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Supplementary Materials for

Branching geometry of valley networks on Mars and Earth and its implications for early Martian climate

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Supplementary Materials

Global aridity and branching angles

The branching angles in Fig. 1 were derived in the same way as in reference (*21*) but using HydroSHEDS' (*46*) stream networks instead of NHDPlusV2 (*49*). Branching angles are measured between the two orthogonal regression lines (black dashed lines, fig. S1) fitted to the two channel segments (blue) upstream of each junction. This definition measures the mean direction of the stream's valley, rather than the local river junction angle. In this way our angle measurement is not influenced by fluctuations like meandering, which strongly depend on the local flow regime and are much less persistent over time than the bifurcation angle between the two upstream valley segments.

The aridity index $AI=P/PET$ was calculated based on precipitation P and potential evaporation data PET from WorldClim (*47*). For the maps in Fig 1A and Fig. 1B, the branching angles and aridity values were averaged over HydroSHEDS' level 4 drainage basins. The color scale runs from yellow for low branching angles and low AI to blue for wide branching angles and high AI. The corresponding correlation function is shown in Fig. 1E where the branching angles were binned with respect to $\log_{10}(AI)$. Colors indicate arid (yellow, $AI < 0.2$), intermediate (green, $0.2 < AI < 2$) and humid (blue, $AI > 2$) climates (*48*). The histograms of the wet and dry tails are shown above the correlation curve and peak around 55° for dry regions and 72° for humid regions respectively. Two sample networks are shown in Figs. 1C and 1D to give a visual impression of the different network geometries in dry and wet regions.

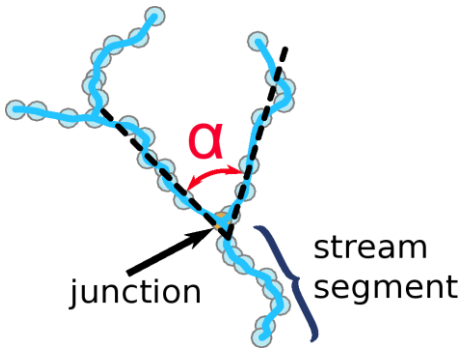

fig. S1. Measurement of the branching angle as defined in (*21*). Each stream segment (blue line) is defined by a series of points (blue circles). The dashed black lines indicate the orthogonal regression fits to the stream segments. The branching angle is measured between the regression lines of the two segments above each junction.

NHDPlusV2 data analysis

To compare Mars' valley networks with those of an arid landscape on Earth, we analyzed the stream networks in the arid southwest of the United States as mapped by the NHDPlus dataset in version 2 (*49*), (see Fig. 2B, fig. S2 and fig. S3). Not only the distribution of branching angles (fig. S2) but also the distributions of valley slopes are comparable to Mars' valley networks (fig. S3); thus, slope differences are unlikely to be masking aridity differences between the Mars networks and the Earth analogues.

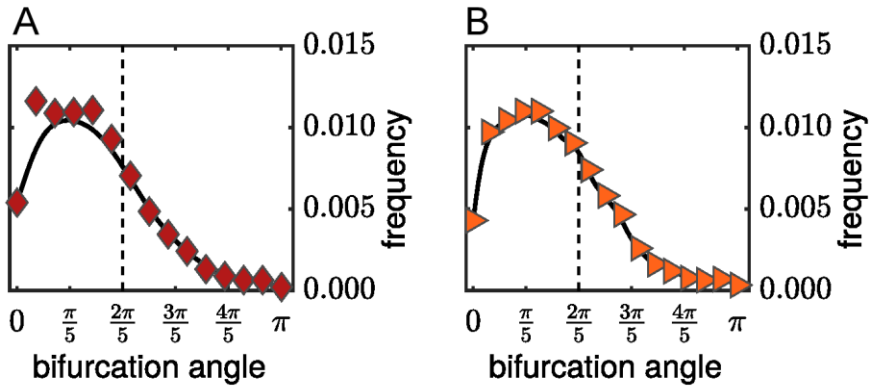

fig. S2. Branching angles for two basins in the arid southwest of the United States. (A) The Lower Green River basin, HUC-1406, and (B) the Escalante Desert-Sevier basin, HUC-1603. The black solid line corresponds to the kernel density smoothed distribution and the dashed line marks the theoretical bifurcation angle of groundwater driven growth (*45*).

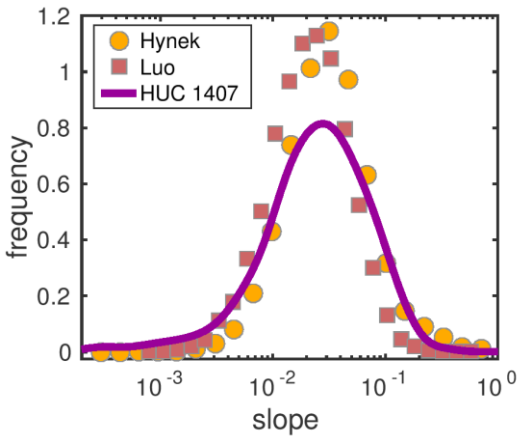

fig. S3. Histograms of valley slope for the two Mars data sets (Hynek and Hoke, orange circles; Luo and Stepinski, rose-colored squares) and the Upper Colorado-Dirty Devil basin (HUC 1407, violet solid line) as mapped by the NHDPlusV2 data set.

NHD data analysis for the State of Alaska

Because NHDPlus data are not available for the State of Alaska, we performed our branching angle analysis for Alaska's the permafrost landscapes based on the raw NHD data provided by USGS (*50*), rather than the more processed NHDPlus. Horton-Strahler orders were calculated using the ArcGIS tool RivEX.

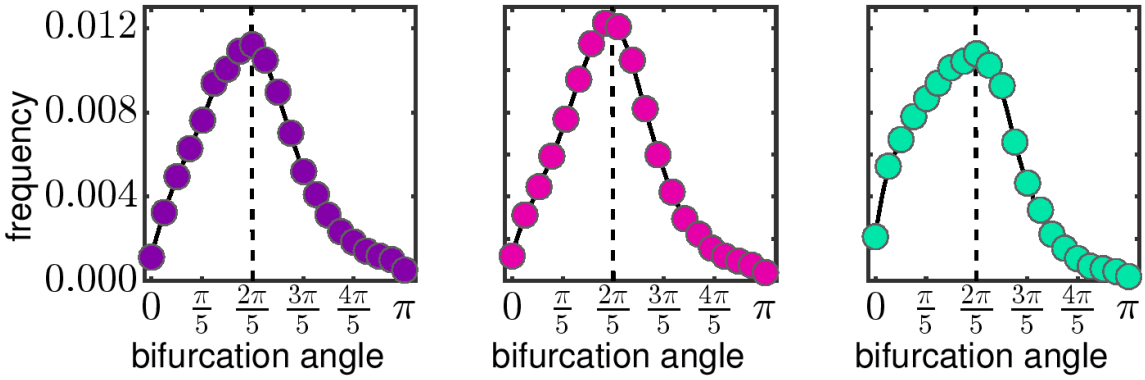

fig. S4. Branching statistics of the raw NHD streams of the State of Alaska (*50*) categorized in regions with continuous permafrost (violet), discontinuous permafrost (magenta), and no permafrost (green). The dashed line marks the theoretical bifurcation angle of groundwater-driven growth. In this figure, in contrast to Fig. 3 in the main paper, first-order channels have not been pruned. Comparing the two figures shows that pruning the first-order channels has a negligible effect on the junction angle distributions. The black solid line corresponds to the kernel density smoothed distribution and the dashed line marks the theoretical bifurcation angle of groundwater-driven growth.