AN ICE-AND-SNOW HYPOTHESIS FOR EARLY MARS, AND THE RUNOFF-PRODUCTION TEST.
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The problem: How can Early Mars climate data and models be reconciled [1,2]? Early Mars had precipitation-fed lakes which individually persisted for >10^{14} yr (plausibly >10^9 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, climate 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 - previously adumbrated by many authors [e.g. 7-9] - is seasonal melting of ice and snow. In this presentation, I review possible tests of this hypothesis, and zero in on one prediction: modest (energy-limited) runoff production.

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 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 (<10^8 yr) of basin-forming impacts – these warm conditions were too brief to permit interior-to-surface groundwater flow. I call this specific ice-and-snow climate hypothesis for Early Mars the vanilla hypothesis (VH).

The vanilla hypothesis is acceptable to many palates: many climate models can achieve ADV-like conditions [12-13], and the VH can also reproduce the best-understood geologic data. Because of the key role of sub-lake ‘through taliks,’ the VH also permits both vertical segregation and vertical integration of the Early Mars hydrosphere [e.g., 14]. On the other hand, many climate models predict climates that were intermittently (or stably) warmer than the ADV [15,16]; conversely, some climate models predict that lake-enabling conditions were very brief [17]. Thus, the VH is not a consensus statement. It is controversial.

What is the most efficient and decisive way to test the VH?

How can the ice-and-snow hypothesis be falsified?:

Paleo-temperature proxies. ~3.9 Ga Mars-meteorite Δ47 indicates near-surface formation at (291 ± 4) K [18]. This is the strongest extant challenge to the VH, but so long as we have only one near-surface Noachian Δ47 data point, it cannot be decisive.

If the Al-clays required element temperatures to form, then the VH is false [19]. But Al-clays can also be produced under cold low-pH conditions [20], so this test awaits better constraints on Al-clay origins.

The lack of evidence for icy conditions along the MSL traverse hints at ice-free lakes [21]. This will be a weak argument until facies models for ice-covered lakes are more developed [22].

Meridianiite (or ikaite) pseudomorphs constrain past temperature [e.g. 23]. In principle, reaction-transport codes combined with mineralogy can also constrain temperature. However, the kinetics of low-temperature soil weathering are incompletely understood. It is unclear whether the amorphous component of Mars materials records low temperatures, low pH, water limitation, or protolith effects [e.g. 24].

Paleo-pressure proxies. Mars atmospheric pressure was likely ≤1 bar around the time rivers formed [e.g. 25], generally favoring colder climate solutions such as the VH [26].

Rainfall can be tested more directly using runoff production. Runoff production cannot exceed snowmelt rate
in a cold climate, or precipitation minus infiltration rate in a rainy climate. High runoff production precludes snowmelt. Rainfall suggests a warm climate. How can runoff production be reliably measured?

Fig. 2. Locations of measurement sites for Early Mars channel width (black) and meander wavelength (red).

The runoff-production test: I am measuring paleochannel widths and meander wavelengths for Early Mars watersheds with well-defined drainage area. The measurement method is the same as in ref. [29]. >250 channel-width measurements and 89 meander wavelength measurements are included, representing 158 drainage areas (Fig. 2). The catalog emphasizes better-preserved (post-Noachian) paleochannels, but includes a re-survey of the early sites listed in ref. [34].

Channel widths and wavelengths are a proxy for paleodischarge [30-33]. Discharge (m³/s) can be divided by drainage area (m²) to obtain a lower bound on runoff-production (mm/hr). If runoff production > (1-3) mm/hr, then a seasonal melting snow-and-ice climate is strongly disfavored [8]. However, high runoff production is consistent with rainfall.

The main surprise so far: Channels are frequently too big (relative to their drainage area) to be easily reconciled with a seasonal-snowmelt climate. Here are several possible reasons for big channels:

• Limited image resolution veils smaller channels (Unlikely to be a severe bias for HiRISE).
• Postfluvial modification has enlarged paleochannels. (Cannot explain wide inverted channels, nor large meander wavelengths).
• Reentry heating from distal impact ejecta turned the sky into a griddle, which flash-melted snow and ice [35]. (Possible for Lyot. Cannot transport enough sediment to form alluvial fans).
• Discharges reflect dam-overtopping, not climate-driven runoff. (Plausible, but only for some sites).
• We see strath terraces or channel amalgamations, not paleochannels [36]. (Plausible for some sites).
• Karst-like modification of paleochannels [37]. (Cannot explain large meander wavelengths).
• Steeper “channels” are debris-flow chutes. (Plausible).
• Published terrestrial width-discharge scalings do not fully account for gravity, steep-slope, and/or permafrost effects. (Plausible).

• Rainfall on Early Mars. (Plausible).

At the conference, I will present the catalog, and discuss the preferred interpretation(s).
