MALEA PLANUM: TIMING AND SCALE OF DEPOSITION AND EROSION ON THE OLDEST OF MARS’ LARGE VOLCANIC PROVINCES  H. Bernhardt1, D. A. Williams1, J. D. Clark1 1School of Earth and Space Exploration, Arizona State University, Tempe, USA (h.bernhardt@asu.edu).

Introduction: Late Noachian-aged Malea Planum has been suggested as the site of large-scale volcanic interactions and as a major source for deposits now filling the adjacent Hellas basin to the north [1-4]. Activity on Malea Planum might also have affected the south polar Dorsa Argentea Formation immediately to the south, which has repeatedly been interpreted as a product of widespread wet-based glaciation affected by volcanic heat [e.g., 5,6]. Furthermore, it has been stated that such large-scale volcanic mobilization and potential gas release should have affected the early martian climate and regional habitability [e.g., 7,8]. To better understand its crucial role in Mars’ history, we are conducting a re-evaluation of Malea Planum based on our ongoing, comprehensive photogeologic mapping of the region and its immediate surroundings (see companion LPSC’19 abstract #1434).

Selected observations and discussion: So far, we identified 20 geomorphologic units using all state-of-the-art datasets (see companion abstract #1434). We compiled a tentative stratigraphy based on superposition relations, with preliminary apparent model ages (AMAs) of the dominant wrinkle-ridged plains, as well as plains- and paterae-AMAs derived by [1,2], as provisional anchor points pending further crater size-frequency measurements on more of our units. Following is a selection of key observations we made so far (ordered from older to younger):

1) Pityusa Patera: Together with similarly sized/aged nearby Malea Patera, Pityusa Patera is the widest (~270 km) and one of the oldest (~3.8 Ga [2]) paterae on Mars. Up to 1,200 m high, layered massifs (Nml) exclusively occur within Pityusa Patera. While [1] mapped the area of Nml as undivided Noachian highlands, higher resolution images show parallel, up to ~160 m wide ridges forming lobate, sometimes circular patterns with apparent wavelengths/diameters of ~1-2 km. We interpret these ridges as surface expressions of truncated, folded layers alternating with less erosion-resistant material. As unit Nml is embayed by the surrounding ridged plains (Npr), we suggest it to be ancient remnants of volcano-clastic deposits, possibly derived from a local source predating Pityusa Patera. This would make Nml the oldest morphologic unit of likely volcanic origin on Malea Planum and one of the oldest on the entire planet. While our preliminary investigation indicates that no other patera on Mars hosts Nml-like material, it bears striking similarity (ridge size/shape/pattern) to terrain exposed beneath the “reticulate terrain” along the western rim of the Hellas basin [4,9], ~1,200 km north of unit Nml. No conclusive interpretation has previously been offered for this material, but a genetic relation to unit Nml, potentially as deformed remnants of once widespread early Noachian volcanic airfall deposits, seems possible and will be investigated further.

2) Ridged plains of Malea Planum: Our ridged plains unit (Npr) is part of unit “lNv” (late Noachian volcanic plains) in the global map by [1]. With over 0.5 x 10^6 km², Npr is the most extensive unit of our mapping area, and probably extends over a total of ~10^6 km² including areas superposed by younger units. Using the same techniques as [1,2], our preliminary measurements indicate eastern Malea Planum (3.54-3.64 Ga) to have an older AMA than its western portions (3.64-3.74 Ga). The error bars adjoin at 3.64 Ga, which is in good agreement with AMAs derived for southeastern-most Malea Planum [2,10], but not with [1], who derived their age of 3.70-3.83 Ga from a small area in the northwestern-most corner of Malea Planum. However, considering the extensive degree of resurfacing of unit Npr (see following paragraphs), we used the oldest age (3.74 Ga, late Noachian) as the preliminary base for the unit. The ridges are mare-like wrinkle ridges commonly found on many martian plains of likely volcanic origin and widely interpreted as shallow thrust faults [e.g, 11]. Concentric ridge patterns occur around Pityusa, Malea, and Amphitrites Paterae, while radial patterns can be seen around all four paterae, i.e., also around Peneus Patera. Malea, Amphitrites, and Peneus Paterae also show concentric normal faults that appear to be overprinted by the wrinkle ridges. The lack of unambiguous normal faults around Pityusa Patera might indicate it to be the oldest patera (i.e., older than Malea Patera but with an overlapping AMA [2]), where supposed crustal extension due to caldera subsidence [12,13] occurred before the ridged plains were emplaced.

3) Streamlined plains: Superposing the wrinkle-ridged plains are plains characterized by extensive overprinting by sinuous channels and ridges of various sizes (unit HNst). Integrated channel networks adjacent
to Pityusa Patera, as well as inverted levees-channel-ridge transitions are abundant on HNst. Based on these observations, we submit the landforms to have formed by subaerial fluvial activity, possibly enabled by regional volcanism. While various channels cut through them, wrinkle ridges do not seem to be covered by HNst but rather transition into it. This implies that tectonization took place after the emplacement of HNst, but also that fluvial activity occurred or continued after wrinkle ridge formation. Although HNst encompasses only ~118,000 km² today, i.e., roughly a tenth of Malea Planum, it likely used to cover the majority of the region, i.e., ~10⁶ km², as occurrences of the streamlined plains can be found all across it. Given HNst’s average thickness of ~40 m, as indicated along well-defined contacts to Npr, this would imply an initial volume ~40,000 km³, ~90% of which (~36,000 km³) have since been removed.

4) Dorsa Argentea Formation (DAF): Comparatively smooth plains, often with lobate, bulged contacts, and containing elongate rimless pits (Sisyphi Cavi) as well as vast, braided networks of sinuous, esker-like ridges (Dorsa Argentea) cover an area of 1.5 x 10⁶ km² adjacent to the south polar layered deposits [e.g., 1,6]. In the global map by [1], this included Sisyph Planum immediately southwest of Malea Planum as well as portions of Pityusa Patera, which aligns reasonably well with unit HNs (smooth material) in our map. Based on the appearance of the DAF/unit HNs in those two locations, we also identified occurrences in Malea Patera as well on the floor of Mitchel crater (see Fig. 1 in companion abstract #1434), the latter of which had previously been interpreted as lava flows [10]. Unit HNs superposes both, Npr and HNst, therefore indicating that DAF-emplacing activity, for which wet-based glaciation that took place up until ~3.5 Ga ago has been suggested [1,6,14], was not confined to the immediate south polar area. Instead, it seems to also have occurred across large parts of Malea Planum (at least up to 60.9° S) after the conclusion of fluvial activity that had overprinted the wrinkle-ridged plains and formed unit HNst. As HNs covers only ~21,000 km² of Malea Planum today, this might also imply that up to ~98% of its former volume (~98,000 km³, adopting an average thickness of 100 m) has since been removed.

5) Pedestal craters: While the occurrence of pedestal craters across Malea Planum had previously been noted [13], we assessed them both quantitatively and qualitatively. We differentiated between a lower population (Hp) that superposes Npr, HNst, and HNs, but is superposed by most degraded crater ejecta (Hcm), as well as an upper population (Hpc), which is superposed by fresh crater ejecta (Acm). At well-defined contacts to Npr, Hpe reaches heights of ~250 m, whereas Hpc rarely exceeds ~100 m. Occurring all over Malea Planum, we mapped 177 occurrences of Hpe (~36,000 km²; ~9,000 km³) and 48 of Hpe (~7,000 km²; ~700 km³). However, even adding ~38,000 km² of ejecta that appear to cover more of Hpe/Hpc, this would imply that only ~5% of once up to 350,000 km³ of material covering most of Malea Planum have been preserved, mostly due to armoring by impact ejecta, while ~330,000 km² where eroded.

Preliminary conclusions: Disregarding crater ejecta and Amazonian veneers, we identified at least six distinct, major depositional units (Nml, Npr, HNst, HNs, Hnp, and Hpc) on Malea Planum spanning a time period from ~3.8 Ga to at least 3.5 Ga. While the wrinkle-ridged plains (Npr) still cover the majority of the region, we suggest that only small percentages of the other five deposits remain. Based on our ongoing mapping and morphometric analyses, volumes on the order of 400,000 to 500,000 km³ of these units might have been removed from Malea Planum. Therefore, while Hesperia Planum likely contributed the majority of the once ~10⁷ km³ of sedimentary Hellas infill [4], Malea Planum should have decisively contributed to the infilling of the adjacent basin. While large-scale volatile mobilization of up to ~10⁶ km³ via volcanic heating has previously been suggested [3] for Malea Planum, our preliminary assessment of the region’s geomorphologic record implies not one catastrophic event, but several distinct episodes of erosion that occurred over several 100s of Ma.

Our future work will include a better characterization of each depositional and erosional period via hyperspectral and radar analyses, assessments of the potentially implied volumes of water/ice, as well as deriving AMAs for all units that lend themselves to reliable crater size-frequency distribution measurements. Our goal is to present a comprehensive investigation of Malea Planum’s geologic inventory and history.