EQUAL-AREA RADIAL CRATER COUNTS AT LARGE COPERNICAN IMPACT CRATERS: IMPLICATIONS FOR LATE-STAGE EJECTA EMPLACEMENT.

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Introduction: Measurement of crater size-frequency distributions (CSFDs) is a useful method to determining the relative and absolute ages of planetary surfaces. It has been used successfully on the Moon for mare surfaces and has been calibrated to Apollo and Luna landing sites. Using high-resolution Lunar Reconnaissance Orbiter – Narrow Angle Camera (LRO-NAC) [1] images, we are attempting to constrain the ages of Copernican complex impact craters using small-area crater counts. Previous CSFD measurements at young, large lunar craters have typically been done on low resolution images and with large count areas. Counting large count areas on NAC images is very time consuming due to the huge number of small impact craters. However, counts on the continuous ejecta blankets of Copernican craters are also highly variable, as was observed in previous counts at Aristarchus Crater [2], Tycho and Copernicus [3], and Giordano Bruno [4]. These issues indicate that a better understanding of the production of small craters within the proximal ejecta blanket is needed.

We devised a counting experiment to show the variability of cratering rate in the ejecta blanket by creating an age profile across the continuous ejecta blanket without operator bias in selecting count areas. We counted in equal-sized areas at regular intervals along a radial path from the crater rim to the edge of the continuous ejecta blanket. This experiment was conducted at four Copernican craters (Aristarchus, Eudoxus, Jackson, Tycho). The results show a consistent trend of decreasing absolute model age (AMA) with increasing distance from the crater rim, and suggests to us a significant influence of self-secondary cratering within the continuous ejecta.

Methods: Lunar Reconnaissance Orbiter – Narrow Angle Camera Images (LRO-NAC) at four Copernican-aged impact craters were obtained that cover a radial line from the rim of each crater to a distance of 1 crater radius (i.e., the end of the continuous ejecta blanket [5]). Count areas were defined as 1 x 1 km squares and spaced at regular intervals radial to the crater rim. Five count areas were placed at 5 km intervals at Aristarchus (40 km diam) (Fig. 1a), six each at Eudoxus (67 km) and Jackson (71 km diam) at 7 km intervals, and seven areas at Tycho (86 km diam) at ~7.5 km intervals. Counts were done using CraterTools [6] in ArcGIS and AMAs were fit using CraterStats [7]. A total of ~20,000 craters were counted with a range of 1.5m – 150 m diameters.

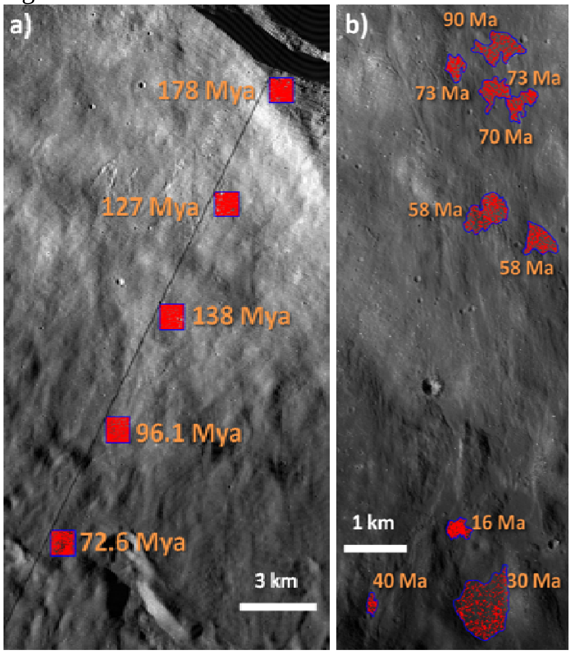

Figure 1: **a)** Equal-area count areas with derived AMAs oriented radially at 5 km intervals from the rim at Aristarchus. b) Melt ponds oriented radially at Aristarchus show similar inverse trends of AMA with distance. (LRO-NAC M102472092).

The traditional procedure for measuring a CSFD is to count on homogeneous appearing areas and avoid secondary crater chains and clusters [8]. Because we are interested in the variation of crater population within the ejecta blanket, our method avoids unintended partiality by standardizing the area selection. Our main limiting factors with this approach are image coverage and solar incidence angles (the ejecta blanket must be covered along a radial line and incidence angles must be favorable for crater counting). At Aristarchus Crater, counts were also made at 9 small impact melt ponds, which were also oriented radially to the rim (Fig. 1b). This was done to test whether the observations made in the equal area counts could be correlated with small areas formed by the cratering process.

Results: All of the Copernican-aged craters analyzed in this experiment showed a distinct trend of decreasing age with increasing distance from the primary crater rim (Fig. 2). These curves can all be fit with a power-law distribution with exponents of between -0.2 and -0.4. A notable outlier is at the count area at 28.5 km from Jackson crater, which is due to counting on a large secondary cluster from some other crater (this is an unfortunate side-effect of the standardized area selection). In none of the count areas were craters larger than 150 m observed, but typically the largest craters are located closest to the crater rim. In such small count areas (1 km^2), the determination of AMA is controlled by the population of large craters (e.g. 60m – 100m bins) in the count area. Counting craters smaller than 10 m do not influence the ages because the production function we used [9] is not valid below this diameter.

Discussion: Previous crater counting tests at Aristarchus Crater indicated that counting on areas of the crater floor is problematic because of the rough surface, including numerous cracks, mounds, and fissures, which make it difficult to determine exact population of small craters [2]. While counting on smooth melt ponds produces easily fit CSFDs, these surfaces seem to give apparent AMAs that are younger than ejecta deposits, in part due to target property differences [3, 10]. Thus, continuous ejecta blankets are the most logical place to count craters. It is well established that continuous ejecta is emplaced largely as a coherent 'curtain' [11, 12]. Accordingly, the ejecta emplacement is thought to reset the surface age. However, counts made on NAC images at Aristarchus [2], Tycho, and Copernicus [3], and Giordano Bruno [4] show a high variability in AMA depending on location and it is necessary to combine the results from many areas to improve statistics.

The results of our test indicate that the AMAs are inversely proportional to the distance from the crater rim, indicating the relative difference in the population and distribution of big craters in the continuous ejecta blanket. Because crater densities and sizes are greater closer to the crater rim it is very likely that they are related to the ejecta emplacement process, probably the result of late-arriving self-secondary craters [13]. The ages are thus a simple way of showing the relative abundance of these self-secondary craters and do not reflect the age of the impact. Comparing the total combined binned 1 km^2 count-area age (131 +/- 8 Myr) to the reported age for more extensive counts done at Aristarchus (193 +/- 11 Myr [2]) shows that there is a large disparity in the CSFD.

A similar AMA trend is observed in impact melt ponds radial to Aristarchus that formed during and immediately following the emplacement of the ejecta. These ponds contain a number of impact craters with morphologies of impacts into still molten pond material [2,10,14]. If the morphologic interpretation is correct, then these craters formed shortly after melt emplacement and could be the result of late arriving self-secondary craters. The occurrence of these "splash" craters in impact melts both within the crater and in the proximal ejecta blanket is important because it indicates that a significant population of self-secondary craters formed in the latest stages of the parent crater formation, and helps support the argument made using CSFDs. The melt ponds in Fig. 1b are connected by numerous channels and appear to have formed at the base of a collection area with flow indicators. It presumably required minutes for the ponds to form, suggesting that the impactors had very high trajectories. However, this is inconsistent with most models for ejecta blanket emplacement [11, 12].

Conclusions: Small, equal-area crater counts done along radial profiles at Copernican-aged impact craters on the Moon reveal a distinct trend of decreasing AMA with increasing distance from the crater rim. This suggests to us that we are observing a significant population of self-secondary impact craters which must be accounted for in the young crater production functions. Our current hypothesis is that this crater population is due to high-trajectory, late-arriving ejecta, but it is difficult to reconcile this with the time it takes for melt ponds to develop and our current understanding of ejecta emplacement through ballistic sedimentation.

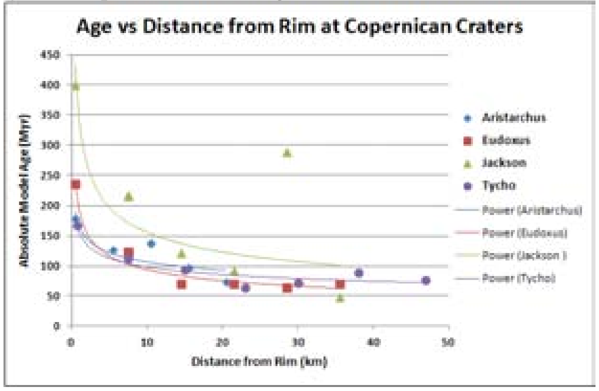

Figure 2: Variation in AMA with increasing distance from primary crater rim

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