PRELIMINARY RESULTS ON THE EVOLUTION OF SMALL CRATER POPULATIONS ON THE MOON.

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Introduction: The Moon is the only solar system body for which we have both crater size-frequency distributions (SFDs) *and* ages of known terrains. These are keystones for understanding the crater production function through time. While there has been previous work developing the lunar production function [e.g., 1, 2, 3], these efforts are decades old. New imaging from Lunar Reconnaissance Orbiter Camera (LROC) and results from dynamical calculations of plausible impactor populations [e.g., 4, 5] encourage a reevaluation, especially at small diameters (D<20 km). For this purpose, we are compiling superposed crater SFDs for several craters with D=80-100 km, and Hausen crater and Birkhoff basin. These provide new data for the small crater distribution (down to D~700 m) over a wide range of locations and lunar history [cf. 6].

Crater Measurement Methods: Within each larger crater, superposed craters are measured manually on the LROC Wide Angle Camera (WAC) mosaic (pixel scale =100 m/pixel) using the 3-point crater tool in JMARS for the Moon (http://jmars.asu.edu/). Points are selected by the investigator along the crater rim. JMARS fits a circle to the points, and outputs center latitude and longitude and crater D. Degradation class is assigned to each crater, ranging from 1 (fresh) to 4 (most degraded). A crater may also be identified as an "obvious secondary" ("OS") by being part of an obvious cluster or chain. Note that our term "All Classes" refers to all degradation classes, excluding "OS"s.

Preliminary Results and Discussion: Fig. 1 shows the "All Classes" SFD for superposed craters within the larger craters in Relative (R) plot format [7]. The larger craters have been divided into groups by their relative age (cumulative density N(D=0.95 km) per 10^2 km^2; Table 1). Here we define these groups as: "old" for >20,000, "intermediate" for 10,000-20,000, and "young" for <10,000. They are plotted separately (Fig. 1a-c) as an attempt to increase comprehensibility. Lines are drawn by eye to illustrate average trends of the data; they are not quantitative fits.

We observe two trends for superposed crater SFDs for the oldest, larger craters (excluding Birkhoff basin; Fig. 1a). For D~0.7-2 km, R-values decrease with increasing D indicating a steeper slope (negative index of power-law SFD). A steep slope is generally characteristic of secondary craters [e.g., 8]; therefore we suggest that these data represent a secondary population for this D range. The second trend is as D increases beyond 2 km, R-values also increase indicating a shallower slope. This slope might be consistent with a primary crater population already observed and named "Population 1" by Strom et al. [9] for *larger* craters. Strom et al. [9] were also able to correlate "Population 1" SFD with the Main Belt Asteroids (MBA) SFD, implying this may represent the production population of *large* primary craters on the Moon. However, we CANNOT necessarily extend "Population 1", and its suggested representation of the primary production population, to the small craters we are observing. First, the frequent similarity between "All Classes" SFDs and degraded class (3 & 4) SFDs, and dissimilarity between "All Classes" SFDs and fresher class SFDS (1

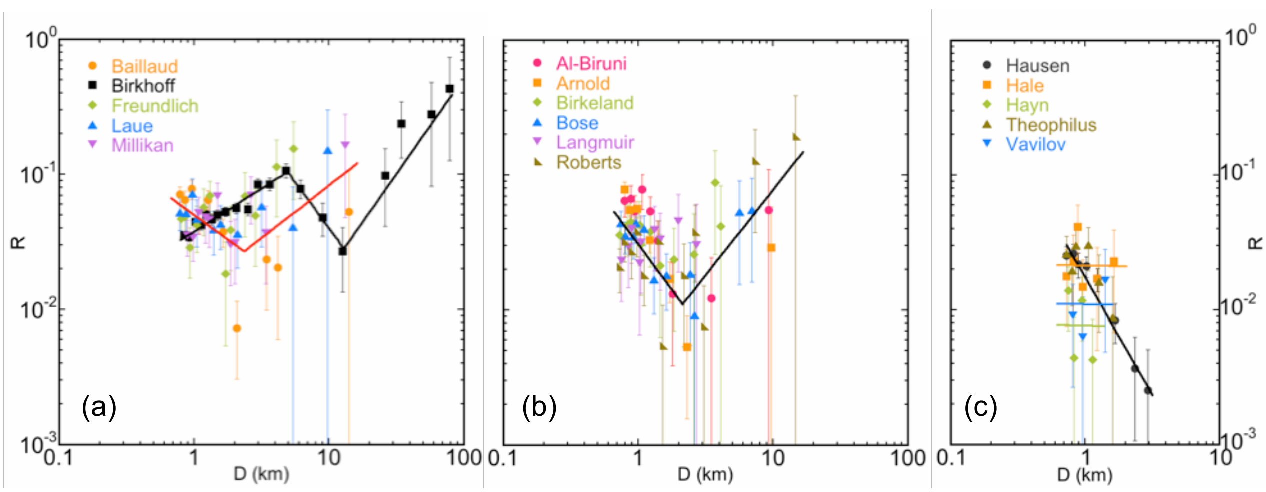

Figure 1. SFDs in R plot format of superposed craters within the larger craters in these relative age subgroups (a) "old", (b) "intermediate", and (c) "young". (See also text and Table 1.) Data is shown for "All Classes". Lines drawn by eye to illustrate general trends discussed in text. (a) red line shows trend for all except Birkhoff, black line is trend for Birkhoff. (c) black line is trend for Hausen and Theophilus, while other lines are for associated data in the same color.

& 2) (e.g., Fig. 2), imply small craters are in degradation equilibrium. Degradation at different rates for different diameters alters the intial production SFD to a new equilibrium population that is not representative of crater production. Second, even though the slope is shallower, we cannot be certain there are no secondary craters, and that we are observing only the primary population. Finally, because the MBA has not been observed down to the size range for producing these small craters, we have no direct comparison to resolve if our data represents a production population.

We observe differences from the other larger craters for superposed craters SFD in Birkhoff basin, which is the largest (D=325 km) and likely oldest (Table 1) examined (Fig 1a). The most prominent is a shift of the secondary population to larger D. A steeper slope occurs at D~4.5-15 km, likely because these are larger basin secondaries from the Moon's basin-forming epoch. For D<4.5 km and D>15 km, a shallow slope consistent with the other SFDs is observed. The shallow slope for D<4.5 becomes apparent only because of minimal contribution from the secondaries, either due to an inherent lack or earlier removal by degradation processes of smaller secondaries.

Fig. 1b shows the data for superposed craters within the "intermediate" aged larger craters (Table 1). These SFDs have more variation in R-values, but the trends are overall similar to the ones observed for the older, larger craters. This hints that characteristics of the crater populations we are observing did not considerably change through formation of the older, larger craters. Future work will define what this time frame is in absolute ages using the Model Production Function (MPF) developed by Marchi et al. [10].

Fig. 1c shows the SFDs of superposed craters within the youngest, larger craters (Table 1). These have big error bars due to poor statistics related to presence of few superposed craters. We suggest a tentative trend of steeper slopes for D=0.7-3 km. This is

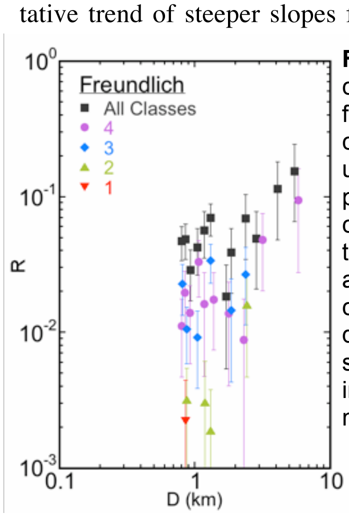

Figure 2. Degradation classes SFDs in R plot format of superposed craters within Freundlich. This plot exemplifies the similarity in classes 3 & 4 SFDs to the "All Classes" SFD, and the lower density of classes 1 & 2 SFDs frequently observed for superposed crater SFDs in our "old" and "intermediate" larger craters.

primarily suggested by Hausen and Theophilus SFDs, but SFDs for the others are not inconsistent. This may imply that we are seeing a secondary population, which would agree with results from the older, larger craters. The issue for larger, younger craters, however, is no obvious source craters to produce secondaries. These craters are typically the youngest in their immediate region. This suggests further investigation into some aspects of secondary cratering, concerning whether they travel farther than currently predicted, or production of self (or auto)-secondaries [e.g., 11].

SFDs for craters on the floors of Hale, Hayn, and Vavilov could also be consistent with a flat slope. Previously, Strom et al. [9], studying younger lunar surfaces, have called this flat slope "Population 2" and correlated it with the Near Earth Object (NEO) SFD, thus demonstrating it is likely a production population. Currently, our data are just too poor to propose that we are seeing "Population 2" at smaller diameters. We are currently compiling superposed crater SFDs for ~25 more larger craters of various ages across the Moon to augment these interpretations.

References: [1] Hartmann, W.K., et al. (1981) in *Basaltic Volcanism on the Terrestrial Planets*. 1049-1127. [2] Wilhelms, D.E. (1985). *LPSC XVI*, p. 904-905 (Abst.). [3] Basilevsky, A.T., et al. (1980) *EMP*. **23**, 355-371. [4] Gomes, R., et al. (2005) *Nature* **435**, 466-469. [5] Bottke, W.F., Jr., et al. (2005) *Icarus* **175**, 111-140. [6] Baldwin, R.B. (1985) *Icarus* **61**, 63-91. [7] Crater Analysis Techniques Working Group (1979) *Icarus* **37**, 467-474. [8] McEwen, A.S. and E.B. Bierhaus (2006) *AREPS* **34**, 535-567. [9] Strom, R.G., et al. (2005) *Science* **309**, 1847-1850. [10] Marchi, S., et al. (2009) *AJ.* **137**, 4936-4948. [11] Plescia, J.B. and M.S. Robinson (2011). *42nd LPSC.* Abst. #1839.

Table 1. Relative Ages of the Larger Craters.

Crater	Relative Age*
Birkhoff	29100±700
Freundlich	26300±3800
Millikan	25800±3100
Baillaud	25600±2300
Laue	25000±3900
Al-Biruni	19800±3300
Birkeland	18800±4200
Bose	16500±2500
Arnold	16000±1900
Langmuir	15500±3900
Roberts	13600±2500
Hausen	7600±900
Hale	7400±2800
Theophilus	7100±2000
Vavilov	3600±2100
Hayn	1800±1000

*N(D=0.95 km) per 10^6 km^2; $\sqrt{n}$ errors, where n = number of craters measured