UNCERTAINTIES IN THE <3 Ga LUNAR IMPACT CRATERING CHRONOLOGY. J. B. Plescia[1]. [1]The Johns Hopkins University, Applied Physics Laboratory, Laurel MD USA 20723-6099 (jeffrey.plescia@jhuapl.edu).

Introduction: The lunar cratering calibration curve [1-4] relating the frequency of impact craters to absolute time was developed on the basis of returned samples and crater counts for the surfaces from which those samples were collected (Figure 1). Analyses of the number of craters superposed on impact crater ejecta blankets [5-11] indicate that a significant amount of self-secondary cratering occurs and thus the number of craters on an ejecta blanket significantly exceeds the number produced by an extra-lunar impact population. As the post 3 Ga portion of the curve is constrained by the ages for impact craters (Copernicus, Tycho, North Ray, South Ray, and Cone) the cratering rate estimated from data on those ejecta blankets would be too high. The result is that the cratering rate since ~3 Ga and the absolute chronology are uncertain.

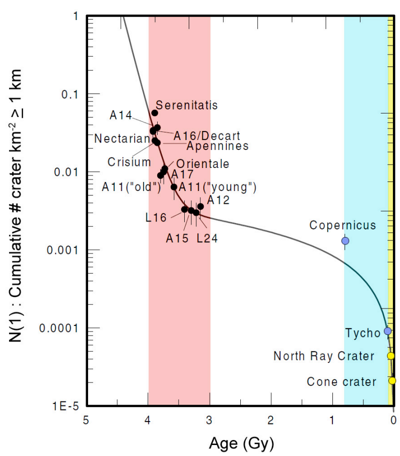

Figure 1. Lunar cratering chronology. The red zone corresponds to the period constrained by ages derived from mare samples. The white zone (3 Ga to 0.8 Ga) corresponds to the period where no constraints exist. The blue zone denotes the period for which constraints are provided by samples interpreted to have come from the target crater. The yellow zone denotes the youngest period corresponding to the timing of the formation of North Ray and Cone craters.

Background: The calibration of the lunar cratering rate is provided by absolute dates for mare surfaces sampled by the Apollo and Luna missions. The number of craters for those mare surfaces is easily determined and because the geology is simple, the average cratering rate since emplacement can be calculated. Numerous samples for the period 3-4 Ga provide tight constraints on the cratering rate. For the period between 3 and ~1 Ga, there are no surfaces for which samples have been dated and thus there are no constraints on the rate. For the period <1 Ga, the rate is constrained by ages for several impact craters. Samples for North Ray and Cone were collected during Apollo and their geologic context and age are clear. Samples that constrain the ages of Copernicus and Tycho craters are more complex. Rays from Copernicus cross the Apollo 12 site and rays from Tycho cross the Apollo 17 site. Samples from those sites are interpreted to have come from those craters [12-16]. Crater counts for the continuous ejecta of those craters provide the calibration points for the rate. While it is an interpretation that the samples came from those craters and that the ages of the samples represent the impact event, it is a plausible interpretation.

Self-Secondary Cratering: Several recent analysis [5-11] have documented the spatial variability of morphology, frequency and distribution characteristics for impact craters on the continuous ejecta and melt deposits associated with lunar craters. These results show: melt deposits always have a lower crater frequency than the continuous ejecta (by a variable amount) and the crater frequency and the size-frequency distribution vary spatially across the ejecta. Discrepancies between the crater frequency on the ejecta and the impact melt deposits have been observed at Giordano Bruno, Copernicus, Tycho, King, and Jackson craters. Spatial variations in the crater frequency have also been observed on the continuous ejecta blankets of Aristarchus, Eudoxus, Jackson, Tycho, North Ray, South Ray and Cone craters. The last three are relevant to the cratering chronology as they have been dated from returned samples.

These cratering characteristics are interpreted [13] to be the result of self-secondary cratering in which small diameter impact craters are formed on the ejecta blanket during the cratering process itself. The concept of self-secondaries dates to Shoemaker et al. [14] who suggested it to explain variations in the crater frequency on Tycho ejecta During emplacement of the continuous ejecta, ejected blocks are impacting the surface and producing craters. Some craters are modified by the continuing impact process and are partly to completely buried by additional fine-grained ejecta, coarse bouldery facies of ejecta, and impact melt.

Impact melt is deposited late in the process as it overlies all other ejecta facies. However, the variable crater frequency on different melt deposits for a given crater and the morphology of some craters on the melt surface suggest that some fraction of the observed craters are self-secondaries. While most impact craters on the melt surfaces appear to be formed in a solid target and exhibit typical impact characteristics, some appear to have formed in a viscid target (Figure 2).

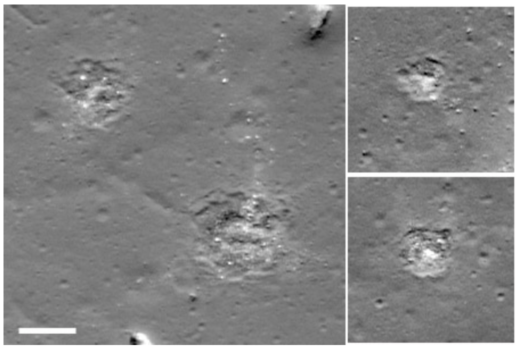

Figure 2. Impact craters into a melt pool at Tycho showing a morphology suggestive of impact into a viscid target (incompletely solidified impact melt). Scale bar is 20 m. LROC image M155314525L.

The concept of self-secondary cratering is critical to the cratering chronology scheme because the basic premise of cratering chronology is that the number of craters is zero when the surface is emplaced (N=0 at t=0). These observations demonstrate that the premise is not true for the ejecta blankets of lunar craters.

[8, 10] have suggested that differences of crater frequencies and size-frequency characteristics between the ejecta and melt result from differences in the target properties. Impact melt would be similar to strong, hard rock whereas the ejecta would be weaker and unconsolidated resulting in different crater sizes for the same projectile properties. Differences in target properties will influence the cratering process. However, if this were the sole reason for the differences in the observed crater frequency then for a given crater, all of the melt deposits should have the same crater frequency and there should be no significant spatial variation of the frequency across the continuous ejecta and, most importantly, the ratio of the frequency on the impact melts to the ejecta should be a constant for all craters (the ratio being a function of the strength ratio of the impact melt and ejecta).

Implications: The implication of self-secondary cratering is that the points in Figure 1 for Copernicus, Tycho, North Ray and Cone all plot too high since the number of craters on the ejecta is a combination of extra-lunar impactors as well as self secondaries. In terms of interpretation of other surface ages, a mare surface, for example, which had the same emplacement age as Copernicus would have fewer craters (since it is not self cratered) and thus would appear to have a younger absolute age. Another example would be a large impact crater whose absolute age was the same as the mare surface at, say, Apollo 12. The crater ejecta would have more craters than the mare surface and the crater would appear older than its actual age.

Since the ratio of crater frequency on the ejecta and the melt is not a constant ratio, a simple correction can not be applied to normalize the counts and provide a correct value for a given crater. The question then becomes - What surface should be used as the calibration point for the cratering chronology?

The interpretation made here is that counts for the continuous ejecta significantly over estimate the extra-lunar flux and thus are inappropriate. Counts for melt surfaces would provide a closer approximation of the flux, but would probably still be an over estimate.

Summary: The process of self-cratering results in the use of crater counts on the continuous ejecta blankets of dated craters of dubious value as the number and size distribution of craters on the ejecta does not reflect a primary extra-lunar flux. Counts on the impact melt (for those craters having such) provide a value closer to primary extra-lunar flux but are contaminated to some unknown degree. Use of continuous ejecta crater statistics will result in an overestimation of the flux and thus artificially young ages. These results also have implications for the martian cratering flux [15-16] as it is extrapolated from the Moon.

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