VENUS: ARE ELASTIC THICKNESSES INFERRED AT CORONAE GLOBALLY REPRESENTATIVE?

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Introduction: Earth's closest planet Venus has been studied at length to help us learn about the diverging evolutionary paths that the two planets took. Features called coronae are potentially key to understanding why Venus does not exhibit plate tectonics. Coronae are officially defined as "quasi-circular features." Named coronae on Venus typically exhibit complex topography and are surrounded by annular ridges of extensional fractures. Despite years of intensive study, their origin remains mysterious. It has been hypothesized that these features form at regions of thin elastic thickness, where widely spaced zones of magma ascent will create the coronae's signature annular ridges [1]. Another hypothesis regarding the formation of coronae is that the sloping flexural signatures found around many of these features are the result of plume-induced subduction. Davaille et al. studied the idea that plumes of hot mantle material rise and produce fractures in the lithosphere through which the molten material then spreads. This upwelling process creates a load on the surface, which leads to lithospheric flexure and eventual subduction of the surface [2]. Other processes such as volcanic loading and/or lithospheric downwelling have also been hypothesized to produce the flexural signatures found around coronae.

The relationship between coronae and other features on Venus and any flexural signatures that may accompany them is an important tool for learning about the mechanisms that shape the surface of the planet. Plate bending models, both broken and continuous, can tell us about more than just the thickness of the lithosphere. We can also use this method to learn about the heat flow and thus the history of Venus' thermal evolution. We aim to understand whether heat flow is particularly high only at coronae, or if the heat flow is globally higher than previously thought on Venus. We intend to answer this question through two methods: 1) exploring correlations between crustal thickness and flexure, and 2) searching for flexure near features such as relatively steep conical edifices that have been proposed to be associated with regions of high elastic thickness.

Previous Work: During the Magellan mission in the early 1990s, scientists completed some of the first comprehensive searches for flexural signatures on Venus [3,4]. Sandwell & Schubert recognized evidence of flexure around Latona Corona and estimated that this area had an elastic thickness of 30 km [3]. Later, Johnson & Sandwell found elastic thicknesses in the range of 12 to 34 km at 17 possible flexure sites [4]. However, these studies were limited because topographic profiles were only extracted parallel to the spacecraft ground track from altimetry data with a resolution of >10 km. Stereo-derived topography has since become available with horizontal resolution improved to ~1–2 km for ~20% of the surface [5].

Evidence for low elastic thicknesses. Recent studies have used modern software tools and stereo-derived topography to examine topographic profiles consistent with lithospheric flexure at an increasing number of features on Venus [6,7]. For example, O'Rourke & Smrekar used topographic profiles of flexural signatures around a variety of coronae along with plate bending models of broken and continuous bending elastic plates to estimate plate thickness and heat flow [6]. Their results showed that the locations of coronae exhibit particularly high heat flow values, but they did not find a difference in plate thickness based on the geologic setting or morphologic type of coronae [6]. Smrekar et al. have continued to build upon this work, exploring even more areas of flexure. By fitting topographic profiles of flexural signatures around over 70 features including coronae and rift belts to an elastic plate bending model, they were able to estimate the elastic thicknesses at these locations. Additionally, they were able to determine the heat flow at all of these locations based on a conversion from elastic to mechanical thicknesses using an assumed rheology for the lithosphere. Elastic thicknesses ranged from ~3 to 30 km, and heat flow ranged from ~21 to 350 mW/m^2 [7]. Interpretation of their data shows that small coronae often form at areas where the lithosphere is thin, and that much of Venus has a high heat flow, contrary to results from stagnant lid models of the planet [7]. Results from research of coronae can have far-reaching applications. Agreement between coronae-derived values and estimates from models of admittance by Anderson & Smrekar indicates that the elastic thicknesses found at coronae may be globally representative rather than due to localized heating [8].

Evidence for high elastic thicknesses. In contrast to results obtained at coronae, some features on Venus have been proposed to signal regions with thick brittle lithosphere. McGovern et al. [1] explored the relationship between lithospheric flexure and the shape of volcanic features on Venus' surface. They used two different magma ascent criteria to explore how three different shapes of features would form. In their models, large conical volcanic edifices most likely form at areas of high elastic thickness, and domical shaped edifices including sets of features labeled "coronae" tend to form at regions of lower elastic thickness. Establishing agreement between local (from modeling topography) and regional (from admittance data) estimates at regions of high elastic thickness would provide robust evidence that the regional estimates are reliable tools with which to infer global patterns of elastic thickness and lithospheric heat flow.

Methods: In this work, we are using established methods, but extending them to new datasets and geologic features. We will further explore crustal thickness rather than elastic thickness, and use flexure models applied to steep edifices in addition to coronae.

Crustal thickness: James et al. determined global crustal thickness values for Venus [9]. They used geoid-to-topography ratios to calculate the values and construct the map [9]. The mean crustal thickness was inferred as ~8-25 km, with a mean value of 15 km used to generate a representative map. We will compare these values to those previously calculated by Anderson and Smrekar, who had found crustal thicknesses ranging from 0 to 90 km [8]. Elastic thicknesses have been determined at 66 coronae that we will also study [6,7]. We first imported the gridded crustal thickness map from James et al. into MATLAB, along with the latitude, longitude, and elastic thickness of each coronae. We then plotted the locations of these 66 coronae onto the crustal thickness map of Venus as red circles which can be seen in Figure 1a. This allows us to gain an understanding of the relationship between coronae and the crustal thickness, to see if they are most likely to form at a particular thickness. Many of the coronae appear to be located in regions with a crustal thickness of 20 km or lower.

We were then able to interpolate the crustal thickness at each of the coronae, allowing us to study both the crustal thickness and elastic thickness for these 66 points. Using this information, we can plot the crustal thicknesses versus the elastic thicknesses to determine if there is a correlation between the two (Figure 1b). This work is ongoing, and we now plan to explore the possibility of correlation further as it could give us new insights into the formation mechanisms of coronae.

Other features: We also intend to search for flexural signatures at features other than coronae. These flexural signatures will appear as the downward sloping shape of the surface bending under a load.

For example, we will investigate regions that are hypothesized by McGovern et al. [1] to have regionally high elastic thickness. These volcanic features should theoretically serve as loads on the surface, and we will investigate this by taking profiles of the topography surrounding them. We will be able to determine if the surrounding topography exhibits signs consistent with flexure by using models of elastic plate bending. Analyzing large conical volcanic edifices and any associated flexural signatures could serve to prove that these features form in regions of high elastic thickness. Studying a variety of features is key to obtaining global constraints on lithospheric properties.

References: [1] McGovern, P. J. et al. (2013), *JGR Planets*, 118, 2423–2437. [2] Davaille, A. et al. (2017), *Nature Geoscience*, 10, 349-355. [3] Sandwell, D. T., & Schubert, G. (1992). *Science*, 257, 766. [4] Johnson, C. L., & Sandwell, D. T., (1994), *Geophysics Journal International*, 119, 627-647. [5] Herrick, R. R. et al. (2012) *EOS*, *93*, 125-136. [6] O'Rourke, J. G., & Smrekar, S. E. (2018), *JGR Planets*, *123*. [7] Smrekar, S. et al. (2019), *VEXAG17 #8035*. [8] Anderson, F. S., & Smrekar, S. E., (2006), *JGR Planets*, 111. [9] James, P. B. et al. (2013), *JGR Planets*, 118, 859–875.

a b

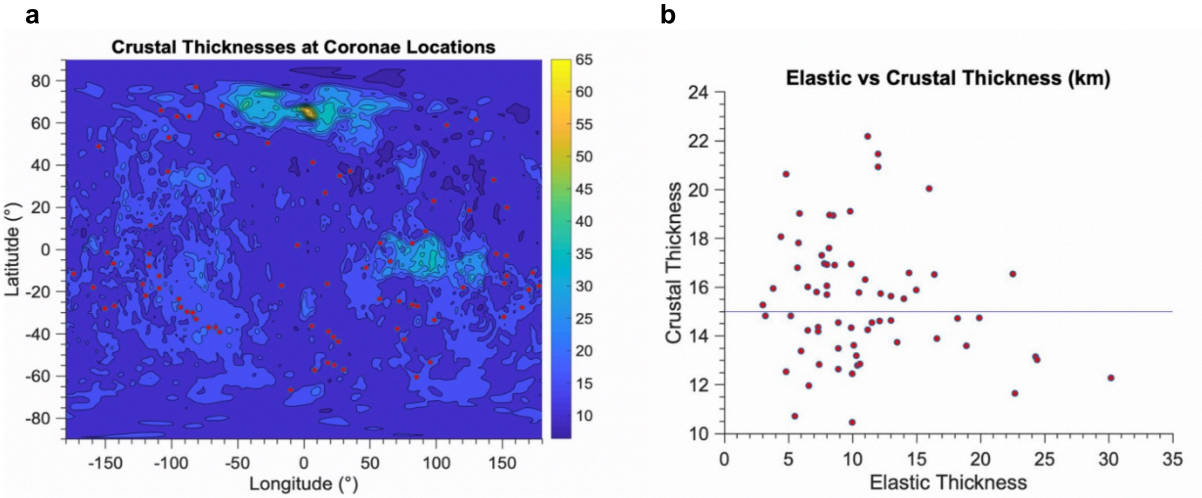

Figure 1: a) Preliminary work suggests that coronae are preferentially located in areas of crustal thickness less than 20 km. The locations of 66 coronae that were previously studied by Smrekar et al. are plotted on the crustal thickness map from James et al. b) Most of the coronae are located at areas of low elastic thickness, as described in Smrekar et al., and we intend to explore whether there is a correlation between crustal and elastic thickness. The blue line indicates the mean crustal thickness (15 km), and one can see that the flexed coronae appear evenly distributed in terms of crustal thickness.