BEDROCK DEGRADATION, MANTLING, AND EXPOSURE PROCESSES ON MARTIAN HIGHLAND PLAINS: REGIONAL VARIATIONS AND POTENTIAL CAUSES.

A. D. Rogers[1] and J. W. Head[2], [1]Stony Brook University, Geosciences Dept. 255 ESS Building, Stony Brook, NY. 11794-2100 (Deanne.Rogers@stonybrook.edu), [2]Brown University Dept. of Earth, Environmental and Planetary Sciences, Providence, RI 02912 USA

Introduction: A fundamental question regarding Martian crustal and regolith development is how ancient bedrock units have been preserved at the surface. Due to the high number of overlapping impacts earlier in Martian history, Noachian bedrock should have been converted to regolith exceeding thicknesses of tens of meters [1]. Yet flat-lying expanses of bedrock or partially mantled bedrock (hereafter, "plains bedrock") are most commonly found in the Noachian highlands units defined by Tanaka et al. 2014 [2] ([3-7]). The present-day existence of Noachian (or Hesperian) bedrock at the surface thus requires additional mechanisms of preservation or exposure, which could include: (1) early, rapid burial and protection from degradation to regolith, followed by later exhumation and exposure [1], or (2) regolith development from bedrock degradation followed by aeolian deflation of fines to remove the regolith and expose bedrock.

Furthermore, plains bedrock exposures are rare in Hesperian volcanic units such as Hesperia Planum, Syrtis Major, and Syria Planum, compared to Noachian highland units. Rather, Hesperian volcanic plains more uniformly exhibit a thick, well-developed regolith [e.g., 8] (**Fig. 1**). This is somewhat puzzling because, assuming no other bedrock degradation processes other than impacts (a lunar-like regolith development model), younger surfaces should exhibit *less* mantling than older surfaces due to the shorter period of bombardment by meteoroids [9].

These observations indicate either spatial or temporal variability in bedrock preservation, mantling and/or exposure, and raise a number of questions about the processes and timing of events that have led to the current distribution of bedrock at the surface. These questions include: (1) How has Noachian bedrock been exposed/preserved over time? (2) Do bedrock surfaces exhibit evidence for deflation? (3) Why is bedrock exposure more prevalent in the Noachian units? (4) What are the potential implications for Noachian climate?

Below we (1) summarize the observations that show differing amounts of bedrock exposure within Noachian and Hesperian highlands plains, and (2) present multiple working hypotheses for the possible causes of differing bedrock exposure across these plains. Understanding the processes which protect and expose these surfaces is important for interpreting the geologic history recorded by the present-day distribution of surface units, and also bears relevance to interpreting the origin and geologic history of other intact, exposed (putative ancient) surfaces such as chloride-bearing units and proposed landing sites.

Observations: Noachian intercrater plains commonly contain areas of elevated thermal inertia (TI, >350 J $m^{-2}K^{-1}s^{-1/2}$ at TES spatial resolution; >500 J $m^{-2}K^{-1}s^{-1/2}$ at THEMIS resolution) that correspond with less-mantled surfaces in visible images. By contrast, Hesperian volcanic plains exhibit TI values between 170-300 J $m^{-2}K^{-1}s^{-1/2}$ and show a subdued appearance consistent with sediment-covered surfaces. Importantly, in locations where the Hesperian lavas contact the Noachian units, a sharp difference in thermal inertia and mantling extent is observed (**Fig. 1c**).

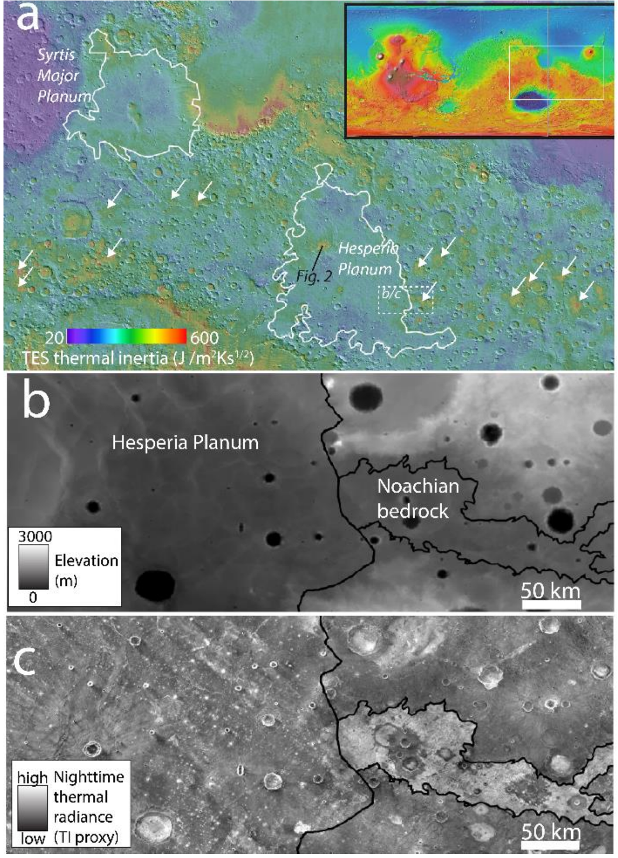

Fig.1. a. Hesperia Planum and Syrtis Major Planum generally exhibit lower TI values than Noachian bedrock units (white arrows). **b.** MOLA elevation. **c**. The bulk of Hesperia Planum exhibits lower TI (dark tones) than adjacent Noachian bedrock (light tones).

Hesperia Planum contains one region of high TI that, in HiRISE imagery, appears devoid of sediment. The bedrock exhibits polygonal jointing similar to thermal contraction cracks associated with columnar basalts on Earth. Columnar joints form within thick lava flow interiors, beneath flow tops that exceed several meters to tens of meters thick [e.g., 10]. Thus the exposure of these forms suggest that several meters of the upper lava flow surface have likely been removed. Bedrock degradation followed by aeolian deflation is likely to have been responsible for this process.

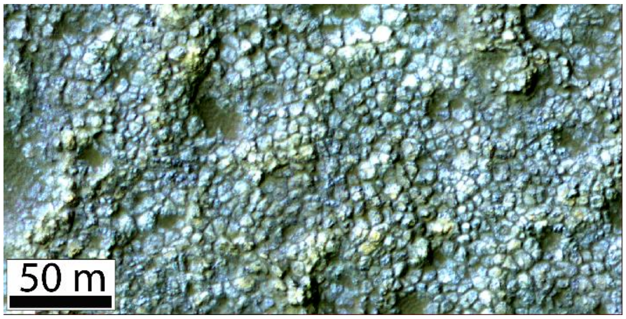

Fig. 2: Portion of HiRISE image (ESP_024644_1600) from high TI location in Hesperia Planum (Fig. 1a). Polygons are ~3-10 m in diameter.

Polygonal jointing is observed in some intercrater plains bedrock locations in Noachian units. Additionally, Noachian plains bedrock commonly appears rough at all scales, but with no smoothing or dune forms present, suggesting aeolian deflation at work in these areas as well. However, evidence for burial and exhumation (e.g. inverted craters and valleys) is also commonly observed in these terrains [7], suggesting multiple preservation mechanisms in Noachian plains.

Discussion: Above, we presented evidence that aeolian deflation of fines has affected plains surfaces and has exposed bedrock in both Noachian and Hesperian highlands units. However, (1) there is an unexplained prevalence of bedrock exposure in the Noachian units, and (2) even in locations where Hesperian plains units directly contact Noachian intercrater plains units, the Hesperian units are more mantled than the Noachian units they overlie (e.g. **Fig. 1c**). Below, we discuss potential reasons for the observed spatial variability in bedrock exposure between Hesperian and Noachian intercrater plains.

1. Preferential aeolian deflation of fines from Noachian intercrater plains. It is possible that erosion efficiency over Noachian plains would have been enhanced by topographically controlled winds across these basins, such as observed on a larger scale across the crustal dichotomy [11]. On the other hand, the extent of the mantling cover closely corresponds with the margins of the Hesperian volcanic units, which is difficult to explain solely with an aeolian mechanism. Testing this hypothesis requires comparisons of plains bedrock locations with modeled wind activity under various atmospheric pressure scenarios.

2. Preferential protection of Noachian bedrock from thick regolith formation. Noachian plains bedrock could have been rapidly buried with a friable and/or volatile-bearing material soon after their primary formation, thereby protecting them from extreme degradation compared to Hesperian plains. Burial could have occurred through (glacio-)fluvial deposition, airfall deposition, and/or ice sheet formation. In the case of ice sheets (e.g. the icy highlands Noachian climate scenario [e.g. 12-13]), if the Noachian bedrock units represent lavas (as suggested for some units by [3-6]), the lavas would have been deposited on top of the ice sheets. Because they are located in topographic lows, any ice melt from those lavas or elsewhere could have refrozen on top of those lavas. In concert with background snow precipitation, the development of surface ice sheets could protect bedrock from smaller impacts and inhibit regolith formation on Noachian-aged surfaces. Conversely, meltwater generated by thicker Hesperian lavas could have drained elsewhere (e.g. [14]) or perhaps lavas were emplaced too late in time for coeval lava/ice accumulation. Another option is that upland ice deposits protected the plains from regolith development, and glacial transport of dust-rich ice left to the lowlands left dust deposits following emplacement of the Hesperian plains. This hypothesis of ice-protected bedrock will be tested through comparison of Noachian bedrock crater size-frequency distributions with modeled distributions assuming impact into and subsequent removal of ice sheets [15].

Alternatively or in addition to this scenario, fluvial or airfall sediment deposition could have protected the bedrock units. This hypothesis will be tested through detailed morphological studies of the Noachian plains bedrock units. For example, preliminary work shows evidence for inverted valleys in some, but not all, bedrock units [6], suggesting that fluvial deposition could have been a factor in early bedrock preservation.

3. Extra mantling in Hesperian plains. A larger amount of mantling over Hesperian plains could have occurred from (1) a later stage of pyroclastic activity following the early Hesperian, volumetrically-dominant effusive stage of volcanism, and/or (2) unique mechanical properties of the last eruptive products, resulting in higher erodibility or faster comminution rates of the Hesperian lavas compared to Noachian plains bedrock units. Other potential contributing factors include regional dust concentration (e.g. [16]) and/or faster rock break-up and mass wasting following wrinkle ridge formation in the Hesperian plains.

Conclusions and implications: Some of these hypotheses are testable with existing data, future mission observations or modeling. The mechanisms by which some areas are protected from degradation while others develop thick mantles deserve further consideration, particularly for understanding the relative roles of primary emplacement processes and preservation in producing the present-day distribution of surface bedrock on Mars.

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