TECTONIC STRESSES ASSOCIATED WITH MANTLE CONVECTION ON VENUS. P. B. James[1,2], [1]Baylor University Department of Geosciences, One Bear Place #97354, Waco, TX 76798, USA (P_James@baylor.edu); [2]The Lunar and Planetary Institute, USRA, Houston, TX 77058, USA.

Introduction: The surface of Venus is scarred by many generations of faulting, with both tensile and compressional structures [1]. Of particular interest are wrinkle ridges and other contractional structures observed in Venus' low-lying plains. Since a number of these low-lying regions are thought to coincide with mantle downwellings, there has long been a qualitative expectation that the inward and downward flow of the mantle under these plains would produce tractions at the base of the lithosphere, and that these tractions may meaningfully contribute to the stress environment that produces these tectonic features (e.g., [2]). In this work, I investigate the stresses produced by previously published patterns in mantle flow.

Method: Dynamic flow kernels may be calculated for a viscous sphere using a propagator matrix calculation [3], and a comparison of these flow patterns to the observed geoid and topography on Venus yields an inferred pattern of mantle flow [4,5]. This mathematical approach also yields information about stresses in the lithosphere, although this information is under-utilized in the planetary geophysics literature.

Under the assumption of a thin lithosphere (valid if the lithosphere thickness T is less than about one tenth the planetary radius R), basal tractions calculated from dynamic flow kernels can be treated as a tangential load vector $\mathbf{q}_T$ within the lithosphere. If this vector field is consoidal (a fancy name for a poloidal field of tangential vectors on a sphere), it may be represented as the gradient of a scalar potential function Ω on a sphere:

$$\mathbf{q}_T = -\nabla\Omega \qquad (1)$$

This quantity can be calculated from published estimates of mantle mass loads (e.g., Fig. 11 of [5]). The mathematical representation of stresses associated with variations in crustal thickness is quite similar: lithostatic stresses are larger within regions of thick crust than thin crust, so stresses are required to support isostatic variations in crustal thickness. This translates to tensile stresses within crustal rises and compressional stresses in regions of thin crust.

The full stress tensor may be calculated from these scalar potential functions for mantle tractions and crustal thickness variations (see Appendix A of [6]). For this work, we only consider membrane stresses and ignore bending stresses. This is appropriate if $l^4T^2 \ll 12R^2$, and it implies that stresses are distributed uniformly throughout the lithosphere. We further consider the "von Mises stress" σ_v, which approximately represents the yield strength that would be needed to withstand the given stress state:

$$\sigma_v = \sqrt{\tfrac{1}{2}[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2]} \qquad (2)$$

where σ_1, σ_2, and σ_3 are the principal stresses. Von Mises stresses for Atalanta Planitia (60ºN, 160ºE) are plotted as a function of lithosphere thickness T in Fig. 1.

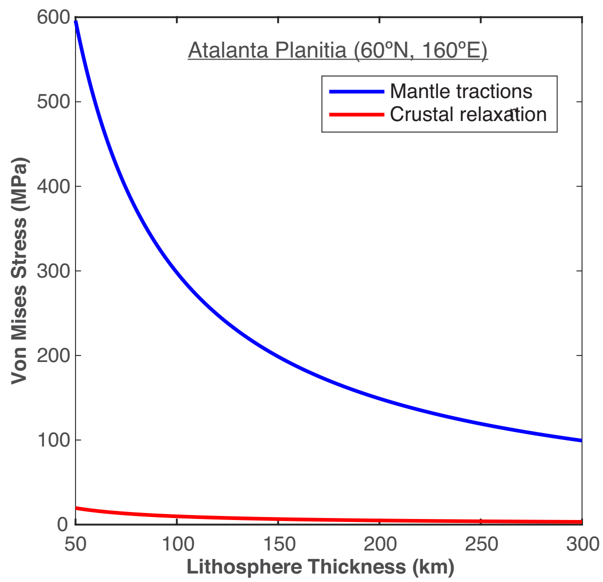

Figure 1 – von Mises stress as a function of lithosphere thickness, T, for mantle tractions (blue) and crustal thickness variations (red).

Results: As shown in Fig. 1, there is an inversely proportional relationship between lithosphere thickness and stress amplitudes. The most compressive non-lithostatic principal stress (σ_3) is plotted in Fig. 2 for crustal thickness variations and in Fig. 3 for mantle tractions. Contour lines in these plots denote 2-km intervals in topography. The vast majority of terrains below zero elevation are associated with some amount of compressive stress from crustal relaxation, and few terrains above zero elevation have any compressive stress beyond lithostatic stress. The stresses resulting from mantle tractions (Fig. 3) largely coincide with those produced by crustal relaxation but are nearly an order of magnitude larger, with peak stresses of up to –260 MPa for a 100-km lithosphere.

Discussion: In order to properly understand the results, it is necessary to consider the meaning of the lithosphere thickness T. The mathematical representation used here suggests that the lithosphere is unbroken and that stresses are constant with depth, but we know that this is not the case on Venus. Brittle yielding likely follows Byerlee's Law near the surface, and ductile flow preferentially relieves stress at depth. The resulting yield strength envelope may result in more stress toward the middle of the lithosphere, perhaps even with a jelly sandwich structure if a weak lower crust exists. In order to compare a more complex rheological profile to a mathematical representation, the appropriate comparison metric is the integral of stress with depth.

If the entire lithosphere yields and produces displacements along a fault zone, this will relieve regional stresses to an extent (e.g., [7]). In this case, stresses from mantle tractions presented here will over-estimate the true tectonic stresses felt on Venus. However, surface strains on Venus are likely small relative to mantle velocities [8], so a no-slip surface boundary condition is almost certainly a more appropriate approximation of the stress state on Venus than a free-slip boundary condition.

References: [1] Byrne P. K. et al., *LPS 49*, this mtg. [2] Leftwich, T. E. et al. (1999) JGR-Planets, 104, 8441–8462. [3] Hager, B. H. and O'Connell R. J. (1981) *JGR*, *86*, 4843–4867. [4] Herrick R. R. and Phillips R. J. (1992) *JGR*, *97*, 16,017–16,034. [5] James P. B. et al. (2013) *JGR-Planets*, *118*, 859–875. [6] Banerdt W. B. (1986) *JGR*, *91*, 403–419. [7] Stein R. S. (1999) *Nature*, *409*, 605–609. [8] Grimm R. E. (1994) *JGR*, *99*, 23,163–23,171.

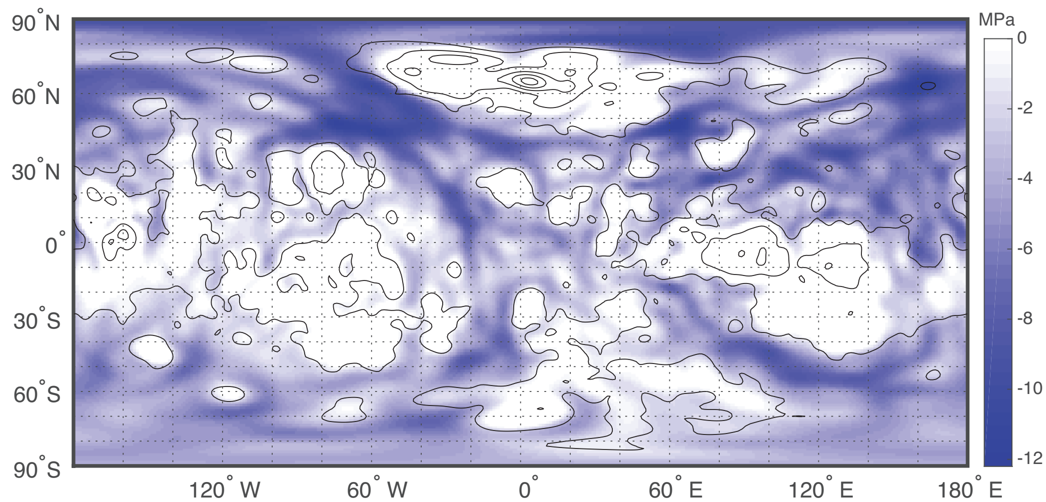

Figure 2 – Magnitude of σ_3 (the most compressive non-lithostatic stress) resulting from lateral variations in crustal thickness. Topography contours with an interval of 2 km are overlaid.

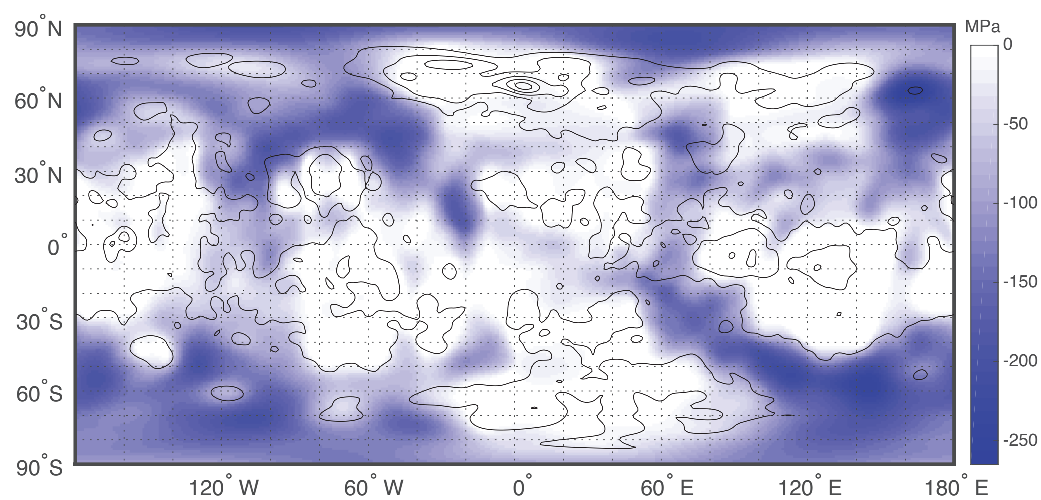

Figure 3 – Magnitude of σ_3 resulting from basal tractions associated with the mantle flow quantified in [5]. Topography contours with an interval of 2 km are overlaid.