes correspond well with several morphologic features commonly associated with crater degradation (and, likely, age).
- All but one (outlier) of the cluster of secondary craters is considerably shallower and more cone-shaped than the rest of the study population. Although 7 craters, all in one cluster, in no way constitutes a statistically significant sample, this suggests a potential for using crater shape measurements to differentiate secondary craters from primaries.

References: [1] Chappelow, JE (2013) *M&PS, 48,* 1863. [2] Chappelow, JE (2014) *45th LPSC*, Abst. #2074. [3] Chappelow, JE (2014), *5th Plan. Cratering Consortium Meeting*, Abst. #1416.

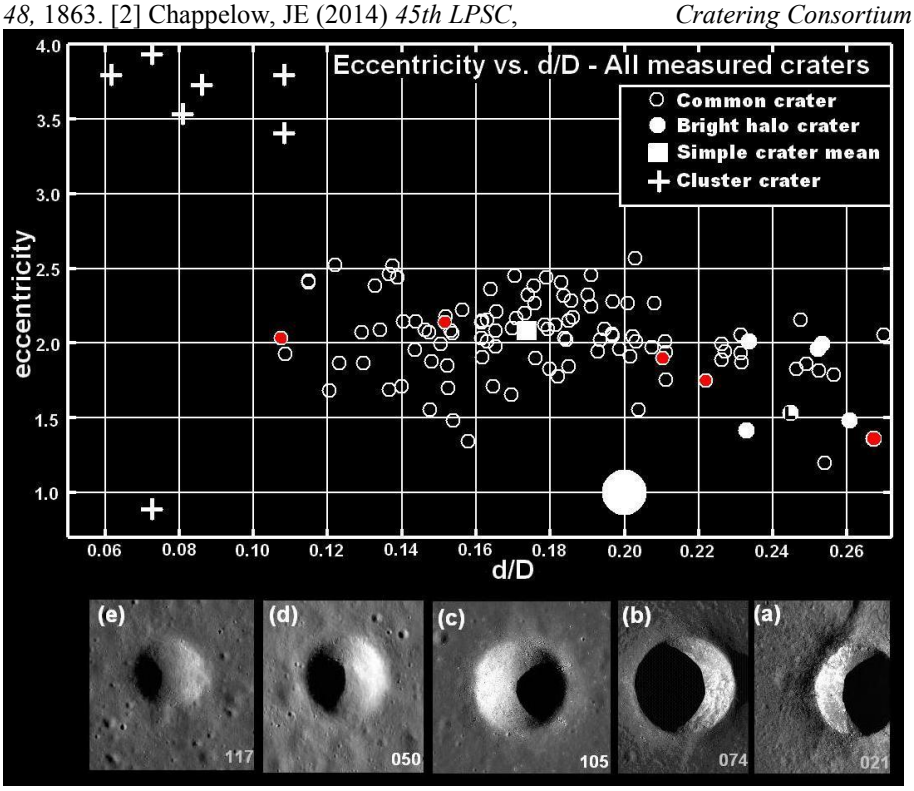

Figure 1: The 124 craters in this study plotted on *e* vs. *d*/*D* axes. The five crater clips shown below the graph demonstrate the progression from very fresh-looking craters (lower right) to very degraded ones (middle left). (The full 'line up' of 117 craters can be found in ref. [3].) Each of the five crater clips corresponds to the data point marked in red above it. A small cluster of very shallow, secondary craters appears at upper left, with one outlier, bottom left. The large white circle marks the existing ideal of $d/D = 0.20$, $e = 1.0$, and the white square marks the mean derived herein: $d/D = 0.174$, $e = 2.09$.

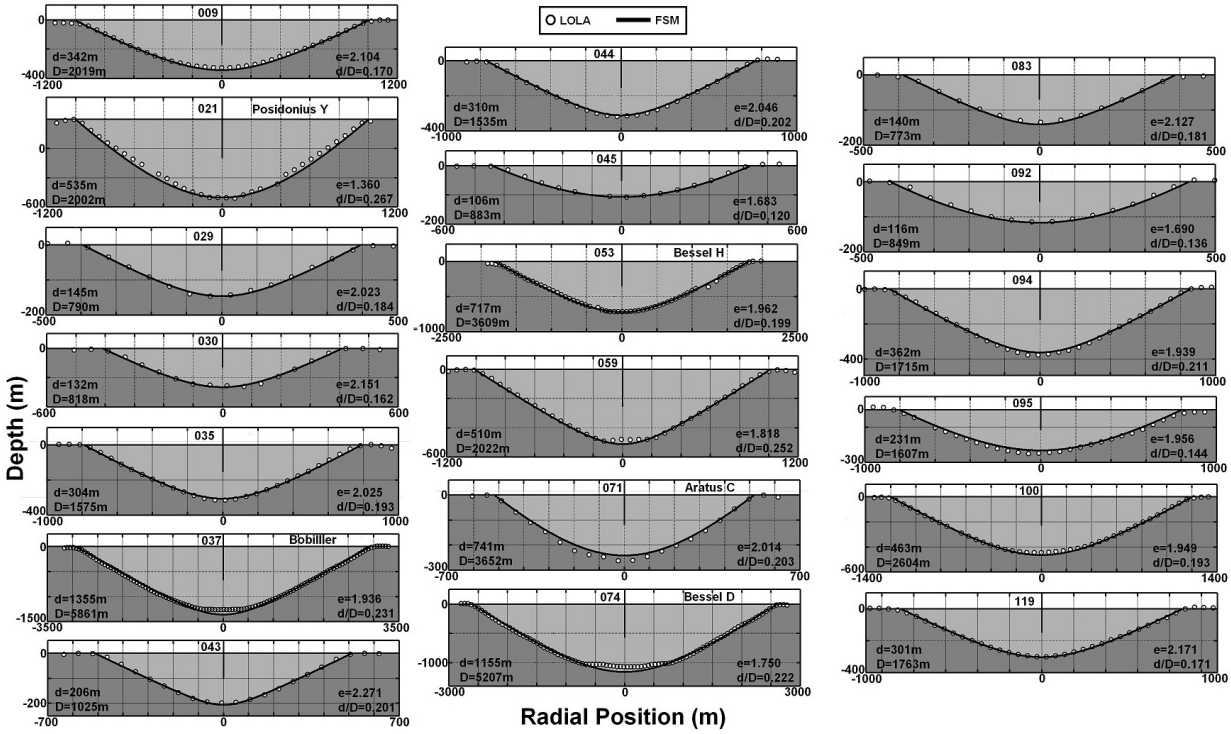

Figure 2: Profiles of 19 craters measured herein and also nearly bisected by LOLA tracks. Flat crater bottoms remain the only areas where the results differ significantly. The LOLA data for craters 009 and 100 show the effects of ground tracks which slightly miss the crater's centers. Note the variation in the crater profiles, in shape (*e*) as well as aspect (*d*/*D*). Craters 009 and 119 closely approximate the mean shape for simple craters derived in this pilot study.