On the Importance of Self-Secondaries

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Secondary craters (i.e., secondaries) are mainly located beyond the continuous ejecta deposits of their parent crater. Self-secondaries are a theoretical secondary crater population that is located on the continuous ejecta deposit of the parent crater. The possible existence of self-secondaries was first proposed by Shoemaker et al. (1969) to explain the cm–m crater density difference on melt deposits and normal ballistic ejecta deposits on the rim of the lunar Tycho crater. However, images obtained by later lunar orbiters (1965–2009) have relative low resolutions compared to the size of possible self-secondaries. Therefore, the existence, much less importance, of self-secondaries has long been ignored. The new generation of high-resolution images (0.5 m/pixel) obtained by the Lunar Reconnaissance Orbiter Camera (LROC) permit detailed study on the population of small impact craters (D<100s m) on the Moon. Since 2009, crater density differences at various locations of continuous ejecta deposits have been confirmed at both Tycho and several other Copernican-aged complex craters (e.g., Giordano Bruno, Aristarchus, Kepler, Copernicus). However, debate about the existence of self-secondaries started at the same time, because different target properties were interpreted to be the major cause for the observed crater density differences. Whether or not self-secondaries dominate small crater populations on continuous ejecta deposits is critical for: (1) completely understanding the cratering physics, because conventional impact ejection model (e.g., Z-model) does not predict near-vertically launched, thus late landed ejecta; (2) better calibrating the crater chronology function, since 4 of the 11 calibration point on the lunar crater chronology function are for Copernican craters and the crater densities were measured on continuous ejecta deposits.

Using high-resolution images, locations where self-secondaries were initially proposed were revisited, and cross comparisons for the size-frequency distribution of crater populations over different ejecta facies suggest that self-secondaries dominate the ejecta deposits of Tycho. Indeed, self-secondaries can cause fast equilibrium on ballistic ejecta deposits. Furthermore, different target properties between the ballistic ejecta deposits and melt pools of Tycho cannot account for the observed crater density differences. This is confirmed by numerical simulation that studied the effect of different target properties on crater size-frequency distribution. The dominance of self-secondaries on continuous ejecta deposits of fresh complex craters is also confirmed on Mercury. Forming self-secondaries requires near-vertical ejection angles and early ejection during the cratering event. Shock mechanics suggest that ejecta forming self-secondaries are launched from a shallow target zone by impact spallation, where rarefraction waves arrive earlier than the peak of shock waves. This stage predates the major impact excavation stage. Therefore, forming self-secondaries should be an inherent product of any impact cratering event. A systematic study of small crater populations around several lunar Copernican craters reveals that the predominance of self-secondaries would decrease with time since subsequently accumulated craters would gradually take the majority of the small crater populations on the continuous ejecta deposits.