EPSC Abstracts
Vol. 5, EPSC2010-609, 2010
European Planetary Science Congress 2010

New crater size-frequency distributions for the lunar craters Tycho and Copernicus: Implications for the lunar chronology and target properties

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Abstract

Images from the Lunar Reconnaissance Orbiter Narrow Angle Camera provide new opportunities to investigate crater size-frequency distributions (CSFDs) on individual geological units at lunar impact craters. We performed new CSFD measurements for the Copernican-aged craters, Tycho and Copernicus, crucial anchor points for the lunar chronology used for deriving absolute model ages across the entire lunar surface. The lunar chronology is also extrapolated for dating other planetary surfaces throughout the Solar System. Our CSFDs for Tycho ejecta are consistent with previous measurements. However, for Copernicus crater, we find significantly lower cumulative crater frequencies, which fit, and thus support, the existing lunar chronologies significantly better than previous data. The new CSFDs measured for Tycho also provide new insights for discrepant relative ages between the ejecta blankets, impact melt pools and flows previously interpreted as evidence for multiphase volcanism at Tycho. Combined with a study of crater units at Jackson crater, discrepant CSFDs may, in some cases, be explained by differences in target properties of differing geologic units, rather than differences in formation age.

1. Introduction

At the Apollo 17 landing site, secondary craters from Tycho (~2200 km away) presumably triggered a landslide on the slope of the South Massif. König [1] and Neukum and König [2] found good agreement between the ages of the landslide and their ages for Tycho, supporting this interpretation.

Samples returned from the landslide revealed exposure ages of about ~100 Ma. Consequently, this age has been interpreted to represent the formation age of Tycho crater [e.g., 3, 4-5]. The Central Cluster, interpreted as secondary craters from Tycho, also have exposure ages of ~100-110 Ma [3-4, 6]. These ages are similar to an exposure age of 96±5 Ma for both the landslide and Central Cluster materials derived by Arvidson et al. [7].

The Apollo 12 landing site is covered with Copernicus ray material, which led Meyer et al. [8] to propose that KREEP glass in the Apollo 12 samples was ejected by Copernicus, and could be used to date the impact. Radiometric ages of samples 12032 and 12033 collected at Head crater have an age of 800-850 Ma [9-13]. Stöffler and Ryder [14] pointed out some problems with this interpretation and concluded, that the age of Copernicus is either well-known at 800±15 Ma or, it can only be inferred to be younger than ~2 Ga. Assuming a constant flux of impactors for the last 3 Ga [e.g., 15-20] and using the radiometric age of North Ray crater (50.3±0.8 Ma) as a calibration point [e.g., 3, 14], the absolute model ages (AMAs) derived from CSFD measurements for the floor of Copernicus and its continuous ejecta blanket are significantly older than these radiometric ages. For example, Neukum determined an absolute model age of 1.5 Ga ($N_{(1)}=1.3x10^{-3}$) [17] and König [1] determined a model age of 1320±310 Ma ($N_{(1)}=(1.0±0.3)x10^{-3}$). While radiometric ages and CSFDs of Tycho, North Ray, and Cone crater are consistent with a constant cratering rate over the last 3 Ga, cumulative crater frequencies at Copernicus crater are too high [e.g., 15-20]. Neukum and König argued that either their counts were affected by a large number of secondary craters or the radiometric ages of the Apollo 12 samples do not date the Copernicus event [2].

2. Results

We dated nine units at Tycho crater, including four individual smooth melt pools outside the eastern and western rims. We also dated a melt pool inside Tycho and the central floor, and three areas on the proximal ejecta blanket. To test a possible genetic link between the Apollo 17 landslide and Tycho crater, we dated three areas on the Apollo 17 landslide. The AMA of the interior melt pool is ~37 Ma. For the exterior melt pools we found ages of ~32-37 Ma. We also dated a hummocky area of the Tycho floor, which yielded an AMA of ~37 Ma, contemporaneous with the melt pool ages. Thus, all investigated melt ponds inside and outside Tycho and the floor of Tycho show similar ages of 32-37 Ma. Crater counts performed in three areas on the proximal ejecta blanket revealed significantly older ages compared to the ages of the melt ponds and the hummocky floor. According to our CSFDs, ejecta areas are between 89 and 118 Ma old. Our crater counts for the three areas on the Apollo 17 landslide revealed ages of 71-94 Ma. Summing all three areas, gives an AMA of 86 Ma, similar to our ages for the Tycho ejecta.

At Copernicus crater we dated 13 units, including three interior melt pools, one exterior melt pool, two areas on the floor, and seven areas on the continuous ejecta blanket SE, SW, and NW of the crater rim. The AMAs of the interior melt pools vary between 131 and 194 Ma. The AMA of the exterior melt pool is 237 Ma. We measured AMAs of 374 and 447 Ma for two floor units. While these ages appear to be different, they are within error of each other. Our crater counts for seven ejecta regions revealed ages of 611, 634, 653, 702, 791, 852, and 1160 Ma. Several ages are consistent with each other within the error. Particularly, the age of 852 Ma is in excellent agreement with the radiometric ages of the proposed Copernicus material from the Apollo 12 landing site. Crater counts of a bright ray area north of the Apollo 12 landing site revealed an AMA of 726 Ma. For the Apollo 12 landing site we found that the population of craters larger than ~300 m are in equilibrium. However, there seems to be a disturbance of craters smaller than ~300 m, consistent with the age of the bright ray of Copernicus.

3. Discussion

The new N(1) ages for the ejecta blanket of Copernicus fit the lunar chronology much better than previous ages [e.g., 15-20]. For Tycho our crater counts are consistent with and confirm previous N(1) ages [e.g., 2, 16]. In summary, our new counts for both Tycho and Copernicus fit, and thus support, the existing lunar chronologies significantly better than previous data.

Differences in ages between the melt pools and the ejecta blankets like the ones observed at Tycho and Copernicus craters were also seen at Jackson crater [21]. We propose that material properties differences between the ejecta and melt units result in larger crater sizes on the ejecta blanket compared to the melt pools, causing differences in the CSFDs that translate to differences in the AMAs [21]. In part, this interpretation is based on the observation of a small impact crater at the contact between a melt pool and the surrounding ejecta blanket at Jackson crater. For this crater, [21] found that the diameter is about 20% smaller on the melt pool compared to the diameter on the ejecta blanket, resulting in an age difference of ~70 Ma.

4. Conclusions

From our CSFD measurements performed for the Tycho and Copernicus craters, we conclude that: (1) the ages of the ejecta blankets agree well with radiometric and exposure ages of the Apollo 12 and 17 landing sites, respectively; (2) our new crater counts for the Copernicus ejecta blanket better fit and support the lunar chronologies than previous counts; (3) the new counts are generally consistent with a first order linear decline of the impact rate over the last 3 Ga; (4) the melt pools appear to be significantly younger than the ejecta blankets, which might be related to different target properties.

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