CHALLENGES USING SMALL CRATERS FOR DATING PLANETARY SURFACES.

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Introduction: Impact craters can be used to estimate the age of a planetary surface, given knowledge of the rate of crater accumulation, and are the primary method for age dating planetary surfaces (excluding Earth) (e.g. [1][2]). The factors shaping crater production at diameters < 100 m are not well understood and under debate. However, because of the frequency at which these craters form, they are utilized to discriminate surface ages of geologically young regions and features at a higher spatial resolution. This level of resolution is required to establish the temporal relation of recent geologic activity on the Moon such as Copernican impacts, including North Ray, South Ray, and Cone craters, sites used to anchor the crater chronology, and Mars such as gully, landslide, and outflow channel formation, volcanic resurfacing, sedimentation, exhumation, dune activity, glaciation and other periglacial landforms, and the possible relation of such features to obliquity variations of ~10^7 y timescale.

Radiometric and cosmic ray exposure ages of Apollo and Luna samples, correlated with crater populations, anchor the lunar crater chronology and provide predicted size-frequency distributions (SFDs) of crater populations for a given surface age. Deviations from the predicted SFD occur through various processes which typically preferentially alter the smaller diameter crater populations, making small craters more challenging to use for age-dating surfaces.

We model crater populations using a Monte Carlo simulation by scaling the observed annual flux of objects colliding with the Earth [3] to the Moon and Mars [4]. This approach results in crater SFDs that are consistent with counts conducted on the ejecta of North Ray crater and Cone crater which have cosmic-ray exposure ages of 50.3 ± 0.8 Ma and 25.1 ± 1.2 Ma, respectively [5].

Target Properties: The resulting crater diameter for a given impact will be influenced by the target properties at small sizes, known as the “strength” scaling regime [6]. This can be seen in Fig. 1 where crater counts were conducted on a fresh lunar impact melt on the ejecta of crater Giordano Bruno [7]. The crater SFD of the melt, a coherent rock unit, differs from counts conducted on the adjacent clastic ejecta, with age estimates that differ by more than a factor 10 due to impacts generating smaller craters on the impact melt. If we assume a hard rock target, we reduce the age discrepancy to a factor of 2.5.

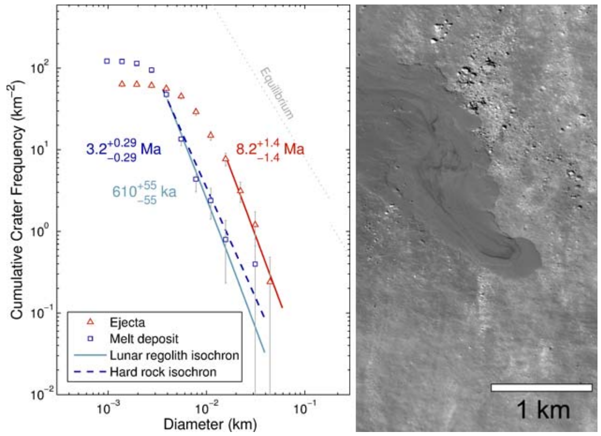

Fig 1. Impact melt deposit on the ejecta of Giordano Bruno crater and crater SFD on and off of the melt deposit with nominal lunar regolith and hard rock isochrons [7].

Self-Secondary Craters: The melt deposit also illustrates another issue that may confound crater counting on the ejecta of craters. A population of craters appear to have been formed just prior to the emplacement of the impact melt deposit (Fig. 2). Shoemaker [8] suggested that fragments ejected at near-vertical angles could fall back onto the ejecta to form self-secondary craters. As the lunar chronology is anchored to crater counts conducted exlusively on crater ejecta in the Copernican, self-secondaries could represent a source of mis-calibration.

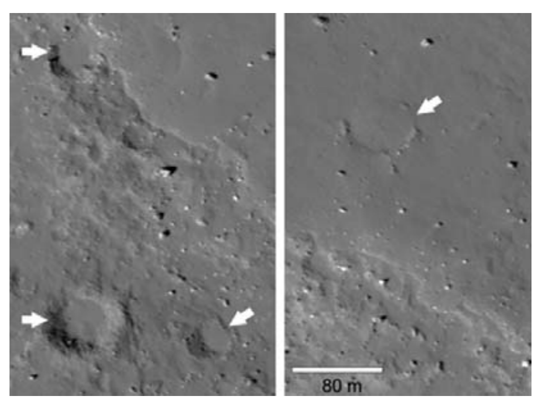

Fig 2. Pre-existing population of craters (white arrows) formed prior to emplacement of impact melt deposit.

Atmosphere: The atmosphere of a planet will influence the crater SFD by removing energy from impactors as they traverse the atmosphere through deceleration, ablation, and possibly fragmentation. The atmosphere of Mars, with an average surface pressure ~6 mbars at zero datum, exerts an influence on the crater SFD at small diameters. This can be seen by comparing crater counts at two young impact craters, Zunil (7.8°N, 166.1°E) and Pangboche (17.2°N, 226.7°E) [4]. Zunil, in Elysium Planitia, is at an elevation of -2.8 km, while Pangboche is near the summit of Olympus Mons at an elevation of 20.8 km, representing an elevation difference exceeding two atmospheric scale heights and a difference in atmospheric density of over an order-of-magnitude at the surface. Our model produces a crater count isochron consistent with an age of ~1 Ma for Zunil, similar to the crater count isochrons of [2]. The same crater count isochron gives an age of 63.3 Ma for Pangboche; however, if we account for the influence of elevation on the atmosphere, our model predicts an age of 35.1 Ma (Fig 3). Additionally, paleopressure variations on Mars, which have been potentially large due to substantial obliquity variations, will influence the crater SFD in a similar manner.

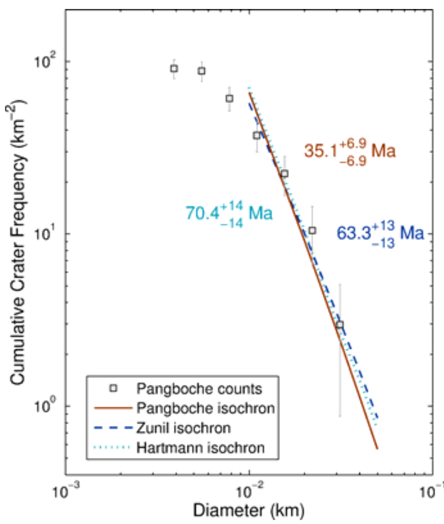

Fig 3. Pangboche crater counts with age estimates using the Hartmann isochron [2], the -2.8 km elevation model isochron [4], and the 20.8 km elevation model isochron [4]. Ages estimated using the Craterstats2 tool [9].

Distant Secondaries: High-velocity fragments can travel far from the primary crater to form isolated craters that may be indistinguishable from a primary crater. Large numbers of these background secondaries have been hypothesized to exist [8], but it remains unclear if and how such background secondaries contribute to observed crater SFDs [10]. Several recent studies (e.g. [11][12]) have presented compelling evidence that secondary craters are likely to be numerous on planetary surfaces and may even predominate at small sizes.

Corinto crater, located south of Elysium Mons, displays dramatic rays visible in nighttime THEMIS imagery (Fig. 4a) [13][14] as ejected material altered the thermosphyical properties of the martian surface over a 2×10^2 area south of the primary. We have identified secondaries in ray segments over 2000 km from the primary crater. The rays are seen in HiRISE to be areas of concentrated secondary craters (Figs. 4b,c).

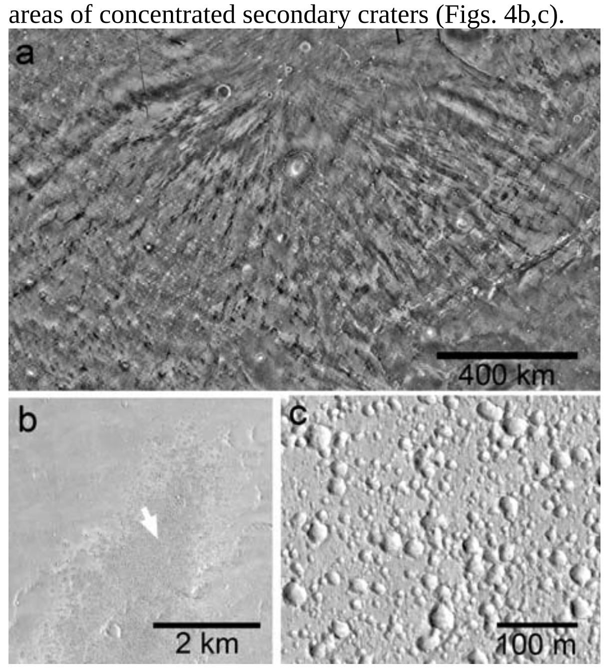

Fig 4. (a) Nighttime THEMIS mosaic showing rays of Corinto crater, Mars. (b) HiRISE image showing rays comprised of dense secondary craters, arrow shows zoom in (c) of secondary craters.

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