The Case for Auto-Secondary Cratering of Ejecta Blankets using Crater Statistics of Young Lunar Craters.
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Introduction: Small-diameter crater size-frequency distributions (CSFDs) and corresponding absolute model ages (AMAs) measured on the ejecta blankets of Copernican-aged lunar craters have been demonstrated to show considerable variation between the ejecta blankets and impact melt deposits [1-10]. Much of the recent effort to reconcile the apparent AMA differences between what are essentially "same-aged" surfaces has focused on the effects of different target properties between impact melt and ejecta blankets. Target rock competency can greatly affect the final crater diameter (up to 20% difference between unconsolidated and consolidated material [e.g., 6, 8]), which in turn will affect crater size-frequency measurements [6-9]. If the surfaces experienced the same incoming flux of craters, then accounting for the differences in SFD and AMA might be accomplished by a target property correction factor [e.g. 7, 9]. However, our measurements of CSFDs on continuous ejecta blankets of the lunar craters Aristarchus and Tycho show that ejecta blankets have accumulated more craters than impact melt deposits, irrespective of crater diameter (Fig 1) [3, 4]. High-resolution equal-area counts of adjacent areas of ponded impact melt and ejecta at Tycho crater show that even to the limit of resolution, there are more craters recorded on the ejecta (Fig 2) [4]. Our work provides evidence that crater populations on ejecta blankets are inflated by auto-secondary craters – craters formed on the continuous ejecta blanket by fragments from the formation of the parent crater [11]. Observations of putative "ghost" craters in impact melt provide further evidence that cratering on the ejecta blanket occurred between the emplacement of the ejecta blanket and the arrival of impact melt ponds (e.g., Fig 2C) [4].

Methods: Craters >50m diameter were counted on continuous ejecta deposits of Aristarchus (42 km diameter) and Tycho (82 km diameter) within the areas shown in Figure 1, using Kaguya TC and LROC-NAC imagery. Point density maps were generated in ESRI ArcGIS made to show the variation in total crater density (irrespective of crater diameter) (Fig. 1). At Tycho Crater, CSFDs in 2.4 km^2 equal-area count regions on an impact melt pond and adjacent ejecta were counted to the limit of resolution (0.5 m/pixel, crater diameters >3m). Counts were done using CraterTools [12] for ArcGIS, and statistics compiled using CraterStats [13], using production and chronology functions from [14].

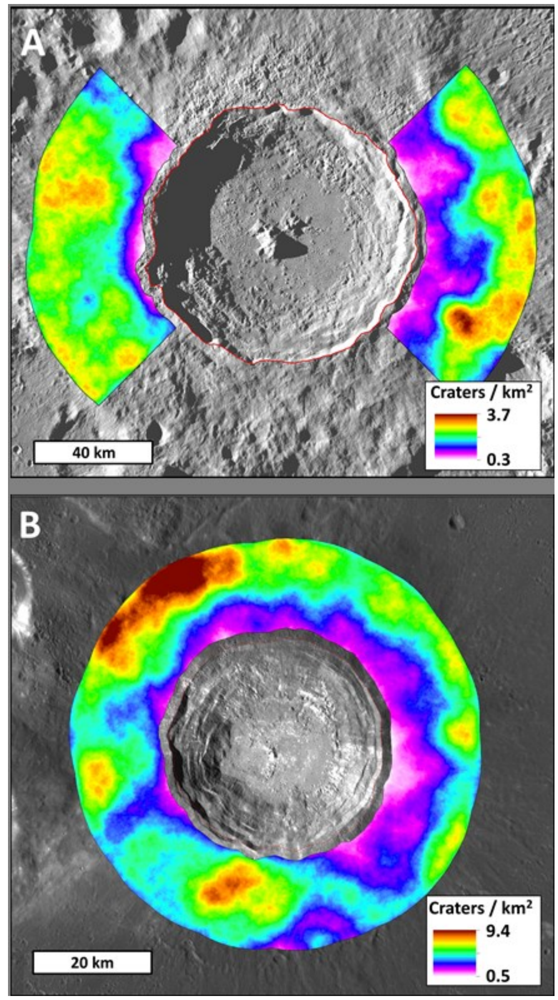

Figure 1: Crater point density maps of a) Tycho and b) Aristarchus Crater showing all craters with D>50m on the continuous ejecta blanket. Low density regions (purple) are highly correlated with ponded impact melt and melt veneers.

Results: The size-frequency distribution of craters at Tycho for the entire count areas differ little from east to west (East N(1): 6.07×10^{-5}, area: $3.91 \times 10^{3} km^2$; West N(1): 5.52×10^{-5}, area: 3.87×10^{3} km^2), equating to AMAs of 65.9 +/- 1.4 and 72.4 +/-1.5, respectively. However, the density of craters increases with distance from the rim of Tycho (Fig. 1A). Melt surfaces at Tycho have even lower values (N(1)=3.4x10-5, area=2.72×10^{2} km^2 AMA=40.6+/-2.2 Ma). Crater density ranges from 0.3 to 3.7 craters/km^2. Low density regions have 3.9 times fewer craters than high density regions. At Aristarchus, similar results are seen (Entire ejecta: N(1)=1.47×10^{-4}, area=$3.78 \times 10^{3} km^2$, AMA=174+/-1.8Ma) [3]. Again, crater density increases with distance from the rim (Fig. 1B), and crater density ranges from 0.5 to 9.4 craters/km^2, with high density regions 4.3 times those of low density regions. Within the high-resolution count areas at Tycho 10,220 craters were counted in the ejecta blanket area, (AMA: ~87 Ma (compared to the cosmic-ray exposure age of Tycho of 109 ± 1.5 Ma [15] and CSFD-derived AMAs of ~85 Ma for small areas and ~124 Ma for large areas [2]). On the melt pond, 6,795 craters were counted (AMA: ~22 Ma). The ejecta count area contains ~33% more craters than the equal-sized melt pond area. The cumulative number of craters (N(1)) is 4x greater on the ejecta blanket [N(1)=7.28x10^{-5}] compared to the melt [N(1)=1.8x10^{-5}] [3].

Discussion and Conclusions: Our results in Figure 1 show that the densities of craters on the ejecta blankets of Tycho and Aristarchus are radially and circumferentially variable, with a general increase in crater density with distance from the crater rim, and that AMAs derived from different areas of the ejecta blanket may differ by up to a factor of 4. Adjacent regions of impact melt and ejecta also differ in cumulative crater frequency (N(1)) and AMA by a factor of 4 in high resolution counts (Fig 2), and to the limit of resolution, it appears that more craters form on the ejecta compared to melt surfaces. The discrepancy between impact melt pond and ejecta blanket SFDs appears to be caused by either the overproduction of craters on the ejecta, or fewer impacts being recorded in impact melt ponds. The population discrepancy between impact melt ponds and ejecta blankets persists even when accounting for a 20% increase in crater diameter that may be due to target property effects on impact melt ponds (blue isochron Fig. 2B). Observations of melt-embayed craters, "ghost" craters, and craters modified by subsequent flow of melt provide strong morphologic evidence that cratering occured on the continuous ejecta blanket prior to the arrival of flowing impact melt. These observations are significant in that ejecta models indicate that continuous ejecta deposits completely reset the surface and should be devoid of craters immediately following its emplacement [10]. Auto-secondary cratering is thus a probable explanation for the increased population of craters on ejecta relative to melt surfaces. Therefore, impact melt ponds, which are the last emplaced surfaces in the impact process, are the surfaces that record the true recent Solar System impact flux.

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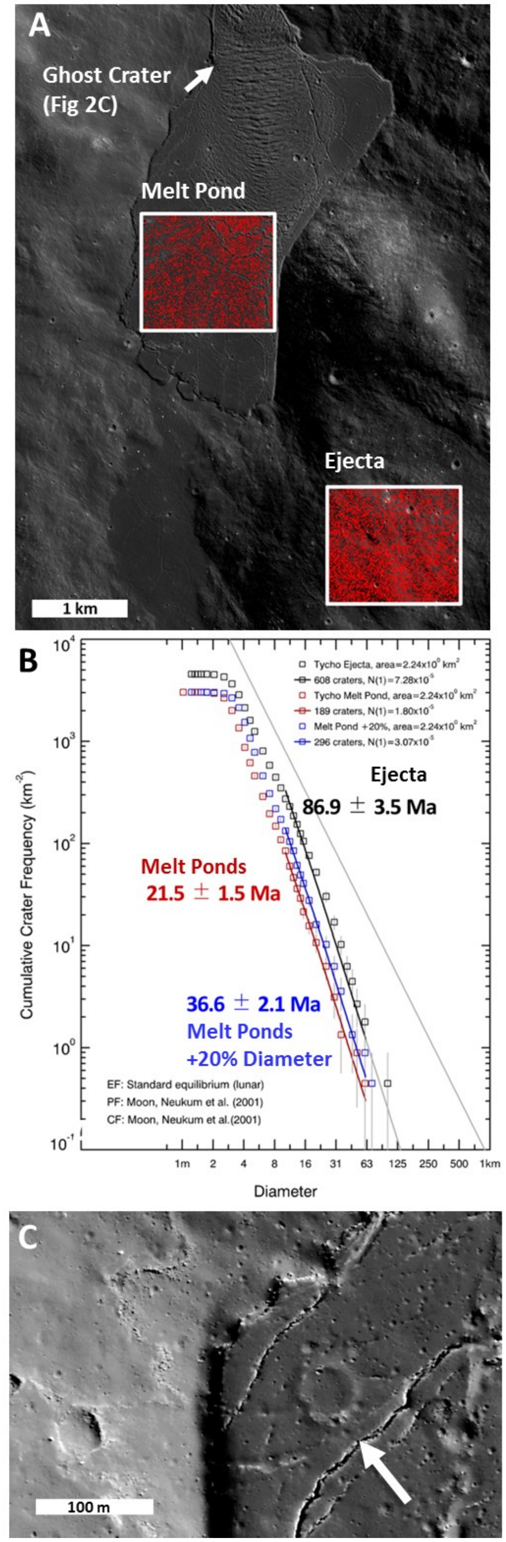

Figure 2: a) NAC equal area counts at Tycho Crater. b) CSFD results from a) including 20% melt pond crater diameter increase (blue isochron). c) example of putative "ghost" crater in impact melt pond (location in 2a) [4].

References: [1] Plescia et al. 2012 LPSC 43, 1614. [2] Hiesinger et al. 2012 JGR 117, E2. [3] Zanetti et al. 2014 LPSC 45, 1528. [4] Zanetti et al. 2015 LPSC 26 1209. [5] Xaio et al. 2012 Icarus 220, 254. [6] van der Bogert et al. 2010 LPSC 41, 2165. [7] van der Bogert et al. 2013 LPSC 43, 1962. [8] Dundas et al. 2010 GRL. 37, L12203. [9] Wünnemann et al. 2012 LPSC 43,1805. [10] Melosh 1989 *Impact Cratering*, 245p. [11] Shoemaker et al. (1969) *in* Surveyor VII Mission Report Part II. *NASA Tech Rept* 32-1265, 9. [12] Kneissl et al. 2010 PSS 59, 1243. [13] Michael and Neukum 2010 EPSL 294, 223. [14] Neukum et al. 2001 Space Sci. Reviews 96, 55. [15] Arvidson et al. 1975 LPSC 7, 25.