UNSCRAMBLING NOACHIAN CRATER EROSION ON MARS. Edwin S. Kite[1] (kite@uchicago.edu)
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Summary: Noachian crater modification records an uncertain combination of fluvio-lacustrine, volcanic and aeolian processes operating over uncertain time-scales. Retrieving fluviolacustrine processes and erosion timescales is enabled by comparison between the erosion states of crosscutting craters. Crater-crosscutting statistics confirm that the more-habitable conditions that are entailed by fluviolacustrine erosion spanned a >>10^6 yr interval.

Background: The Martian landscape was modified by processes that preferentially filled in low ground prior to the Late Noachian / Early Hesperian peak in valley network incision (Fassett & Head, Icarus, 2011; Irwin et al., JGR, 2013). This early modification can best be constrained by studying closed-basin, low-latitude craters, which are anomalously shallow and have subdued rims relative to their younger, "fresher" appearing neighbors (Mangold et al., JGR, 2012; Craddock et al., JGR, 1993). The degraded state of these ancient craters is the best evidence for globally distributed and sustained surface liquid water (and thus habitable conditions) on pre-3.8 Ga Mars (Craddock & Howard, JGR, 2002). (Phyllosilicates also record pre-3.8 Ga liquid water, although the relative contribution of surface, deep subsurface and impact-ejecta aqueous environments to forming these phyllosilicates is not understood; compare Ehlmann et al., Nature, 2011 and Carter et al., Icarus, 2015). The bimodal distribution of crater-infilling states is better explained by fluvial erosion than by other processes (Forsberg-Taylor et al., JGR, 2004), at least in Sinus Sabeus (Grant, JGR, 1987). This is because fluviolacustrine processes rapidly fill in deep craters but only slowly fill in shallow craters, so that a rapid deterioration in habitability would leave few craters with <50% infilling. Subsequent accumulation of essentially unmodified craters builds up the other, deep-floored peak in the distribution of crater-infilling states. The curious absence of integrated drainage paths can be understood in terms of impacts competing with fluvio-lacustrine processes (Howard, Geomorphology, 2007). There is direct evidence for fluvial activity in the form of radial drainage networks in the form of inverted channels at some craters in Terra Sabea. At Terra Sabea and at many other ancient draping deposits dispersed across Mars, "weathering sequences" of Al-rich clays overlying Fe-Mg-rich clays have been located, consistent with persistent surface liquid water (Carter et al., Icarus, 2015). The NWA 7034 basaltic breccia contains Noachian-aged rounded clasts, indicating fluvial transport. Finally, Curiosity has confirmed that at least one shallowed crater floor (<3.8 Ga) is filled by fluviodeltaic sediments and was habitable (Grotzinger et al., Science, 2014). Taken together, these data establish the plausibility of a fluviolacustrine contribution to >3.8 Ga crater infilling but they do not constrain its relative importance nor its timing.

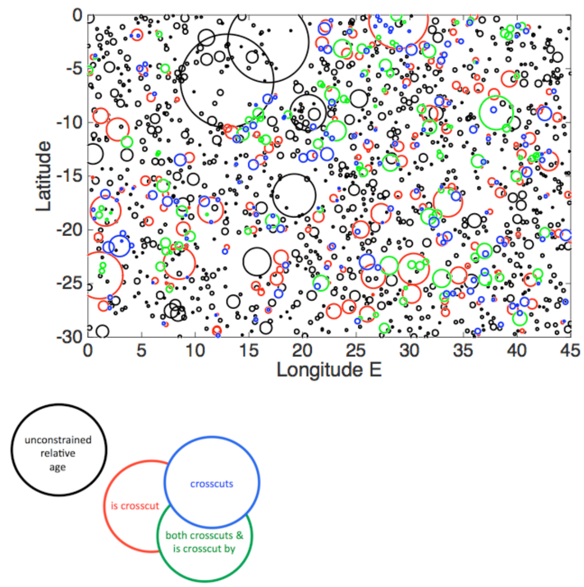

Figure 1. Crater-crosscut assignments in the Sinus Sabeus quandrangle (note that not all crosscuts are included in database). Crater positions and radii are from the Robbins et al. JGR 2012 database. Only craters with diameter > 8 km are shown.

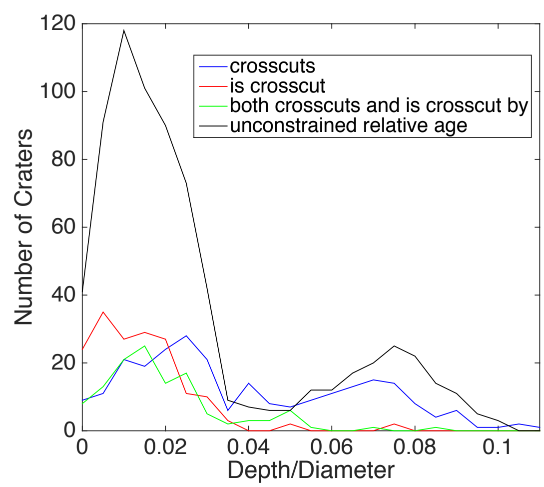

Figure 2. Depth-diameter (d/D) distributions for craters > 8 km in Sinus Sabeus (using the Robbins et al. JGR 2012 database). Considering only heavily-eroded craters (d/D < 0.05), craters that are crosscut tend to be more heavily-eroded than the craters that crosscut them, as previously noted by Craddock & Howard (JGR, 2002).

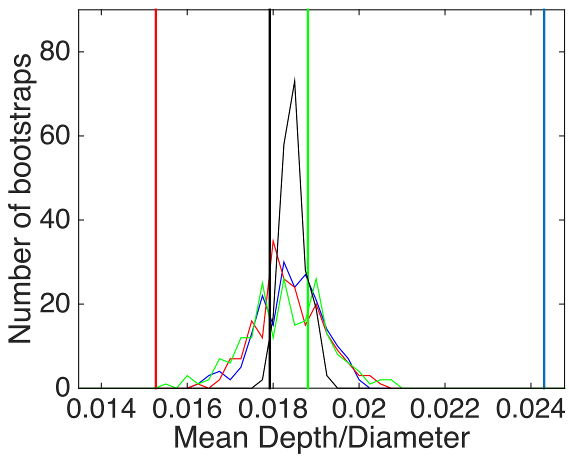

Figure 3. Thick vertical lines show the mean depth-diameter for craters with d/D < 0.05 for the four crater sub-populations identified in Figure 1. (Black – unconstrained relative age; blue – crosscuts another crater; red – is crosscut by another crater; green – both crosscuts and is crosscut). The thin lines show the mean of bootstrap distributions for the same sub-populations (200 bootstraps for each sub-population). The null hypothesis of a single brief spike of erosion predicts that the red and blue lines should both lie within the range spanned by the bootstrap distributions. This null hypothesis is rejected with high statistical significance, implying that the more-habitable conditions that are entailed by fluviolacustrine erosion spanned a long interval.

Basic open questions remain: The potential of crater-erosion data to quantify the prevalence and persistence of pre-3.8 Ga surface liquid water remains largely untapped. Basic open questions include: (1) Did fluviolacustrine activity dominate pre-3.8 Ga crater modification, or was it subordinate to processes that did not require surface liquid water? (2) For how long did fluviolacustrine activity continue? Previous work suggests, but does not confirm, that fluviolacustrine activity was indeed the dominant crater-modification process and that it operated over an interval spanning $\geq 10^8$ yr during the Noachian (Craddock and Howard 2002, Howard 2007, Irwin et al. 2013, Carr & Head 2010). This hypothesis can be tested by using crosscutting relationships to establish time-sensitivity kernels (beta distributions), and then use those kernels to reconstruct fluviolacustrine infilling as a function of time during the pre-3.8 Ga interval.

This can be done by analyzing and simulating relative erosion for multiplets (pairs, triplets and quadruplets) of overlapping ancient craters whose relative age is constrained by crosscutting relationships.

To test these ideas, we identified crosscutting relationships between craters > 8 km diameter in the Sinus Sabeus quadrangle. Confirming previous observations (e.g. Craddock & Howard, JGR, 2002), we found that the most ancient craters are more infilled than younger (but still Noachian) craters. This relationship is highly statistically significant (Fig. 3).

Complications: Craters can be occluded by other craters, and also by inter-crater sedimentation and flooding processes. Therefore the expected distribution of crosscuts between craters may be a function of the erosion history of the terrain – precisely what we are trying to infer using the crosscuts! Loopy belief propagation may be required to take account of these effects.

Work in progress: We are extending our approach to take account of more complicated distributions of craters (triplets, quadruplets …) and to other regions on Mars. We will convert the results to absolute time using crater-chronology functions. Future work will include forward modeling of erosion using a landsape-evolution model (e.g., MARSSIM).

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