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Origin of discrepancies between crater size-frequency distributions of coeval lunar geologic units via target property contrasts

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ABSTRACT

Recent work on dating Copernican-aged craters, using Lunar Reconnaissance Orbiter (LRO) Camera data, re-encountered a curious discrepancy in crater size-frequency distribution (CSFD) measurements that was observed, but not understood, during the Apollo era. For example, at Tycho, Copernicus, and Aristarchus craters, CSFDs of impact melt deposits give significantly younger relative and absolute model ages (AMAs) than impact ejecta blankets, although these two units formed during one impact event, and would ideally yield coeval ages at the resolution of the CSFD technique. We investigated the effects of contrasting target properties on CSFDs and their resultant relative and absolute model ages for coeval lunar impact melt and ejecta units. We counted craters with diameters through the transition from strength- to gravity-scaling on two large impact melt deposits at Tycho and King craters, and we used pi-group scaling calculations to model the effects of differing target properties on final crater diameters for five different theoretical lunar targets. The new CSFD for the large King Crater melt pond bridges the gap between the discrepant CSFDs within a single geologic unit. Thus, the observed trends in the impact melt CSFDs support the occurrence of target property effects, rather than self-secondary and/or field secondary contamination. The CSFDs generated from the pi-group scaling calculations show that targets with higher density and effective strength yield smaller crater diameters than weaker targets, such that the relative ages of the former are lower relative to the latter. Consequently, coeval impact melt and ejecta units will have discrepant apparent ages. Target property differences also affect the resulting slope of the CSFD, with stronger targets exhibiting shallower slopes, so that the final crater diameters may differ more greatly at smaller diameters. Besides their application to age dating, the CSFDs may provide additional information about the characteristics of the target. For example, the transition diameter from strength- to gravity-scaling could provide a tool for investigating the relative strengths of different geologic units. The magnitude of the offset between the impact melt and ejecta isochrons may also provide information about the relative target properties and/or exposure/degradation ages of the two units. Robotic or human sampling of coeval units on the Moon could provide a direct test of the importance and magnitude of target property effects on CSFDs.

1. Introduction and background

Recent work on the lunar chronology using Lunar Reconnaissance Orbiter (LRO) Camera (Robinson et al., 2010) data has re-encountered a curious discrepancy in crater size-frequency distribution (CSFD) measurements between impact units that was observed, but not understood, during the Apollo era. For example, at Tycho, Copernicus, and Aristarchus craters, CSFDs of impact melt deposits give statistically significantly younger relative (e.g., Shoemaker et al., 1968; Strom and Fielder, 1968a,b; Hartmann, 1968) and absolute model ages (AMAs) (e.g., Hiesinger et al., 2012; Zanetti et al., 2011) than impact ejecta blankets, although these two units formed simultaneously (e.g., Fig. 1a). This effect has also been observed at craters Jackson (van der Bogert et al., 2010) and

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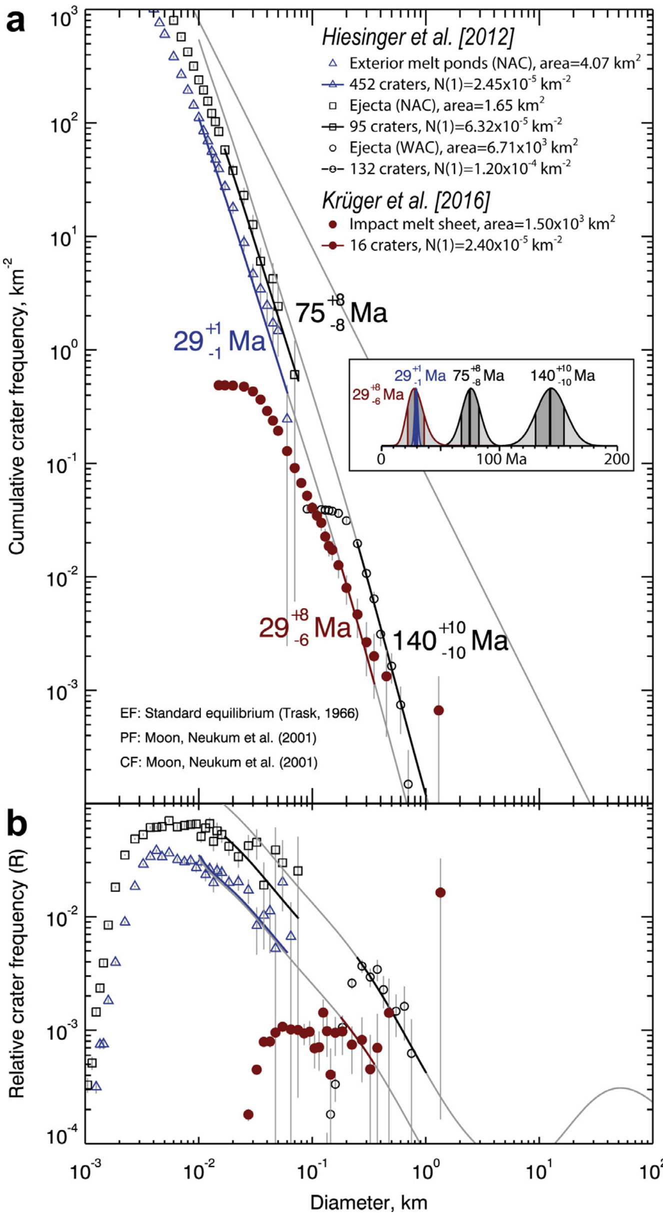

Fig. 1. CSFDs in (a) cumulative and (b) relative plots for Tycho crater from Hiesinger et al. (2012) (blue triangles, black squares and open circles), compared with a new CSFD of the Tycho impact melt sheet (red circles) (Krüger et al., 2016). Absolute model ages determined using Poisson timing analysis exhibit age probability functions representing distinct age determinations (inset).

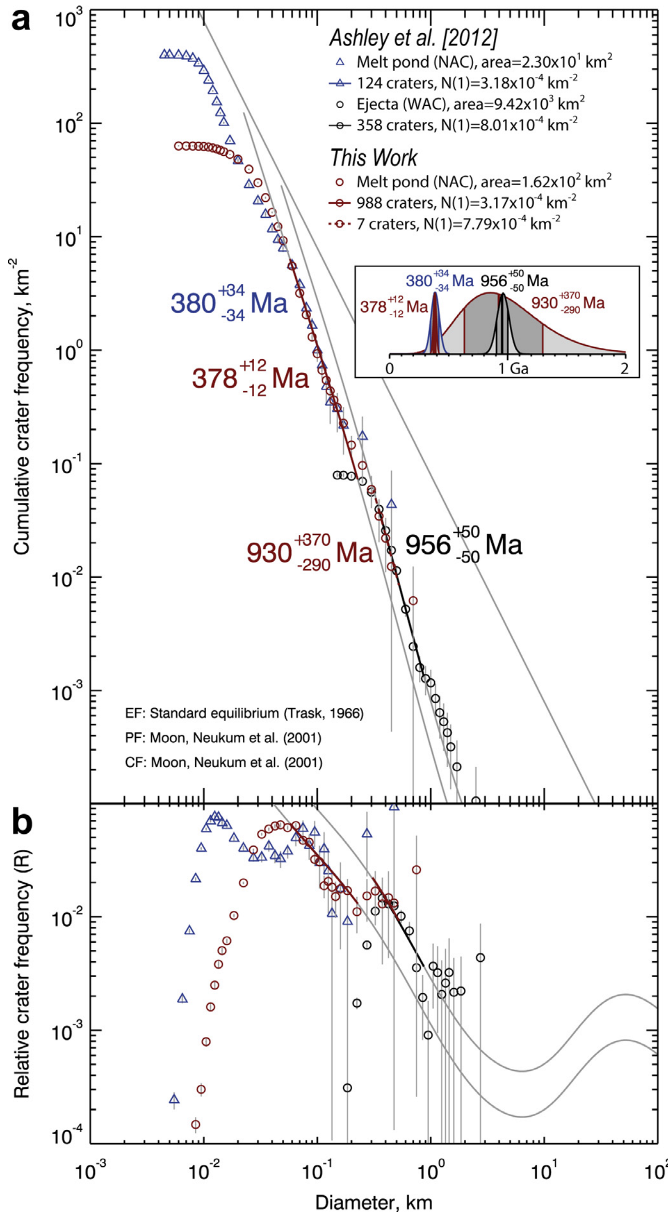

Fig. 2. CSFDs in (a) cumulative and (b) relative plots for King crater from Ashley et al. (2012) (blue triangles and black circles), compared with a new CSFD of the King crater impact melt pond (red circles). Absolute model ages determined using Poisson timing analysis exhibit age probability functions showing that the two young ages are statistically identical and the two old ages have a >68% probability of being the same (inset, the dark gray portion of each distribution represents ±34% of the probability function). The likelihood that the data points fit with an age of 930 Ma could instead have an age of 378 Ma is much less than 16%.

King (Schultz and Spencer, 1979; Ashley et al., 2012) (e.g., Fig. 2a). Possible reasons for the discrepancy include differing illumination angles, occurrence of subsequent volcanism and/or the formation of endogenic craters, layering within the target, pollution of the primary crater population by distant/field secondary and/or self-secondary craters, and the effects of differing target properties on the size-distribution of the small craters (<~1 km diameter). Understanding the causes of discrepancies in CSFDs of small craters on contemporaneous units is important for ensuring the appropriate use of CSFDs for the derivation of AMAs and understanding their limitations, particularly for young and spatially limited geological units.

1.1. Illumination conditions

The potential influence of illumination conditions on CSFDs was discussed in detail by Hiesinger et al. (2012) and references therein. While differences in illumination conditions can cause discrepancies in CSFD measurements (Soderblom, 1970; Young, 1975; Wilcox et al., 2005; Ostrach et al., 2011), Hiesinger et al. (2012), Ashley et al. (2012), Zanetti et al. (2011, 2012, 2013, 2014, 2015), van der Bogert et al. (2010), and the current study use image data with similar illumination conditions or measured multiple count areas within a single image. Thus, illumination conditions cannot explain the discrepancies between the CSFDs of impact melt and ejecta units.