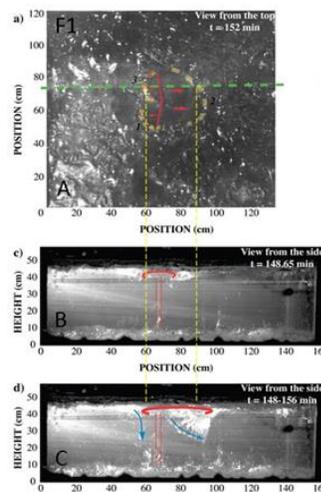


GRAVITY MODELING OF SUBDUCTION ON VENUS. S. M. Tomlinson¹, S. E. Smrekar², and A. Davaille³
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Introduction: Unlike Earth, Venus lacks a global system of plate tectonics; a process directly related to heat loss and likely related to planetary habitability. This makes the factors influencing the initiation of plate tectonics an important study in rocky planet evolution. Given Venus' similarity to Earth in size, composition, and heat production; fundamental questions include: why does Venus lack plate tectonics and how does Venus lose its heat through a single plate? Here we study plume induced subduction, a process which could be related to the early stages of plate tectonics. To do this we study subsurface density variations inferred from modeling gravity and topography data at two corona, Artemis and Quetzalpetlatl to look for similar density variations predicted by recent laboratory experiments (Fig. 1). In these experiments, one sided



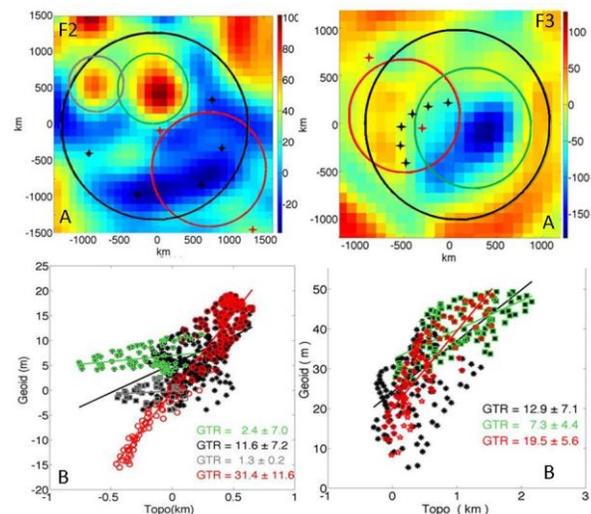
subduction is achieved via a mechanism similar to a concept proposed by [1]. (F1) shows the experiment in an aqueous dispersion of colloids dried from above and heated from below. The side views (1B-C) show the vertical cross-section along the green line in the top view (1A). The hot plume has been highlighted in red. Its impact under the surface skin results in three arcuate bulges (in yellow on (1A)) and three subduction zones along those bulges (in bright white on (1B-C)).

Background: Coronae are features unique to Venus. One possible formation mechanism consists of an upwelling mantle plume interacting with the lithosphere. Although there is no evidence of distinct plates on Venus, [2] showed many trenches occurring at some coronae are strikingly similar to terrestrial ocean-ocean subduction zones, and several studies have provided mechanisms which could link plumes to subduction zones. [1,3-4] Whether subduction is occurring on Venus despite its single plate is not well understood and could be happening via a plume induced subduction process. This form of localized subduction provides a

mechanism to initially break the lithosphere, potentially allowing plate tectonics to follow.

Methods and Results: To model subduction, we calculate geoid-to-topography ratios (GTRs) for specific features at each corona and fit a profile of the Bouguer gravity data across each corona's trench using a model of a cold, dense subducting thermal lithosphere with a low density basaltic crust.

Data analysis-GTR. The geoid anomaly decreases as the compensation depth increases, giving a larger GTR. GTRs for two of the largest coronae are shown in (Fig. 2-3). GTRs at the trenches (31.4 ± 11.6 m/km (Artemis) and 19.5 ± 5.6 m/km (Quetzalpetlatl)), are far greater than other regions at each coronae- consistent with a slab at depth.

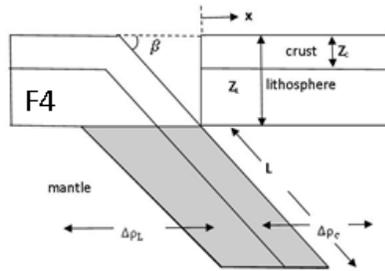


Artemis Results-GTR. (Fig. 2). (2A) Regionally corrected Bouguer gravity (gravity due to topography removed from free air gravity) showing subsurface density variations for Artemis corona. Due to a topographic plateau to the north, a best fitting plane is removed from the free air gravity, topography, and geoid separately before performing the GTR and slab model analysis. Black crosses show the trench location, red markers show the profile location in (Fig. 5). (2B) shows the GTRs for regions indicated by circles in (2A): Black, red, green, and grey points show the GTRs for the entire coronae, the region of the trench, and the rifts to the north and northwest, respectively

Quetzalpetlatl Results-GTR (Fig. 3). (3A) shows the Bouguer gravity for Lada Terra. Black and red crosses as in (Fig. 2). The large negative anomaly in

the center is accounted for in the slab model analysis (see Fig. 5B). (Fig. 3B) shows the GTR for circular regions in (3A). Green markers indicate Boala coronae.

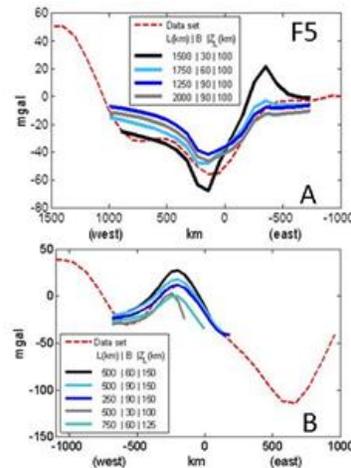
Data analysis-Slab model. The subducting slab model consists of a low density crust and high density thermal lithosphere. (Fig. 4) shows a diagram of the slab model (not to scale), where only shaded region is modeled. The model incorporates crustal density contrast $\Delta\rho_c$, thermal lithospheric density contrast $\Delta\rho_L$, crustal



thickness, Z_C , lithospheric thickness, Z_L , plate length, L , and subduction angle, β . The crustal and mantle densities are based on Earth's measurements, 2900 and 3300 kg/m^3 , respectively. The thermal density contrast is estimated by $\Delta\rho_{\text{Thermal}} \approx \rho_M \alpha \Delta T/2$, where $\alpha = 2.4 \times 10^{-5} \text{ K}^{-1}$, is the coefficient of thermal expansion and $\Delta T/2$ is the mean temperature difference across the lithosphere; based on the surface ($\sim 460\text{C}$) and estimated mantle temperatures ($\sim 1300\text{C}$), giving $\Delta\rho_L \approx 32 \text{ kg}/\text{m}^3$. The other four parameters vary incrementally. β is 30, 60 or 90° , based on lab experiments (Fig. 1 & [6]). Z_C and Z_L range from 10 to 50 km and 75 to 200 km, in increments of 10 and 25 km, respectively. The plate length increases in increments of 250 km, ranging between 20-80% of the corona diameter [6]. This corresponds to 500-2000 km for Artemis and 250-1000 km for Quetzalpetlatl. The resolution of each model was lowered to match that of the data using a running average technique and then compared to the data via RMS error analysis.

Slab mode results. All preferred models have an $\text{RMS} < 10 \text{ mgal}$, a crustal thickness of 10 km and subduction angle between $60-90^\circ$ for Artemis, and $30-90^\circ$ for Quetzalpetlatl. For Artemis (radius=1300km), preferred models have a lithospheric thickness and slab length between 75-100 km and 500-1500 km, respectively. For Quetzalpetlatl (radius=650km), preferred models have a lithospheric thickness and slab length between 100-150 km and 250-750 km, respectively. (Fig 5) shows the results of the slab model analysis. The origin indicates the lowest topographic point in the trench. Distance increases from the trench toward the corona center. Artemis (5A). The regional slope in gravity and topo due to the plateau to the north is removed. At Quetzalpetlatl (5B), a 30 mgal correction is added to account for the large negative anomaly in the

corona center, likely due to a low density plume. Because the model anomaly goes to zero at large distance from the trench,



from the trench, the 30 mgal correction was chosen to align the model and data far from the site of subduction. The same models are preferred without the correction but have an RMS greater by approximately 10 mgal.

Discussion and Conclusions: The GTR uncertainties are relatively high, which could be caused by the low resolution of the gravity data relative to the size of the specific features. In both cases, the GTR of the trench region is much larger than other regions of the corona. The density anomalies at Quetzalpetlatl are consistent with a subducting slab in the presence of a hot mantle plume. This finding offers support to surface thermal emissivity data interpreted as indicating volcanism $< 2.5 \text{ mya}$ and probably much younger, 250,000 years or less. [7] At Artemis, there is strong evidence that the topography has been uplifted from below, and the negative gravitational anomaly is consistent with low density material such as a plume. Gravitational anomalies at both coronae can be fit using a dipping slab model over a large parameter space with plate lengths constrained by laboratory experiments. This suggests that Artemis and Quetzalpetlatl could be active sites of plume initiated subduction; causing local resurfacing in the corona centers. Plume-initiated subduction could lead to the development of plate tectonics, but may require cooler, stronger lithosphere to allow plates to develop [6].

References: [1] Sandwell D.T. and G. Schubert (1992) *Science*, 257, 766-770. [2] McKenzie D. et al. (1992) *J. Geophys. Res.*, 97, 13, 533-13. [3] Schubert G and D. T. Sandwell, (1995). [4] Smrekar S.E., and E.R. Stofan (1997) *Science* 277, 1289-1294. [5] James, P.B., M.T. Zuber, R.J. Phillips (2013) *J. Geophys. Res.*, 118, 859-875. [6] Smrekar, S. E et. al. (2016) Plume Induced Subduction on Venus, submitted. [7] Smrekar S.E. et. al. (2010) *Science*, 328, 605-608.

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