

## Geophysical Research Letters

# Supporting Information for

### Persistent or repeated surface habitability on Mars during the Late Hesperian – Amazonian

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### Introduction

This supporting section provides an overview of the prior probabilities used in the Monte Carlo estimation as Text S1. Figure S1 provides a global map for each interbedded crater used in this study. Figure S2 provides images, location information, and ratings for each interbedded crater considered during the CTX-based search. Figure S3 provides comparable information regarding the supplementary HiRISE-based interbedded crater search. All figures were created in ArcMap.

#### S1 Prior probabilities on parameters in the Monte Carlo error estimation.

Obliteration depth fraction ( $\varphi$ ): Assuming the present-day erosion surface is a random cut through the alluvial fan deposit and (sub)parallel-to-stratigraphy,  $\varphi$  bounds the range of erosion depths over which an embedded crater will be visible (whether or not it is correctly classified as an embedded crater). We adopt a log-uniform prior in the range 0.04 (rim height; Melosh 1989) to 0.2 (original crater depth; Watters et al. 2015).

Atmospheric filtering: This corresponds to the fraction of impactors that endure ablation and fragmentation in the atmosphere and form hypervelocity impact craters. We adopt a simple, but physically reasonable, parameterization model in which the Popova correction factors are translated to larger atmospheric pressures in proportion to the higher atmospheric density (Hartmann 2005). We adopt a log-uniform prior on atmospheric pressure (at the time and place of the impacts), from 6 mbar to 1 bar. Higher pressures remove a great proportion of the small impactors, and thus a longer time interval is needed to build up the observed embedded-crater density.

Crater flux: Crater flux was higher than today on Early Mars. We use the chronology function of Michael et al. (2013) and assume a flat prior on age between 2.0 Ga and 3.6 Ga. Earlier ages correspond to greater crater fluxes, and thus faster inferred accumulation rates.

Strength of target: The strength of alluvial-fan deposits at the time of impact is unknown. We assume a log-uniform prior on target strength between 65 KPa (desert alluvium) and 10 MPa (well-cemented sedimentary rock; Okubo 2007, Grindrod et al. 2010). Given a target strength, we use the formula in Dundas et al. (2010) to find the size of impactor that is required to form a crater of the observed diameter. This allows us to calculate the flux of impactors of the required size, normalized to the same flux for target strength of 10 MPa by interpolation in the crater production function of Michael (2013). We assume that the Holsapple  $K_1$  parameter decreases (0.132à0.095) log-linearly over this strength range, and the Holsapple  $\mu$  parameter increases (0.41à0.55) log-linearly over this strength range. The resulting correction is small for 1 km-diameter craters, but reaches a factor of ~2 for small craters. A weaker target accumulates large craters more swiftly, because small impactors (which are more numerous than large impactors) can produce larger craters in weak targets.



**Figure S1:** Candidate embedded craters (red stars) are concentrated at equatorial regions, although they can be found in alluvial fans at all latitudes.



**Figure S2 (a):** FIDo, Go1\_018545\_2187 (CTX), 523m diam., 72.320W 38.408N, rated 3, synfluvial or prefluvial (b): FID1, ESP\_017477\_2190 (HiRISE), 198m diam., 72.566W 38.512N, rated 2, synfluvial or prefluvial (c): FID2, ESP\_032513\_1985 (HiRISE), 143m diam., 169.845W 18.236N, rated 3, synfluvial



(d): FID<sub>3</sub>, Do<sub>4</sub>\_028689\_1801 (CTX), 143m diam., 164.779W 0.573N, rated 1, synfluvial or prefluvial (e): FID<sub>4</sub>, Do<sub>4</sub>\_028689\_1801 (CTX), 338m diam., 164.735W 0.560N, rated 2, synfluvial or prefluvial (f): FID<sub>5</sub>, Do<sub>4</sub>\_028689\_1801 (CTX), 180m diam., 164.687W 0.669N, rated 1, synfluvial



(g): FID6, D04\_028689\_1801 (CTX), 268m diam., 164.604W 0.664N, rated 2, synfluvial (h): FID7, D04\_028689\_1801 (CTX), 81m diam., 164.710W 0.788N, rated 3, synfluvial (i): FID8, ESP\_01638\_1925 (HiRISE), 294m diam., 141.744E 12.513N, rated 3, synfluvial or prefluvial



(j): FID9, Go2\_018834\_1546 (CTX), 149m diam., 33.984W 27.066S, rated 2, synfluvial (k): FID10, ESP\_025950\_1580 (HiRISE), 224m diam., 39.754W 21.611S, rated 1, synfluvial (l): FID11, Go2\_018874\_1561 (CTX), 323m diam., 45.806W 23.657S, rated 3, synfluvial



(m): FID12, ESP\_017713\_1530 (HiRISE), 1113m diam., 28.218W 26.682 S, rated 2, synfluvial (n): FID13, G03\_019559\_1536 (CTX), 219m diam., 27.253W 27.999 S, rated 3, synfluvial (o): FID14, P21\_009432\_1520 (CTX), 294m diam., 27.290W 27.875S, rated 2, synfluvial



(p): FID15, P21\_009432\_1520 (CTX), 229m diam., 27.320W 27.851S, rated 3, synfluvial (q): FID16, ESP\_016935\_1520 (HiRISE), 589m diam., 27.403W 27.844S, rated 2, synfluvial (r): FID17, P21\_009432\_1520 (CTX), 328m diam., 27.345W 27.712S, rated 3, synfluvial



(s): FID18, G21\_026561\_1530 (CTX), 311m diam., 28.023W 24.983S, rated 2, synfluvial (t): FID19, ESP\_011327\_1530 (HiRISE), 224m diam., 75.698E 26.610S, rated 2, synfluvial (u): FID20, B17\_016417\_1568 (CTX), 198m diam., 74.602E 23.275S, rated 3, synfluvial



(v): FID21, B17\_016417\_1568 (CTX), 122m diam., 74.602E 22.996S, rated 2, synfluvial (w): FID22, B17\_016417\_1568 (CTX), 273m diam., 74.623E 23.040S, rated 3, synfluvial (x): FID23, G02\_018834\_1546 (CTX), 4999m diam., 34.156W 25.374S, rated 1, synfluvial



(y): FID24, P15\_007053\_1846 (CTX), 623m diam., 129.192E 2.313N, rated 2, synfluvial (z): FID25, D06\_029687\_1766 (CTX), 247m diam., 51.963W 2.651S, rated 1, synfluvial or prefluvial (aa): FID26, D07\_029846\_1523 (CTX), 133m diam., 69.514W 27.827S, rated 3, synfluvial or prefluvial



**Figure S3 (a):** FID0, ESP\_016039\_1560, 85m diam., 53.598W 23.658S, rated 3 (b): FID2, ESP\_018874\_1560, 54m diam., 53.769W 23.743S, rated 2 (c): FID3, ESP\_018874\_156, 222m diam., 53.763W 23.757S, rated 2



(d): FID4, ESP\_029221\_1565, 75m diam., 80.735 E 23.379S, rated 3 (e): FID5, ESP\_025625\_1580, 65m diam., 39.606W 21.485S, rated 3 (f): FID6, ESP\_025625\_1580, 74m diam., 39.587W 21.506S, rated 2



(g): FID7, ESP\_025625\_1580, 82m diam., 39.656 W 21.570S, rated 2 (h): FID8, ESP\_025625\_1580, 126m diam., 39.651W 21.579S, rated 2 (i): FID10, ESP\_028579\_1580, 58m diam., 39.223W 21.844S, rated 1



(j): FID12, ESP\_028579\_1580, 60m diam., 39.249W 21.871S, rated 2 (k): FID1, ESP\_016039\_1560, 106m diam., 53.589W 23.644S, rated 3