**Evidence for late-Noachian flood volcanism in Noachis Terra, Mars and the possible role of Hellas impact basin tectonics.** A. D. Rogers[1] and A. H. Nazarian[1], [1]Stony Brook University, 255 Earth and Space Sciences Building, Stony Brook, NY 11794-2100, USA (Deanne.Rogers@stonybrook.edu).

**Introduction:** Large expanses (10-100 km diameter) of in-place rock units in Noachis Terra, detected using Mars Odyssey THEMIS nighttime radiance images and derived thermal inertia, permit investigation into the processes that formed the crust in this region. As described by [1], these rocky units exhibit an enrichment (~10%) in olivine and/or pyroxene relative to low thermal inertia, sediment-dominated plains material in the region. They speculated that the units were likely volcanic in origin. Here we expand the original study region of [1] by a factor of ~8, and also use new spectral and imaging data sets from Mars Reconnaissance Orbiter (MRO) and Mars Odyssey, as well as spectral and topographic data from Mars Global Surveyor (MGS), to better understand the origin of these units and the relative timing of volcanic and tectonic events.

**Study Region and Previous Work:** The study region, which spans from 350 to 60°E, 0 to -40°S, is dominated by Noachian and Hesperian-aged units [2]. Much of the region is characterized by low (<0.15) albedo, heavily cratered terrain which has been dissected by immature fluvial networks in many places (Npld, Npl1, Npl2). The study region includes some of the thickest crust on Mars, and is partially comprised of high-standing annulus ejected during the Hellas impact event [e.g. 3] (~4.0-4.1 Ga [4]). Fault-bounded, elongate troughs up to ~100 km wide and ~1000 km long that trend roughly parallel with the curvature of western Hellas Basin are present. These "concentric canyons" were interpreted by [5] to have formed relatively early in the Hellas tectonic sequence, possibly during collapse of the transient cavity.

**Observations**

***1. Distribution, age and morphologic characteristics of high thermal inertia surfaces.*** High thermal inertia (TI) surfaces are primarily concentrated on the eastern side of the study area (**Fig. 1**). Though the majority of the high-TI regions are associated with crater floors, a few are associated with intercrater plains surfaces or the floors of large troughs (**Fig. 1**). The rocky units have undergone extensive degradation and partial-to-complete burial by impact ejecta and sediments. Ridges are observed on nearly all intercrater plains units; they are curvilinear, ~$10^2$ m wide, and confined to the rocky intercrater plains units. Small, raised linear features (possible dikes) of <100 m width are found within the exposures in a few locations.

Crater frequency curves were generated for each of the plains exposures by counting and measuring craters with diameters down to 100m on projected MRO CTX images. Assuming the retention age equals the emplacement age, all exposures are estimated to have formed between ~3.9 and 3.65 Ga.

HiRISE images reveal that at least two lithologies are present within some of the bedrock units; these lithologies vary in texture and tone and composition (**Fig.s 2-3**). This stratigraphy is well preserved in only a few locations. Polygonal fractures are commonly observed within both the dark-toned and light-toned units. Of the 17 HiRISE images that were examined, no evidence for fine-scale layering was observed within the high-TI units in the intercrater plains and troughs. Some high-TI units within crater floors do exhibit fine-scale layering, and likely differ in origin than the intercrater plains and trough units.

***2. At least two mafic units found in stratigraphy.*** The two units observed in HiRISE images (**Fig. 2**) exhibit spectral differences in THEMIS images. The possibility of multiple spectral units in the bedrock was noted by [1]; however, the dearth of supporting high-resolution imagery at the time of that study prohibited detailed analysis at that time. The lower unit has a lower emissivity between ~11.0-12.5 µm relative to 9-10µm (**Fig. 3a**). However, in general, both units appear basaltic, and similar to TES Surface Type 1 (a commonly observed basaltic spectral shape derived by [6] using TES data) (**Fig. 3**). Derived modal abundances from TES data over each unit indicate that the upper unit is distinguished from the lower unit by 1) a higher feldspar-to-pyroxene ratio and 2) a dominance of the low-Ca variety of pyroxene (modeled high-Ca:low-Ca pyroxene proportions are ~1:5, versus 1.5:1 in the lower unit). Modeled olivine abundance in the bedrock units is between ~7-10%. CRISM data support these interpretations and show no evidence for alteration minerals. Using THEMIS surface spectra from multiple images, we determined the locations where each unit is definitely or tentatively present (**Fig. 1**).

***3. Spatial association with Hellas ring structures.*** Nearly 60% of the intercrater rocky units are co-located with a trough structure, with some found on the floors of the troughs or partially burying the troughs. The mapped rocky units are observed both outside and basinward of the main basin scarp (**Fig. 1**). Within the study region, high-TI plains units are not observed westward of the outermost concentric canyon.

**Discussion and Implications:** We infer a volcanic origin for the some of the crater floor bedrock units and all of the intercrater plains and trough bedrock units, based on the following observations: massive, rugged texture, lack of evidence for fine-scale layering, possible dikes, mafic composition with lack of evidence for minerals deposited in aqueous environments. The LN/EH ages rule out Hellas impact melt as an origin for these units. The extensive area and rarity of flow fronts implies low viscosity, high effusion rates, and high magma volumes. The preserved igneous stratigraphy likely represents effusive lavas of varying composition, similar to flood basalt sequences on Earth. On Earth, the changing chemical composition associated with members of a flood basalt sequence are due to changing magma sources and/or varying amounts of crustal assimilation.

The spatial association with Hellas ring structures and confinement within the outermost Hellas ring suggest that fracturing related to the Hellas impact and subsequent tectonics may have enabled magma ascent through thick crust. Thermal evolution models allow for some melt at the base of the crust during this time period [7-8] particularly if located under areas of thickened crust [8]. Flexure caused by Hellas basin loading (~3.8 Ga) has previously been suggested as a mechanism for enabling voluminous volcanism in Hesperia and Malea Plana [5] (**Fig. 4**); this process may also apply to the units presented here. The role of multiring impact basins in rim volcanism [5] is further supported by our observations.

Melt migration enabled by multiring impact basin fracturing might apply to other, similar rocky exposures in Tyrrhena and Iapygia Terrae [9], which are located in a section of highlands between Hellas and Isidis basins (**Fig. 4**). However, mafic rocky units, while rare, do occur in other parts of the Martian highlands relatively far from large impact basins [10]. In those regions, other mechanisms may be needed to explain their origin.

Identification of these units as volcanic materials is important because it extends previous estimates for total global volumes of lava [e.g 11], which affects estimates of volatile release into the Martian atmosphere. The combination of heat and water associated with this volcanism would have led to hydrothermal environments and precipitation in the late Noachian, conducive to clay formation and habitability in both the surface and subsurface. We conclude that multiring impact basin formation on early Mars may have played a role in martian climate that has perhaps been underestimated in the past.

**References:** [1]Rogers,AD et al.(2009) *Icarus, 200*,2,446-462. [2]Greeley,R and Guest,J(1987) *USGS Misc. Map I-1802-B* [3] Neumann et al. (2004) *JGR, 109, E08002*. [4]Frey HV(2006) *JGR,111, E08ZS91* [5]Wichman,R. and P.Schultz(1989) *JGR, 94*, 17333-17357. [6]Bandfield JL et al. (2000)*Science, 287*, 1626-1630. [7]Hauck SA and Phillips RJ(2002), *JGR 107*, E75052. [8]Schumacher S and Breuer D (2007), *GRL 34*, L14202. [9]Rogers AD and Fergason RL (2011), *JGR*, *116*, E08005.[10]Nazarian AH and Rogers AD (2013), this conference [11]Greeley R and Spudis PD(1981) *Rev. Geophys Space Phys. 19*, 13-41.

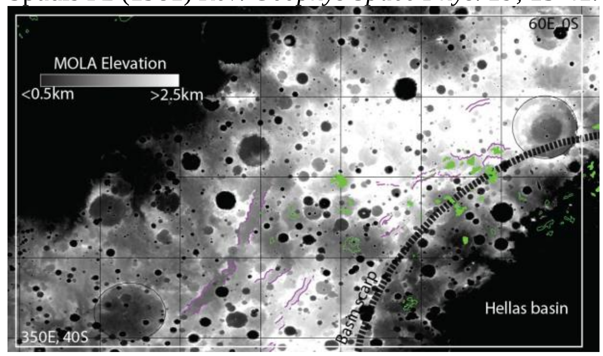


**Figure 1**. Study region. Green filled polygons show basaltic high-TI units. Unfilled polygons are high-TI but do not exhibit basaltic spectral character. Purple lines show Hellas-concentric graben.


**Figure 2**. Portion of HiRISE image ESP_017262_1560_COLOR.JP2 showing two mafic units observed within some of the high-TI exposures.

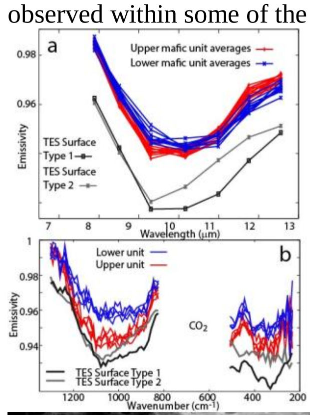


**Figure 3** (left). Typcal THEMIS (a) and TES (b) spectra of the light-toned and dark-toned units compared with TES Surface Types 1 and 2 [6].

**Figure 4** (below). Context of mapped units (blue) compared to other Hellas basin rim volcanics (cyan). Other possible Hellas and/or Isidis-related mafic rocky exposures from [9] are shown (orange).