EXTENSIONAL TECTONICS AND NEW CRATER STATISTICS OF THE NORTHERN THARSIS PROVINCE, MARS. P. Kronberg[1] and E. Hauber[2], [1]Institut für Geologie und Paläontologie, TU Clausthal, Leibnizstr. 10, D-38678 Clausthal-Zellerfeld; kronberg@geologie.tu-clausthal.de. [2]DLR-Institute of Space Sensor Technology and Planetary Exploration, Rudower Chaussee 5, D-12489 Berlin-Adlershof, Germany; Ernst.Hauber@dlr.de

Introduction: Geologic mapping of Mars has led to a global stratigraphic framework [1] and a rather comprehensive synthesis of the tectonic history of Mars (see [2] for a summary of present knowledge). Up to now, special attention has been paid to the key area of martian tectonics, the Tharsis province, and its radially oriented extensive graben systems. Individual tectonic events in particular areas of the Tharsis province have been identified by a detailed structural analysis and have been assigned to 5 stages through time [e.g. 3].

Our recent studies refer to the Northern Tharsis province where three regional extensional units, the Mareotis Fossae, Tempe Fossae, and Alba Patera region reveal major differences in upper crustal behaviour under changing extensional stress fields in space and time. Detailed photogeologic structural mapping of Viking orbiter photomosaics has been used for an inventory of different fault patterns and their spatial occurrence. Of special interest are differences in geometry and kinematics of extensional faulting. To establish the ages of tectonic events, we use new crater counts on high-resolution digital photomosaics of selected areas.

Mareotis Fossae: The Mareotis Fossae are represented by an extensive system of subparallel linear faults and simple graben trending northeast (45°-60°E). It is observable over an area of about 700 km across strike and 1,200 km along strike. Individual graben are 2-5 km wide and 60-80 km in length. Elevation data from the Mars Observer Laser Altimeter (MOLA) indicate (present) graben depths of 50-100m, locally, and wall slopes of up to 8°. Images from the Mars Observer Camera (MOC) show that they are partly eroded and in many places filled in by wind-blown sand and/or volcanic material (e.g. image #50704). Along strike, linked graben systems can be traced over hundreds of kilometers, often in en-echelon settings. The graben show a rather uniform spacing and do not vary greatly in displacement along strike. Pits and pit chains can be observed, more often and to a larger extent towards southwestern Tempe Terra. As the oldest observable extensional unit, the Mareotis Fossae form the structural background pattern of the Tempe Terra region crossing geological units of Noachian and Hesperian systems (highly deformed terrain materials, the Tempe formation unit and even lower units of the Alba Patera formation as mapped by [4]). Obviously, the faults and graben swarms of the Mareotis Fossae resulted from widespread upper crustal extension throughout the Northern Tharsis province. However, the exact mechanisms of graben formation in the Tempe Terra region (as well as in other extensional zones of Mars) are still under discussion: tension cracks, dyke propagation or non-volcanic extension? (see [2] and references therein). If the Mareotis Fossae were surface expressions of dykes and comparable to terrestrial structures such as the Mackenzie dyke swarm [5], they could be related to an early magmatic center situated northwest of the Tharsis Montes as already suspected by previous authors [6]. If one excludes the dyke component in graben formation, the Mareotis Fossae could be seen as part of a radially oriented graben system related to a broad crustal uplift and associated extensional faulting. Modelling can explain the directional trend of the various graben systems around Tharsis [7]. However, it does not yet provide an explanation for initiation and development of the rather uniform and very extensive graben series around Tharsis that has no terrestrial analogues with respect to structural style and extent. Whatever their origin is, the Mareotis Fossae resulted from so far unknown mechanisms of widespread upper crustal extension throughout Northern Tharsis.

Tempe Rift: Structural style and spatial occurrence of the Mareotis Fossae differ strongly from a rather complex extensional system trending northeast-southwest (45°E). It crosses Tempe Terra over a length of about 1,400 km at widths between 50 km and 100 km and broadens gradually southwestward. In contrast to the Mareotis Fossae, this extensional system, informally named "Tempe Rift" by the authors, resulted from localized extensional deformation of martian crust. It shows several similarities to terrestrial continental rifts as far as dimension, extent, structural setting, and associated volcanism are concerned. These characteristics are not covered by what is conventionally named "Tempe Fossae" in USGS maps. According to our observations, the latter include various kinds of extensional structures of different origin and age.

Results from our mapping indicate that the Tempe Rift is a complex extensional unit with along strike changes in rift width, rift architecture, and rift topography. One can differentiate three rift segments. The northeastern segment (about 350 km along strike) is characterized by few but extensive steep normal faults with large throw bordering a rift valley up to 50 km wide, outlining also a deep internal graben, 15 km wide and about 120 km long. Towards southwest, the rift changes into a complex series of horst and graben patterns and step fault terrains. Fundamental structures of the central segment (about 260 km long and 100 km wide) and the southwestern segment (about 570 km long and widening up to 230, maybe 300 km) are several en-echelon and sinuous rift basins (up to 150 km long and 10-20 km wide) separated by a few internal structural highs (horst schollen). MOLA data indicate

an altitude difference of up to 850 m between rift shoulders and rift floor (central rift segment). The rift basin might be covered by wind-blown sand and volcanic deposits to a larger extent. For example, a MOC image (#49105; 8m/px) crossing the northern rift segment shows subdued craters filled by material of unknown origin, very likely some sort of aeolian blanket [8]. On the other hand, a lobe-like feature at ≈49°N, 63°W suggests a volcanic origin for the rift floor material. Therefore, elevation differences obtained by MOLA measurements must, as in the case of other topographic depressions, be considered as minimum values. Correspondingly, the wall slopes should be locally flattened by aeolian mantling.

Rift related volcanism is found at two centers: one in the central segment of the Tempe Rift where a (strato?)volcano seems to sit on a structural high reaching a relative topographic altitude of 1,300 m above adjacent rift shoulders according to MOLA data. The observation that the volcano is affected by several larger normal faults indicates early- to synrift activity. A second and much larger volcanic center is situated in the southwestern segment where the rift reaches its largest width (about 300 km). Here, axial rift structures are overlain by unaffected volcanic deposits. Statistics of our new crater counts on this large volcano, previously mapped as volcanic construct of unknown age [4], indicate an age of 3.51 Gy (after model II of [9]). This late Hesperian age should give an upper limit of rifting activity and marks the end of an important regional event in the tectonic history of the northern Tharsis province, related presumably to a regional magmatic uplift. Initiation and development of the Tempe Rift might be contemporaneous with stage 3 of the time scale proposed for martian tectonic history [10].

According to results from photogeological mapping, the Tempe Rift is cross-cutting the pre-existing graben swarms of the Mareotis Fossae that originated from an earlier and quite different extensional stress field still to be dated.

Alba Patera: A third variety of upper crustal extensional deformation on Mars is found along the immense extensional zone related to the Alba Patera broad shield volcano and observable over 2,300 km along strike and up to 1,200 km across strike. The horst graben pattern along the flanks of the shield volcano (related to a domal magmatic uplift) is quite different from mapped structures of the Mareotis Fossae and the Tempe Rift as far as dimension, extent, geometry, and kinematics of extensional faulting are concerned. It is also interesting to see that the horst/graben pattern occurring along the higher parts of the shield (with north-northeast trending series of graben, 5-10 km wide and 50-80 km long) changes along and across strike into a system of subparallel, narrow but extensive ("simple") graben (0.5 - 1 km wide and up to 270 km long). At present, we extend our studies to the Alba Patera region for a detailed inventory and interpretation of fault patterns and fault geometries as well as for extending our crater counts to selected areas of the Alba Patera region and its surroundings. A preliminary analysis of available MOC images reveals that graben appear to be less affected by mantling of volcanic or aeolian material (e.g. images #43205, #43206) than in the Mareotis Fossae and the Tempe Rift. This might indicate a younger age. Alternatively, the higher elevation of the terrain might prevent intense aeolian deposition of sand. However, this is not the case on Arsia Mons [8], so elevation differences are not likely to be responsible for the observed contrast in morphology.

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