

**THE FORMATION MECHANISM OF THE SOUTH THARSIS RIDGE BELT, MARS.** E. Karasoz<sup>1</sup>, J. C. Andrews-Hanna<sup>1</sup>, J. M. Dohm<sup>2</sup>, and R. C. Anderson<sup>3</sup>, <sup>1</sup>Department of Geophysics, Colorado School of Mines, Golden, CO, ekarasoz@mines.edu, jcahanna@mines.edu, <sup>2</sup>Department of Hydrology and Water Resources, University of Arizona, Tuscon, <sup>3</sup>Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA.

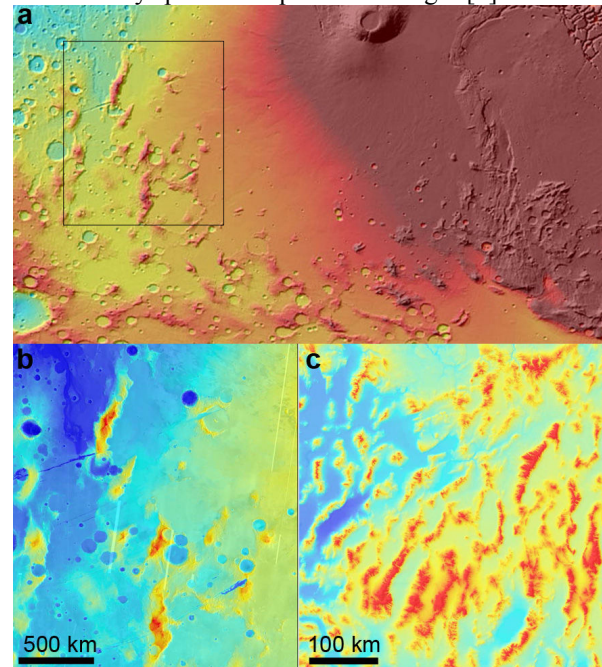
**Introduction:** The South Tharsis Ridge Belt (STRB) partially surrounds Tharsis in an arc around the southwest part of the rise (Figure 1a,b). The ridge belt consists of 29 large ridges [1] separated by distances up to 110 km, with average relief of 1.6 km above the surrounding plains. The STRB is among the oldest tectonic features associated with Tharsis, and thus may provide key information on its early evolution and the ancient tectonic history of Mars.

Detailed photogeologic mapping of the STRB was carried out by Schultz and Tanaka [1], who concluded that the ridges formed by combination of a buckling instability and thrust faulting. This conclusion was supported by the periodic spacing of the ridges and geomorphic characteristics consistent with thrust faulting. However, here we note that the STRB bears a striking resemblance to the Basin and Range province of the western US, highlighted in Terra Sirenum (see *Anderson et al.*, this edition), and thus may be an extensional tectonic province. Here, we evaluate both extensional and compressional hypotheses for the origin of the ridges using evidence from topographic profiles, deformed craters, boundary element modeling, and crustal thickness models. Though no one model explains all aspects of the ridges, the topography of the ridges and crustal thinning associated with the belt support an extensional origin. This has significant implications for the incipient development of Tharsis and possibly pre-Tharsis phases of Mars' evolution.

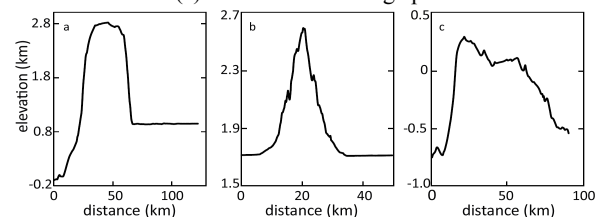
**Regional tectonic geomorphology.** When the shape, size and separation of the ridges are considered, STRB resembles the Basin and Range (BR) province (Figure 1c), both of which are characterized by series of parallel mountain ranges separated by broad valleys. The BR ridges are bounded by listric normal faults that, together with ductile deformation of the lower crust, accommodate regional extensional strain of 250% [2]. This geomorphologic similarity makes BR a strong analogue to test the extensional origin.

For a compressional analog for the STRB, Amenthes Rupes (AR) is selected as a well-defined lobate scarp. AR is also a large quasi-linear ridge of high relief. However, unlike both the STRB and BR, lobate scarps are not observed to occur in populations with regular spacing between the ridges. It has been suggested that surface-breaking thrust faults combined

with a buckling instability may generate a population of uniformly spaced compressional ridges [1].



**Figure 1.** Topographic maps of (a,b) the South Tharsis Ridge Belt on Mars and (c) the Basin and Range province on Earth.

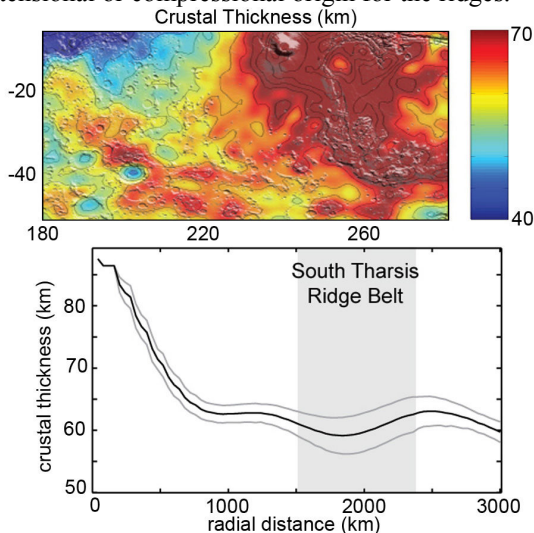


**Figure 2.** Profiles of ridges in the (a) South Tharsis Ridge Belt, (b) Basin and Range, (c) Amenthes Rupes.

**Topographic profiles.** We first examined topographic profiles of the ridges for comparison with both the Basin and Range ridges and lobate scarps as analogs. Topographic profiles of the STRB ridges are characterized by symmetric slopes on either side of the ridges, with an average value of 0.14 (Figure 2a). The ridges commonly exhibit an elevation difference from one side of the ridge to the other, likely a result of the accumulation of lava on the Tharsis-facing side. Another important characteristic is the flattened tops of the ridges. Taken together, the steep symmetric slopes and flat tops suggest that the ridges are bound by symmetric faults on either side. Topographic profiles of BR show crested tops, and their slopes are

symmetric with a value of 0.14 (Figure 2b). The crested tops appear to be the result of fluvial erosion of the ranges. In contrast, topographic profiles of AR (Figure 2c) differ significantly from STRB and BR. Average values for the front and back slopes are 0.13 and 0.04, respectively, which shows a strong asymmetry, with only the steeper slope corresponding to a fault scarp. Tectonic modeling suggests that STRB ridges are bound by fault scarps on both sides to generate the observed symmetric scarps. If these ridges are formed by thrust faulting, then the two faults would cross-cut each other at depth unless the faults exhibit steep dips, close to or exceeding the thrust fault lockup angle of  $60^\circ$  for a friction coefficient of 0.6 [3].

**Craters.** The STRB contains many impact craters that can help resolve the strain history of the region. Departures from circularity may be used as indicators of the sense and magnitude of the strain [4]. However, when the aspect ratios of these craters are considered, craters are observed that are both elongated and shortened in the direction orthogonal to the ridges. Elongation and/or shortening of the craters may suggest that this region has undergone several different tectonic regimes, but do not clearly favor either an extensional or compressional origin for the ridges.



**Figure 3.** Crustal thickness of STRB and average profile.

**Crustal thickness.** Crustal thickness models [5] indicate that the crust comprising the STRB is thinner than that in the highlands to the west by  $\sim 5$  km (Figure 3). This thinning of the crust is indicative of extensional deformation, suggesting an extensional strain of  $-0.10$ . For comparison, the horizontal tectonic deformation for each ridge and the province as a whole is calculated. The strains calculated for normal faulting are in the range of  $-0.0016$  to  $-0.0006$  for fault dips ranging from  $45^\circ$  to  $70^\circ$ , respectively. In order to accommodate a strain of  $-0.10$ , exceedingly gentle

fault dips are needed ( $<5^\circ$ ). This dip is less than the observed average dips of the scarps bounding the ridges. This suggests that the amount of strain is underestimated if only faulting is considered, and some additional mode of extension is required. This is consistent with the BR where the extension of the lithosphere by  $\sim 250\%$  greatly exceeds the strain that would be calculated based on ridges bound by normal faults with typical dips.

**Discussion.** The presence of old structures and highly deformed craters suggest that STRB was formed during the incipient stages of Tharsis development and perhaps earlier, as in Terra Sirenum there are structures and structurally-controlled basins that may be independent of the ridge-belt system (see *Anderson et al.*, this edition). The region may have undergone different tectonic regimes, including both extension and compression. This is supported by the complex tectonic record, including the Noachian-aged STRB circumferential to Tharsis, Noachian-Hesperian-aged graben radial to Tharsis, and Hesperian wrinkle ridges circumferential to Tharsis [6]. The orientation of the STRB indicates that the most tensile principal stress direction at the time was radial to Tharsis, and thus orthogonal to the tensile hoop stresses that arose later from the membrane-flexural support of the rise. One possible mechanism for generating radial tensile stresses is through flexural uplift above a plume head during the earliest stages of Tharsis development. However, flexure alone is insufficient to drive extension of the lithosphere by 10%. It may be that additional extension could arise in response to tractions on the base of the lithosphere from the mantle. These large strains are indicative of a partially mobile lithosphere early in Mars' history.

In summary, when considering the shape, size, spacing, and symmetry of the ridges, the Basin and Range is the best analogue for the STRB, arguing for an extensional origin. The symmetry in the topographic profiles does not resemble compressional features, which are distinctly asymmetric. Crustal thinning in the region is significant since it strongly favors the extensional origin. If the South Tharsis Ridge Belt did indeed form through basin and range-style extension, it would have significant implications for the early stages of Tharsis evolution and perhaps a more ancient phase of Mars evolution.

**References:** [1] Schultz R. A. and Tanaka K. L. (1994) *JGR*, 99, 8371-8385. [2] Zoback M. L. et al., (1981) *Phil. Trans. R. Soc. Lond.*, 300, 407-434. [3] Scholz C. H. (2002) *Cambridge University Press*. [4] Tanaka, K. L. and Golombek M. P. (1994) *LPS XXV*, p. 1377-1378. [5] Neumann G. A. et al. (2008) *LPS XXXIX*, Abstract #2167. [6] Anderson, R. C., et al., (2001) *JGR* 106, 20563-20585.