EVALUATING MAGMA ASCENT AT PAVONIS MONS, MARS USING STRESS FROM FLEXURE

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Introduction: Pavonis Mons has a number of concentric volcanotectonic features, such as grabens, collapse pits, and rilles, that surround the flank of the edifice. Many of these features are likely the surface manifestations of buried dikes where the dike hits a buried layer of ice and the volatiles in that layer are volatilized and out-gassed [6]. Pavonis Fossae (Figure 1) is the largest of these concentric features and will be the subject of this abstract. One of the main controls on the location of them is the local stress field, as magma and fractures will want to propagate along the principle axis of least compressive stress, i.e. most tensile. Therefore, where we see tensile stress is where we expect to see these features from on the surface. For Tharsis, specifically Pavonis, the largest control on this stress field comes from lithospheric flexure due to top-loading. The amount the lithosphere bends is controlled by the elastic thickness of the lithosphere (Te), as tensile stresses from the bending of a rigid plate will occur further from the edifice as the thickness increases [7,8].

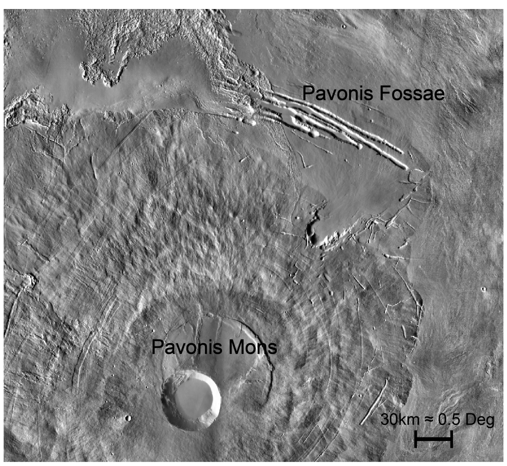

Figure 1: Pavonis Fossae in relation to Pavonis Mons. Figure made using THEMIS data.

Some different spatio-spectral localization studies have used admittance and correlation spectra to constrain the T_e below most of the major features of Mars. Specifically, some have looked at the volcanic edifices of Tharsis, including Pavonis as these volcanoes represent massive loads on the lithosphere and can be used to study the T_e of the lithosphere when the feature formed. In these studies Pavonis has often been the most difficult one to constrain. In [1,2,4] there was not a satisfactory fit for the entire spherical harmonic spectrum and had to be broken up into two ranges. [3] opted to treat this discrepancy as a two-stage loading model, with a stage corresponding with one of the spectrum ranges.

In this abstract we model how flexure from top-loading controls the stress field through the elastic plate and creates favorable pathways for magma to buoyantly ascend and create these volcanotectonic features. Through this modeling we hope to match up the expected location for these features to form and where they actually occur. This will also give us a way to resolve the model fitting discrepancy from admittance modeling and associate different tectonic sets with different growth periods.

Procedure: Our modeling methodology includes loading terms from topography and the density contrast at the moho, utilizing the formulation derived by [9]. For now we just use the special case of lithospheric flexure with a constant shell thickness. In the future we plan to implement the full formulation with a varying shell thickness to more realistically model lithospheric flexure. For local studies, such as this one, the use of the special case formulation is adequate, but for regional and global studies it'll be more robust to utilize a varying shell thickness.

In order to holistically model the flexure expected from Tharsis MOLA data is used for the topography of the volcano and the moho relief is calculated from a gravity inversion, with the algorithm laid out in [10]. For now only the topography from Pavonis is used. This topography is captured using a circular filter in a spherical harmonic representation of the data. We used gravity model GMM3_120 from [5] in our inversion. To solve for the flexure and stress regime expected we solve equations 87 and 88 of [9] for the flexure and equation 73 of the same paper for the stress at a distance ζ from the midplane of the elastic plate. Surface stress is solved for at $\zeta = h/2$ where h is the elastic thickness of the lithosphere. In order to create a stress profile through the lithosphere, ζ was varied from $h/2$ to $-h/2$, reflecting the stress through the midplane and to the bottom of the elastic plate. In essence, a 3D volume of stress was created that we can then slice and analyze. In this treatment of stress, positive is compressive whereas negative is tensile.

Results: From this modeling procedure we take our 3D stress volume mentioned before and slice it to look at stress profiles as we change depth and latitude. We assume that, without the magma stalling out in the subsurface, the magma will reach the surface where we see the least amount of compressive stress (negative in this case). Figure 2 shows a Latitude-depth slice of the $\sigma_{\theta\theta}$ stress through the elastic plate, also known as the hoop stress. Figure 3 shows the same slice except with a T_e of 25km instead of 50km. With a T_e of 25km, that corresponds with a surface location of about 7-10 degrees (413-590 km) away from the edifice. With a T_e of 10km, shown in figure 4, the location is about 4-6 degrees away, corresponding well with Pavonis Fossae. We chose to only show the hoop stress in this abstract but we can just as easily extract the $\sigma_{\phi\phi}$ and $\sigma_{\theta\phi}$ stress using this formulation.

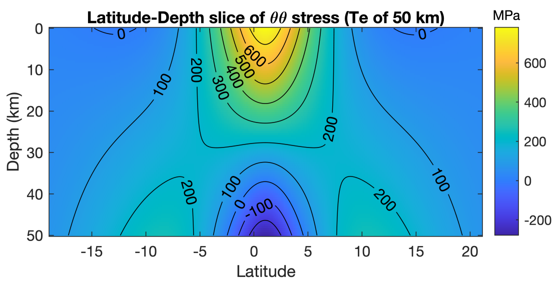

Figure 2: Stress profile through the elastic plate with a T_e of 50km.

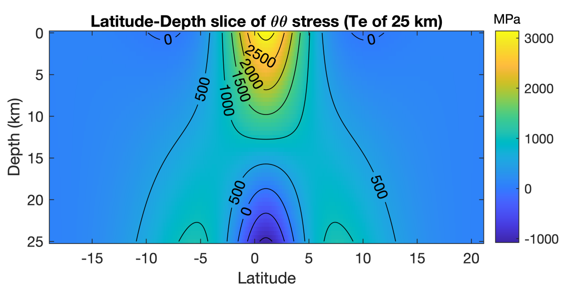

Figure 3: Stress profile through the elastic plate with a T_e of 25km. Note the change in magnitude and location of stresses.

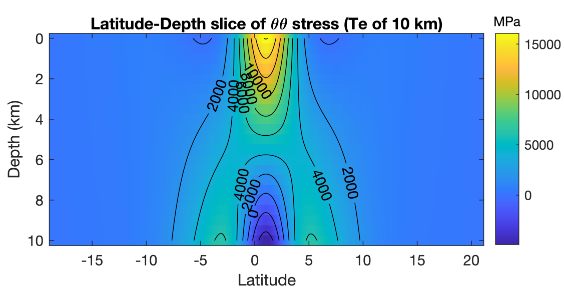

Figure 4: Stress profile through the elastic plate with a T_e of 10km. Note the change in magnitude and location of stresses. This T_e matches up the tensile stresses seen at the surface with where Pavonis Fossae is located.

Discussion: The location of tensile stresses moving away from the edifice as T_e increases points at how most of these volcanotectonic features were likely created when both Pavonis Mons, and Mars as a whole, were much younger. This is because heat flow is the largest control on T_e, and as a planet ages the heat flow decreases, and thus T_e also decreases. One thing to note is that as T_e is smaller, the magma reservoir could theoretically be at a shallower depth and allow for magma ascent. This means that there could be smaller, feeder reservoirs, or large sills, that can initiate ascent.

The shape of these stress profiles favors an upside-down y shaped saddle, with high compressive stress directly underneath the edifice that transitions to tensile stress surrounded by compressive stress. If the magma reservoir was located directly underneath the edifice at the base of the elastic plate then the magma would have to overcome the confining compressive stress as it rises and move off to areas of lower compressive stress.

Future Work: In order to better quantify how we expect magma to ascent in these stress envelopes, we will incorporate a descent-gradient algorithm to figure out where the magma will preferentially propagate. This will be used in conjunction with a buoyancy calculation to make sure that as the magma ascents along the axis of least compressive stress that it won't stall out into a sill. Without inherent buoyancy the stress state will not matter as the magma will stay in place and might only be transported laterally. One concept we will explore is the different locations of potential deep magma reservoirs and shallower magma chambers that could allow for ascent. A similar methodology [8] has been used to evaluate magma ascent on Io.

In this abstract only the topography of Pavonis was considered. In the future this will be expanded to include the topography of all of Tharsis in order to see if the stress state imposed by the other Montes constructively or destructively interferes with the stress state of Pavonis. Further on this approach can be applied to the other Tharsis Montes and Olympus Mons to evaluate the other concentric volcanotectonic features seen. Likely the magmatic plumbing system of the Tharsis Montes complex is interconnected, thus by analyzing the stress state from flexure we can investigate different distributions of magma chambers and scenarios of ascent.

References: [1] M. Ding, et al. *JGR: Planets*, 2019. [2] A. Broquet and M. A. Wieczorek. *JGR: Planets*, 124(8):2054–2086, 2019. [3] M. Beuthe, et al. *JGR: Planets*, 117(E4), 2012. [4] V. Belleguic, et al. *JGR: Planets*, 110(E11), 2005. [5] A. Genova, et al. *Icarus*, 272:228–245, 2016. [6] L. Montési. *Special Paper of the Geological Society of America*, 352:165–181, 2001. [7] P. J. McGovern, et al. *Journal of Geophysical Research E: Planets*, 118(11):2423–2437, 2013. [8] P. J. McGovern, et al. *Icarus*, 272:246–257, 2016. [9] M. Beuthe. *Geophysical Journal International*, 172(2):817–841, 2008. [10] M. Wieczorek and R. Phillips. *Journal of Geophysical Research E: Planets*, 103(E1):1715–1724, 1998.