STRIKE-SLIP FAULTING AND THE TECTONIC EVOLUTION OF MARS. Jeffrey C. Andrews-Hanna[1] and Maria T. Zuber[1] ([1]Department of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139-4307, jhanna@mit.edu)

Introduction: The tectonic and geodynamic evolution of Mars has been dominated by the formation of the Tharsis volcanic rise. Inversion of the gravity and topography demonstrated that the radial graben surrounding Tharsis are best explained by the stresses generated by membrane-flexural support of the rise [1,2]. However, the presence of an additional global horizontally compressive stress field driven by the contraction of the planet must be invoked to explain the superimposed wrinkle ridges concentric to the rise [3,4]. Furthermore, there is growing evidence for strike-slip faults on Mars [5-7], but their locations conflict with the predictions of the loading models. We consider the tectonic evolution of Mars under the combined influence of both the Tharsis loading-induced stresses and an assumed contractional stress field, leading to predictions of widespread strike-slip faulting, depending on the stress balance. We present evidence for a new set of ancient strike-slip faults, and compare the model predictions with both the previously documented and newly identified faults.

Modeling: The loading stresses in the crust are calculated using the model of [8]. The predicted style of tectonism is based on the orientations of the principle stress directions, neglecting the threshold stress required to initiate faulting [9]. The effects of global contraction are represented by adding uniform horizontal compressive stresses of successively increasing magnitude to the loading-induced stresses, until a globally compressional stress state is achieved. The increase in the horizontal compressive stress changes the balance between the principle stress directions, pushing regions originally predicted to have experienced normal faulting into first the strike-slip faulting and finally the thrust faulting regime (Figure 1). The predicted style of faulting when both loading and contractional stresses are considered differs greatly from that based on the loading stresses alone, with widespread areas existing within the strike-slip faulting regime for part of their tectonic history.

Tectonic Evidence: As a transitional state between extensional and compressional tectonism, the distribution of strike-slip faults at a given stage in Mars history is a strong diagnostic of the global stress state at that time. Potential strike-slip faults can be identified on the basis of their orientation relative to the paleo-principal stress directions indicated by nearby wrinkle ridges and graben, the nearly linear surface trace required to accommodate lateral motion, the asymmetric vertical throw across the fault resulting in leading quadrant uplift [7], or by the lateral offset.

A group of strike-slip faults were previously identified in the region northwest of Tharsis on the basis of their orientation, linear trace, and asymmetric vertical throw [6,7]. These faults were interpreted as having formed in the Early Amazonian, though we suggest that the onset of faulting may have occurred earlier. The location of these faults coincides with a region of predicted extensional tectonism by the simple loading model.

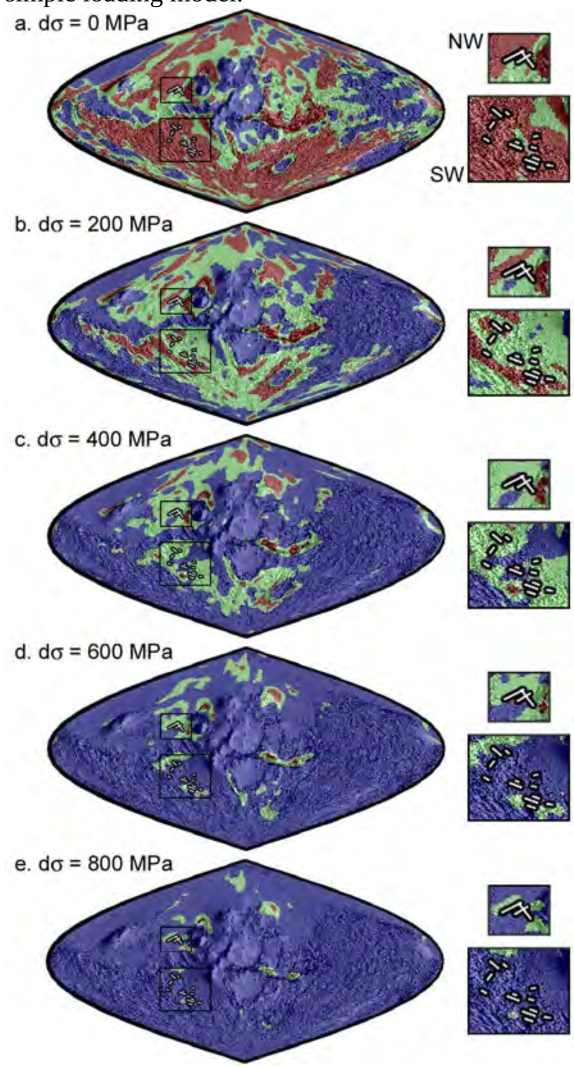

Figure 1. Predicted style of tectonism as a result of the superposition of loading stresses and contractional stresses of magnitude dσ (blue = compressional; green = strike-slip; red = extensional) in sinusoidal projection with superimposed MOLA shaded relief. Locations of strike-slip faults identified by [6,7] (NW) and in this study (SW) are shown.

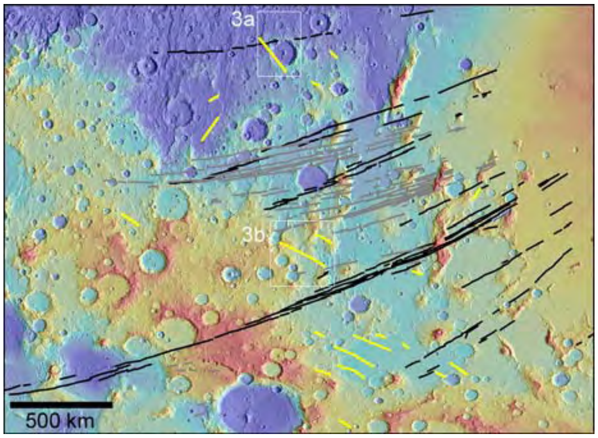

Figure 2. Distribution of strike-slip faults (yellow) and stages 1 (gray) and 3 (black) graben southwest of Tharsis.

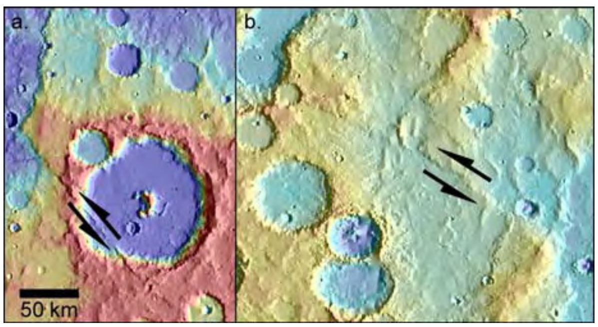

Figure 3. MOLA topographic shaded relief map of (a) a large strike-slip fault intersecting a crater and (b) a fault showing asymmetric vertical uplift.

Based on the criteria outlined above, we have identified a population of potential strike-slip faults southwest of Tharsis (Figure 2). One candidate strike-slip fault was identified as a 200-km-long linear scarp with positive relief (Figure 3a). The fault is at nearly a 30˚ angle from the stage 1 graben [10], and crosses one of the stage 3 graben without offsetting it, suggesting formation during stage 1 tectonism in the Noachian. The rim of a crater intersected by the fault is offset by 5-7 km, consistent with the displacement predicted by terrestrial displacement to length ratios [11]. A similar offset is also observed in a low ridge of friable material cut by the fault. Other faults in the population appear to have formed during stage 3 tectonism in the Hesperian. Further south, another potential strike-slip fault with a length of 180 km exhibits asymmetric vertical throw across the fault, with a leading quadrant uplift of approximately 200 to 400 m (Figure 3b).

Discussion: Comparison of the locations and ages of the strike-slip faults with the model results provides us with snapshots of the global stress field at two distinct times in Mars history. If we assume the majority of the loading stresses were in place by the end of the Noachian, we can make a quantitative estimate of the accumulated global contractional stress at the time of strike-slip faulting. The southwest strike-slip faults require addition of contractional stresses of between 200 and 500 MPa in the Late Noachian to Early Hesperian, while the localization of faulting northwest of Tharsis during the Late Hesperian to Early Amazonian requires contractional stresses between 500 and 700 MPa (Figure 1). These stresses can be converted to strains, giving values of 1.5 to 3.8×10^{-3} and 3.8 to 5.3×10^{-3}, for the older and younger faults respectively, in agreement with the inferred global strain across the wrinkle ridges of several $\times10^{-3}$ [4]. Thus, the termination of strike-slip faulting southwest of Tharsis in the Early Hesperian, while strike-slip faulting continued northwest of Tharsis into the Early Amazonian suggests the growth of global contractional stresses during this time.

The above constraints on the contractional history of Mars can be compared with theoretical estimates. Models of the thermal evolution of Mars [12] allow us to calculate the global contractional strain as a result of secular cooling to be ~4 and 7 $\times10^{-4}$ in the Late Noachian to Early Hesperian and Late Hesperian to Early Amazonian, respectively. The estimated contractional strains from the strike-slip faults suggest the requirement of an additional source of contraction. Possible candidates include rapid early cooling of an initially hot Mars, volcanic outpouring during Tharsis formation, early growth of a solid inner core, phase changes within the mantle during cooling, or enhanced convective heat loss in a wet mantle.

Through a combination of tectonic mapping and geodynamic modeling, strike-slip faults allow us to place quantitative constraints on the stress and strain history of Mars. Future work will refine the tectonic history by considering the timing and stress requirements of individual faults within these populations. The resulting constraints on the contractional history of Mars will shed light on the geodynamic evolution of the planet.

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