MARS, ALWAYS COLD, SOMETIMES WET: NEW CONSTRAINTS ON MARS DENUDATION RATES AND CLIMATE EVOLUTION FROM ANALOG STUDIES AT HAUGHTON CRATER, DEVON ISLAND, HIGH ARCTIC.

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Introduction: Analysis of crater modification on Mars and at Haughton Crater, Devon Island, High Arctic, which was recently shown to be significantly older than previously believed (Eocene age instead of Miocene) [1], suggest that Mars may have never been *climatically* wet and warm for geological lengths of time during and since the Late Noachian.

Impact structures offer particularly valuable records of the evolution of a planet's climate and landscape through time. The state of exposure and preservation of impact structures and their intracrater fill provide clues to the nature, timing, and intensity of the processes that have modified the craters since their formation. Modifying processes include weathering, erosion, mantling, and infilling. In this study, we compare the modification of Haughton through time with that of impact craters in the same size class on Mars. We derive upper limits for time-integrated denudation rates on Mars during and since the Late Noachian. These rates are significantly lower than previously published and provide important constraints for Mars climate evolution.

Modification of Haughton Crater: Recent Ar-Ar dating of impact melt breccia samples from Haughton Crater have led to a significant revision of the age of the impact structure from 23+/-1 Ma as previously widely published, to 38+/-2 Ma, placing the Haughton impact event in the Eocene rather than the Miocene [1].

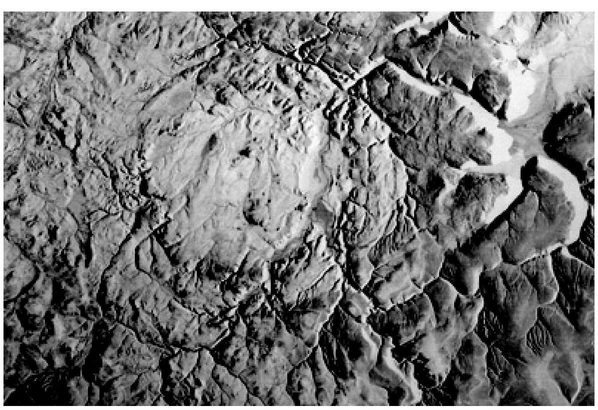

Fig.1: Haughton impact structure, Devon Island, High Arctic. Diameter: ~20 km. New Ar-Ar age: ~3.8×10^7 Ma (Sherlock et al. 2005) [1]. (Airborne S-band radar. Geological Survey of Canada / NASA HMP).

Haughton has experienced substantial erosion from the Eocene to the present under a regional climate that has evolved from generally temperate and wet for the first 10^7 years, to cold and increasingly arid for the last 10^7 years, including several episodes of cold-based glaciation in the Pleistocene. The crater's original raised rim and outer ejecta blanket are no longer preserved. Intracrater melt breccia deposits and subsequent intracrater sedimentary fill have also been significantly incised and eroded. Previous studies of crater modification at Haughton which assumed a Miocene age for the structure led to estimates of time-integrated average regional denudation rates of less than ~10^1 microns.yr^{-1} [2,3]. Haughton's new Eocene age implies that this average regional denudation rate must have been even slower than previously estimated, in the $10^0 - 10^1$ microns.yr^{-1} range instead.

Current denudation rates on Devon Island associated with active glacial meltwater flow are significantly higher, in the ~10^2-10^3 microns·yr^{-1} range [4], but these apply only locally and for durations < 10^2-10^4 years.

Crater Modification on Mars during and since the Late Noachian. Many martian craters have experienced multiple episodes of weathering, erosion, mantling and burial over time. Orbital imaging data from Viking, MGS and MO show how some craters have experienced very complex modification histories.

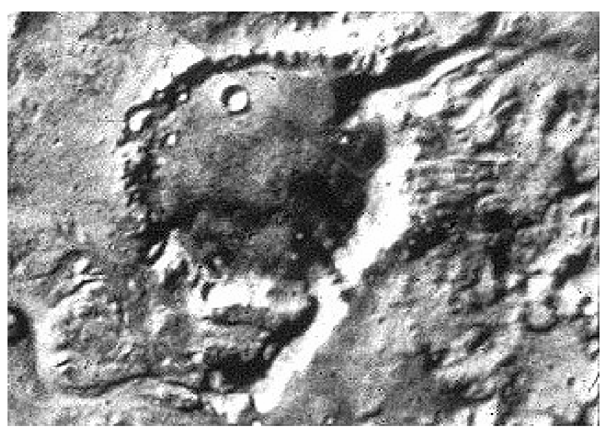

Fig.2: Northport Crater, Ancient Highlands, Mars. Diameter: 20 km. Estimated Age: ~ 2.5 – 3.8×10^9 yrs. (Viking Orbiter data. Mosaic. NASA).

Figures 1 and 2 provide a comparison between Northport Crater in the martian Ancient Highlands and Haughton Crater. The two structures are of similar diameter (~$2x10^4$ m). Although Northport is greater in age than Haughton by at least two orders of magnitude, Northport still presents a well-defined rim, remnant ejecta blanket material, and only limited dissection of surrounding uplands, and thus exhibits significantly less cumulative degradation and erosion than Haughton [3]. In light of Haughton's new Eocene age, average regional denudation rates during the Late Noachian as derived for the Northport Crater region are revised downwards from previous estimates to ~10^{-2} microns·yr^{-1}. Similarly, average regional post-Noachian denudation rates are adjusted to 10^{-4}-10^{-3} microns·yr^{-1}.

Discussion: Based on the analysis of a diverse suite of H_2O-related landforms in terrestrial polar regions (Devon Island, High Arctic; Dry Valleys, Antarctica) viewed as possible analogs for a range of martian features, Lee and McKay [3] had put into question any requirement for extended episode(s) of warm and wet climate in Mars's past. They suggested that geologically transient episodes of localized H_2O cycling, forced by exogenic impacts, locally enhanced endogenic heat flow, and orbit-driven short-term local environmental change under an otherwise cold, low pressure (≤10^2 mbar) global climate, would be *sufficient* to account for Mars's gloabl record of aqueous activity. A Mars that was climatically cold throughout its history (since the End of the Heavy Bombardment in the Late Noachian), and only occasionally and locally warm and wet was envisioned [3]. This *"Mars, Always Cold, Sometimes Wet" model* is consistent with results (difficulties) encountered in modeling efforts attempting to support any warm martian climate hypothesis [5], [6]. The model is also consistent with recently proposed mode of formation of small valley networks by ice cover melting [7, 8] and with Mars's record of evidence for transient localized surface aqueous activity in recent times (within the latest 10^8 years) [4, 9]. The new findings reported here reinforce this model by showing *how little* denudation has actually taken place in Mars's Ancient Highlands, and quantify Mars's global climate evolution by providing quantitative constratints on *time-integrated* erosion rates. While Ancient Highland craters on Mars are indeed significantly more degraded and heavily eroded than lunar craters, they remain remarkably well preserved compared to terrestrial impact structures that have experienced only moderate erosion by terrestrial standards. Table 1 summarizes integrated denudation rates for selected arid regions on Earth and values published for Mars.

TABLE 1. Integrated Denudation Rates on the Earth and Mars.

Denudation Setting	*Denud. Rate (microns/yr)*	*Refs.*
Earth*		
Arid Regions, Average	10^1 - 10^3	[10]
Antarctica, Dry Valleys	10^0	[11]
Devon Island, Average*	10^1	[2, 3]
	10^0 - 10^1	This Study
Devon I., Glacial Melt	10^2 – 10^4	[4]
Mars**		
Highlands, Late Noachian	10^1	[12]
	10^{-2} – 10^{-1}	[3]
	10^{-2}	This Study
Post Noachian	10^{-2}	[13]
	< 10^{-3} – 10^{-2}	[3]
	10^{-4} – 10^{-3}	This Study

* Denudation rates shown are for the present, unless otherwise indicated. Average values for Devon I. are integrated from the estimated time of formation of Haughton Crater.

** Values for Mars are integrated from the Late Noachian.

Conclusion: Our results indicate that Mars's record of impact crater degradation, particularly in the Ancient Highlands, cannot be interpreted to imply that Mars was *climatically* warm and wet for any (geological) length of time during or since the Late Noachian.

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