CONSTRAINTS ON VENUSIAN CRUSTAL AND LITHOSPHERIC PROPERTIES FROM MAGELLAN DATA.

A. B. Kucinskas, and W. B. Banerdt, *Jet Propulsion Laboratory 301-150, 4800 Oak Grove Drive, Pasadena CA 91109, USA (algis@chronos.jpl.nasa.gov).*

Providing constraints on lithospheric support and on isostatic or dynamic compensation for Venusian surface features (and thus on crustal and elastic and thermal lithospheric thicknesses) should provide insights into the geodynamic evolution of these features. In turn, these studies can lead to a better understanding of Venus' tectonic and thermal history. In the absence of in-situ data (e.g., seismic, heat flow, and compositional), correlations of gravity and geoid (equipotential surface) anomalies with topography variations offer a means to achieve this goal. However, it is necessary to consider additional constraints than that offered by the topography and gravity data sets when making geophysical interpretations. This is due to the non-unique association of gravity observations with internal mass distributions as well as the fact that gravity and topography correspond mainly to the current state of the planet under study. Previous studies performed for Venus and Mars have shown that the state of stress (magnitude and orientation) at the surface of a planet, inferred from tectonic features recognized in surface imaging data such as the Magellan synthetic aperture radar (SAR) data set, is particularly useful as such a constraint [1,2]. An important advantage of images of tectonic features is that they record the response of the surface to the past sequence of geologic events. Thus the stress field history can help constrain present lithospheric structure and processes as well as give insights into their evolution.

The Magellan mission to Venus achieved near global and high resolution coverage of the planet in SAR imaging, altimetry, radiometry, and gravity mapping [3,4,5]. Magellan imaging data confirmed earlier indications of an absence of a global system of interconnected spreading centers on Venus, indicating the absence of Earth-style plate tectonics at least at the present epoch. Magellan also confirmed that the gravity field (and geoid) of Venus is correlated to the topography. This strong positive areal correlation, along with the fact that the amplitudes in the power spectrum of gravity for uncompensated topography are significantly larger than that for observed gravity, implies that much of the surface topography is compensated [6,5]. This can be interpreted as an indication either that much of the long-wavelength Venusian topography is isostatically compensated at depth, implying a thick (300-400 km) present-day background lithosphere with negligible, "sluggish lid" convective stresses [7,8,6,9,10], or that it is maintained essentially by dynamic support associated with mantle convection and a thinner (100 km) background lithosphere [11,12]. Another major result of the Magellan mission was the finding that the global population of impact craters on Venus' surface seems to be characterized by a near random spatial distribution yielding a mean surface age of approximately 500 Ma [13,14]. Based on these observations, two end-member classes of models for the geologic history of Venus emerged: 1) a uniformitarian model, arguing that resurfacing on Venus is widely distributed in time, with near steady-state heat loss via plumes and/or delamination and with a thin, stable lithosphere [13]. 2) A "catastrophic" scenario [14] which hypothesizes that Venus experienced a global, short-lived resurfacing event some 500 Ma ago and since then tectonic and volcanic activity have greatly reduced. The latter hypothesis has lead to thermal evolution models which predict a thick and transient thermal lithosphere on Venus today [e.g., 7].

Images of the Venus surface from Magellan SAR revealed widespread volcanic and tectonic features of different types [15,16]. The various physiographic provinces found on Venus display significant differences in apparent depth of compensation between types, suggesting a variety of modes of compensation [e.g., 7,10]. Venus' surface has been divided into two main units: plains which cover approximately 70 percent of the planet, and highlands. Using selection criteria based on tectonic style, regional morphology, and gravity characteristics, Venusian highlands can be divided into three main classes [16]: 1) broad domal rises, such as the volcanic swells of Atla and Beta regiones, are characterized by extension and comprise rift valleys and large volcanoes which may be supported by elastic stresses in the lithosphere. Whereas there is a consensus that the broad swells may be the result of a rising mantle plume, there is ongoing debate as to whether they are supported primarily isostatically, via thermal thinning of a thick lithosphere [6,10], or dynamically [11,12]. 2) Plateau-shaped highlands such as Ovda Regio in western Aphrodite Terra are dominated by tessera features or complex ridged terrain (CRT) which seem to record multiple episodes of deformation. It has been argued that tessera terrain in general experienced initial compressional deformation resulting in ridges followed by extension [17], although other authors [18] propose an extensional phase prior to compression. However, there is currently good agreement among researchers that tessera plateaus are presently isostatically maintained by Airy-type crustal thickening [6,10,11]. 3) The northern continent-like highland of Ishtar Terra is the site of complex tectonic regimes [19,20]. Ishtar includes the high plateau of Lakshmi Planum in the west, surrounded by narrow mountain belts made up of ridges interpreted as compressional folds and thrust faults. Eastern Ishtar comprises the Fortuna tessera terrain.

Lowland areas on Venus comprise essentially: 1) plains characterized by linear belts of graben or ridges, and corona features [e.g., 21], and 2) a few deep basins such as Atalanta Planitia. Compressive stresses seem to dominate in the Venusian plains, as evidenced by the pervasive "wrinkle ridges" and contractional ridge belts. Stratigraphic and local cratering records inferred from Magellan SAR imagery suggests an overall sequence of tessera formation followed by plains emplacement then coronae-rift-volcanoes [e.g., 17].

In order to better evaluate and constrain support mechanisms for loads on the surface of Venus and thus constrain tectonic and thermal evolution, we model lithospheric stresses (magnitude and orientation) at both global and regional scales. Relationships between the latest spherical harmonic representations of Venus topography and gravity are used, together with stress field information derived from SAR imaging, to constrain stress field models and support mechanisms for surface features and their implications for crustal and lithospheric properties. Results of the stress field and support studies are used, along with additional information from stratigraphic studies, the global and regional cratering record, and laboratory estimates of Venusian lithospheric strength, to constrain the tectonic and thermal history of both individual regions and the planet as a whole. In this study we use a planetary thin shell formulation [1], which includes both bending and membrane stresses, to compute stress distribution on the surface of Venus and investigate the support of topographic loads. The main advantages of this formulation are the generality and flexibility of the loading function as well as the ability to model both short-wavelength lithospheric support and long-wavelength compensation mechanisms. The adopted lithospheric model includes laterally varying density anomalies at two depths corresponding to simultaneous undulations on a crust-mantle boundary and variations in upper mantle density. For a given set of lithospheric model parameters (e.g., mean crustal, elastic lithosphere and mantle density anomaly thicknesses, crustal and upper mantle densities) values for the vertical displacement, excess in crustal thickness, and mantle density anomaly required to satisfy the gravity and topography boundary conditions are computed, along with the resulting stress field. The calculated stresses are then compared to stress directions inferred from observed tectonic features in order to further constrain the models. Constraints to the models are provided by the following: 1) gravity: we use the latest 180th degree and order "MGN180U" spherical harmonic solution [22]. 2) Topography: we utilize a recently improved 360th degree and order harmonic solution [23]. 3) Stress directions identified by various published geologic mapping efforts [e.g., 15,16,17,18,19,21]. 4) Other constraints are provided by the cratering record, identified stratigraphic sequences, high strength of the Venusian lithosphere inferred from laboratory studies of dry diabase [24],and the results of other flexural and compensation studies [6,8,11,25].

We first implemented the modeling on a global scale, using only lower degree and order harmonic coefficients for comparison with [1], along with mean values of 30 km for the crust [8] and 35 km for the elastic lithosphere [25]. Preliminary results predict low-density mantle beneath swells such as Atla and Beta, and thick crust accompanied by higher-density mantle under plateaus such as Ovda. The tectonic features of Ishtar indicate either downward deflection or other processes such as lateral tectonics. However, several studies [e.g., 8,6,10,25] suggest significant regional variations in crustal and lithospheric thicknesses on Venus. This implies that a single simple lithospheric model cannot explain the global gravity/geoid relationship with topography. This warrants applying our stress modeling method to the detailed analysis of specific regions on Venus where a variety of different tectonic processes and support modes are at work. Regional stress modeling is now made possible by the high resolution of the Magellan data sets. We will present the results of such modeling, using the full resolution of the harmonic models, in several tectonically repesentative regions on Venus.

References: [1]Banerdt, W.B. (1986). *JGR* **91** 403–419. [2]Banerdt, W.B., et al. (1992) *In Mars, University of Arizona Press, Tucson.* [3]Saunders, R.S., et al. (1992) *JGR* **97** 13,067–13,090. [4]Ford, P.G., and G.H. Pettengill (1992) *JGR* **97** 13,103–13,114. [5]Sjogren, W.L., et al. (1997) *In Venus II, University of Arizona Press, Tucson.* [6]Kucinskas, A.B., and D.L. Turcotte (1994) *Icarus* **112** 104–116. [7]Turcotte, D.L. (1993) *JGR* **98** 17,061–17,068. [8]Grimm, R.E. (1994) *Icarus* **112** 89–103. [9]Solomatov, V. S., and L. N. Moresi (1996) *JGR* **101** 4737–4753. [10]Moore, W.B., and G. Schubert (1997) *Icarus* **128** 415–428. [11]Simons, M., et al. (1997) *Geophys. J. Int.* **131** 24–44. [12]Smrekar, S. E., et al. (1997) *In Venus II, University of Arizona Press, Tucson.* [13]Phillips, R.J., et al. (1992) *JGR* **97** 15,923–15,948. [14]Schaber, G.G., et al. (1992) *JGR* **97** 13, 257–13,301. [15]Head, J. W., et al. (1992) *JGR* **97** 13,153–13,198. [16]Solomon, S. C., et al. (1992) *JGR* **97** 13,199–13,256. [17]Gilmore, M. S., et al. (1997) *JGR* **102** 13,357–13,368. [18]Hansen, V. L., and J.J. Willis (1996) *Icarus* **123** 296–312. [19]Kaula, W. M., et al. (1992) *JGR* **97** 16085–16120. [20]Kucinskas, A.B., et al. (1996) *JGR* **101** 4,725–4,736. [21]Banerdt, W. B. et al. (1997) *In Venus II, University of Arizona Press, Tucson.* [22]Konopliv, A.S. et al. (1999) submitted to Icarus. [23]Rappaport, N. J. et al, (1999) submitted to Icarus. [24]Mackwell, S. J., et al. (1997) *In Venus II, University of Arizona Press, Tucson.* [25]McKenzie, D., and F. Nimmo (1997) *Icarus* **130** 198–216.