THE INFLUENCE OF LITHOSPHERIC FLEXURE AND VOLCANO SHAPE ON MAGMA ASCENT AT LARGE VOLCANOES ON VENUS. M. E. Rumpf[1] and P. J. McGovern[2], [1]Department of Geology, State University of New York at Buffalo, Buffalo, NY 14261, USA (rumpf@buffalo.edu), [2]Lunar and Planetary Institute, 3600 Bay Area Blvd., Houston, TX, 77058, USA (mcgovern@lpi.usra.edu).

Introduction: Volcanoes on Venus are believed to be formed in the same manner as terrestrial hot spot volcanoes. A variety of volcano edifice shapes exists ranging from conical to those with domical shapes or wide plateau tops [1,2]. Beyond this spectrum exists a class of features called coronae: structures characterized by annular topography and tectonics [3]. The origin of coronae is controversial; however, many have lava flows originating from their topographic rises, suggesting a volcanic constructional origin.

Flexural stresses induced by volcano loading can exert a strong influence on the ascent of magma through the lithosphere [4]; the local lithospheric thickness controls the stress state and therefore may influence growth and subsequent morphology of volcanoes. Here we study these effects beneath large volcanic edifices using analytic flexure modeling. The stress states are used to determine the regions near a volcano where magma would preferentially ascend thus predicting growth patterns and volcano shape. Theoretical magma ascent patterns are then compared to several Venusian volcanoes using synthetic aperture radar images and altimetry data collected from the Magellan mission [5] to yield insights to their origin.

Models: We calculate deflections and stresses due to volcanic loading on the lithosphere using the elastic "thick-plate" analytic flexure solution of Comer [6], in axisymmetric geometry. The shape of a volcanic edifice is broken down into a series of harmonics via the Hankel transform (the axisymmetric equivalent of the Fourier transform), and the flexural responses from each harmonic are superposed to get the final solution. We considered three edifice shapes, starting with a cone. A truncated (flat-topped cone) was generated via subtraction of a small cone from a large one, and a further subtraction generated an annular edifice that resembles Venusian coronae.

Volcanic loads of varying shape, height, and radius were applied to the lithosphere. We assumed crustal and volcano densities of 2800 kg/m^3 and a mantle density of 3300 kg/m^3. The response of the lithosphere to a load is controlled by the thickness of the elastic layer, T_e, which was assigned values ranging from 5 to 50 km. The code calculates the radial normal stress σ_{rr} and the tangential or "hoop" normal stress $\sigma_{\theta\theta}$ in the horizontal plane. For a given edifice, deflections and stresses were calculated as functions of radius from the axis of symmetry and of depth within the plate [6].

Volcano growth simulations were conducted using incremental self-similar (constant slope) growth scenarios. In most cases, the flexural depression was assumed to be filled with a material of the same density as that of the volcano. For some models, this assumption was not made and the infill height was considered when setting the height of the volcano.

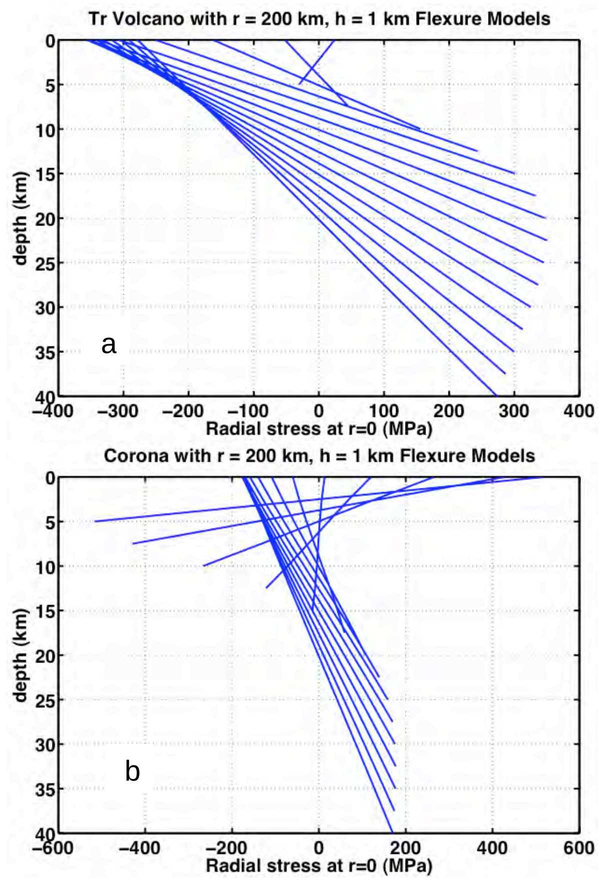

Figure 1. Radial stress as a function of depth at center of edifice due to flexure from a volcanic load of radius 200 km and height 1 km. Lines represent elastic thickness increments in 2.5 kilometer steps. Represents stresses due to (a) truncated cone edifice; (b) corona.

Magma Ascent: Volcanoes grow by transport of molten rock (magma) from an anomalously warm region in the mantle (hotspot) to the surface. The state of stress in the lithosphere controls the ability of magma to ascend through vertical intrusions (dikes) in two ways. First, dikes tend to form perpendicular to the least compressive principal stress [7]. Thus, horizontal extensional stress (by convention, positive in sign) is necessary for magma ascent. Second, a positive stress gradient $d\sigma/dz$ is needed to force magma upwards through the lithosphere into the edifice [8,9]. In reality, buoyancy and excess magma pressure forces allow magma with slightly negative values of stress or stress gradient to ascend [8]; we set our magma ascent criteria accordingly. There are two horizontal stress components, radial σ_{rr} and hoop $\sigma_{\theta\theta}$, so the stress orientation and stress gradient ascent criteria must be evaluated for each. Horizontal intrusions (sills) are not accounted for. Stresses in the edifice load are not modeled; the stress state at the top of the lithosphere is considered to apply throughout the edifice [4].

Results: Fig. 1 shows σ_{rr} at the center of the edifice as a function of depth for T_e between 5 and 40 kilometers. Over this entire range, conical volcanoes show large negative stress gradients and compressive stresses at the top of the lithosphere. Such stresses would halt magma flow into the edifice. For a truncated cone, the stresses and gradients are similar except for low T_e: stresses are low for T_e = 10 km, and at T_e = 5 km the gradient switches sign such that the least compressional stress moves from the bottom to the top of the lithosphere (Fig. 1a). Here extensional stresses can fracture the edifice, creating paths for dike intrusion. This effect is found over a wider range of T_e (up to 15 km) for coronae (Fig. 1b).

Conical features returned negative stress gradients and compressive stresses near the top of the lithosphere for low T_e. At high elastic thicknesses (T_e > 40 km) magma ascent criteria are met over a wide radius range that includes the center of the edifice, which would tend to maintain the conical shape. For a truncated cones, however, shutoff of magma ascent near the center would be required to reinforce the shape: this is observed for intermediate T_e values (around 20 km; Fig. 2a). Corona formation was preferential in thin lithosphere models (T_e < 20 km), for which corona loads produce two restricted zones of magma ascent; one on the inside of the ridge and one on the outside (Fig. 2b). This would tend to maintain the annular ridge shape of the corona.

Discussion: As the self-similar volcanic load at the top of the lithosphere grows, the resulting flexure changes. As the volcano expands radially, the flexural response gets pushed outwards in radius as well. For thin lithospheres, the characteristic wavelength of flexure is so small that the lithosphere beneath the center of a wide volcano can "unflex", relieving the high magnitudes of flexural stresses near the center. This effect is small for conical volcanoes, but significant for truncated cones and even more so for corona shapes. In the latter case, the "unflexing" can lead to "re-flexing" in the opposite sense (concave downward) to that of the cone model, generating the very large positive stress gradients seen in Fig. 1b.

Calculated stress states for Kokyanwuti Mons (a truncated dome volcano) and Aruru Corona are shown in Fig. 2. For both models, areas where ascent criteria are predicted are consistent with lava flows seen in Magellan images. Fracturing is seen in many areas where a high stress state is predicted. A few inconsistencies may be due to circumstances not considered in this study including earlier states of the corona.

Conclusions: Volcano shape appears to be partially determined by the local lithospheric thickness. Thus, analysis of volcano shapes can give insight into the thickness of the lithosphere during periods of individual volcano growth. Combined with interpretation of local geology, this may enable understanding of the regional and thermal evolution of Venus based on the distribution and ages of volcanic features [10].

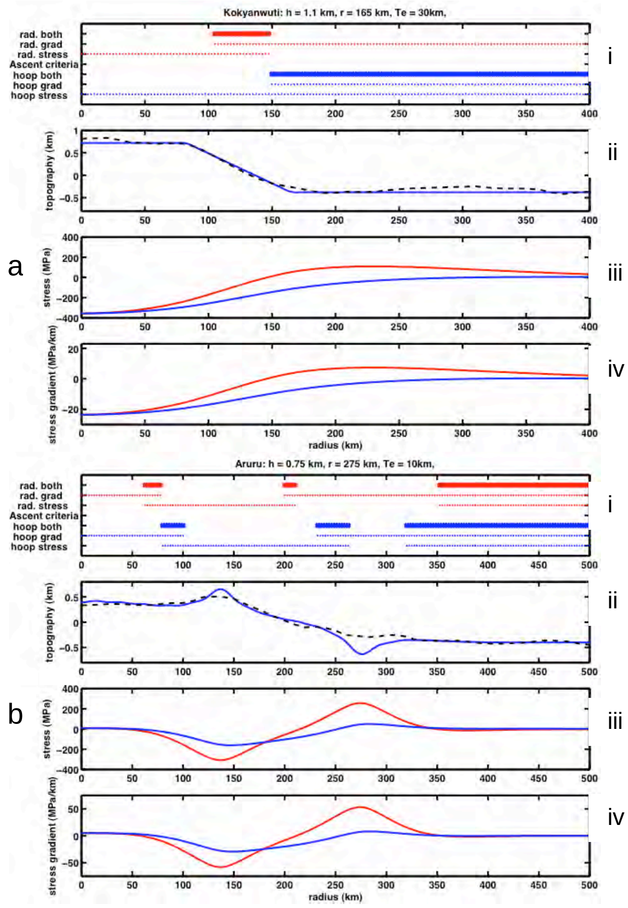

Figure 2. For (a) Kokyanwuti Mons and (b) Aruru Corona, radial and hoop stresses are represented in red and blue, respectively. (i) Dotted lines respectively indicate regions of positive to slightly negative stress gradients and positive to slightly negative stress at the bottom of the lithosphere. Solid lines indicate where both criteria are met. (ii) Dashed line is the circularly averaged topographic profile of the feature and solid line is the model edifice. (iii) Stresses at the top of the lithosphere. Positive stress is considered extensional. (iv) Stress gradient in lithosphere.

References: [1] Head et al., JGR, 97, 13, 153, 1992; [2] R. R. Herrick et al., *JGR*, *110*, doi:10.1029/ 2004JE002283, 1992; [3] E. R. Stofan et al., *JGR*, 97, 13,347, 1992; [4] P. J. McGovern and S. C. Solomon, *JGR*, *103*, 11,071, 1998; [5] Saunders et al., JGR, 97, 13,067, 1992; [6] R. P. Comer, GJRAS, 72, 101, 1983; [7] E. M. Anderson, *Proc. R. Soc. Edinburgh*, *56*, 128, 1936; [8] A. M. Rubin, *Annu. Rev. Earth Planet. Sci.*, *23*, 287, 1995 [9] P. J. McGovern, *LPS XXXVII*, abstract 2459, 2006. [10] P. J. McGovern and M. E. Rumpf, *LPS XXXVIII* (this volume), 2007.