Martian Climate Variations Driven By Obliquity Excursions: Evidence From Small-Crater Populations.
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Introduction: An unusual concentration of glacial features is found in Greg crater (east of Hellas, Lat. 38˚ S), exactly where Forget et al. (1) predicted extreme ice deposition rates during episodes of high obliquity (>45˚). Such episodes occurred quasi-episodically, on timescales of few Ma, during the last few 10s of Ma (2, 3). The last four episodes occurred about 5.5, 8, 9 and 15 Ma ago (2). Thus, ice-rich mantling episodes occur in some regions of Mars and modify landscapes on these timescales. Complimentary crater chronometry techniques indicate that, indeed, the sharpest small craters survive only from the time since those last high-obliquity episodes (3). The size dependence of small-crater survival times allows us to probe the depths affected by the mantling.

A Useful Diagram and Evidence for Obliquity-driven Climatic Episodes: To examine this problem we (3) introduced a diagram of estimated crater survival times versus crater depth, based on the crater isochron system (4,5). A horizontal bar in the diagram marks the ages of the last four high-obliquity episodes. This diagram (Fig. 1) shows that craters with depth ≤ ~10 m, in areas interpreted as ice rich mantling, survive only from the time of the last few high-obliquity episodes of ice rich mantling. "Windows" in the mantle reveal older (exhumed?) surfaces that show higher crater densities. The same diagram, limited to sharp-rimmed, undegraded craters (Fig. 2) shows the effect very strongly, craters shallower than ~10m post-dating the last mantling episodes (see also Fig. 3). These observations suggests an order-of-magnitude depth on the order of 10 m for the topographic effects of the last few episodes of high-obliquity climatic episodes.

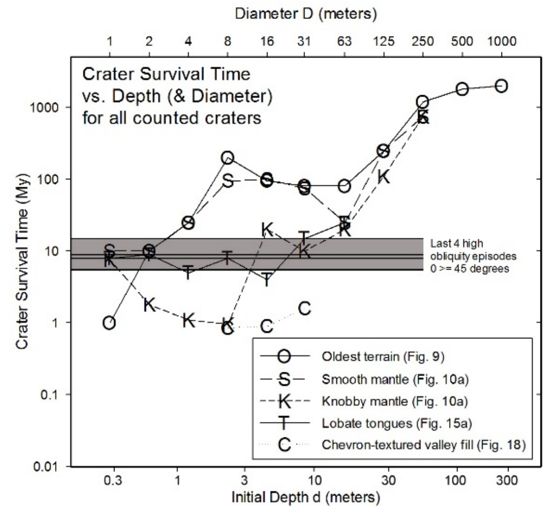

Figure 1. This diagram, showing estimate crater survival time versus initial crater depth (bottom scale), can be used to probe the vertical dimension of stratigraphy vs. age. Data are from Martian crater Greg (3). Curves O and S give data points for large, eroded craters for which ice-rich mantling is only a skin effect, and for surfaces interpreted to be "windows" (where recent ice-rich mantling has been removed, so that only older, ice-depleted, compacted mantle surfaces are exposed). Curves K, T, and C, however, refer to surfaces of glacial structures and "knobby" ice-rich terrain, associated with recent mantle sublimation. On surfaces interpreted as currently ice-rich mantle, only craters shallower than ~10m survive from the era since the last four episodes of high obliquity. Larger craters with greater relief survive for longer time periods.

Using small craters to Examine Stratigraphy and Erosion-Deposition-Exhumation effects. A grosser result at larger scales (smaller craters survive for shorter times) has been known since 1965. I refer to it as the Őpik effect, after the earliest Martian work to point it out (6, 7). It is stronger (if rarely remembered) on Earth: small impact craters survive for less time that large craters. The Őpik effect thus allows quantitative study of relative and absolute erosion-deposition-exhumation effects on Mars.

The use of decameter scale craters to analyze Martian history has been questioned (8), but dividing crater densities by newly measured primary crater production rates (8) offers an upper limit on crater retention ages (i.e. crater survival times), in the 5-30m diameter range where the production rates are best measured. In other words, that technique measures the time required to create all the visible craters in that size range, assuming they are all primaries. The somewhat lower ages (by factor 3-4) derived from the isochron system thus suggest that a significant fraction (0.6-0.8??) of the decameter craters are scattered "field secondaries" (5). Exciting quantitative improvements in these techniques will apply as we learn more about the primary crater production rate, now being measured by Daubar and HiRISE colleagues (8).

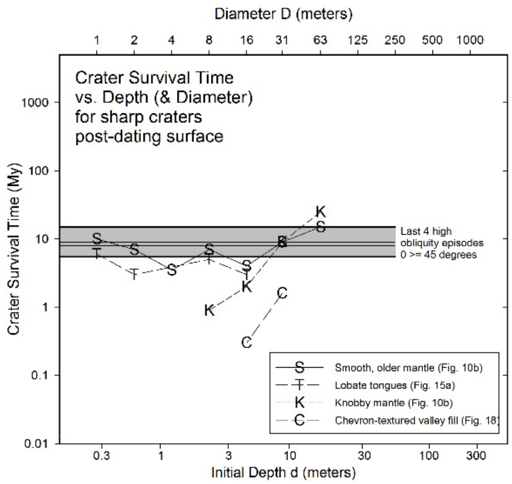

Fig. 2. Same diagram as Fig. 1, for surfaces in Greg crater, but showing only sharp-rimmed, well preserved craters. Such craters, if shallower than ~10, survive only since the last 1 to 4 episodes of obliquity over 45˚, hence giving quantitative estimates of mantling history and climatic variation. The diagram suggests craters of depth < ~10m are degraded if they experience more than 1 or a few episodes of obliquity-driven mantling, and sharp craters in that size range allow us to “see” only back through the last few episodes of high-obliquity climate conditions.

Conclusion: My current, larger set of accumulated crater count data suggest that the above result --- decameter-scale craters surviving only since the last high-obliquity episodes --- applies in many, but not all, Martian areas. This suggests that obliquity-driven climatic variations, with few-Ma timescales, dominate the human-scale topography of Mars in many regions. As on Earth, we need to rely on erosion and exhumation effects to see the oldest stratigraphy on Mars.

References: [1] Forget, Francois, R. M. Haberle, F. Montmessin, B. Levrard, J. W. Head, 2006. Formation of Glaciers on Mars by Atmospheric Precipitation at High Obliquity. Science, 311, 368-371. [2] Laskar, J., M. Gastineau, F. Joutel, B. Levrard, P. Robutel 2004. A new astronomical solution for the long term evolution of the insolation quantities of Mars. LPSC XXXV, Abstract 1600. [3] Hartmann, W. K., Veronique Ansan, Nicolas Mangold, Francois Forget, Daniel C. Berman. 2014. Comprehensive Analysis of Glaciated Martian Crater Greg. Icarus, 228: 96-120. [4] Hartmann, W. K., and G. Neukum 2001. Cratering chronology and evolution of Mars, in Chronology and Evolution of Mars, Eds. R. Kallenbach, J. Geiss, and W. K. Hartmann. Eds. R. Kallenbach, J. Geiss, and W. K. Hartmann. (Bern: International Space Science Institute; also Space Sci. Rev., 96, pp. 165-194.) [5] Hartmann, W. K. 2005. Martian cratering 8. Isochron refinement and the history of Martian geologic activity Icarus, 174, 294-320. [6] Öpik, E. J. 1965. Mariner IV and craters on Mars. Irish Astron. J. 7, 92. [7] Öpik, E. J. 1966, The Martian surface. Science 153, 255. [8] Daubar, I., A. McEwen, S. Byrne 2013, How Accurately Can We Date Recent Climate Change on Mars? 44th LPSC Abstract 2977.

Fig 3 Example of glacial structure and mantled terraine on north wall of crater Greg, showing few superimposed craters. Downhill slope is toward bottom. HiR PSP_002676_1415.