

NOACHIAN HIGHLAND CRATER DEGRADATION ON MARS: ASSESSING THE ROLE OF REGIONAL SNOW AND ICE DEPOSITS IN A COLD AND ICY EARLY MARS. D. K. Weiss¹ and J. W. Head¹, ¹Department of Geological Sciences, Brown University, Providence, RI 02912, U.S.A. (david_weiss@brown.edu)

Introduction: The faint young sun [1,2] has led to the supposition that early Mars was cold [3-5]. The presence of valley networks and the degraded state of highland craters, however, has led many investigators to suggest that the martian climate in the Noachian was warm and wet, and that precipitation [6] in the form of rainfall [7] and fluvial activity are the likely causes of crater degradation. Recent climate models, however, have shown that climactic conditions in the Noachian may not have been favorable for liquid water precipitation [8,9], and that regional snow and ice deposits, much like those inferred to be present in the Amazonian (Fig. 1) [10], pervaded the Noachian highlands [11]. Recent climate models have shown however, that unlike the Amazonian, slightly increased atmospheric pressures in the Late Noachian could allow the atmosphere to behave adiabatically [8], a scenario in which the Noachian southern highlands acts as a cold trap and preferentially accumulates atmospheric snow and ice deposits [11, 12]; *Late Noachian Icy Highlands scenario*.

Martian Noachian highland craters may give insight into conditions on early Mars. Martian Noachian highland craters (Fig 2) differ from fresh martian craters (Fig 2 & 3) in that they possess 1) subdued crater rims [7,13,14]; 2) flat/shallow floors [7,13,14]; 3) a paucity of craters <~15 km in diameter [13,16-18]; 4) channels superposing crater rims and ejecta facies [7,13,14,18]; and 5) a relative absence of ejecta facies [7,13,14].

These characteristics have been variously explained by 1) burial by air fall deposits [19-23]; 2) erosion by groundwater sapping [24]; 3) erosion by rainfall and surface runoff [6,7,14]; 4) impact-induced seismic liquefaction [25]; or 5) a complex interweaving of erosion, deposition, and cratering [26]. In this study, we reexamine the degradation state of Noachian highland craters and assess the possibility that a cold and icy climate might have

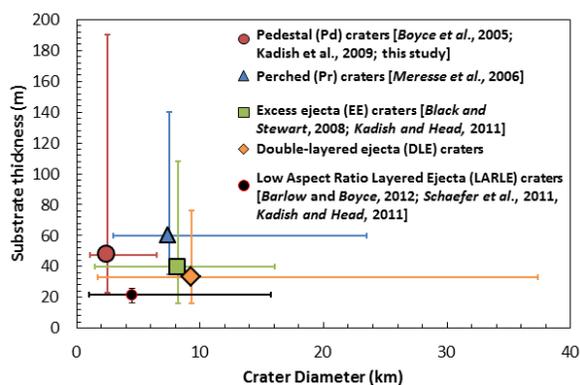


Figure 1. Icy substrate thicknesses for a variety of EE crater classes.

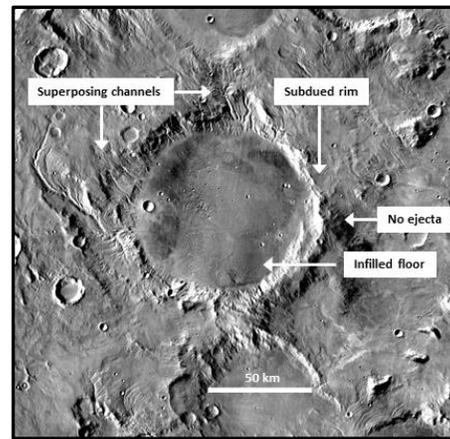


Figure 2. Typical Noachian highland crater and characteristics.

contributed to their unusual characteristics.

Degradation state of Noachian highland craters:

The morphology of Noachian highland impact craters suggests that they have been heavily degraded [7], although the mode of degradation has been debated (see [7]). In the Amazonian, the presence of regional ice and snow deposits has been shown to affect the impact cratering process (e.g. [27-30]). We examine the effects of regional snow and ice deposits on the formation and subsequent modification of Noachian craters and test the hypothesis: Could the degradation state of these craters be accounted for by regional snow and ice deposits?

Formation:

Impact into regional snow and ice deposits would form craters analogous to several morphologies of Amazonian craters (e.g. DLE, Pd, LARLE craters) (Fig. 1), which have been hypothesized to form in a decameters-thick snow and ice surface layer [27-31]. Because some of the depth of these craters are accommodated by the surface snow and ice layer, and some of the rim structural uplift would be present in the hectometers-thick snow and ice substrate [32], the subsequent sublimation and/or melting of the near-rim ice in a later, different climate regime may lower the observed rim height. Craters that penetrate through the ice will produce a smaller crater cavity in the underlying rocky substrate, and may be infilled more easily.

Modification:

In the Amazonian glacial periods, material from crater rims was being backwasted and infilling the craters in the absence of fluvial activity [33-36], a process evident by the preservation of concentric crater fill (CCF) deposits and lobate debris aprons (e.g. [33-37]) in the mid-latitudes of both hemispheres of Mars. This same process would be active during a cold and icy Late Noachian and could be a major contributor

to the flat and shallow floors and subdued rims of Noachian highland craters: material backwasted from the rim would fill the crater [14]. Furthermore, any insolation induced top-down melting, such as that suggested for the formation of Amazonian gullies (e.g. [38,39]), would generate runoff from the melting surface snow and ice deposits and this would further erode the rim and ejecta facies, infill the crater, and generate the characteristic superposing channels of Noachian highlands craters.

Basal melting: We suggest that craters that form in decameters-thick surface ice layers in the Amazonian (DLE, Pd, LARLE craters) are good analogues to craters that may form in the Noachian highlands in the *Late Noachian Icy Highlands scenario*. These craters are unusual in that the snow/ice deposits they form in would still be present beneath their ejecta facies during modification, and overlying the crater during periods of snow deposition. If basal melting occurred, fluvial erosion by the melting of snow and ice deposits, which may be both above and below the ejecta facies of these craters, would erode crater rims and ejecta, infill the crater, and generate superposed channels. Although the geothermal gradient in the Noachian is poorly known [40], previous investigators [5,41] have shown that it may be possible to generate basal melting only in instances of hectometers to kilometers thick ice and snow deposits. We note that the Noachian highlands ice budget may be only ~280 m if the Amazonian snow and ice deposits are supply limited to ~50 m [32, 33], and thus the Noachian regional snow/ice deposits would likely be of insufficient thickness to generate basal melting. Ejecta deposition on top of the regional snow and ice deposits, however, has not been previously considered. If Amazonian craters that form in decameters-thick surface ice layers (DLE, Pd, LARLE craters) can be considered Noachian highlands crater analogues, tens to hundreds of meters of ejecta would be deposited on the underlying regional snow and ice deposits subsequent to impact. The low thermal conductivity of ejecta overlying the snow and ice deposits could potentially raise the geotherm enough to generate basal melting of the snow and ice. Our preliminary calculations taking into account plausible Noachian geotherms [12, 40] suggest that a 10 m increase in overlying ejecta thickness corresponds to approximately $\sim 1.8^\circ\text{C}$ basal temperature increase; the presence of 50 m of ejecta overlying 250 m of firm/ice increases the basal temperature by $\sim 18^\circ\text{C}$. These factors relax the geotherm and atmospheric temperature constraints required to generate basal melting of regional snow and ice deposits in the Noachian, especially in the near-rim areas where ejecta is thickest. Consequently, it may have been possible for hectometers thick snow and ice deposits on steep near-rim slopes to generate basal melting and thus fluvial erosion, which could contribute to ejecta facies and rim erosion, rim/ejecta channel superposition, and crater infill.

If atmospheric warming pulses occurred near the Noachian-Hesperian boundary (e.g. [42]) it is plausible

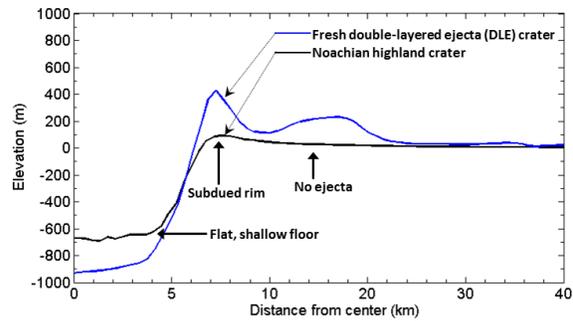


Figure 3. Altimetric profile of fresh Amazonian DLE crater (blue line) and Noachian highland crater.

that these could have influenced the modification of Noachian craters. The emplacement of the Late Noachian-Early Hesperian Ridged Plains might have generated planet-wide warming [42-46], which could have potentially created short lived “thermal pulses”, which would significantly affect Noachian highland crater morphology in the presence of regional snow and ice deposits. If a thermal pulse occurred, fluvial erosion by the melting of snow and ice deposits, which may be both above and below the ejecta facies of Noachian highlands craters, would erode crater rims, ejecta, infill the crater, and generate superposed channels.

Conclusion: We find that snow and ice deposits present in the highlands during the Noachian and/or possible subsequent thermal pulses responsible for the widespread melting of the deposits are plausible factors to explain many of the unusual characteristics of Noachian highland craters, and warrants further testing and analysis.

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