# CAN WE DATE VERY YOUNG SURFACES?

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**Introduction:** The age of a planetary surface can be determined from the size-frequency distribution (SFD) of craters that have accumulated on its surface. This requires knowledge of the rate that craters of a given diameter accumulate over time (e.g., [1][2]). Smaller craters must be utilized to date young surfaces; however, small crater populations are challenging to use as there is uncertainty in their production and they are more prone to modification.

Modeled absolute ages rely on radiometric and cosmic-ray exposure ages derived from lunar *Apollo* and *Luna* samples. These ages provide calibration points for crater SFDs on the units from which they were acquired. The commonly used chronology derived by *Neukum et al.* [1] is expressed as the sum of all craters $D \geq 1$ km = $N(1)$ as a function of time. For very young surfaces however, $D \geq 1$ km craters may not be available for counting and therefore the value of $N(1)$ is not directly observed, but rather extrapolated from smaller craters using a modeled production function that describes the expected crater SFD over a wide range of diameters fit to the observed range of crater diameters. Any uncertainty in the production function, or deviation in observed crater SFDs from the production function, will therefore propagate into an error in the model age.

We assess the reliability of the most often used chronology and production functions for the Moon [1] and Mars [2] at small crater diameters on very young surfaces and show how modification of the crater SFDs through various processes may propagate into errors in age estimates. This is done by developing an independent chronology and production function from the observed present-day impact rate. This assumes the present-day cratering rate is representative of the recent past for which we apply our modeled production function. Short-term variations in the rate of cratering have likely occurred and the question of whether the observed present-day impact rate is representative of the long-term average is an outstanding question.

**Impact rate:** We have compiled several sources to estimate the SFD of impactors impacting the Earth and Moon [3-10] (Fig 1). The distribution of impactors in cm to m range relevant to $D < 100$ m craters generally follow a power-law distribution. From global optical and infrasound surveys of airburst, *Brown et al.* [4] estimated an order of magnitude higher number of impactors at diameters tens of meters than previous estimates. This led to a predicted shallower power law slope than implied by other observations. Reanalysis of the redetection statistics from the surveys by

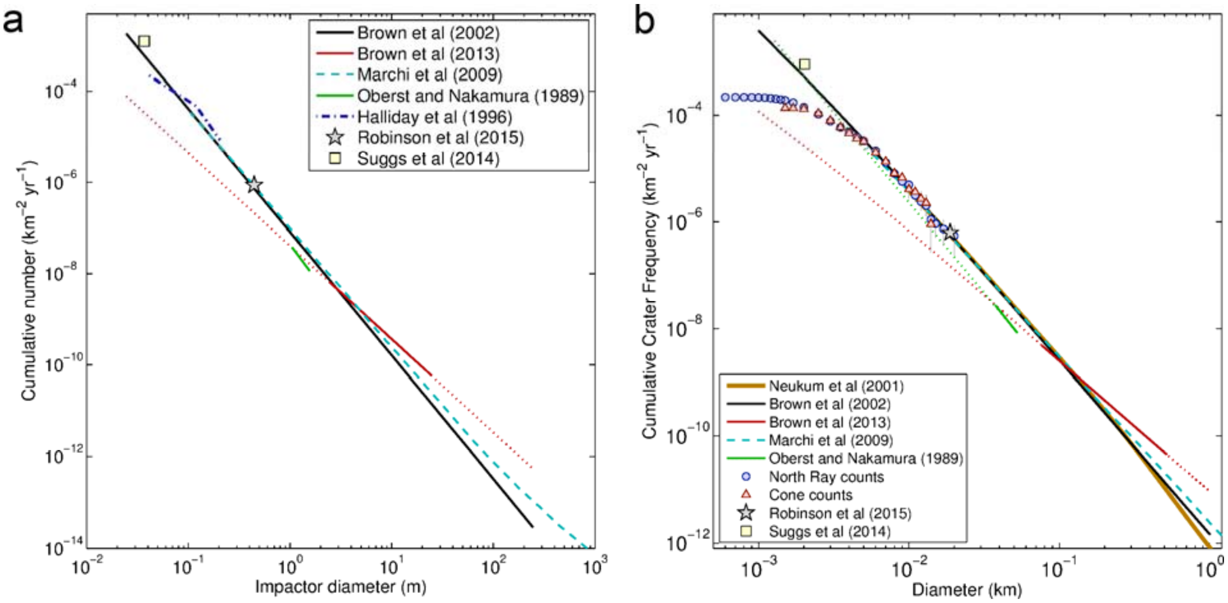

Fig 1. (a) Impactors and (b) lunar craters normalized by area and time to an annual flux/production for comparison. Convertion between impactors and craters is done assuming pi-scaling with nominal regolith target properties (see [10] for more details).

*Boslough et al.* [11] resulted in much closer agreementto bolide frequency estimates. The power law fit of *Brown et al.* [3] provides a good fit to several estimates of the impactor population at this size range and we assume this for the annual flux of objects colliding with the Earth. From this we model crater populations using a Monte Carlo simulation and derive a production function and chronology function for young surfaces on the Moon and Mars.

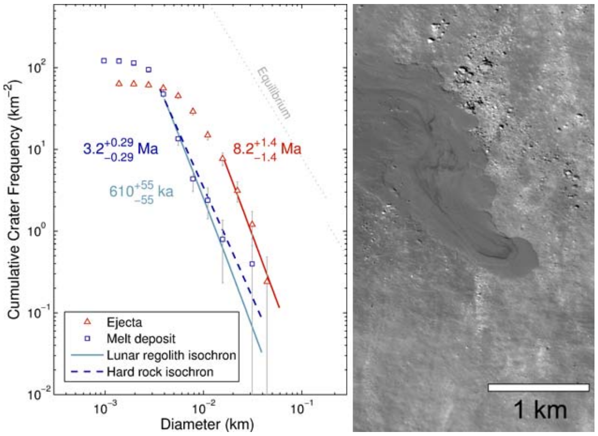

Fig 2. Impact melt deposit on the ejecta of Giordano Bruno crater and crater SFD on and off of the melt deposit with nominal lunar regolith and hard rock production functions [14].

**Results:** *Williams et al.* [10] demonstrated that this approach results in crater SFDs consistent with crater counts of the ejecta of North Ray and Cone craters, two of the anchor locations in the lunar chronology, and produces model ages similar to their cosmic-ray exposure ages of 50.3 ± 0.8 Ma and 25.1 ± 1.2 Ma, respectively [13].

This demonstrates that useful ages may be modeled for young surfaces. However, several factors influence crater SFDs and may lead to errors in model age estimates, such as: variations in target properties, deceleration and ablation of impactors by an atmosphere, secondary and self-secondary craters formed from high velocity fragments ejected by the primary impact event, or erosion and deposition modifying crater topography. These processes preferentially alter the smaller diameter craters and can result in changes in the SFD power law slope and the derived model ages. For example crater counts conducted on a fresh lunar impact melt on the ejecta of crater Giordano Bruno produce a model age estimate that differs by more than a factor 10 than the adjacent clastic ejecta, even though these surfaces formed near-instantaneously. This likely results from differences in target properties and the presence of self-secondary craters which appear to have pre-populated the ejecta prior to emplacement of the impact melt [14]. Utilizing a production function corresponding to a hard rock target reduces the discrepancy in age to a factor of 2.5 (Fig 2).

From the example of Giordano Bruno, it is clear that small craters can yield model ages with substantial errors, and if sources of these errors go unrecognized and are not accounted for, they have the potential to confound geologic interpretations.

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