THE DEEP STRUCTURE OF CORONAE ON VENUS: THE BETA-ATLA-THEMIS REGION . Kelly Peterson, *Department of Geology, University of Kansas, Lawrence KS,* Walter S. Kiefer, *Lunar and Planetary Institute, Houston TX 77058, kiefer@lpi.usra.edu, http://www.lpi.usra.edu/science/kiefer/home.html.*

Coronae are circular to elliptical tectonic structures on Venus, typically a few hundred kilometers across and often associated with volcanic activity. They are generally believed to be the surface expression of upwelling mantle diapirs [1]. Gravity modeling can provide insight into the subsurface structure of coronae. Previous gravity models of coronae have emphasized determining parameters such as the average crustal and lithospheric thicknesses [2,3]. In this work, we analyze the spatial variability of crustal thickness and mantle densities at large coronae in the Beta-Atla-Themis region of Venus.

Model

We apply a two-layer inversion model, adapted from a study of the global gravity and topography of Mars [4]. This model uses gravity and topography to constrain the density anomalies in two shells at two different depths in the planet. Similar approaches have been applied to other regions of Venus by several research groups [5-7]. In this model, the shallow shell is assumed to represent variations in crustal thickness, supported by a combination of Airy isostasy and elastic flexure. We assume a mean crustal thickness of 25 km and an elastic lithosphere thickness of 20 km. Our results are not particularly sensitive to the precise choice of lithospheric thickness.

The deeper shell is assumed to represent density anomalies in the mantle of Venus, which drive whole-mantle convective flow. This flow deforms the surface, which contributes to the overall topography. The model gravity anomaly is the sum of contributions from the mantle density anomalies and from the mass anomalies associated with the induced topography at the surface and the core-mantle boundary [8]. The viscosity structure is a high viscosity near-surface layer, representing the upper thermal boundary layer, over an isoviscous mantle [9]. We do not have sufficient observational constraints to invert for density anomalies as a function of depth in the mantle. As a first approximation, we assume that the density anomalies are vertically continuous from 100 km depth (the base of the upper thermal boundary layer) to 700 km depth; the results should therefore be interpreted as a vertically averaged mantle structure. We have also considered models in which the mantle density anomalies extend to greater depths, but for the wavelengths that dominate our study regions, including deeper density anomalies has little affect on the solutions.

Using spherical harmonic representations of the gravity and topography of Venus [10, 11], we invert on a term-by-term basis for the crustal thickness variations and mantle density variations necessary to exactly reproduce the observed gravity and topography. Results for the shallow density shell are expressed in terms of the equivalent surface topography produced by the variations in crustal thickness. Density anomalies in the deep shell are converted to equivalent thermal anomalies assuming a thermal expansion coefficient of $3x10^{-5}K^{-1}$. The inversion is complete to spherical harmonic degree 40, corresponding to a resolving half-wavelength of 475 km. In practice, a diapir of a given diameter will have power over a range of spectral wavelengths, including some power at wavelengths longer than the resulting corona diameter. Thus, we should be able to detect diapirs that are somewhat smaller than 475 km in diameter. However, because of the resolution of the models, the thermal anomalies mapped here will generally be less than the total amplitude of the anomalies. In this study, we consider the Beta-Atla-Themis region, which contains the highest concentration of coronae and of volcanic structures on Venus [12,13]. Our focus is on large coronae in this region, but we also consider other significant structures (rifts, large volcanos, tessera). We have excluded the Beta Regio and Atla Regio volcanic provinces from our study domain. Detailed analyses of the gravity and topography of Beta and Atla have been published elsewhere [e.g., 9, 14].

Results

Hecate Chasma: Hecate Chasma contains many large coronae. Figure 1 shows the mantle temperature anomalies for this region. Geologic mapping [15] provides some guide to the relative ages of the coronae. Coronae that are relatively young (as judged by morphology and superposition relations) tend to show up as warm anomalies in Figure 1. Older coronae concentrate in regions with approximately normal mantle temperatures. The hottest anomalies shown are associated with two volcanos, Polik-Mana and an unnamed feature. The crustal thickening map (not shown) indicates the importance of volcanism at many of these coronae, including some that are not visible in the temperature anomaly map. Subduction has been proposed on the western margin of Taranga [16], but we see no evidence for it in the thermal anomaly map.

Kawelu Planitia: The coronae chain in southern Kawelu Planitia occurs in a region of slightly cool mantle temperatures and moderate crustal thickening. These results suggest that the chain is relatively old (allowing time for the original thermal anomalies to cool) and had little associated volcanism. Both conclusions agree with geologic mapping of the region [17].

Parga Chasma: The strongest thermal anomaly in Parga Chasma is at Maram Corona (+50 K). Weaker thermal anomalies occur at Atete and Javine. In general, mantle thermal anomalies are weaker along Parga than along Hecate. This suggests that Parga is, on average, older than Hecate and has had more time for hot anomalies to cool. Based on geologic mapping, a three-arm propagating rift system was proposed in central Parga [17,18]. However, the pattern of thermal anomalies does not correlate with the proposed rift history, casting doubt on the propagating rift model. Subduction has been proposed on the northern margin of Atete [16], but we see no evidence for that in the thermal anomaly map. The crustal thickening map indicates that volcanism was an important process at some past time in the southeastern section of the chasma. The mantle in this region has no meaningful thermal anomaly, so this volcanism is presumably no longer active.

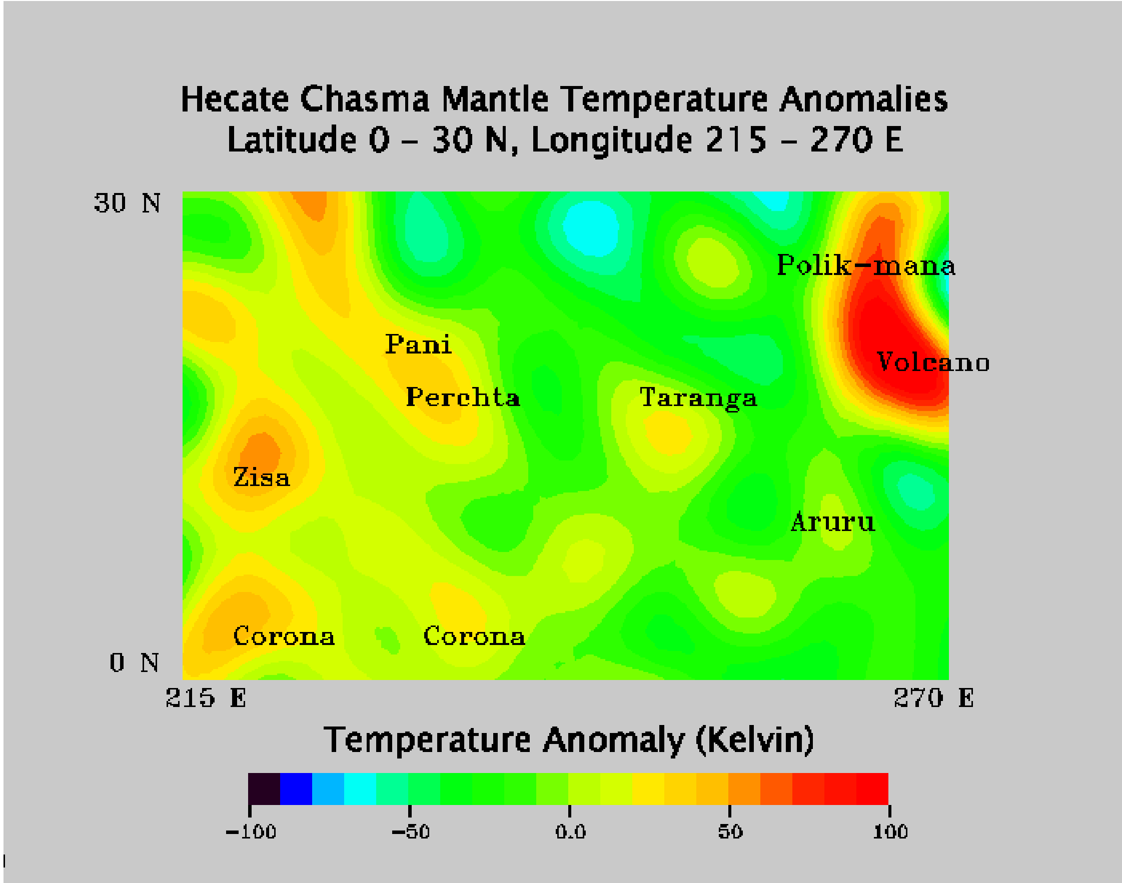

Figure 1: Mantle temperature anomalies (departures from the average mantle temperature) in Hecate Chasma.

Themis Regio: Most of these coronae are located over nearly normal mantle, with temperature anomalies of less than 20 K. The largest thermal anomalies (+50 K) are located at Shiwanokia Corona and at Tefnut Mons. The crustal thickening map indicates the importance of volcanism at many of these coronae, producing up to 1 km of topography.

Phoebe Regio and Devana Chasma: Most of Phoebe Regio's topography is the result of thickened crust. High temperature anomalies occur only near the corners of the highlands, at the volcano Yunya-Mana Mons in the south, an unnamed volcano (2 S, 287 E) in the northeast, and along the fracture belt east of Uretsete Mons. The largest thermal anomaly in our study region (+150 K) occurs along Devana Chasma. There is a 500 km offset in the rift system at 10 N, and the hot thermal anomalies are not continuous at this offset. This suggests that the two rift segments formed separately, with one segment propagating southward from Beta Regio and the other propagating northward from Phoebe Regio.

Implications

These results indicate that hot thermal anomalies exist at a variety of large coronae in the Beta-Atla-Themis region. This supports the diapir model for corona formation. Other large coronae are now regions of average mantle temperatures but must have been hotter in the past, as inferred from the volcanism required to explain the crustal thickness maps. Conductive cooling through a 100 km thick thermal lithosphere requires a minimum of 100 million years for a diapir to lose its thermal signature. This sets a minimum range of ages for corona activity in this region.

[1] Stofan et al., pp. 931-965 in *Venus II*, Univ. Arizona Press, 1997. [2] Schubert et al., Icarus 112, 130-146, 1994. [3] Smrekar and Stofan, Icarus, 139, 100-115, 1999. [4] Kiefer et al., JGR 101, 9239-9252, 1996. [5] Bills and Fischer, JGR 97, 18,285-18,294, 1992. [6] Grimm and Phillips, JGR 97, 16,035-16,054, 1992. [7] Herrick and Phillips, JGR 97, 16,017-16,034, 1992. [8] Richards and Hager, JGR 89, 5987-6002, 1984. [9] Kiefer and Hager, JGR 96, 20,947-20,966, 1991. [10] Konopliv et al., Icarus 139, 3-18, 1999. [11] Rappaport et al., Icarus 139, 19-31,1999. [12] Squyres et al., GRL 20, 2965-2968, 1993. [13] Crumpler et al., Science 261, 591-595, 1993. [14] Smrekar, Kiefer, and Stofan, pp. 845-878 in *Venus II*, Univ. Arizona Press, 1997. [15] Hamilton and Stofan, Icarus 121, 171-194, 1996. [16] Schubert and Sandwell, Icarus 117, 173-196, 1995. [17] Chapman and Zimbelman, Icarus 132, 344-361, 1998. [18] Chapman, USGS Map I-2613, 1999.