EARLY MARS: COLD CLIMATE, WARM AND WET GROUND, AND TRANSIENT ICE COVERS.
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Introduction: Investigations of a range of high-fidelity geomorphologic analogs observed at the Haughton impact structure and surrounding areas on Devon Island in the polar desert of the High Arctic suggest that Early Mars was not warm and wet as commonly viewed, but instead likely climatically cold, at least partially ice-covered, with a locally and transiently warm and wet regolith.

Two classical interpretations of orbital images of the martian surface are at the root of the conventional vue that Early Mars was warm and wet: 1) impact craters in the ancient highlands on Mars appear relatively eroded compared to craters on the Moon and other airless bodies, suggesting that it rained on Early Mars; 2) small valleys networks were caused by liquid water flowing under open air at a relatively low rate of discharge (compared to the catastrophic floods that formed outflow channels), implying that Mars had a relatively thick and warm atmosphere. Despite the fact that small valley networks on Mars actually present morphologies that are in many ways distinct from terrestrial subaerial river valleys, and climate modelers have been finding it extremely difficult, if not impossible, to make Early Mars climatically warm because of the Faint Early Sun, the view that Early Mars was warm and wet has remained a predominant view.

In this paper, we offer a synthesis of our observations on Devon Island made over the past decade and a half under the auspics of the NASA Haughton-Mars Project, and show through quantitative comparisons of high-fidelity morphologic analogs between Devon Island and Mars, that a very different model of Early Mars emerges.

Denudation on Early Mars. Analysis of impact crater modification on Mars and on Devon Island suggests that denudations rates commonly used for Mars may be significantly overestimated [3]. Given that the age (39 Ma), state of modification, and the climatic history of Haughton Crater are relatively well known, it is possible to put constraints on the climatic history (*effective denudation*) experienced by impact craters of known or estimatable age on Mars based on their observed state of preservation.

In light of the recent discovery of well preserved distal impact ejecta blanket material at Haughton, the average denudation rates on Devon Island's high plateau are estimated to range between 0.1 to 1 micron/yr, i.e. even slower than previously estimated [1,3]. By comparison, Northport Crater on Mars, which is similar in size to Haughton but is likely greater in age by almost two orders of magnitude, remains better preserved than Haughton (Fig. 1). Average denudation rates for Northport, and by extension on Early Mars (Late Noachian) are close to 10^{-3} microns/yr, i.e., much lower (by 3 to 4 orders of magnitude) than classically estimated [4]. Thus, Mars may have never been climatically warm and wet for geological lengths of time during and since the Late Noachian [3]. It likely never rained on Early Mars.

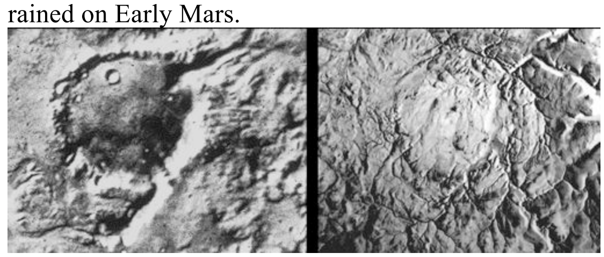

Figure 1. Left: Mars, Northport Crater (D = 20 km; Age ≥ 3 Ga) (NASA); Right: Devon Island, Haughton Crater (D = 20 km; Age = 0.039 Ga) (Geol. Surv. of Canada). Northport's rim and ejecta blanket are better preserved than Haughton's.

Small Valley Networks as Subglacial Meltwater Channel Networks: Small Valley Networks (SVNs) on Mars are generally hypothesized to have formed either as a result of surface runoff following rainfall, or as a result of groundwater seepage associated with hydrothermal sources. However, SVNs on Mars are morphologically different in several specific ways from common terrestrial river valley networks formed under subaerial conditions [5]. Meanwhile, Devon Island and other areas of the Arctic and Antarctica present similar-sized and smaller valley networks that display the same specific and unusual traits as those characterizing the martian SVNs (Fig. 2).

The valley networks on Devon are glacial meltwater channel networks formed mostly in a subglacial regime [5, 6]. The SVNs on Mars, which are often interpreted as fluvial features formed under open air, are more likely to have formed as subglacial meltwater channels, i.e. fluvial features formed under the overburden and structural control of transient surface ice covers, with liquid water flowing subglacially over substantial distances in a confined regime, under powerful hydraulic pressures and gradients. The apparent structural control of SVNs would be inherited from the geometry of these former ice covers, as seen near the edge of the Devon Island ice cap today.

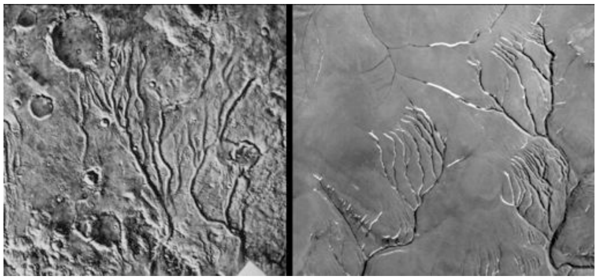

Figure 2. Left: Mars: : Small Valley Networks. Image width is 200 km (NASA); Right: Devon Island: Glacial meltwater channel networks, formed mostly under a subglacial regime. Image width is 10 km (NASA HMP).

The Cold And Wet Early Mars Model: The picture that emerges from our investigations is one in which the planet's atmosphere was both thin and cold early in its history, much as it is today, consistent with the Faint Early Sun. In spite of a frigid climate, a dynamic hydrologic cycle was in place on Early Mars, powered mainly by impact cratering and volcanism, both of which were significantly more active then than today.

Impacts and volcanism would excavate H_2O from the regolith and inject it into the atmosphere where it would immediately condense onto the surface in the form of localized ice deposits. Because i) impact rates on Early Mars were higher than at present, ii) volcanism was more active, and iii) the planet's average heat flux was also higher, the near-surface regolith on Mars was significantly warmer, and ice covers deposited on top of this regolith were able melt from their base, forming the small valley networks and leaving surrounding uplands uneroded. The martian landscape was therefore one of patchy and transient ice covers, tepid and soggy basal regolith, frozen lakes, and otherwise dry exposed ground.

A cold and wet early Mars model is consistent with our new estimates of denudation rates in Anicient Highlands, with the specific morphologic characteristics of the Small Valley Networks, and with the Faint Early Sun. Models invoking a thick CO_2 atmosphere and substnatial greenhouse warming are unnecessary.

Mars Always Cold, Sometimes Wet: It should be noted that key geologic features commonly attributed to fluvial erosion later in Mars history likely have a glacial origin as well [1, 7]. Tributary canyons along the rim of Valles Marineris, for instance, closely resemble terrestrial glacial trough valleys and are likely the result of glacial selective linear erosion rather than sapping or any other form of liquid water erosion [8]. The tributary canyons were likely carved by streaming ice (much like outlet glaciers in Antarctica today).

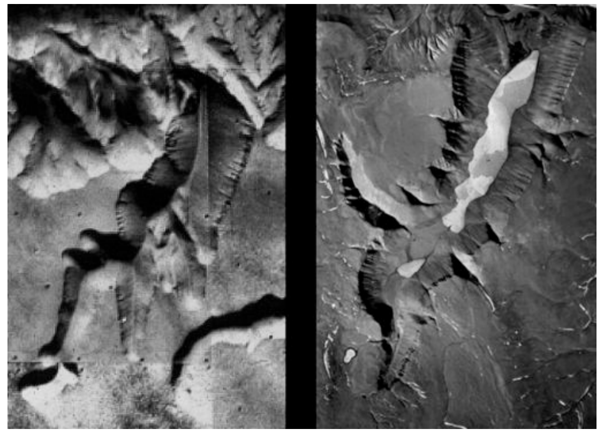

Figure 3: Left: Mars: Tributary canyons along the Ius Chasma section of Valles Marineris; Right: Devon Island: Astronaut Canyon, a glacial trough valley formed by streaming ice.

Similarly, small valley networks observed on the flanks of volcanoes, including younger structures, do not imply recent, short term, and drastic climate change (warming). Instead, consistent with their proposed mode of formation on Early Mars, they are more likely the result of basal melting under fresh ice covers deposited on the flanks of the volcanoes following recent episodes of volcanic activity.

Conclusion: Field geology investigations at and near Haughton Crater on Devon Island reveal a number of terrain features and processes that may offer remarkable analogs for those encountered on Mars, in particular in relation to Early Mars and the history of H_2O. Our investigations suggest that Early Mars was more likely a climatically cold planet with transient ice patches and a locally and transiently warm regolith, not a planet that experienced a warm and wet climate,

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References: Use the brief numbered style common in many abstracts, e.g., [1], [2], etc. References should then appear in numerical order in the reference list, and should use the following abbreviated style:

[1] Lee, P. and C. P. McKay (2003) LPS XXXIV, Abstract #2127. [3] Lee, P. et al. (2005) LPS XXXVI, Abstract #2270. [4] Carr, M. H. (1995) Icarus. [5] Lee, P. & J. W. Rice, Jr. (1999) 5th Mars Conf.. [6] Lee, P. et al. (1999) LPS XXX. [7] Lee, P. and C. P. McKay (2007) 39th DPS. [8] Lee, P. (2000) LPS XXXI, Abstract #2080.