A REVISED GEOLOGIC HISTORY FOR THE MAJOR FLOW UNITS IN EASTERN ELYSIUM PLANITIA, MARS.
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Introduction: The Elysium Volcanic Province includes several of the youngest lava flows on Mars, with multiple phases of activity having produced overlapping lava flow units over the past 2.5–234 Ma [1]. Our study area is located in the eastern part of Elysium Planitia, and includes Rahway Valles to the North and Marte Vallis in the South (Fig. 1). The surficial material is generally interpreted as young ʻaʻā and pāhoehoe lava flows [1–4], with a Middle and Late Amazonian surface age [1, 2]. However, there are contrasting interpretations of the morphological features especially in Rahway Valles, which have also been attributed to fluvial [e.g., 5, 6] and fluvioglacial processes [7].

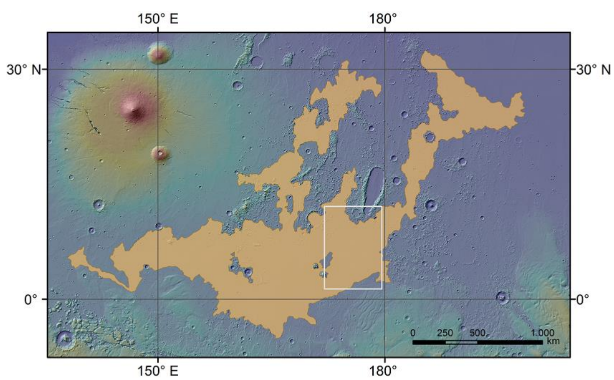

Fig. 1 Context map of the Elysium Volcanic Province with Late Amazonian lava flows shown as a tan colored overlay above a MOLA colorized hillshade model (blue –5,460 m and red –13,700 m). The inset white outline shows the location of our study area.

In this study, we present original geological and facies maps of Eastern Elysium Planitia as well as new geochronologic constraints based on crater size–frequency distributions (CSFDs). Combing these results with subsurface radar reflectors identified in MRO SHARAD data from Morgan et al. (2013) [8] enables us to better constrain the geologic timing of flow units within the region and infer their origins as either volcanic, fluvial, or fluvioglacial products.

Data and Methods: This study utilizes a regional mosaic of 311 images that were obtained by the MRO CTX camera (6 m/pixel) [9], combined with observations from the MRO HiRISE camera (0.3 m/pixel) [10], Mars Express HRSC data (25 m/pixel) [11] and MGS MOLA data [12]. The CTX mosaic was used to generate a 1:200,000-scale map of the major geological units in the study area (examined at a digitizing scale of 1:50,000) and subdivided, on the basis of morphology, into facies with a mapping scale of 1:100,000 (examined at a digitizing scale of 1:25,000). All mapping was completed using ESRI software ArcGIS 10.4. To create a chronology of geological events within our study area, we developed CSFDs of the youngest geological units in the region and digitized 6,589 craters in an area covering 157,000 km^2 by using the CraterTools software from the Freie Universität Berlin [13] and CraterStats 2.0 [14].

Results: *Geological Mapping and Geochronology:* We created a geologic map covering an area of 281,000 km^2 (see inset in Fig. 1). From oldest to youngest, the geologic units in this region include: (1) Noachian to Hesperian bedrock; (2) the Medusae Fossae materials; and (3) the Cerberus Plains. Beside these units, the area contains (4) Crater material. Mapping results for the geologic older units (i.e., units 1 and 2) are consistent with other studies [e.g., 2, 3]. However, previous work [1, 2] divided the Cerberus Plains into two major units of significantly different geologic age. To reevaluate this chronology we divided the area for the CSFD-analyses into a northern and a southern portion. Analysis of the CSFDs gives a surface age, with a factor of two in uncertainty, of 20.0 ± 0.5 Ma for the northern part (based on 1,647 craters and an area of 31,000 km^2), whereas the southern part of Cerberus Plains material is 8.8 ± 0.1 Ma, (based on the CSFD relationships of 3,690 craters within 126,000 km^2).

Facies Mapping: The Cerberus Plains were investigated in more detail using a facies-based approach to explore the possible origins of the surficial material. The map consists of 19 distinct facies belonging to 5 groups defined by: (1) smooth surface texture; (2) rough surface texture; (3) platy facies; (4) furrows and irregular pattern; or (5) linear features.

Interpretation and Discussion: *Facies*: Facies belonging to Group 1 are generally interpreted as the interior of pāhoehoe-like lava flows, either lava-rise plateaus and lava-rise pits, or volcanic plains exhibiting fracture patterns. In contrast, the Group 2 facies are interpreted to present ʻaʻā or rubbly lava flows. The facies defined by plates (Group 3) and furrows (Group 4) are interpreted to present a disrupted crust that results in plates, stranded terraces, streamlined islands or compressional ridges and furrows. The origins of linear features in the Group 5 are challenging to interpret. Previous studies have attributed them to being products of fluvial erosion [1, 3] and fluvioglacial processes [7]; however, this work interprets the linear features as the products of lava emplacement. Ridges can form in different volcanic settings for example: (i) as squeeze-ups of lava, like those observed in 1783–1784 A.D. Laki lava flow [15]; (ii) in platy-ridged terrain [15] as a consequence of compression; or (iii) elongated tumulus formed by inflation above a lava tube as observed in Hawaii [16] and in the Tharsis Plains on Mars [17].

Revised Geologic History: Geological mapping and CSFDs reveal that Rahway Valles and Marte Vallis are infilled by Late Amazonian-age material, rather than being composed of two units of significantly different ages (i.e., the Late to Middle Amazonian-age AEc_2 unit and Late Amazonian-age AEc_3 unit), as previous studies have suggested [1, 2, 8]. The geological evolution of the Cerberus Plains involved at least the following sequence: (1) Lava flows, and perhaps aqueous floods, were erupted from the Cerberus Fossae in Grótjá Valles to form the widespread AEc_2 unit, which flowed through Rahway Valles and Marte Vallis before debouching onto the Amazonis Planitia (125 Ma [18]; 500 Ma [1]). The AEc_2 unit has since been partially buried by younger lava flows and is not exposed at the surface within Rahway Valles and Marte Vallis. However, its distribution may be inferred from the presence of a widespread subsurface radar reflector identified in SHARAD data [8]. In our study, the formerly recognized deeper reflector (L2R) is attributed to base of the AEc_2 unit. (2) The next major unit includes a lava flow that moved from North to South through Rahway Valles sloping toward Marte Vallis. This region, within limits of uncertainty, has a model age of ~20 Ma. This unit is inferred to be the L1R radar reflector described by Morgan et al. (2013) [8]. Based on our CSFDs, the unit is too young to be AEc_2, but consistent with the age of the AEc_3 unit, and for convenience we refer to it here as AEc_{3A}. (3) Subsequently, a major unconformity developed between the emplacement of the surficial flow units in Rahway Valles and Marte Vallis. This unconformity corresponds to the R3 third radar reflector, identified by Morgan et al. (2013) [8], and we agree that this reflector corresponds to the base of 20–40-m-deep erosional channel produced by a catastrophic aqueous flood that was released from a now buried segment of the Cerberus Fossae in the eastern Cerberus Plains region. (4) The most recent geologic unit to have been emplaced was a major lava flow unit that travelled from West to East through Marte Vallis, infilling the older aqueously carved channel and generating thin overbank flows that partially mantled the southern parts of Rahway Valles. This young flood lava flow, AEc_{3B}, emplaced the two lava type endmembers pāhoehoe and ‘a‘ā and is further characterize by plates, compressional ridges and streamlined islands. The CSFDs associated with this unit implies a model age of 8.8 Ma. (5) After these major volcanic events there was a gradual process of aeolian mantling as well as impact cratering.

Conclusions: This work refines the overall emplacement chronology for the major flood basalt units in Eastern Elysium Planitia. Our results show that the region has been resurfaced by a unit(s) of much younger ages (~8.8–20.0 Ma), as has been previously suggested [1, 2, 8]. The surface contains textures, which strongly associated to volcanic lava flow fields, especially ‘a‘ā and pāhoehoe, linear compressional ridges and extensional rifts as well as platy-ridged terrain. Lava flows emplaced in the northern and southern portion could represent different stages of a single eruption, or they could be the products of two distinct eruptions separated in time by only a few millions of years, or less. Furthermore, our results vastly improve constraints on the timing of the last major aqueous flooding event that modified Marte Vallis. Combining the SHARAD reflectors, presented in Morgan et al. (2013) [8], with our new chronological results, we infer that the youngest erosional unconformity must have developed between the emplacement of the two most recent lava flows exposed in the region, which implies that a catastrophic aqueous flooding event occurred in in Marte Vallis approximately 20.0−8.8 Ma ago.

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Acknowledgements: We thank Serena Annibali for processing the MOLA tracks and C. W. Hamilton acknowledges funding support from the NASA Mars Data Analysis Program (Grant # NNX14AN77G).