DETAILED GEOMORPHOLOGIC-TECTONIC MAPPING OF THE TEMPE TERRA REGION, MARS UNDER CONSIDERATION OF CHRONOSTRATIGRAPHIC ASPECTS

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Introduction: We have completed a new 1:3,000,000 geomorphologic-tectonic map of Tempe Terra along with parts of sorrounding units based on Context Camera [1] (CTX) image data at ~6 mpx^{-1} resolution. CTX data gaps that only make out a few percent of the mapping area were filled with data acquired by the High Resolution Stereo Camera [2, 3] (HRSC) at resolutions between 12.5 to 25 mpx^{-1}. While the focus of this map lies on the study of recent surface processes and the complex volcano-tectonic history that has sustainably shaped Tempe Terra, adjacent units associated with the formation of major geologic regions (Arcadia Planitia, Kasei Valles, Tharsis) were also included to get a comprehensive insight in the regional geology. To improve stratigraphic positions of geomorphologic units, we performed extensive measurements of crater size-frequency distributions on HRSC and especially CTX data to derive relative and absolute model formation ages. In contrast to previous investigations that were based on Viking data of lower resolutions (50-100 mpx^{-1} [4]) (130-300 mpx^{-1} [5]), our map represents a more advanced study of the Tempe Terra region owing to the higher resolution and better image quality of CTX data. In the following sections we summarize some of the key findings of our detailed mapping approach.

Labeatis Mons: The best-preserved of the 3 larger volcanoes in Tempe Terra is Labeatis Mons, a steep sided dome, situated inmidst the southwestern rift segment at 37.4°N/76.0°W. It might be the result of an ascending mantle plume which also commonly occur within terrestrial rift systems such as the East African Rift System [6, 7, 8] or the Baikal Rift System [9]. Numerous overlapping lava flows extend radially from its center with farthest extensions up to 100 km to the north and 122 km to the south and southwest. Within former studies [5, 10, 11, 12] boundaries of Labeatis Mons were roughly drawn along the disappearance of faults that carve into late Noachian smooth plains (Ntfl). While this approach is not very precise because faults only slowly fade whereas demarcation becomes a bit arbitrary, scarps of lobate flows (Fig. 1) and flow fronts that form the boundary to the sorrounding unit Ntfl are well discernable in CTX data and were mapped in detail. The great importance of Labeatis Mons for determining the times of rift activity of Tempe Fossae has already been made clear by [10, 12] who measured crater size-frequency distributions (CSFD's) of key areas revealing a model formation age of the main volcanic edifice of 3.51 Ga which is highly consistent with own age determinations of 3.53 Ga. However, our detailed investigation of the volcano using CTX data reveals new insights into relative and absolute stratigraphic relations between volcanic emplacement and rifting. Narrow lava flows (Fig. 1a) which represent later eruptions and should therefore be younger than 3.53 Ga (or 3.51 Ga) are cut by major curvlinear border faults of Tempe Fossae and linear, narrow faults of Mareotis Fossae. Thus, rifting or at least faulting seems to have been active after the latest eruptions.

Ancient lakes and river beds: In the eastern part of Tempe Terra, Nochian cratered units are often carved by irregular, often labyrinth-like, flat-floored and rimless topograpic depressions. In times when precise topography data of Mars were not yet available, these depressions and channels were falsely interpreted as lava flows, issued from a circular central depression at 43.98°N/61.50°W e.g. by [13, 14, 5]. This is in fact not surprising considering the low resolution of small scale Viking data which they used for their investigations. However, the utilization of high-res CTX data combined with topography data acquired by the Mars Orbiter Laser Altimeter [15] (MOLA) leave no doubt

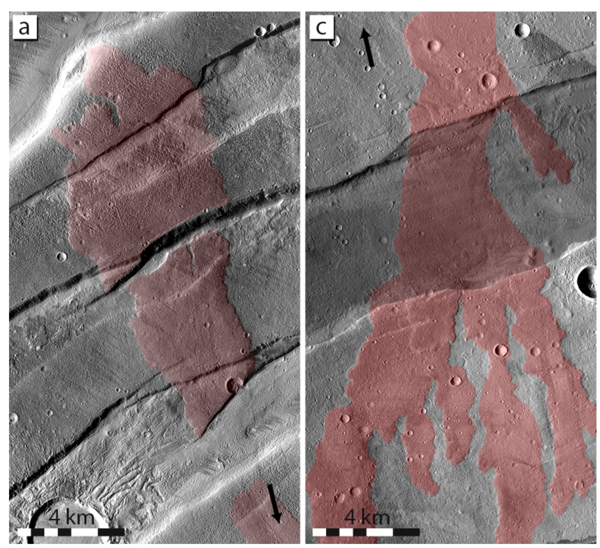

Figure 1: a) Sinusoidal projection (clon = 76.74°W) of CTX image P20_008972_2175. One of many north trending lava flow lobes (in red) that extend from Labeatis Mons. Curvlinear faults of Tempe Fossae have subsequently cut younger lava flows. b) Sinusoidal projection (clon = 75.46°W) of CTX image P20_008972_2175. In contrast to the north trending flows, south trending volcanic eruptions rather appear branched as an assemblege of many overlapping narrow flows. They are cut by long but narrow linear graben of Mareotis Fossae. Black arrows in both images point towards the center of Labeatis Mons.

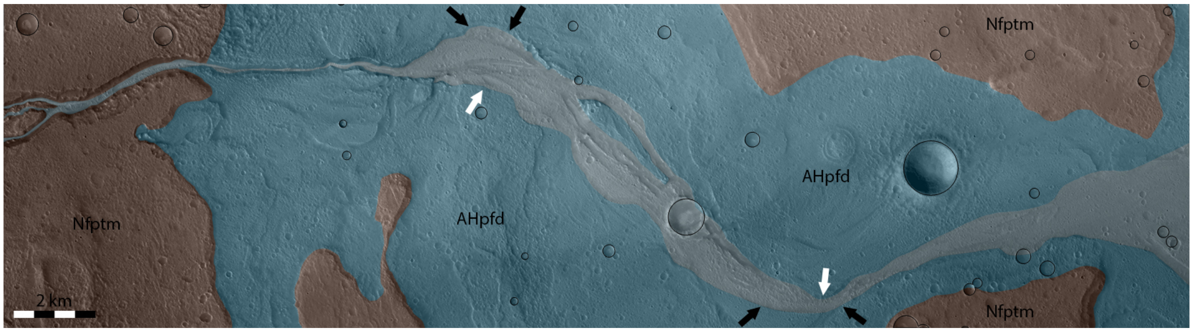

Figure 2: Morphologic indications for Hesperian and Amazonian fluvial activity. This small meandering stream resp. the remaining dry river bed (marked in bright blue) which looks like a miniature Kasei Valles has subsequently cut through unit Nfptm and even through the Amazonian-Hesperian plains interpreted as ancient lakes and/or rivers beds. Black arrows indicate the convex riverbank, while white arrows indicate the concave riverbank. Center of CTX image P13_006229_2157 lies at N35.08°/E-56.35°. Flow direction is from the west to the east, indicated by streamline-shaped islands and MOLA topography data.

that these features are depressions instead of volcanoes with radial extending narrow lava flows.

Another type of depressions that have carved into Noachian cratered plateau units are long, winding and short but wide valleys with tributary channels and landforms that stronly resemble ancient river beds (Fig. 2). These winding valleys and possible ancient lake beds generally follow the decreasing elevation towards the northern lowlands.

Volcano-tectonic evolution: According to numerical models, faster extension rates which produce high local extensional deformations that can lead to continental rifting only occur within the thermally younger, and therefore warmer lithosphere. In contrast to this, spreading and widening of the area, that is incorporated in the extensional deformation is expected to occur within a cooler and thickened lithosphere at slow deformation rates [16]. Thus widening and crustal thickening are thougth to generally mark the end of rifting. For Tempe Terra, this would mean, that the larger rift valley to the northeast should have formed earlier in Mars history when geothermal gradients were higher and the lithosphere thinner. By progressive cooling of the planet with simultaneous thickening and strengthening of the lithosphere, extension rates slow down which result in spreading of the rift, as observed for the southeastern part of Tempe Fossae. This is in accordance with the stratigraphic distribution of volcanic edifices within Tempe Terra and a decrease in size and therefore in volume of erupted materials. First volcanic activity is indicated by the formation of the ancient, large and heavily eroded pre- to synrifting volcano [10, 12] at 44.6°N/70.0°W that is dissected by many faults of Tempe and Mareotis Fossae [14]. Early and Late Hesperian rift related volcanic edifices are situated within central Tempe Terra at 38.4°N/70.2°W and 37.4°N/76.0°W and have sustainably shaped the rift geometry. Early to Late Amazonian volcanic activity can only be observed in the western Tempe volcanic province as clusters of numerous small low shields [17].

Summary: Many boundaries of geomorphologic units previously mapped e.g. by [4, 5] could have been refined during our mapping. Besides boundaries that were mapped as uncertain or were not recognized owing to lower resolutions of used image data in previous investigations have been verified or established for the first time. By the use of our new map, combined with precise age determination of many units, we were able to considerably improve the overall stratigraphy of Tempe Terra. Additionally, we were able to narrow formation intervals of many fault arrays of Tempe and Mareotis Fossae.

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