Venus as a Mantle Plume Laboratory, S. E. Smrekar[1] and E. R. Stofan[2], 1) Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109; 2) Proxemy Research, 20528 Farcroft Lane, Laytonsville, MD 20882.

The similarity in the size and bulk density between Venus and Earth give them a similar capacity for heat production. Yet Venus shows no evidence of plate tectonic. Instead, it experienced wide spread resurfacing approximately 750 m.a. (1), possibly driven by global crustal overturn (2,3). The rate of geologic activity declined following this resurfacing, leading to the hypothesis that Venus is currently in a stagnant lid convective regime (4-6).

Despite the differences in tectonic style, Venus has many Earth-like hotspot rises (e.g. 7-9). Seven volcanic rises are very similar to terrestrial hotspot rises, in that they have extensional rifts, large shield volcanoes, broad topographic swells, and gravity anomalies suggesting deep compensation (10-11). These are the primary hotspots, with a possible origin as plumes rising from the core mantle boundary. A recent analysis of the data available for terrestrial hotspots suggests that a limited number of primary plumes arise from the core-mantle boundary on the Earth (12). Other secondary plumes are generated as when a super plume impinges on the upper mantle-lower mantle boundary spawning smaller thermal instabilities, or are due to local rifting and melting (12,13). Within this definition, Venus and Earth appear to have a comparable number of primary plumes.

Secondary plumes on Venus have a very different character on Venus than on Earth. Coronae are believed to form over small-scale upwellings. There are over 500 coronae, with 95% having a diameter between 100 and 400 km (14). Although most coronae have associated volcanism, they are defined on the basis of their annulus of fractures and their topographic morphology. Although the volcanism, radial extensional fractures, and the dome or plateau morphology found for many coronae are consistent with typical models of mantle upwelling, coronae differ in key ways. They are typically smaller and have a range of topographic forms, with nearly half of all coronae having interior depressions. Fracture annuli are not observed at larger hotspots either on Venus or Earth.

A variety of models have been proposed to explain the unusual topographic morphology of coronae. Koch and Magna (15) proposed a spreading drop model to form some of the interior depression topographic forms. A model in which an upwelling plume lead to delamination of the lower lithosphere at the edges of the plume explains most topographic forms (16). A plume impinging on a depleted mantle layer can generate surface depressions (17).

One possible explanation for the lack of coronae on Earth is that the presence of a low viscosity zone under the oceanic lithosphere causes the plume head to spread laterally and dampen any surface topography (16). This would be particularly pronounced for small plumes. Under continents, small plumes might be unable to deform the lithosphere, particularly in the presence of a depleted mantle layer. Alternatively Jellenik et al. (17) propose that coronae form on Venus due to the absence of subducting slabs. Without slabs to cause enhanced thermal gradients at the core mantle boundary, smaller scale plumes form. The effect of buoyancy can also create different scale plumes (18).

Recent work examining the admittance signature for coronae suggests the possibility that the density structure of the lithosphere plays a key role. Smrekar et al. (21) examined the admittance signature for those coronae that have a fracture annuli 50% or less complete, defined as Type 2 coronae (22). No relationship is seen between either crustal or elastic thickness and diameter, as suggested by prior models (15,20). Instead, the elastic and crustal thickness correlate with some topographic morphologies. Rim only coronae, which are predicted to from through isostatic rebound (16), have a more limited range of estimated crustal thickness (50-100 km) than other topographic forms (19). Rim only coronae are predicted to form rimmed depressions, once isostatic and thermal equilibrium are reached. These coronae typically have a bottom loading signature and relatively large elastic thickness values, consistent with formation via delamination of the lower lithosphere.

Additionally, nearly half of the coronae in the gravity survey appear to be isostatically compensated (21). All of the topographic forms considered in the gravity survey are represented in the isostatically compensated group. These coronae are interpreted to be inactive, implying that all morphologies can represent the final state of a corona (19). This includes topographic forms such as domes and plateaus that are typically assumed to indicate the presence of a plume at depth. In fact, none of the plateaus and domes studied had a relatively thin elastic lithosphere, large depth of compensation, and bottom loading signature that is consistent with a plume at depth (21).

The results of the gravity survey suggest that processes such as delamination and isostasy play a significant role in the formation and compensation of coronae. Some coronae may even form via delamination without a plume to initiate the process. Type 2 coronae, which were examined in the gravity survey (21), are more commonly found in the plains than along fracture belts. The plains regions may be tectonically inactive areas, which could favor the transition of basalt to eclogite (14,21). The presence of a high-density layer at depth would tend to favor delamination.

A stagnant lid regime results in a lithosphere that does not cool monotonically. Instead the mantle heats up over time, causing the lithosphere to remain at a constant thickness or even thin with time. The tectonic stability of the lithosphere in such a regime would allow slow phase transitions to occur, favoring delamination and allowing isostasy to be achieved over time. These processes may be key to understanding why coronae form only on Venus, the effects of a stagnant lid on tectonic history, and the relative contribution of upwelling plumes to the formation of coronae and heat loss on Venus.

References.

[1] McKinnon, W.B et al., Cratering on Venus: Models and observations, In *Venus II* (Bougher, S. W., Hunten, D. M., Phillips, R. J., eds.) pp. 969-014, Univ. of Arizona Press, Tucson, 1997.

[2] Parmentier, E.M. and P.C. Hess, Chemical differentiation of a convecting planetary interior: Consequences for a one plate planet such as Venus, *Geophys. Res. Lett., 19*, 2015-2018, 1992.

[3] Turcotte, D.L., An episodic hypothesis for Venusian tectonics, *J. Geophys., Res., 98*, 17601-17068, 1993.

[4] Moresi, L., and V. Solomatov, Mantle convection with a brittle lithosphere: Thoughts on the global tectonic styles of the Earth and Venus, *Geophys. J. Int., 133*, 669-682, 1998.

[5] Reese, C.C., V.S. Solomatov, and L.N. Moresi, Non-Newtonian stagnant lid convection and magmatic resurfacing on Venus, *Icarus, 139*, 67-80, 1999.

[6] Solomatov, V.S., and L.N. Moresi, Scaling of time-dependent stagnant lid convection: Application to small-scale convection on Earth and other terrestrial planets, *J. Geophys. Res., 105*, 21,795-21,817, 2000.

[7] Senske, D.A., G.G. Schaber and E.R. Stofan, Regional topographic rises on Venus: What are they telling us? *J. Geophys. Res., 97*, 13257-13301, 1992.

[8] McGill, G., Hotspot evolution and Venusain tectonic style, *J. Geophys. Res., 99*, 23349-23161, 1994.

[9] Smrekar, S.E., E.R. Stofan, W.S. Kiefer, Large volcanic rises on Venus, in *Venus II*, eds. S.W. Bougher, D.M. Hunten, and R.J. Phillips, Univ. of Arizona Press, Tucson, pp. 845-878, 1997.

[10] Stofan, E.R., S.E. Smrekar, D.L. Bindschadler, and D. Senske, Large topographic rises on Venus: Implications for mantle upwellings, *J. Geophys. Res.*, 23, 317-23,327, 1995.

[11] Brian, A. W., E.R. Stofan, J.E. Guest, and S.E. Smrekar, Laufey Regio: A newly discovered topographic rise on Venus, *submitted*, 2003.

[12] Courtillot, V., A. Davaille, J. Besse, and J. Stock, Three distinct types of hotspots in the Earth's mantle, *Earth Planet. Sci. Lett., 205*, 295-308, 2003.

[13] Anderson, D. L., The thermal state of the upper mantle: no role for mantle plumes, *Geophys. Res. Lett, 27*, 3623-3626, 2000.

[14] Glaze, L.S., E.R. Stofan, S.E. Smrekar, S.M. Bologa, Insights into corona formation through statistical analyses, *J. Geophys. Res., 107* (E12), doi:10.1029/2002JE001904, 2002.

[15] Koch, D.M., and M. Manga, Neutrally buoyant diapirs: A model for Venus coronae, *Geophys. Res. Lett., 23,* 22-228, 1996.

[16] Smrekar, S.E., & Stofan, E.R. Corona formation and heat loss on Venus by coupled upwelling and delamination, *Science. 277*, 1289-1294. 1997.

[17] Jellenik, A. M., A. Lenardic, M. Magna, The influence of interior mantle temperature on the structure of plumes: Heads for Venus, tails for Earth, *Geophys. Res. Lett, 29*, doi:10.1029/2001GL014624, 2002.

[18] Davaille, A. Simulatneous generation of hotspots and superswells by convection in a heterogeneous planetary mantle, *Nature, 402*, 756-760, 1999.

[19] Smrekar, S. E. and E. R. Stofan, Effects of Lithospheric Properties on the Formation of Type 2 Coronae on Venus, in press, *J. Geophys. Res. Planets*, 2003.

[20] McGovern, P.J., S.C. Solomon, Growth of large volcanoes on Venus: Mechanical models and implications for structural evolution, *J. Geophys. Res., 103*, 11,071-11,101, 1998.

[21] Smrekar, S.E., R. Comstock, and F. S. Anderson, A gravity survey of Venusian Type 2, in press., *J. Geophys. Res. Planets,* 2003.