PROPERTIES, ORIGINS, AND PRESERVATION OF ANCIENT OLIVINE-BEARING BEDROCK: IMPLICATIONS FOR NOACHIAN PROCESSES ON MARS, A. D. Rogers¹, J. C. Cowart¹, J. W. Head², N. H. Warner³, A. Palumbo², and M. P. Golombek⁴, ¹Stony Brook University, Stony Brook, NY, USA (deanne.rogers@stonybrook.edu), ²Brown University, Providence, RI, USA, ³SUNY Geneseo, Geneseo, NY USA, ⁴Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

Introduction and significance: Many intercrater plains and degraded impact craters in the Noachian highlands contain flat-lying, relatively high thermal inertia (TI) surfaces (“bedrock”) that commonly show modest enrichments in olivine and/or pyroxene compared to surrounding materials (Fig. 1). These surfaces have maximum TI values above 500 J m⁻² K⁻¹ s¹/² in THEMIS images; some units exhibit TI values well above 900 J m⁻² K⁻¹ s¹/². These physicochemically distinctive units occur in dozens of isolated exposures ranging from ~2x10⁻² to ~3x10⁻⁴ km² in area and exhibit morphologies indicating reduced/minimal sediment mantling. The units lack evidence of fine-scale layering in HiRISE imagery, and also lack evidence of aqueous alteration in spectral data [1-7].

Fig. 1. Global distribution of high TI intercrater plains exposures (white) [7]. Surfaces with TES TI values > 325 J m⁻² K⁻¹ s¹/² were delineated using the qualitative THEMIS nighttime radiance mosaic. TI values quoted in text are derived from THEMIS nighttime imagery, from the warmest (least mantled) portions of the delineated bedrock unit.

The origin(s) of these units is uncertain. In past studies, an effusive volcanic origin was generally favored on the basis of the relatively high TI, distinctive composition, and the difficulty of spatially concentrating olivine over such large scales through sediment transport and sorting [1-6,8]. However, the lack of volcanic morphologies (e.g. flow lobes, source vents), as well as the degraded nature of these units and limited vertical exposure makes their origin(s) uncertain.

The widespread, distinctive nature of these units makes them significant; ascertaining their origins, preservation and early modification history is an important aspect of understanding the geological processes and environments that were occurring on early Mars. In this work we present a set of new observations that suggest that some of these Noachian bedrock units may have non-volcanic or non-effusive volcanic origins.

Observations: 1. The bedrock units have not followed the same degradation and regolith development path as known volcanic plains. Hesperian volcanic plains have developed a thick regolith [9, 16] and have a notable lack of bedrock exposure compared to Noachian cratered terrains [10]. Even where Hesperian volcanic plains are in direct contact with older bedrock, a striking difference in TI and regolith cover is observed, such that Hesperian plains are more mantled than the older subjacent bedrock units [10] (Fig. 2). A candidate explanation for this is that the Noachian bedrock was rapidly buried and then recently exposed [10], however an alternative explanation is that the Noachian bedrock units are mechanicially weak/fine-grained materials that break up into fine-grained materials [e.g. 11,12] that are more easily moved by wind. In contrast, competent Hesperian lavas would have comminuted into blocky/coarser-grained, less-mobile materials. Additional examples of high TI (less mantled) units subjacent to Hesperian lavas are observed in Gusev crater [13] and NE Syrtis (Fig. 3). In those locations, significantly mantled Hesperian lavas directly abut older, less mantled rock units. In Gusev crater, the older units may represent olivine-bearing basaltic tephas, similar to the Algolqin-class rocks investigated by the Spirit Rover [14]. At NE Syrtis, the older units contain sulfates and aqueously altered basaltic units [15]. Both of these rock types would likely be mechanically weak compared to unaltered basaltic lavas, such as those present in the Hesperian volcanic plains [e.g. 17].

Fig. 2. Near the southern margin of Syrtis Major, light-toned, basaltic bedrock (higher TI) underlies darker toned basaltic lavas (lower TI). (a) THEMIS TI over THEMIS daytime radiance. (b) Portion of HiRISE image ESP_036579_1795. Light-toned bedrock contains isolated bedforms. Lows within darker-toned Syrtis lavas are covered by sediment.

2. Quantitative analyses of bulk composition suggest that some olivine-bearing bedrock units are not significantly compositionally distinct from surrounding low TI units. Early work examining Noachian bedrock focused on eastern Noachis Terra, where bedrock units are most abundant and exhibit the highest TI values [2,4]. There, many bedrock surfaces are clearly compositionally distinct (more mafic bulk mineralogy) from the surrounding low TI plains, crater walls and ejecta, confirmed by spectral extraction and comparison for some of the regions. We have extended these analyses to bedrock
units in other highland locations, and find that some units are not spectrally distinct from surrounding materials (e.g. [7], Fig. 4).

![Fig. 3. Examples where Hesperian lavas abut older, likely mechanically weak materials (see text). (a) Gusev (b) NE Syrtis. The differences in surface TI expression may result from differences in friability.](image1)

![Fig. 4. Example of olivine-bearing bedrock unit with minimal difference in bulk composition from surrounding low TI units. (a) CRISM MSP OLV-INDEX (b) TES 507 cm⁻¹ index (an indicator of bulk mafic content [3]) (c) THEMIS spectra from on and off the bedrock unit.](image2)

Discussion: The observations discussed above indicate that some olivine-bearing bedrock units may represent mechanically weak materials, such as sedimentary or pyroclastic units. True thermal inertia values from these units would help to address this question; for example, Mini-TES derived thermal inertia values from individual blocks at Gusev crater showed that Adirondack class (Hesperian) basalts exhibited TI values of ~1200 J m⁻² K⁻¹ s⁻¹/², whereas Columbia Hills rocks exhibited values around ~600 J m⁻² K⁻¹ s⁻¹/² [18]. However, locating THEMIS pixels with fully unmantled exposures is a challenge. Detailed thermal modeling using THEMIS images spanning multiple times of day are underway to constrain underlying bedrock TI of these units [19].

Where the differences in bulk primary mineralogy between the bedrock and surrounding low TI materials is minimal, a sedimentary origin remains a strong explanation for these materials; however, lithification must have occurred with minimal amounts of water, as aqueous minerals are not observed in these units. Units significantly different in bulk composition from surroundings likely require a volcanic (effusive or pyroclastic) or other explanation. One such hypothesis is described below.

The influence of large Noachian-aged impact cratering events [20-21] has recently been revisited and the timeline of events and geological effects updated in order to understand the climatic implications for early Mars [22-23]. For basin-scale impact events, the vaporized silicate portion of the expanding vapor plume should be globally and homogeneously distributed and is predicted to condense out at very high temperatures and fall as hot spherules to the surface; the deposit will initially be sufficiently hot that it is likely to behave as rheomorphic flows, filling low-lying areas before final cooling and solidification. On the basis of this analysis, [22] suggest that an alternative interpretation to extrusive volcanism for Noachian-aged mafic silicate layers may be that of exposed remnants of silicate condensate layers of Noachian large craters and basins, with mineralogies representing crust and possible mantle contributions processed by the impact and vapor plume evolution, and subsequent silicate condensate layer emplacement [22-23]. We are currently further assessing this as one of our hypotheses for the origin of these high TI Noachian surfaces.

Concluding remarks: Intercrater plains bedrock units are variable in composition and morphology, and probably have different origins [e.g. 8,22,24]. The preservation and aeolian exposure history of these units is likely a key factor in their spatial distribution and in giving rise to their relatively high TI values compared to average values for low-dust regions. A close examination of the properties of each exposure is underway [7].

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