HOW SMALL IS TOO SMALL? A MODEL FOR ASSESSING RETENTION AGE UNCERTAINTIES WHEN DATING SMALL AREAS.

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Introduction: For the past several decades, methods for determining absolute ages of planetary surfaces using craters have been developed and refined by a number of researchers [1-3]. Due to volcanic and geomorphic processes occurring over time, however, erosional or mantling resurfacing events will typically change the crater population, often removing craters from the small-diameter end of the distribution [4]. At the large-diameter end of the distribution, craters are more likely to survive, but the base age of the unit is strongly influenced by this tail and the method of binning can result in loss of information [4]. With the increase in high-resolution imagery, smaller scale features are being discovered, like alluvial fans and deltas, leading to questions about their timing. But the small and coarse tail effects on crater populations can cause large errors when attempting to date smaller surfaces, as the smallest craters are likely to be influenced by erosional processes, and the presence of just a few large craters could lead to erroneously old ages.

Here we have developed a simple model to address the uncertainty within an individual cratering model age measurement, specifically focused on determining the errors in ages derived from smaller areas (i.e. 10,000 down to 100 km^2) because of the growing interest in dating smaller scale features. We first address the case in which we have an ideal surface, such that all volcanic and geomorphic processes are neglected, before considering how low to moderate long-term rates of erosion and crater infilling affects surface age uncertainty.

Methods: In both our "non-eroding" and "eroding" models, 200,000 km^2 surfaces were generated with crater populations ranging between 60 m and 64 km as defined by the Hartmann isochrons for Mars for 3.5 Ga (Early Hesperian) and 1 Ga (Middle Amazonian) [2004 iteration, 1]. The center coordinates of each crater were determined using a random number generator, with the only constraints being that the craters must not extend past the 200,000 km^2 area and that all of the craters for a given age, as defined by Hartmann [1], be present (i.e. craters cannot obliterate one another). This model does not try to reproduce any true physical processes, like fragmentation mechanics to generate secondaries, rather it assumes that the isochrons as defined by Hartmann [1] are the theoretical size-frequency distributions for well-preserved surfaces of a known age. These "ideal" cratered surfaces were then randomly subsampled over smaller and smaller areas (10,000 km^2 down to 100 km^2), the number of subsamples chosen such that 200,000 km^2 was sampled for the smallest sub-area (i.e. n=2000 for 100 km^2). Then for each subsampled area the crater populations within that area were compared to Hartmann's 0.1 to 4.0 Ga isochrons. Normalized RMSE was used to determine the best fit between the subsampled data and known isochrons (at 0.1 Ga intervals) and a sample age was assigned.

For the "eroding" model, the obliteration model of Smith et al. [5] was used, which accounts for erosion and infilling (defined by a beta term in the Smith et al. model) and the resulting effect on the crater diameter distributions (i.e. number of craters/area versus crater diameter), as shown in Figure 1 for a combined rate of erosion and infilling of 100 nm/year on the 3.5 Hartmann isochron.

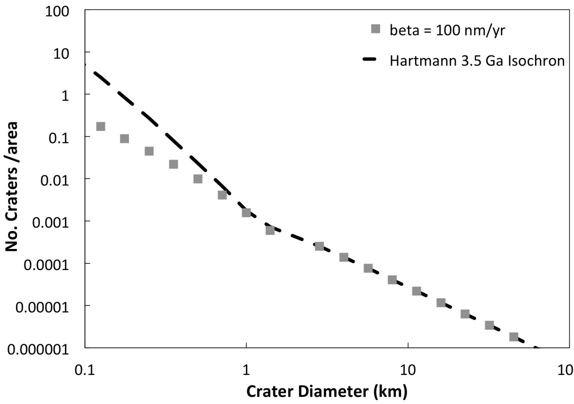
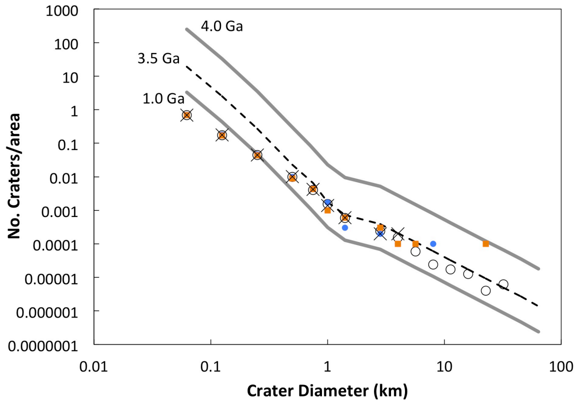


Figure 1. Crater diameter distribution as defined by the Hartmann 2004 iteration [1] shown by dashed black line (for 3.5 Ga) and the effect that 100 nm/yr of erosion and infilling ("beta") would have on that distribution (per Smith et al. [5]) shown by grey squares.

Selected Model Results:



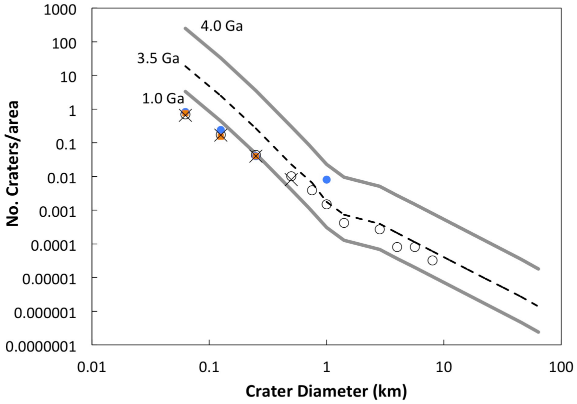


Figure 2. (a) Hartmann plot where the thick grey lines represent the 4.0 Ga (upper) and 1.0 Ga (lower) isochrons, respectively, and the dashed line represents the 3.5 Ga isochron, which is the age of the "true" surface. The orange triangles and blue circles show the results for two individual crater counts taken from a 10,000 km^2 subsampling area, where 100 nm/yr of erosion and infilling has been taken into account. The open circles represent the average crater frequency for all 2000 subsamples and the X's represent the mode. (b) The results are now shown for two individual crater counts taken from a 100 km^2 subsampling area.

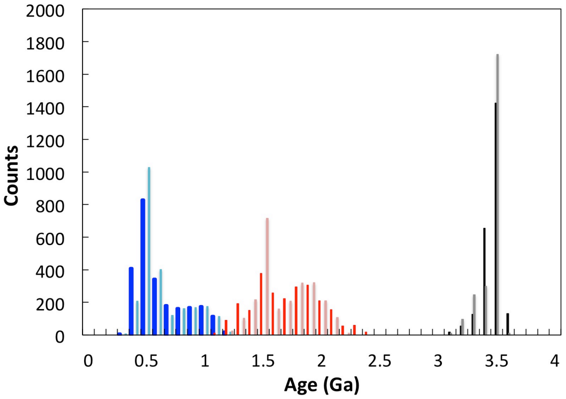


Figure 3. The distribution of ages from the "non-eroding" model for the case of 10,000 (light) and 1,000 (dark) km^2 subsampling areas for true surface ages of 0.5 Ga (blue), 1.5 Ga (red), and 3.5 Ga (black). The distribution of ages that result from subsampling the 0.5 Ga surface and 3.5 Ga surface are right-skewed and left-skewed, respectively, while the 1.5 Ga distribution is more normal.

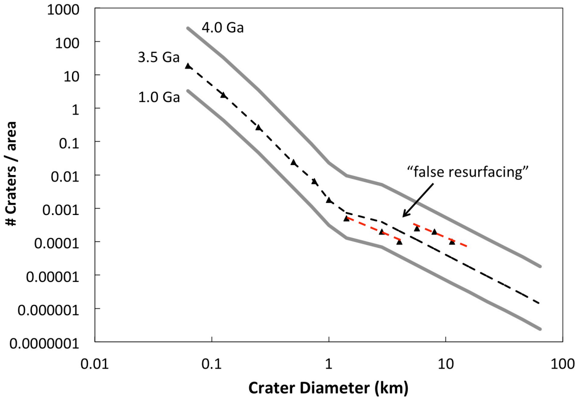


Figure 4. An example of a "false resurfacing" event; individual subsample taken from a 10,000 km^2 area with an initial surface age of 3.5 Ga (no erosion). This occurs in ~5% of the generated distributions.

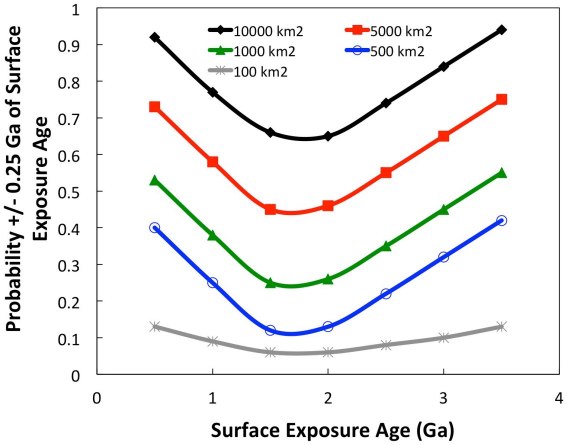


Figure 5. Curves of constant area are shown where the probability of being ± 0.25 Ga within the true surface age, for a moderately eroded surface (beta = 100 nm/yr), is on the y-axis and the true surface age (in Ga) is on the x-axis.

Discussion and Conclusions: Our results show, quantitatively, that crater counting to estimate age of small surfaces, especially ~100 km^2, has unavoidable large uncertainties and leads to a narrow range of crater sizes in which the correct age may be reflected in the crater density functions that are used to date surfaces. This range decreases with decreasing surface area and increasing erosion and infilling. Steps in the isochron data, in which crater density data are shifted downward for some crater sizes, are often cited as indicators of resurfacing events. We find, however, that such steps occurred randomly in ~5% of the crater size-frequency distributions we generated. This can lead to large errors when determining which tangential isochron is used to assign a surface age. Our modeling suggests that, in general, the least reliable ages occur between 1 and 3 Ga years. Younger surfaces preserve the smaller craters and older surfaces collect larger ones, both improving the probability of obtaining the correct age. For areas less than 1000 km^2 and true ages of 1 to 3 Ga, there is only a 20 to 40% probability of the calculated age lying within 0.25 Ga of the true value, where as for surfaces smaller than 500 km^2 the corresponding probabilities drop to about 10 to 20%.

References: [1] Hartmann (2005) *Icarus,* 174, 294-320 [2] Hartmann et al. (1981) *Basaltic Volcanism on the Terrestrial Planets* [3] Ivanov (2001) *Space Sci. Rev.*, 96, 87-104 [4] Michael and Neukum (2010) *Earth and Planetary Science Letters*, 294, 223-229 [5] Smith et al. (2008), *Geophysical Research Letters*, 35, L10202.