HOW SMALL IS TOO SMALL? A SIMPLE MODEL FOR ASSESSING UNCERTAINTIES OF INDIVIDUAL CRATER AGE MEASUREMENTS FOR MARTIAN SURFACES. M. C. Palucis and W. E. Dietrich, Department of Earth and Planetary Science, University of California - 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]. Combined, this 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). 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. This model does not address the systematic errors that may arise from uncertainties in the production or chronology functions or from assumptions made about the impactor population over time or in comparison to the Moon.

Methods: In both our "non-eroding" and "eroding" models, 200,000 km^2 surfaces were generated with crater populations ranging between 250 m and 64 km as defined by the Hartmann isochrons for Mars for 3.5 Ga, 2 Ga, and 1 Ga [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 125 km^2), the number of subsamples chosen (n=1600) such that 200,000 km^2 was sampled for the smallest sub-area (i.e. 125 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. A histogram of ages was produced for a given subsample size, as well as the mean crater size subsampled.

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.

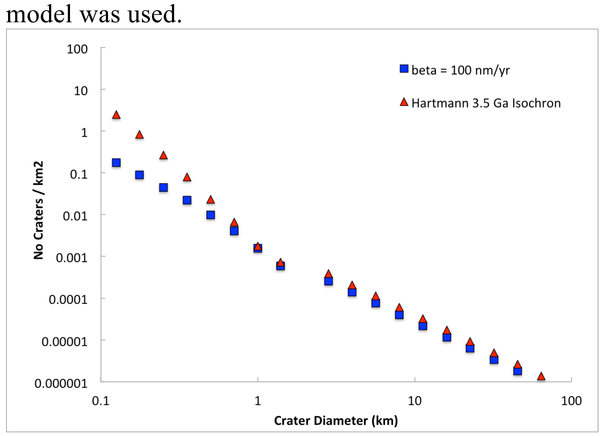

Figure 1. Crater diameter distributions as defined by the Hartmann 2004 iteration [1] shown in red and the effect that 100 nm/yr of erosion and infilling would have on that distribution (per Smith et al. [5]) shown in blue.

Initial Results: Our model findings are shown in Figures 2 through 4 for surface ages of 3.5 Ga, 2.0 Ga, and 1.0 Ga, respectively. In each figure, the mean surface age from 1600 sub-sampled areas is plotted as a function of the sub-sample area itself (12,500 km^2 down to 124 km^2). The error bars show the range of calculated individual ages for each sub-sample area (no error bars are shown when the entire 200,000 km^2 area was sampled as all craters are being counted and there is no variation in age). In the case of a 3.5 Ga surface (Figure 1), when erosional and infilling processes were less than 10 nm/yr, the *mean* surface age for areas as small as 125 km^2 resulted in an accurate age determination, but the variation in individual surface age estimates increased as the sub-sampled area decreased from 12,500 km^2 down to 125 km^2. For areas less than 1000 km^2, individual ages ranged from 2.6 Ga to 3.9 Ga. At higher erosion rates (i.e. 100 nm/yr), the mean calculated surface age decreased with decreasing sub-sampled area, and the range of individual surface ages varied from 0.1 to 3.9 Ga. For 2.0 and 1.0 Ga surfaces (Figures 3 and 4), when erosional and infilling processes were less than 10 nm/yr, the mean surface age actually increased with decreasing area. When erosion rates are increased to 100 nm/yr, however, the opposite occurred and the mean surface age decreased with decreasing area.

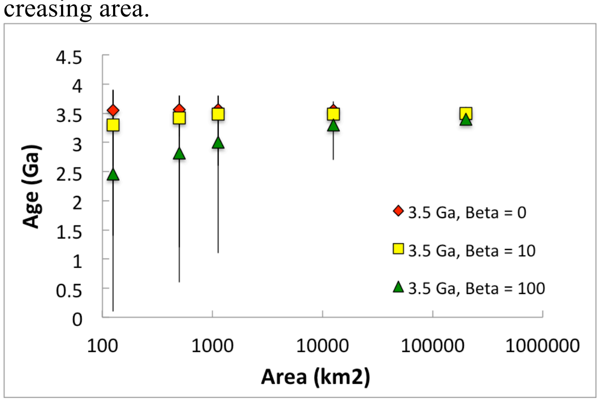

Figure 2. Mean surface age as a function of sampled area (n=1600) for beta = 0 (no erosion), beta = 10 nm/yr (low erosion) and beta = 100 nm/yr (moderate erosion) for an ideal 3.5 Ga surface (per Hartmann 2004 iteration).

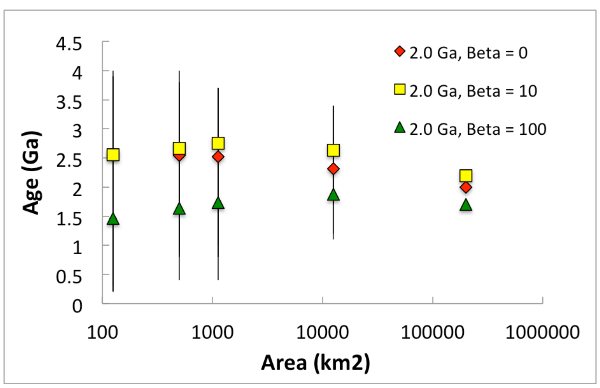

Figure 3. Mean surface age as a function of sampled area for an ideal 2.0 Ga surface.

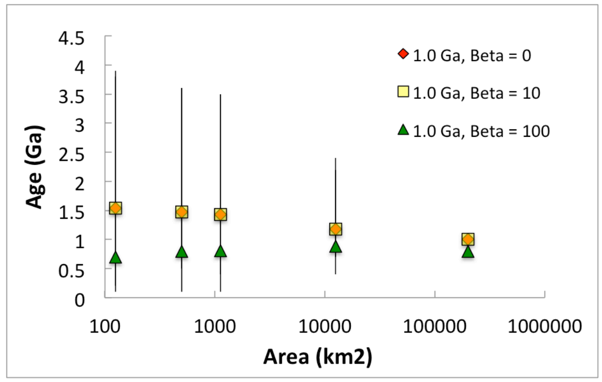

Figure 4. Mean surface age as a function of sampled area for an ideal 1.0 Ga surface.

Interpretations and Current Work: Our initial results from this simple model suggest several things when using crater counting to ascertain Martian surface ages for small landforms. Firstly, if the long-term rates of crater erosion are low (i.e. tens of nm/yr), then there is a minimal effect on the calculated surface age for a given area. A much larger effect in this case is the area of the surface itself, as smaller areas, especially areas less than ~1000 km^2, can give erroneous dates. This seems especially true for surfaces of late Hesperian to Amazonian in age (Figures 3 and 4).

For higher rates of erosion (>100 nm/yr), craters in the 0.25 to 1 km size class begin to be effected, especially for older surfaces. When crater counting smaller areas on these older surfaces, erroneously young ages may be determined. As shown in Figure 2 for 100 nm/yr of erosion, when counting surface that are only 125 km^2 or less, on average, one would determine the surface to be ~1 billion years younger than it actually is. This issue is less pronounced for younger surfaces, as shown in Figure 4, where for smaller areas (<1000 km^2) one might determine an age of 0.6-0.8 Ga for a surface that is actually 1 Ga. This suggests, for more easily eroded deposits, especially those that are smaller with few large craters, crater counting may yield incorrect information about timing and evolution. Current work aims to continue developing this model to incorporate more mechanistic erosional processes than those of Smith et al. [5] and to use it in conjunction with crater counting performed on depositional landforms within Gale crater, which are discussed by Dietrich et al. [8], to determine if it is possible to develop a better chronology for their timing and evolution.

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.