Geologic Tests for Snowmelt Runoff on Early Mars

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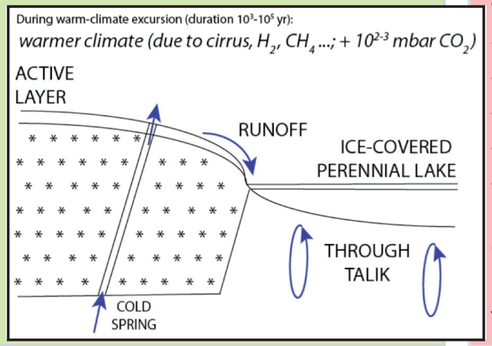
Early Mars: warm and wet, or cold and icy?

How can Early Mars climate data and models be reconciled [1,2]? Early Mars had precipitation-fed lakes which individually persisted for $>10^{(3\text{-}4)}$ yr (plausibly $>10^5$ yr), with strong evidence for intermittency [e.g., 3]. Textural and mineralogic evidence requires groundwater flow and exchange with surface waters [e.g., 4]. However, models struggle to achieve mean annual temperatures above the freezing point [5], and mineralogy indicates $<10^8$ yr exposure to water [6]. One hypothesis for reconciling these findings (shown at right) is seasonal melting of ice and snow [e.g. 7-9] .



Testing the ice-and-snow hypothesis

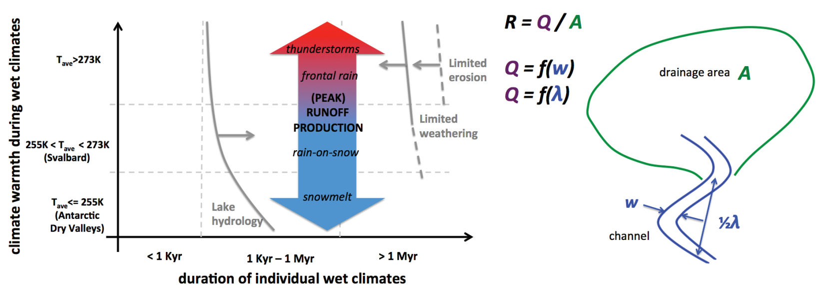
An ice-and-snow hypothesis: "*During the middle Noachian through early Amazonian, Mars experienced individually prolonged, but increasingly infrequent excursions to temperatures as warm as the floors of the Antarctic Dry Valleys (ADV) today – perhaps as warm as the Putorana Plateau. During these relatively-warm excursions, perennial lakes existed beneath ice cover [10]. Taliks beneath these lakes, and narrow conduits through permafrost that were maintained either by high solute concentration or by advection, permitted surface-interior hydrologic circulation [11]. Warmer-than-Central-Siberia temperatures occurred only in the immediate aftermath (<10^2 yr) of basin-forming impacts – these warm conditions were too brief to permit interior-to-surface groundwater flow.*" Alternatives to this hypothesis include climates that were intermittently (or stably) warmer than the ADV [12,13]; conversely, some climate models predict that lake-enabling conditions were very brief [14]. What is the most efficient and decisive way to test the ice-and-snow hypothesis?

Previous tests

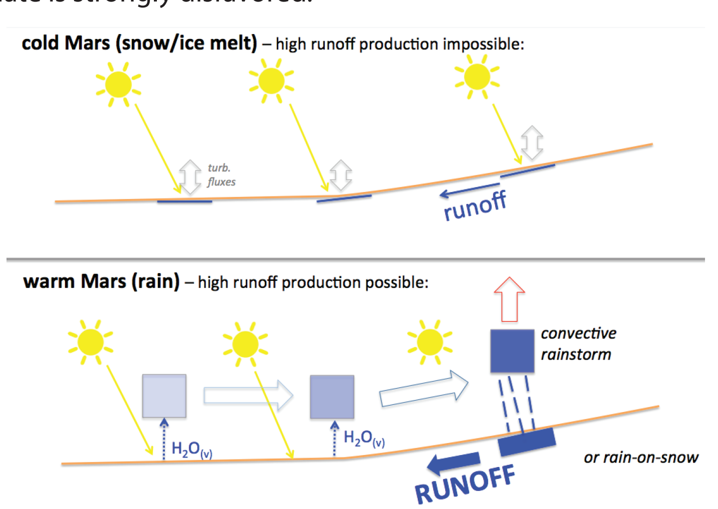
~3.9 Ga Mars-meteorite Δ^{47} indicates near-surface formation at (291±4)K [15]. This is the strongest extant challenge to the ice-and-snow hypothesis. The lack of evidence for icy conditions along the MSL traverse hints at ice-free lakes [16]. Meridianiite (or ikaite) psuedomorphs constrain past temperature [e.g. 17]. Mars atmospheric pressure was likely <1 bar around the time rivers formed [e.g. 18], generally favoring colder climate solutions. Lakes are consistent with icy climates because thin ice cover can be sustained by latent heat transport. Rainfall would strongly disfavor the ice-and-snow hypothesis. Softened crater rims have been proposed as evidence for rainsplash erosion [19]. However, many non-rainsplash processes can soften crater rims. High drainage density has been proposed as evidence for rainfall [20]. However, snowmelt landscapes can have high drainage density.

Our test: cold Mars models of wet climates are falsified if runoff production was high

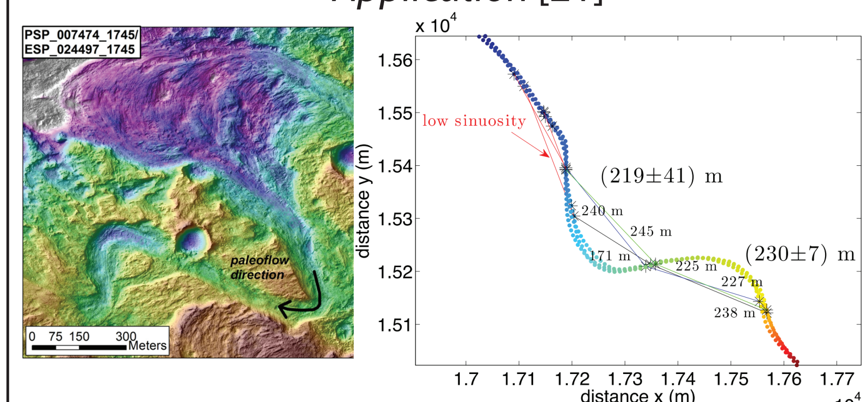
Principle



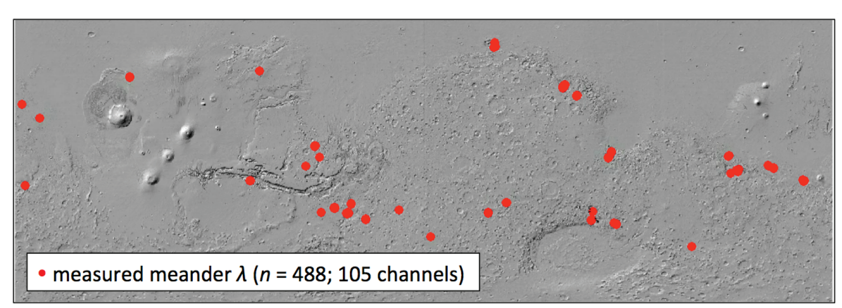
Runoff production cannot exceed snowmelt rate in a cold climate, or precipitation minus infiltration rate in a rainy climate. High runoff production precludes snowmelt. We are measuring paleochannel widths and meander wavelengths for Early Mars watersheds with well-defined drainage area. The measurement method is the same as in ref. [21]. We measure paleochannel widths, w, and meander wavelengths, λ; convert to discharge Q using gravity-corrected scaling relations from Earth rivers [22-25], and divide by catchment area (A) to get runoff production, R (mm/hr). If R >(1-3) mm/hr, then a seasonal melting snow-and-ice climate is strongly disfavored.

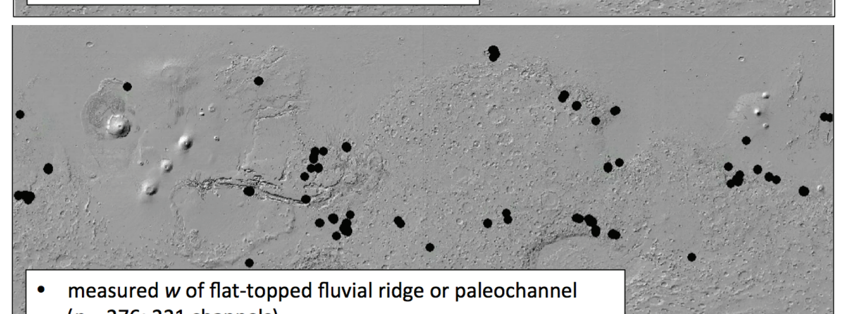


Application [21]

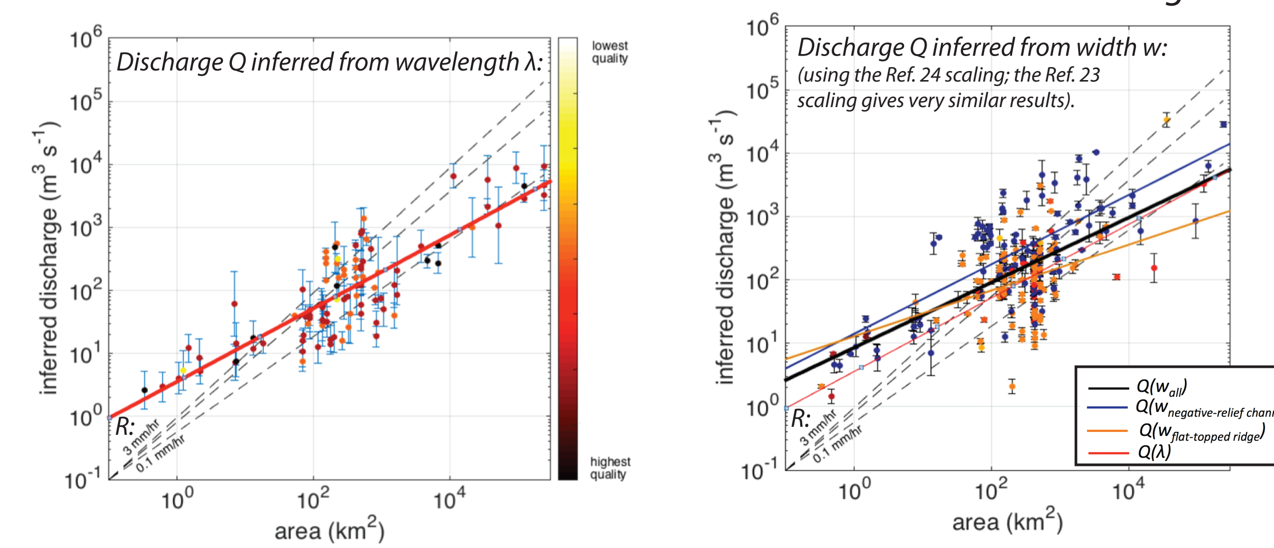


Repeated ArcGIS traces are merged and analysed in MATLAB.
172 drainage areas are represented.
50.0% of our sites have HiRISE anaglyphs or DTMs.





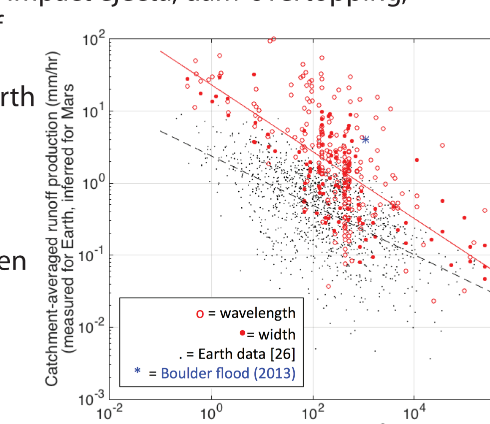
Result: rivers on Mars were wider than rivers on Earth for the same drainage area



The main surprise so far: Channels are frequently too big (relative to their drainage area) to be easily reconciled with a seasonal-snowmelt climate. As expected from Earth data [26], scatter is high. At Earth sites, the width of flat-topped ridges can record channel-belt width (not channel width) [27]. On Mars, width-inferred and wavelength-inferred paleodischarges agree, consistent with the interpretation [28] that well-preserved flat-topped sinuous ridges record channel width.

Summary: fine grain sizes, or rainfall on Mars?

We have ruled out the possibilities that my observations result from limited image resolution, postfluvial modification, flash-snowmelt due to reentry heating from distal impact ejecta, dam-overtopping, karst-like modification of paleochannels, or misinterpretation of debris-flow deposits. We might be measuring strath terraces or channel belts at some sites, but not most. Published work on Earth permafrost-river hydraulic geometry does not support a large permafrost correction. Two possibilities remain:



(1) Rivers on Earth adjust their depths to just mobilize sediment [e.g. 29-30]. Therefore, if grainsize on Mars was small [31], then modest river depths could transport sediment, so discharge could be small (consistent with snowmelt) for a given width.

(2) Rainfall on Early Mars.

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