A MODEL FOR ASSESSING UNCERTAINTIES ASSOCIATED WITH INDIVIDUAL CRATER AGE MEASUREMENTS FOR SMALL AREAS (<1000 km^2). M. C. Palucis and W. E. Dietrich, Department of Earth and Planetary Science, University of California at Berkeley, Berkeley, CA, mpalucis@berkeley.edu and bill@eps.berkeley.edu

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]. Isochrons, which are defined as the crater size-frequency distribution for a surface of a specified age (assuming the absence of erosional processes or obliteration), were initially derived from crater size-frequency distributions on the lunar maria that were calibrated with radiometric dating of lunar rock samples before being converted for use on the Martian surface [1]. Due to volcanic and geomorphic processes over time, 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]. These small and coarse tail effects 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 (<1000 km^2) because of the growing interest in dating small scale features such as alluvial fans and deltas. 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 (12,500 km^2 down to 80 km^2), the number of subsamples chosen such that 200,000 km^2 was sampled for the smallest sub-area (i.e. n=2500 for 80 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. Depending on the experiment, we used all crater bin sizes, a sub-set of crater bin sizes, or individual crater size bins to determine the best-fit age.

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. Based on isotopic data from the MSL Curiosity rover, scarp retreat rates of mudstones at the distal end of the Peace Vallis fan over the past ~80 Ma averaged 750 nm/year [6], but global erosion rates across Mars may vary greatly depending on location and lithology [5,7]. The same subsampling and dating procedure as described above for the "non-eroding" model was used.

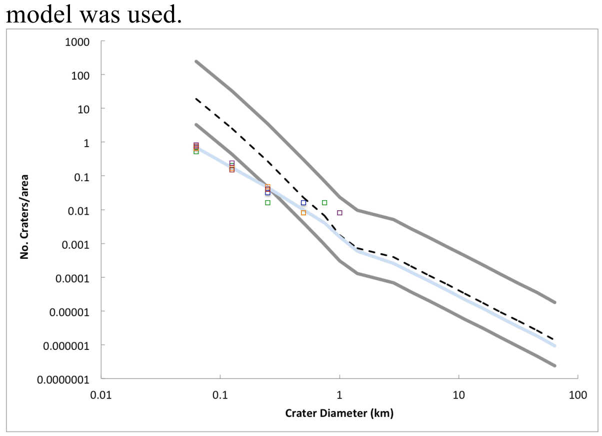

Figure 1. Crater diameter distribution as defined by the Hartmann 2004 iteration [1] shown by dashed line (for 3.5 Ga) and the effect that 100 nm/yr of erosion and infilling ("beta") would have on that distribution (per Smith et al. [5]) shown in blue. The boxes show individual model outputs for a subsampled area of 125 km^2. The upper grey line is 4.0 Ga and the lower grey line is 1.0 Ga for reference.

Initial Results: Below are some initial results from our model, where we alter erosion and infilling ("beta") from 0 to 100 nm/yr. In Figures 2 and 3 we show the probability of determining the correct surface age within +/- 0.25 Ga of the true age (in this case 3.5 Ga in Figure 2 and 1.0 Ga in Figure 3) for subsampled surface areas ranging from 125 to 12,500 km^2. For these two cases, we determine the best-fit age using crater sizes ranging from 250 m to 64 km. When minimal erosion and infilling occurs on very old surfaces (black and grey triangles), there is a 70% probability or greater that the distribution of craters will give the true surface age, even for areas that are on the order of 100 km^2. When erosion and infilling is moderate on old surfaces (beta=100 nm/yr, white triangles), surfaces less than 1000 km^2 fall below a 50% probability of retaining a crater distribution that represents the true surface age. For a surface that is much younger (Figure 3), the probability of a surface retaining a crater distribution that yields the true surface age is less than 50% for all cases, unless minimal erosion has occurred and the surface area is greater than 12,500 km^2. As younger surfaces have less cratering, decreasing the sampling area leads to the loss of larger (and rarer) impacts and has a larger effect on the crater frequency (i.e. number craters/area) for the smaller crater populations. In Figure 4 we show the range of crater sizes that have a 90% probability of yielding the true surface age of 3.5 Ga (+/- 0.25 Ga) as a function of erosion and infilling ("beta") and subsample area. For the case of a 3.5 Ga surface, craters ranging from 0.25 to 1 km retain the most information about the surface's true age, though this range decreases with increasing erosion and decreasing subsampled area. For Amazonian-aged surfaces (not shown), there is almost no crater size bin that accurately reflects the true surface age, unless the area is greater than 12,500 km^2 and minimal erosion and infilling has occurred.

Initial Conclusions: Our initial results from this model suggest several things when using crater counting to ascertain Martian surface ages for small landforms. First, crater counting alone on small surfaces cannot give an exposure age with certainty due to loss of information at the lower end (due to erosion and infilling) and upper end of the distribution (due to a low probability of counting large craters). Secondly, for small areas, there is a constraint on the range of crater diameters that may retain information about the surface's true exposure age. This range decreases with decreasing surface area and increasing erosion and infilling.

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 [6] Farley et al. (2013) *Science Express*, 10.1126 [7] Hartmann and Neukum (2001) *Space Sci. Reviews*, 96, 165-194 [8] Dietrich et al. (2013) LPSC Abstract #1844, VIL.

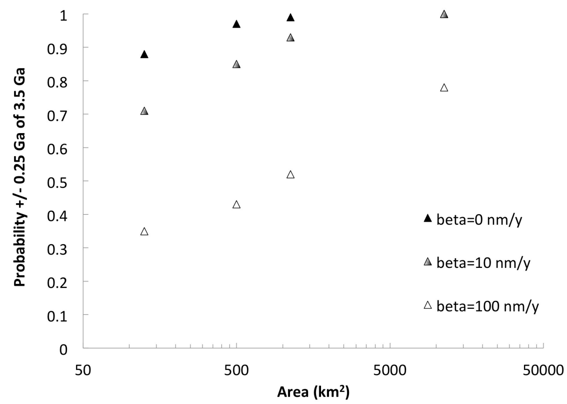

Figure 2. The true surface age is 3.5 Ga and all crater size bins were used to determine the best-fit age. The number of subsamples taken for each subarea (125-12500 km^2) was 1600.

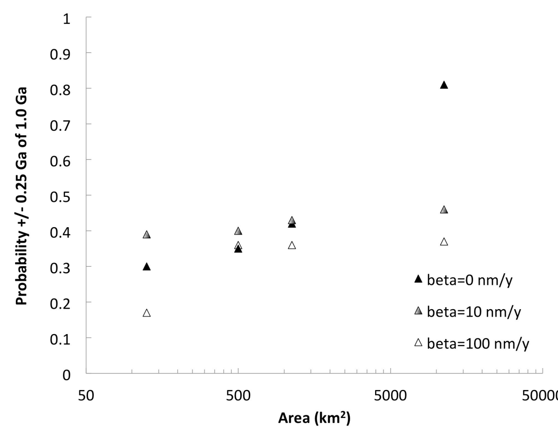

Figure 3. The true surface age is 1.0 Ga and all crater size bins were used to determine the best-fit age. The number of subsamples taken for each subarea (125-12500 km^2) was 1600.

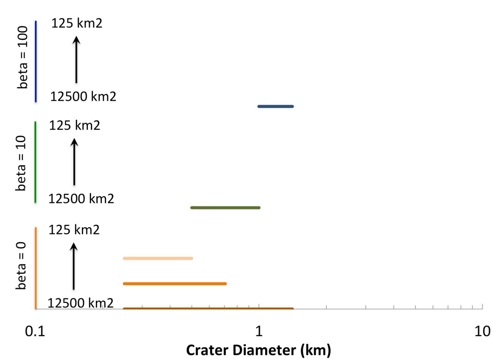

Figure 4. Range of craters that have a >90% probability of being within +/- 0.25 Ga of 3.5 Ga