PARGA CHASMA: CORONAE AND RIFTING ON VENUS. S. E. Smrekar[1], E.R. Stofan[2], W. R. Buck[3], and P. Martin[4], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA; ssmrekar@jpl.nasa.gov; [2]Lamont-Doherty Earth Obs., Palisades, NY, 10964 (buck@ldeo.columbia.edu); [3]Proxemy Research, ellen@proxemy.com; [4]Dept. Physics, University of Cambridge, England, CB30HE; pm313@phy.cam.ac.uk.

Introduction: The majority of coronae (quasicircular volcano-tectonic features) are found along rifts or fracture belts, and the majority of rifts have coronae [e.g. 1,2]. However, the relationship between coronae and rifts remains unclear [3-6]. There is evidence that coronae can form before, after, or synchronously with rifts [3,4]. The extensional fractures in the rift zones have been proposed to be a result of broad scale upwelling and traction on the lower lithosphere [7]. However, not all rift systems have a significant positive geoid anomaly, as would be expected for an upwelling site [8]. This could be explained if the rifts lacking anomalies are no longer active. Coronae are generally accepted to be sites of local upwelling [e.g. 1], but the observed rifting is frequently not radial to the coronae and extends well beyond the coronae into the surrounding plains. Thus the question remains as to whether the rifts represent regional extension, perhaps driven by mantle tractions, or if the coronae themselves create local thinning and extension of the lithosphere. In the first case, a regional extension model should be consistent with the observed characteristics of the rifts. In the latter case, a model of lithospheric loading and fracturing would be more appropriate. A good analogy may be the propagation of oceanic intraplate volcanoes [9].

Our goal in this study is to examine whether models of regional scale extension can explain the observations. We apply the uniform lithospheric extension model of Buck [10] to Venus conditions. Buck [10] examined the competing effects of differences in buoyancy and lithospheric strength that result from lithospheric thinning in a rift zone. In this framework, compositional buoyancy opposes rifting. The thicker, unrifted crust is relatively more buoyant, resulting in a force pushing inward toward the rift. Thermal buoyancy forces are typically much smaller, but act to reinforce local rifting. As the thinned lithosphere is hotter and less dense than the surrounding lithosphere, the buoyancy force pushes outward from the rift. The yield strength of the thinned lithosphere is reduced, which acts to localize deformation in a narrow zone. Thus wide rift zones are produced in regions where crustal buoyancy forces are dominant, such as in area of relatively thick crust. Higher heat flow, stronger crustal rheology, and lower strain rate also favor the formation of wide rift zones. On Venus, we expect stronger crust and lower strain rates relative to Earth. As described below, Zc (crustal thickness) and Te (elastic thickness), which is a rough proxy for heat flow, have recently been estimated [11]. Thus we can compare rift width, Te and Zc to predictions for narrow versus wide rifting under uniform extension.

Observations: We use a global admittance map to determine the variation in Te and Zc in the Parga Chasma region [11]. Modeling of the global admittance map using both top and bottom loading indicates that sections of the rift have distinct lithospheric properties. Zc varies from 0 to 80 km and Te ranges from 0 to 50 km.

We use the Magellan radar images and stereo topography to classify the Parga Rift system, which extends between Atla and Themis Regiones. The Parga rift system is extremely complex, with numerous branches that form at a range of angles to the main, NW-SE trending rift. The rifts have a central trough, 60-250 km wide, and 0.2-4.0 km deep. Additionally the extensional fractures typically extend out as much as 230 km beyond the actual topographic trough. The intensity of fracturing also differs from segment to segment, with some sections having very closely spaced fractures, and others more widely spaced fractures.

Venus Modeling: Here we use a model of dry diabase to describe crustal flow [12]. We use the model of rifting developed by Buck [10] to determine if regional extension is consistent with the observed style of rifting and estimated lithospheric properties. We examine a range of Zc (10, 30, and 60 km) and heat fluxes. The heat flux is a function of the crustal heat production and heat flux from the mantle. For crustal heat production, we use a value of 6.4e-7 Wm^{-3}, as used by Buck [10] for the Earth. Although the heat production on Venus is not well constrained, the measurements of U, The, and Ka made in the plains indicate that it may be comparable to terrestrial oceanic values. We vary the mantle heat flux (qm = 10, 25, 50 mW/m^2) to simulate different amounts of heating due to corona-related upwellings or broad-scale mantle upwelling. Including heat production in the crust results in a steeper gradient in the crust. For the 3 input values of mantle heat flux, this gives a crustal thermal gradient of 8.7, 13.3, or 20.9°/km, respectively, with the lithospheric gradient roughly 5

°/km less. Using a surface temperature of 460°C, this gives a temperature of 700°C at depth 28, 18, and 11 km (or 39, 26, and 16 for T=800°C). For terrestrial mantle material, the brittle-ductile transition is around 600-800°C, and up to 450°C for the crust [13]. Dry diabase is closer in strength to the terrestrial mantle than the crust. The exact transition temperature is a function of strain rate and is not well determined, particularly for a dry diabase rheology, so we will use this as a representative value for comparison to Te estimates. Initial runs have a uniform extensional velocity of 0.1 cm/yr.

For this first set of 9 runs (Zc = 10, 30 and 60; q_m=10, 25, 50 mWm^{-2}) with the extensional velocity set to 0.1 cm/yr, only those models with Zc = 10 km result in wide rifting. Results of the case with the highest heat flow (qm=50 mWm^{-2}) indicate that wide rifting will develop for a surface heat flux in excess of ~90 mWm^{-2} (Figure 1). The total force becomes positive (resulting in wide rifting) at slightly higher values of surface heat flow for thicker crust (Figure 1). This result can be understood by considering that wide rifting requires strengthening of the lithosphere with extension. For thin crust, further thinning the crust becomes an even more significant portion of the lithosphere, causing the lithospheric strength to increase. For high heat flow, the crust is weak and flows readily, reducing the crustal buoyancy force.

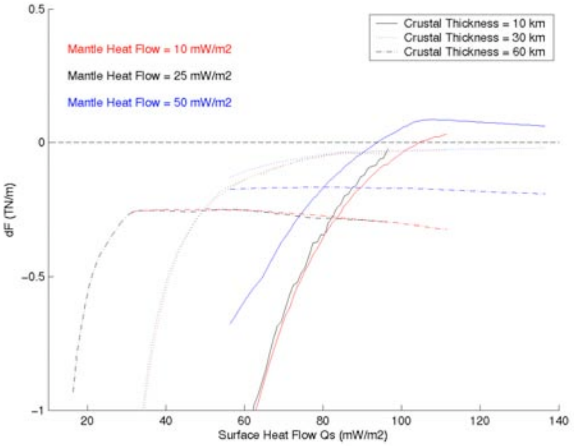

Figure 1. Results for the total estimated force change due to extension are shown for initial runs with an extensional velocity of 0.1 cm/yr versus the surface heat flux, which increases as the crust thins.

Discussion: Rifts in Parga Chasma range from 60 to 240 km in width. By terrestrial standards, these are wide rifts. However, the same classification may not apply to Venus. Our initial results for a dry diabase rheology and an extensional velocity of 0.1 cm/yr show that wide rifts (strength increases with rifting) will occur for Zc = 10 km and mantle heat flux of 50 mWm^{-2}, or for somewhat smaller heat flux values and larger Zc values. This range of Zc and implied approximation to Te fall within the range estimated for some segments of Parga Chasma. The implication is that wider rift segments are likely to have thinner crust, if this model is correct. The next step is to determine the conditions under which each segment of Parga Chasma, with its specific lithospheric properties can be considered wide or narrow. Given estimates of Zc and Te, which can be used to constrain the thermal gradient and associated heat flux, the primary unknown parameter is the extensional velocity. Our study will examine different velocities for consistency with the data.

Future Work: Several tasks are planned to fully address this problem. First, models will be run over a wide range of parameters to establish the conditions (extensional velocity, crustal thickness, and thermal gradient) under which a transition from narrow to wide rifts occurs. Using a classification of admittance values [11,14] we will more precisely determine Zc and Te values for all resolvable sections of the Parga rift. These values will be compared to the rift and fracture characteristics to determine if the estimated Zc and Te values are consistent with a given uniform extension rate and to determine if Venus has wide and narrow rifts in a manner analogous to Earth. One possibility is that the fracture pattern that extends beyond the trough represents the development of a wide rift and that the trough represents a narrow rift. The role of heat flow in controlling rift width, most likely in the form of heating due to coronae, will be examined.

References: [1]Stofan, E.R., et al. (1997) in *Venus II*, U. AZ Press, pp. 845-878. [2] Stofan, E.R. et al. (2001) *GRL*, *28*, 4267-4270. [3] McGill, G.E. (1994) *JGR, 99*, 23,149-23-161. [4] Hamilton, V. E. and E.R. Stofan (1996) *Icarus, 121,* 171-194. [5]. Bleamaster, L.F. and V.L. Hansen (2004) *JGR-Planet*, doi: 10.1029/2003JE002193. [6] Herrick, R.R. (1999) *GRL, 26*, 803-306. [7] Squyres, S.W. et al. (1993) *GRL, 20*, 2965-2968. [8] Herrick, R.R. and R.J. Phillips (1992) *JGR, 97,* 16,107-16,1034. [9] Heironymus, C.F. and D. Bercovici (2000) *EPSL, 181*, 539-554. [10] Buck, W.R. (1991) *JGR, 96*, 20,161-20,178.[11] Anderson, F.S., and S.E. Smrekar (2005) *LPSC XXXVI,* #1804. [12] Mackwell, S.J., M. E. Zimmerman and D.L. Kohlstedt (1998) JGR, 103, 975-984. [13] Chen. W.P., and P. Molnar (1983) JGR, 88, 4183-4214. [14] Smrekar, S.E. et al. (2003) *JGR-Planets,108,*doi: 10.1029/2002JE001935.