New Insights into Crater Obliteration in the Noachian Highlands of Mars. Samuel J. Holo and Edwin S. Kite University of Chicago, Department of Geophysical Sciences, Chicago, IL, 60637 – holo@uchicago.edu

Introduction: The Noachian highlands of Mars are heavily-cratered terrain that, in their geology, record pre-valley-network Mars, the climate of which remains enigmatic (e.g. [1]). The majority of craters on Noachian terrain are degraded (e.g. [2]), and several aspects of the Noachian highland landscape can be explained by the interplay of impact cratering and erosion of crater rims by fluvial erosion [3,4]. Further, examination of the latitudinal/elevational trends in crater density and morphometric properties has prompted studies on the history of climatic forcing on crater modification and degradation (e.g. [2,5]).

The size-frequency distribution (SFD) of craters in the Noachian highlands exhibits a paucity of craters < ~32 km in diameter, relative to extrapolation from isochron fits to larger craters (e.g. [6,7]). This is commonly interpreted to result from the obliteration of craters by the same surface processes that cause the aforementioned crater modification (e.g. [1,2]). However, the observed crater SFD may also be explained by an impactor size-frequency distribution that has changed through time, rather than crater obliteration (e.g. [8]).

If caused by crater obliteration, the Noachian crater size-frequency distribution implies ~1 km of terrain-averaged erosion [4,6]. This estimate exceeds the implied amount of erosion by valley networks by several orders of magnitude [9]. Thus, the pre-valley-network era may represent the period of Mars' history with the most fluvial erosion. In this work, we examine the spatial statistics of craters to assess the link between crater degradation and crater obliteration on the Noachian highlands.

Datasets and hypotheses: We used a global geologic map of Mars [10] and 2 pixel-per-degree (ppd) gridded MOLA data to generate a 2ppd map of Noachian highland units (eNh, mNh and lNh) with their associated elevations (smoothed by nearest-neighbor averaging to avoid sampling crater bottoms). Combination of this map with a global database of Martian craters [11] enables us to ask four main questions:

- Is there a signal of a latitude control on crater obliteration?
- Is there a signal of an elevation control on crater obliteration?
- Does the degradation of equatorial craters on Noachian terrain leave a measurable signal of spatial clustering relative to fresh craters?
- Do craters in the 4 km to 32 km range on Noachian terrain show a spatial clustering signal more similar to (a) that of the degraded Noachian crater population or (b) that of the fresh crater population?

Effect of Latitude: To examine the effect of latitude on spatial crater density, we placed each pixel of our 2ppd map into 10° latitude bins and determined the number of craters (within a given size class) per unit area for each latitude bin (Figure 1). We found that the spatial density of small craters drops by a factor of ~2 at latitudes > ~40° (Figure 1). This effect diminishes rapidly with increasing crater diameter and does not seem to affect craters > 32 km in diameter. However,

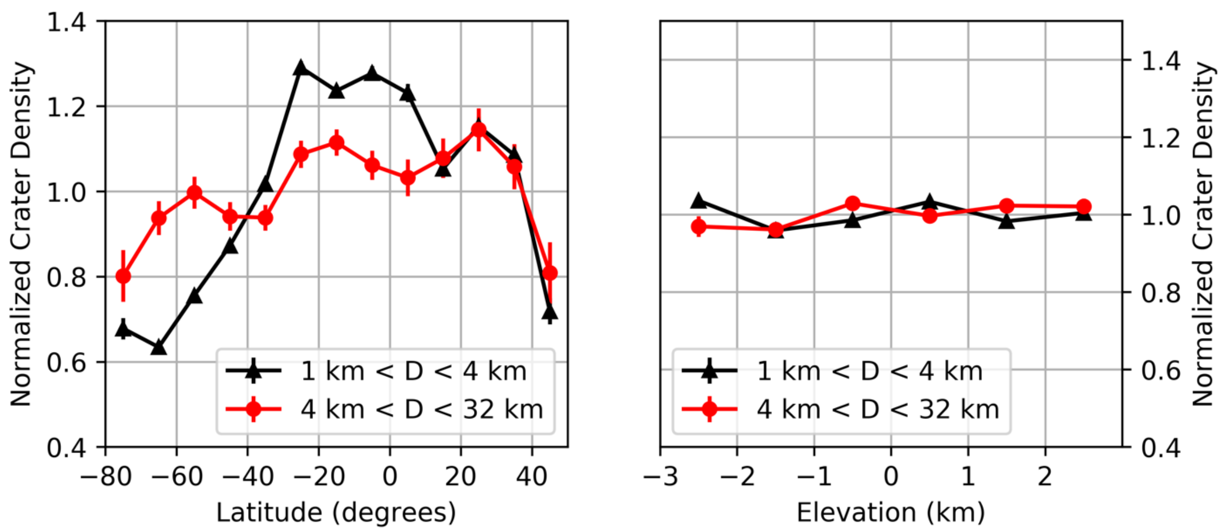

Figure 1. Mean-normalized spatial crater density as a function of latitude, elevation, and crater diameter. Errors are 2-sigma and are often smaller than the marker.

the paucity of small craters that is characteristic of crater SFD's on Noachian terrains persists at all latitudes.

We interpret our observed signal as Amazonian obliteration of small craters on Noachian terrains in the polar regions. This is consistent with the finding that crater-wall slope degradation (by presumably ice-associated processes) has continued throughout the Amazonian in the polar regions [5]. Our findings suggest that crater degradation can indeed cause crater obliteration but that latitudinally driven processes cannot explain the relative paucity of small craters on Noachian terrain.

Effect of Elevation: Placing our map in 1 km elevation bins, we found no significant effect of elevation on crater density in any size bin. This is seemingly at odds with previous observations of degraded crater density [2] and crater-wall slopes [5], which have been used to argue for prolonged crater degradation at low elevations. However, the inferred modification processes need not be responsible for the obliteration of (most of) the craters. The observed degraded Noachian craters could, for example, be the fluvially-modified remnants of a population that was largely obliterated by a second, elevation-insensitive process. Alternatively, the SFD of Mars impactors could have changed since the Noachian.

Spatial Clustering: To assess whether or not the spatial pattern of craters in the 4 – 32 km diameter range is consistent with a changing impactor SFD, we utilized a metric of spatial clustering: the two-point correlation function (2CF) [12]. The 2CF is a measure of excess (or deficit) probability of finding pairs of point observations separated by a distance within a given bin [12]. Further, a robust estimation scheme of the 2CF and its errors [12] enable straightforward computation of the 2CF for craters on Noachian highlands units.

We computed the 2CF for craters 4-8 km in diameter and found that those qualitatively labeled as fresh in [11] were consistent with uniform across a range of distances (Figure 2). Craters labeled as degraded were significantly clustered at scales < ~20° (Figure 2). This result is qualitatively the same for craters 1- 4 km in diameter but may suffer from bias due to incomplete labeling of degradation state at small diameters [11].

Neglecting degradation state, we found that both the 1-4 km and 4-32 km Noachian crater populations are consistent with a uniform spatial distribution (Figure 2). We conclude that if the 4–32 km section of the Noachian crater SFD is dominated by the remnants of crater obliteration, then the obliteration process produced no detectable deviations from spatial uniformity and is inconsistent with the signature of crater degradation.

Conclusions: We found that Amazonian polar processes degrade and obliterate craters but that there was no global elevation control on equatorial crater obliteration in the Noachian. The 4-32 km section of the Noachian crater SFD is consistent with spatially uniform, requiring either spatially uniform crater obliteration (inconsistent with the clustering signal from crater degradation) or a changing impactor SFD over time (e.g. [8]).

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References: [1] Irwin et al. (2013) *JGR-Planets.* [2] Craddock and Maxwell (1993) *JGR-Planets.* [3] Forsberg-Taylor et al. (2004) *JGR-Planets.* [4] Howard (2007) *Geomorphology.* [5] Kreslavsky and Head (2018) *GRL.* [6] Robbins et al. (2013) *Icarus.* [7] Quantin-Nataf et al. (2019) *Icarus.* [8] Strom et al. (2005) *Science.* [9] Luo et al. (2017) *Nature Communications.* [10] Tanaka et al. (2014) *USGS SIM-3292* [11] Robbins and Hynek (2012) *JGR-Planets.* [12] Landy and Szalay (1993) *ApJ.*

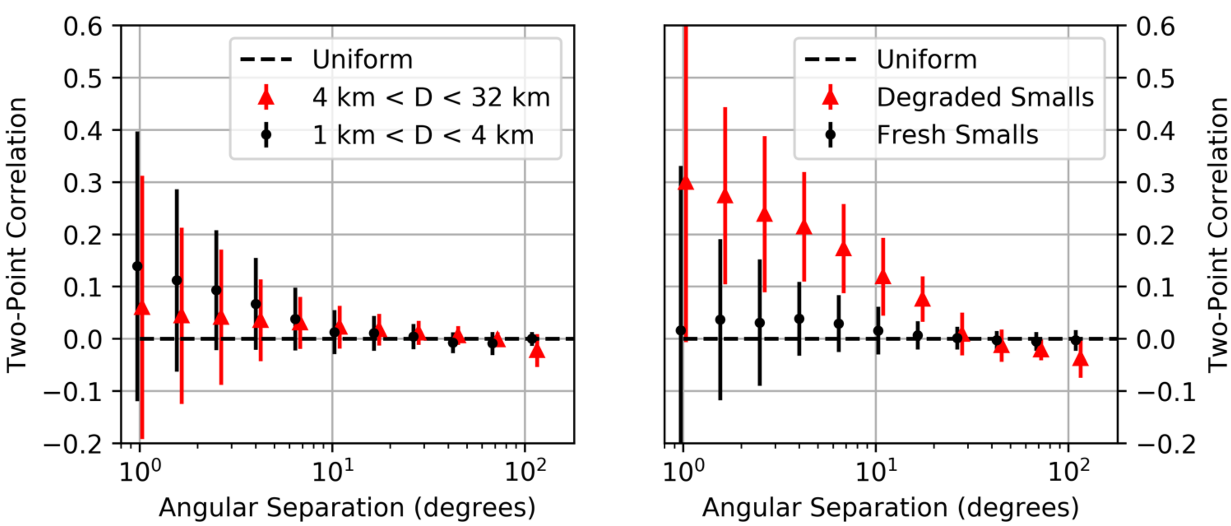

Figure 2. Two-point correlation function (spatial clustering) for different diameters and degradation states ("smalls" are considered craters 4 to 8 km in diameter only). Errors are 2-sigma.