A GLOBAL SURVEY OF LITHOSPHERIC FLEXURE AT PANCAKE DOMES ON VENUS REVEALS INTERMEDIATE ELASTIC THICKNESS.

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Introduction: Volcano shape as seen on the surface can be used to make inferences about planetary interiors that are scientifically key but otherwise very difficult to obtain. Volcanoes act as a vertical load on the surface, causing the lithosphere to bend. We use evidence of lithospheric flexure to learn about the elastic thickness and heat flow at the locations of volcanic features on Venus.

McGovern et al. (2013) [1] used magma ascent criteria to determine the elastic thickness at which different types of volcanic features are expected to form on Venus. They hypothesized that some coronae formed where the elastic thickness is thinnest, less than 10 km. Domical volcanoes are expected to form typically in regions of intermediate elastic thickness (~10 to 40 km). Large conical volcanoes are expected to form usually where the elastic thickness is thickest, over 40 km.
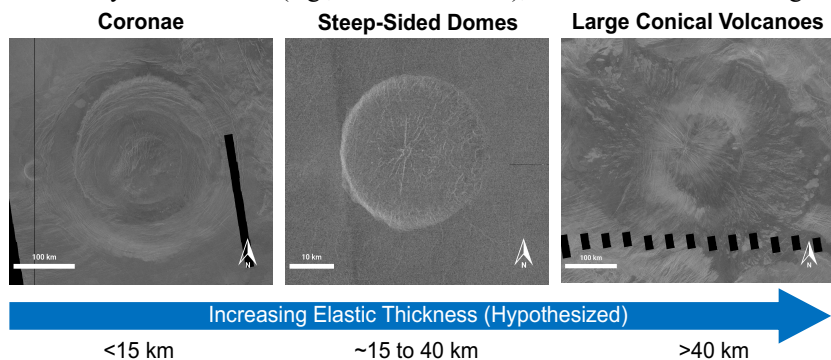
We focused our study on steep-sided domes, also called pancake domes, for which the connection between morphology and elastic thickness was previously untested. Originally, we attempted to infer the elastic thickness at large conical volcanoes. However, the flexural moats necessary for our study are not visible around these features. McGovern et al. (1997) [2] explain that the moats around large conical volcanoes were likely filled in by later lava flows. Others have determined that coronae are indeed often associated with thin lithosphere. For example, O'Rourke and Smrekar (2018) [3] located flexural signatures around coronae using newly available stereo topography. By using plate bending models, they found elastic thicknesses of about 5 to 15 km at most coronae. Smrekar et al. (2019) [4,5] derived elastic thickness at over 70 features including coronae, finding thicknesses ranging from ~3 to 30 km. They also converted elastic to mechanical thicknesses using an assumed rheology of the lithosphere to calculate the heat flow at these locations. Their estimates for heat flow ranged from ~21 to 250 mW/m^2. This study confirmed that many coronae are indeed associated with both thin lithosphere and high heat flow. Thin elastic thickness estimates derived from plate bending models generally agree with regional estimates derived from admittance data.

Methods: We used JMARS to conduct the first global survey of lithospheric flexure around steep-sided dome volcanoes on Venus. We drew topographic profiles at intervals of 45 degrees around 75 steep-sided domes. The profiles were trimmed to begin at the deepest part of the flexural moat and all elevations were normalized to zero. The profiles extended about 800 km into the surrounding area. For domes located within the swaths of stereo-derived topography, we drew our profiles using this dataset. The stereo-derived topography is available for about 20% of the surface and has a horizontal resolution an order of magnitude better than the Global Topographic Data Record (GTDR) collected from the NASA Magellan Mission.

We viewed the topographic profiles in MATLAB to determine which domes showed evidence of flexure. Flexural signatures appear as a moat around the dome, followed by a topographic rise and forebulge, before the topography flattens out. Some profiles were not used because they encountered interfering topography that interfered with our ability to identify flexural signatures. We identified flexural signatures in 29 profiles around 14 steep-sided domes. Using an axisymmetric model along with a curve-fitting algorithm, we calculated the elastic thickness for each profile showing evidence of flexure. A yield stress envelope then converted the elastic thickness to mechanical thickness, allowing us to determine the surface heat flow at each location. We used a Monte Carlo method to calculate uncertainties and to take the average of all profiles around domes for which multiple profiles showed flexural signatures.

Results: *Elastic thickness.* When considering all profiles, we found an average elastic thickness of ~15 km. The results varied significantly based on the domes' proximity to coronae (Figure 2a). For domes near coronae (e.g., within ~800 km), the elastic thickness ranged

Coronae	Steep-Sided Domes	Large Conical Volcanoes

Increasing Elastic Thickness (Hypothesized)

<15 km   ~15 to 40 km   >40 km

Figure 1: How does elastic thickness influence volcano morphology? Images of volcanic features taken in JMARS using SAR imagery from NASA Magellan.

from ~3–14 km. For domes not near coronae, the elastic thickness ranged from ~9–38 km—noticeably distinct.

Surface heat flow. Our derived surface heat flows also varied significantly based on proximity to coronae (Figure 2b). For domes near coronae, the surface heat flows ranged from ~104–279 mW/m^2. For domes not near coronae, the surface heat flows ranged from ~29–109 mW/m^2, with an average of ~57 mW/m^2. This average is close to the predicted global heat flow on Venus according to some thermal evolution models such as Gillman & Tackley (2014) [6].

Conclusions: Our results verified the hypothesis that steep-sided domes are generally associated with regions of elastic thickness ranging from ~10–40 km. The values we infer at present-day represent the minimum thickness of the elastic lithosphere since the load was emplaced. We can thus use the distribution of steep-sided domes to make inferences about the elastic thickness on Venus. Though flexural studies are not always possible given the limited resolution of the available topography, one can use the presence of steep-sided domes to infer that the elastic thickness was likely ~10–40 km near the domes when they formed, although a few domes may form on thinner or thicker lithosphere.

We also provide further evidence that coronae are often associated with thin lithosphere and high surface heat flow. Our elastic thickness estimates are consistent with regional values derived from gravity data [7]. Additionally, we reproduced results by Russell and Johnson [8] for Narina Tholi, a dome on the edge of a corona. Our estimate of ~4 km at this location is similar to Russell and Johnson's estimate of ~2–3 km.

Stereo-derived topography proved to be a valuable tool for this analysis. While this dataset only covers ~20% of the surface, over 40% of the flexural signatures were revealed using the stereo data. Future spacecraft missions to Venus are vital. Better data would enable more precise analyses of a wider range of features. Higher resolution topography and gravity data are urgently needed to reveal different features and allow us to better understand Venus's evolution.

References: [1] McGovern et al. (2013), *JGR Planets*, *118*(11), 2423–2437. [2] McGovern (1997) *JGR Planets*, *102*(E7), 16303–16318. [3] O'Rourke & Smrekar (2018), *JGR Planets*, *123*(2), 369–389 [4] Smrekar et al. (2019), *VEXAG17 #8035*. [5] Smrekar et al. (2021) in prep. [6] Gillmann & Tackley (2014), *JGR Planets*, *119*(6),1189-1217 [7] Anderson & Smrekar (2006), *JGR Planets*, *111*(8), 1–20 [8] Russell & Johnson
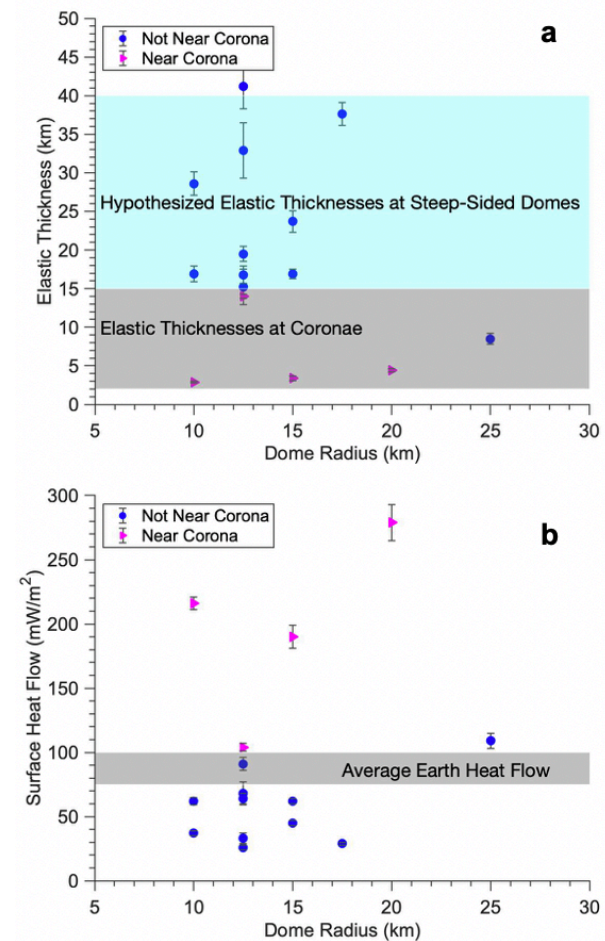
Figure 2: Derived elastic thicknesses (a) and surface heat flows (b) at steep-sided domes on Venus. Domes near coronae have "coronae-like" values. Nearly all other domes have elastic thicknesses ~15–40 km, in agreement with the prior predictions from Figure 1.