FAULT SYSTEM EVOLUTION OF TEMPE TERRA, MARS: REGIONAL AND LOCAL SIGNIFICANCE.

C. J. Orlov[1], E. K. Bramham[1], M. Thomas[1], P. K. Byrne[2], E. Mortimer[1] and S. Piazolo[1], [1]School of Earth and Environment, University of Leeds, UK (eecjo@leeds.ac.uk), [2]Department of Earth and Planetary Sciences, Washington University in St. Louis, USA.

Introduction: The structurally complex region of Tempe Terra, at the northeast edge of the Tharsis Rise (Figure 1), is of substantial interest for understanding the tectonic history of Tharsis, and Mars more broadly. Tempe Terra is a plateau consisting largely of Noachian to Hesperian volcanic and highland units [1] with a high concentration of extensional deformation. This region is of interest because it preserves rocks and structures from the early evolution of Tharsis and lies along the trendline formed by the alignment of the Tharsis and Uranius Montes volcanoes [2], which we refer to as the Tharsis Montes axial trend (Figure 1). Improved high-resolution image and topographic data coverage and recently revised geological unit assignments [1] provide an opportunity to build on previous investigations of the region and to review the structural history of Tempe Terra in unprecedented detail. Here, we present the results of detailed structural mapping of a 2.3 million km^2 study area covering the entire Tempe Terra plateau (Figure 1), which includes the separation of the 23,711 identified faults into sets based on their orientation, age, and cross-cutting relationships. We use this information to provide a revised history of fault-related deformation in Tempe Terra, and discuss the relative roles of regional- and local-scale tectonic factors in shaping the features we observe.

Structural Mapping: With images from the Mars Express High Resolution Stereo Camera (HRSC, 12.5 m/pixel resolution) and Mars Odyssey Thermal Emission Imaging System (THEMIS, 100 m/pixel resolution), we mapped more than 23,000 normal faults that we then classified into 20 sets based on detailed analysis of orientation and relative age (Figure 2). Tempe Terra is characterized by widely distributed, cross-cutting faults and graben that predominantly trend northeast. The regional architecture shows a concentration of structures through the center of the plateau in a ~500 km-wide, NE-trending zone that follows the Tharsis Montes axial trend. The spatial density of faulting within this zone, and across the plateau, increases to the west, i.e., with greater proximity to Tharsis.

Fault sets comprise numerous subparallel graben, but vary in scale from regionally extensive to locally confined (Figure 2). Early Hesperian sets H3, H4, and H5 cover a much larger area than any other sets, and account for 70% of the 273,706 km total cumulative length of the Tempe Terra fault population. Fault sets

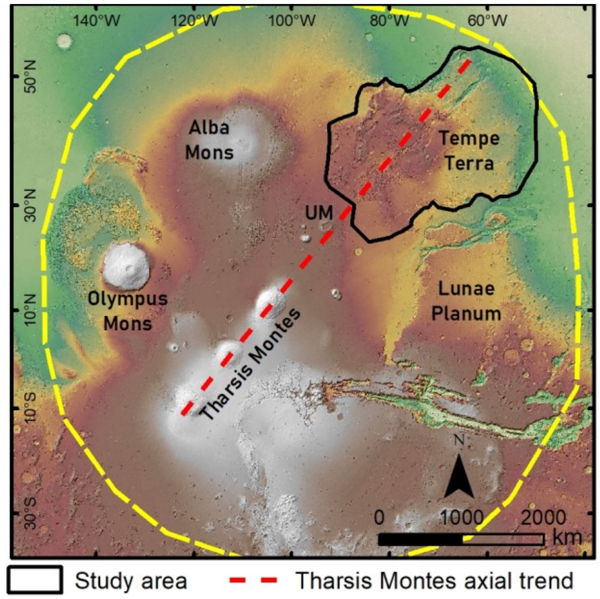

Figure 1: *The Tempe Terra region. This is a shaded relief map showing the location of our study area within the Tharsis Rise, with elevation from the colorized HRSC–MOLA DEM. UM = Uranius Mons; the yellow dashed line indicates the approximate perimeter of the Tharsis region.*

were assigned relative positions in time using cross-cutting relations and the buffered crater counting technique [3, 4], and range in age from Middle Noachian to Amazonian–Hesperian. These relative ages provide a basis for characterizing the history of faulting in Tempe Terra.

Deformation History: Tempe Terra has experienced multiple episodes of tectonic deformation, but although the region has been active through the lifespan of Tharsis, the majority of extensional strain appears to have occurred over a relatively short period during the Early Hesperian.

The earliest preserved fault activity in Tempe Terra is Middle Noachian in age, and deformation is concentrated to the northeast of the plateau, expressed as swarms or clusters of linear graben. Regional and local tectonic activity then peaked in the Early Hesperian, with development of the Tempe Rift [5, 6] and the concentration of NE-oriented faulting along the Tharsis Montes axial trend. This deformation is consistent with the peak of extensional and shortening deformation associated with Tharsis from the revised tectonic history of Tharsis by Bouley et al. (2018) [7]. The final phase of deformation is from the Late

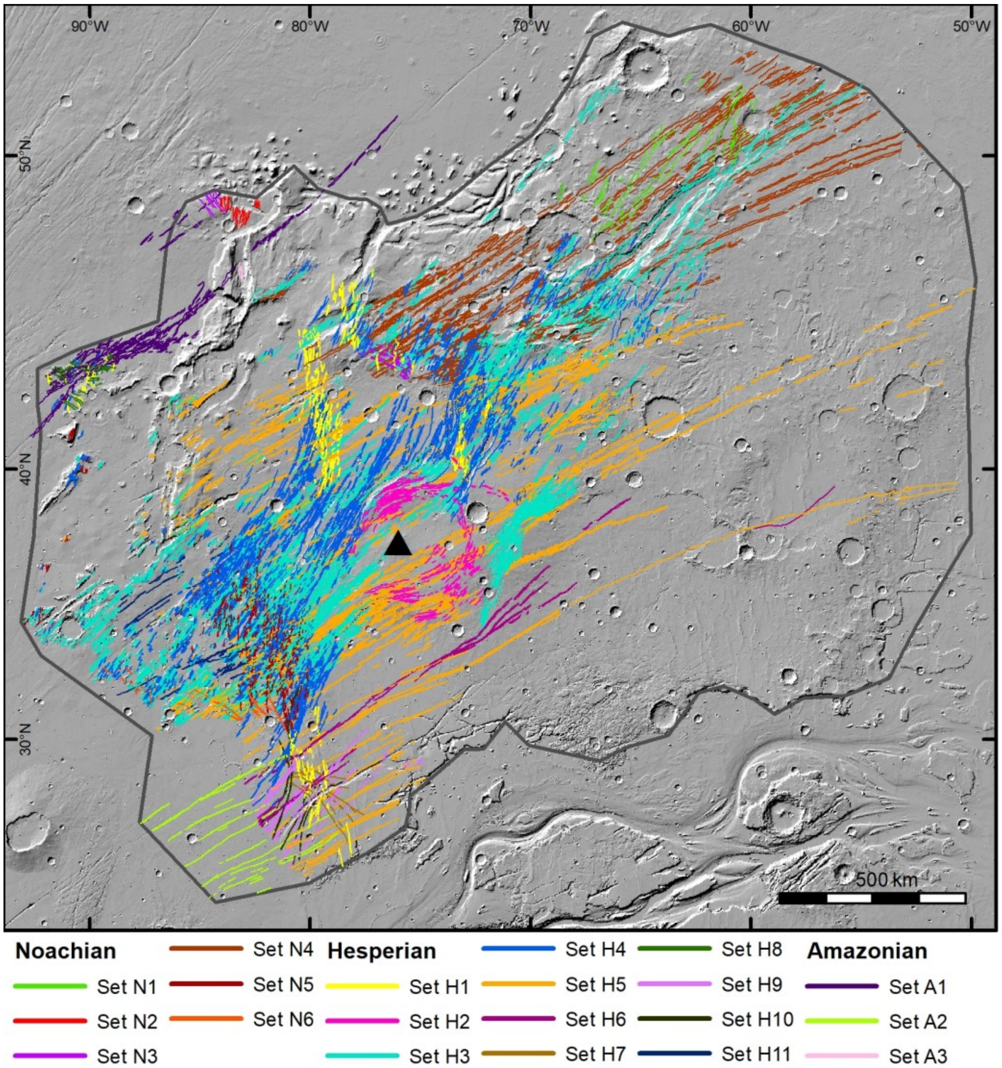

Figure 2: *All fault sets identified in the Tempe Terra study area. The black triangle is Labeatis Mons. The base map is shaded relief MOLA elevation data in Mars Mercator projection.*

Hesperian to Early Amazonian, and is confined to the western edge of the study area. Fault activity from this period is probably related to volcanic centers outside Tempe Terra, such as Alba Mons (Figure 1).

Controls on Faulting: A combination of regional and local stresses has produced the varied and complex faulting we observe in Tempe Terra (Figure 2). In particular, local volcanic activity and regional tectonism from the growth of Tharsis are both likely to have been major influences on the development of structures here.

Regional extensional stresses generated by the growth of the Tharsis tectonic bulge and its major shield volcanoes have long been interpreted to be the cause of vast radial fault systems surrounding Tharsis [2]. In Tempe Terra, these regional stresses are expressed by regionally extensive fault sets following two trends: the NE-oriented Tharsis Montes axial trend, and an ENE-oriented trend centered north of the Tharsis Montes. These large-scale regional trends have dominated the development of structures in Tempe Terra.

On a local scale, radial extensional stresses generated by volcanic centers such as Labeatis Mons, the largest volcanic construct in the study area, have influenced the morphology of several Early Hesperian fault sets. The localized influence of Labeatis Mons produced a set of concentric faults (H2), and caused regional sets to be curved or deflected around the volcanic center (Figure 2).

Structural inheritance has also likely impacted the manifestation of faulting within Tempe Terra. Pre-existing structures from earlier phases of deformation are known to exert major control on the development of later fault sets in rifting scenarios [e.g., 8]. The repetition of fault trends, and therefore stress orientations, in Tempe Terra through time indicates that, in addition to the presence of a deep, ancient, and long-lived tectonic fabric in this region of Mars, there has been substantial potential for the reactivation of fault sets throughout the area.

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