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Charting the Decline of Mars Surface Habitability

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Abstract.

Mars is the only world whose surface is known to have become uninhabitable, but the timing, tempo, spatial pattern, and cause of this shut-down remain unclear. These unknowns are encoded in the distribution in space and time of geologic proxies for ancient climate: dry rivers, water-altered sediments, and paleolakes. For many of these features, global databases exist – but these have not been synthesized nor quantitatively analyzed (with correction for dry-era resurfacing), and the timing of shut-down remains elusive. We analyze the global database, plus a new global chronologic dataset, and compare to the new understanding from climate models. We find: (1) Although evidence for surface liquid water becomes more patchy after the Late Noachian / Early Hesperian (LN/EH), Mars surface habitability did not shut down until <3 Ga [1-2]; this is a conservative estimate, and will be updated at the conference. (2) LN/EH valley networks (VNs) were less dense below -1 km. (3) Sedimentary rocks in the catalog of [3] (mostly Hesperian in age) formed mostly at low elevations, with a latitudinal preference. (4) Late Hesperian & Amazonian (LH/A) alluvial fans and deltas formed preferentially below -1 km elevation, with strong latitude preference. These observations are all consistent with CO_2 loss as the driver for the decline (both in elevation, and in spatial pervasiveness) of Mars surface habitability. However, our current analysis of the data does not rule out the alternative explanation of loss of non-CO_2 greenhouse warming (at constant p_{CO2}).

1. Methods and Results.

Our input data consist of (a) a global Mars valley networks catalog [4], (b) the sedimentary rocks database of [3], (c) the Smithsonian Institution fans/deltas database [5], and (d) our ongoing CTX crater count on LH/A impact crater ejecta blankets mapped by [6]. In some cases, the data points are weighted (e.g. multiplying by valley network length). In some cases threshold criteria (e.g., in the fan database, a minimum confidence level and a minimum fan area) are also applied. After these steps, the data is then combined with MOLA topography to assess latitude-elevation formation preferences. In order to back out formation preferences, we use geologic maps to mask for dry-era resurfacing and normalize to terrain abundance (e.g. [6-7]). Example results are shown in Figs. 1-2.

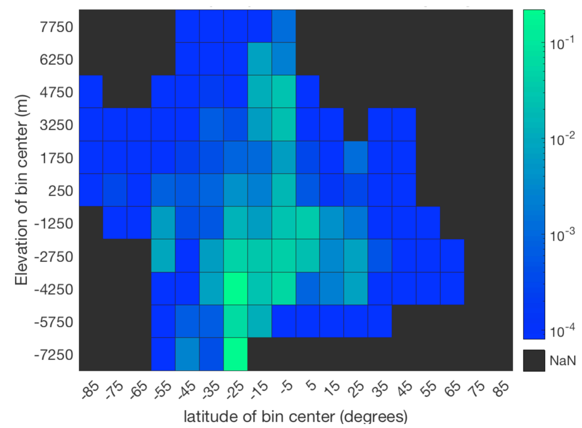

Fig. 1. Example latitude-elevation plot (for sedimentary rocks catalog of [3]), normalized to wet-era terrain abundance.

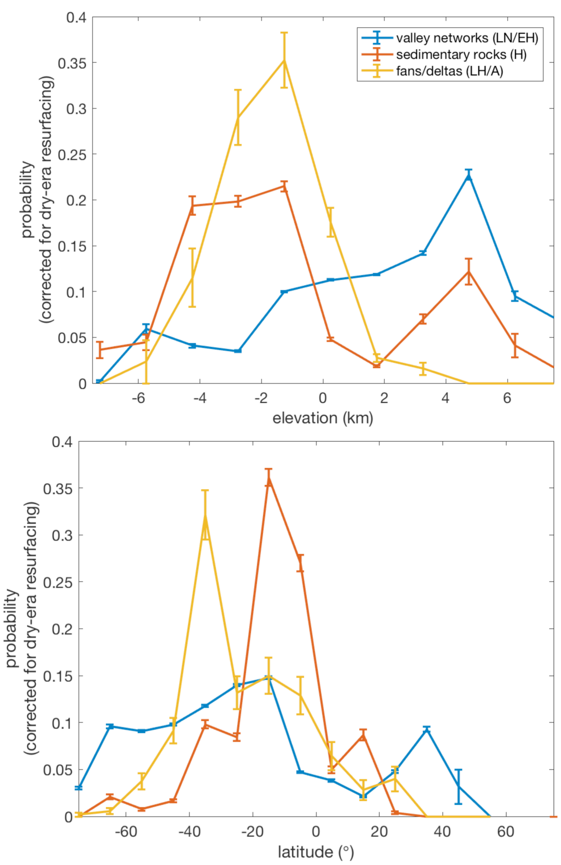

Fig. 2 Marginalized results for (top) elevation and (bottom) latitude. Normalized to wet-era terrain abundance. 1σ error bars are shown.

2. Interpretation and Discussion.

The valley networks, most of the alluvial fans, and many of the sedimentary rocks, record a past more-habitable climate [11]. Basic climate models (e.g. energy balance models) predict that snow/ice will be most stable at low elevation when $p_{CO2} < 0.1$ bar, and most stable at high elevation when $p_{CO2} >> 0.1$ bar [8-10]. Basic climate models also predict that latitude preferences will be sharp at p << 0.1 bar but muted at high p_{CO2} [10]. Finally, very strong non-CO_2 greenhouse warming is needed to explain the LN/EH valley networks, although the source of the non-CO_2 warming is unknown [11-12]. We interpret the data in light of currently available climate models. (The models continue to improve, so our interpretations might be wrong).

The high-elevation preference of VNs, combined with limited latitude control (both suggested by Fig. 2), is consistent with p_{CO2} >0.1 bar (as previously noted; [10]). Very strong non-CO_2 warming is needed to explain high-elevation runoff (rain or snowmelt). An intermediate elevation preference for the alluvial fans, if real, is hard to explain without snow/ice melt. Snow/ice melt could occur at high p_{CO2}, if non-CO_2 warming had waned to the point where high ground was always cold. Snow/ice melt could also occur at intermediate p_{CO2}, for which snow/ice is theoretically most stable at intermediate elevation [9,13]. Snow/ice melt is also supported by the patchiness of the alluvial fans and their preferred orientation [5]. The low elevation preference of the sedimentary rocks is consistent with (1) groundwater [14] combined with annual-mean $T_{surf} > 273$K, or alternatively (2) snow accumulation at low pressure, combined with either cryogenic weathering or seasonal melting [9,15].

Dating the last river-forming-climate is hard (in part because the youngest habitability-era features are small and crater-dating of small features is unreliable), so we are taking a statistical approach [16]. Analysis of the age of craters with fans, relative to the age of craters without fans, shows that Mars surface habitability did not shut down until <3 Ga.

Overall, the data synthesis shows clear trends in the strength and sign of latitude and elevation preferences between geologic epochs. With improving time resolution thanks to CTX-based crater counts, and combined with the results of morphological studies (e.g. [16-17]), we are getting a better handle on the paleoclimate causes of these trends (Fig. 3). In turn, the paleoclimate-versus-time constraints can improve our understanding of the climate changes that were responsible for the decline in Mars surface habitability.

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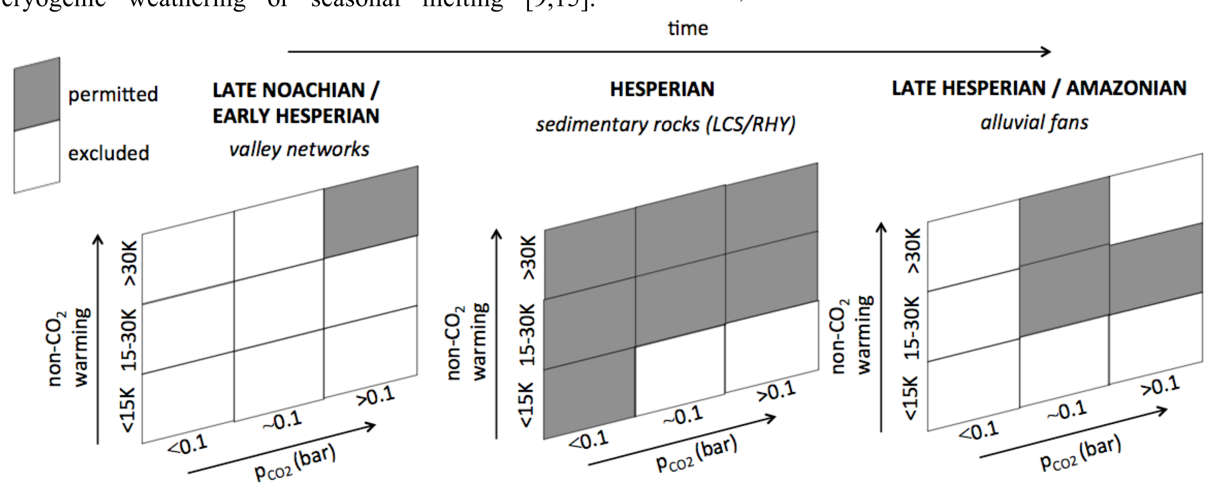

Fig. 3. Climate evolution inferred here. LCS/RHY = Laterally Continuous Sulfate / Rhythmite facies of [19].