NOACHIAN HIGHLAND CRATER DEGRADATION ON MARS: ASSESSING THE ROLE OF REGIONAL SNOW AND ICE DEPOSITS IN A COLD AND ICY EARLY MARS. D. K. Weiss[1] and J. W. Head[1], [1]Department 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 could not have supported 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 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]. 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 previously 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 contributed to their unusual characteristics.

Degradation state of Noachian highland craters: The morphology of Noachian highland impact craters

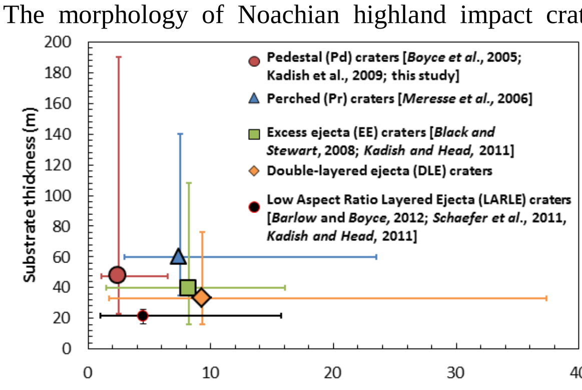

Figure 1. Icy substrate thicknesses for a variety of EE crater classes.

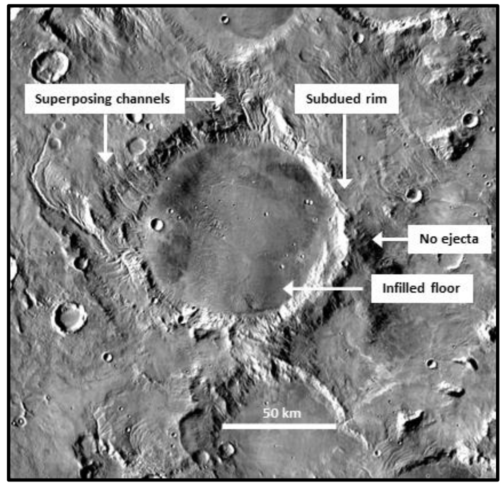

Figure 2. Typical Noachian highland crater and characteristics.

suggests that they have been heavily degraded [7], although the mode of degradation has been debated (see [7]). In tha 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 snow and ice substrate, 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. Much like Amazonian DLE and LARLE craters, the low-friction interface offered by the surface snow and ice deposits will serve to enhance runout distances [30], effectively distributing a thinner ejecta facies over a wider area. This process could allow the ejecta to be more easily eroded by subsequent aeolian and fluvial processes.

Modification: In the Amazonian glacial periods, material from crater rims was constantly being backwasted and infilling the craters in the absence of fluvial activity [32-35], a process evident by the preservation of concentric crater fill (CCF) deposits and lobate debris aprons (e.g. [32-36]). This same process would be active during a cold and icy 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 substantially [13]. Furthermore, any top-down melting, such as that seen in the Amazonian (e.g. [37,38]), would generate runoff processes 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 anologues to craters that may form in the Noachian highlands in the *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 [39], previous investigators [5,40] have shown that it may be possible to generate basal melting only in instances of hectometers thick ice and snow deposits. We note that the Noachian highlands ice budget may be only ~100 m if the Amazonian snow and ice deposits are supply limited to ~50 m [32], and thus the Noachian regional snow/ice deposits may 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. This overlying material would effectively raise basal snow/ice temperatures by inhibiting heat diffusion within the snow/ice deposits. Our preliminary calculations taking into account plausible Noachian geotherms [12, 39] suggest that a 50 m increase in overlying ejecta thickness corresponds to approximately ~5°C basal temperature increase; the presence of 100 m of ejecta overlying 100 m of firn/ice increases the basal melting temperature by ~10.5°C. These factors relax the geotherm and atmospheric temperature constraints required to generate basal melting of regional snow and ice deposits in the Noachian. Furthermore, craters ~ <25 km in diameter that would form DLE craters [29] concentrate thick deposits of ejecta in the inner ejecta facies, allowing smaller craters to achieve higher basal temperatures than otherwise expected. Consequently, it may have been possible for hectometers thick snow and ice deposits on steep slopes to generate basal melting and thus 1) fluvial erosion; 2) basal erosion of the underlying bed during downward ice flow, and 3) raises the possibility of intra-ejecta spring

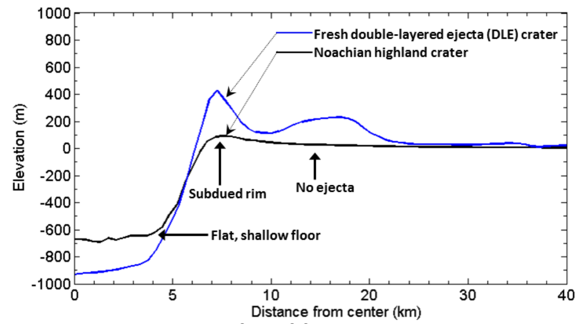

Figure 3. Altimetric profile of fresh Amazonian DLE crater (blue line) and Noachian highland crater.

development, which could contribute to ejecta erosion and channel development.

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