Introduction: The quantification of lithospheric dynamics on Mars is of fundamental importance to the understanding of Martian geologic history and surface morphology. The global stress field associated with gravitational potential energy differences (GPE) constitutes a significant fraction of the total stress field. In [1], we discuss deviatoric stress fields obtained based on MOLA topography and crustal thickness from [2] and [3] respectively for viscous rheologies. Given that flexure is important on Mars [4, 1], solutions for elastic rheologies are likely to be more important. We use a finite-element thin sheet approach to solve the full 3-D force-balance equations for vertically integrated deviatoric stress magnitudes and orientations within the lithosphere associated with horizontal gradients in GPE for elastic rheologies. We assume \( \rho_{\text{crust}} = 2900 \text{ kg.m}^{-3} \), \( \rho_{\text{mantle}} = 3500 \text{ kg.m}^{-3} \), \( g = 3.7 \text{ m.s}^{-2} \) and various elastic thickness. Our stress solutions depend on the rheology only through the ratio of shear and bulk moduli. The associated strain depends also on the shear moduli for the Martian crust and mantle. Our solutions depend on the elastic thickness. We use a reference elastic thickness of \( \approx 92.84 \text{ km} \), a value which was defined in [1] as the maximum depth of the crust derived from the topography and crustal thickness from [2] and [3].

Lithospheric Stress Models: To first order, the elastic stress solutions do not differ from the viscous stress solutions [1] and are consistent with a tectonically inactive region relaxing due to the excess and deficit of mass. Thus, topographic highs e.g., Tharsis Mons, Olympus Mons, and Alba Patera, are in deviatoric extension, while topographic lows e.g., Valles Marineras and impact basins, are in deviatoric compression. Furthermore, short wavelength features are regionally supported and, for example, several lowlands e.g., Isidis and Argyre Planitae, are in deviatoric extension.

We explore elastic rheologies with varying Poisson’s ratio and varying shear moduli for the Martian crust and mantle. Varying the Poisson’s ratio from 1/3 to 1/5 produces small changes in magnitude, but not style, of stress and strain. Varying the elastic thickness, produces changes in both the magnitude and style of stress and strain; with increasing depth, stress magnitudes slightly increase, while strain magnitudes quickly decrease. Fig. 1B-1E show the stress and strain solutions for the Tharsis region from Fig. 1A for elastic rheology with Poisson’s ratio of 1/3, \( \mu_{\text{crust}} = 4 \times 10^{10} \text{ Pa} \) and \( \mu_{\text{mantle}} = 8 \times 10^{10} \text{ Pa} \), for elastic thicknesses of 0.5 and 3 times the reference elastic thickness (note the differences in the scales).

Comparison With Surface Features: Fig. 1A shows a structural map and digital elevation model of the Tharsis region from [5]. The major tectonic features are narrow planetary grabens (in brown), wrinkle ridges (in red), and a compressive peripheral belt (in blue). Grabens tend to radiate out from the central Tharsis region as well as the Olympus Mons and Alba Patera. The formation of such features requires extensional stresses circumferential to Tharsis, in agreement with our deviatoric lithospheric strain fields (Fig 1D-1E). However, a lesser fit is obtained for the graben structures around Alba Patera where the stress field becomes compressional at the northernmost extent of these grabens. Increased elastic thickness predicts increased length of these graben features, especially northeast of Alba Patera. However, increased elastic thickness changes the style of strain in the southern part of Tharsis where, in addition to the circumferential extension, a large component of radial compression appears in regions consistent with the location of the compressive belt structures.

The formation of wrinkle ridges is largely debated [6, 7] but they require horizontal shortening. For the wrinkle ridges in Fig. 1A, our fit for the structures in Lunae Planum is slightly improved from the viscous solutions of [1] and nonexistent for those in Solis, Melas, and Felis Dorsa. However, calculations of [4] show the importance of flexural loading to the stress field in the region, which provides compression at higher elevations on Tharsis that may explain some of these wrinkle ridges.

Figure 1. (A) Structural map of the Tharsis region. Extensional grabens are shown in brown, compressive wrinkle ridges in red, and the compressive peripheral belt is in blue [5]. Horizontal deviatoric stresses for elastic rheology with Poisson’s ratio of 1/3 and elastic thickness of (B) 0.5 and (C) 3.0 times the reference elastic thickness. Strain associated with (D) stresses from (B), and (E) stresses from (C) for $\mu_{\text{crust}} = 4 \times 10^{10}$ Pa and $\mu_{\text{mantle}} = 8 \times 10^{10}$ Pa (note the differences in scales).