RIFT STABILITY ON VENUS: IMPORTANCE OF WEAKENING PROCESSES AND STRAIN RATE. A. A. Martone and L. G. J. Montesi, University of Maryland, Department of Geology, College Park, MD 20742, USA (amartone@umd.edu, montesi@umd.edu).

Introduction: Although Venus lacks a global network of plate boundaries, local tectonic features are strongly reminiscent to the Earth’s [1,2]. In particular, zones of lithospheric extension often form a localized fault-bounded depression, or rift [3,4]. Such features indicate that lithospheric-scale localization is indeed possible on Venus, although it is not sufficient to enable plate tectonics. To understand how the localization characteristics of Earth and Venus differ, we model the stability of rifts against continued extension for Venusian conditions and determine that strain rate probably exerts the principal control on rift morphology. By contrast, the morphology of rifts on Earth depends mainly on the structure of the lithosphere. Therefore, we conclude that localization at lithospheric scale on Venus requires high enough stress and possibly magmatic activity, which depends much more on local characteristics than it would on Earth.

Rift Morphology: Most rifts on Venus are located in an equatorial belt from Thetis Regio to Beta Regio [1]. Rifts appear fault dominated, although volcanic activity, in the form of central volcanoes and/or coronae is locally important. Rifts typically feature an elongated depression bounded by faults, with secondary faulting bringing additional complexity [4].

Beyond these general traits, two main categories of rift may be defined. Narrow rifts consist of a single, well-defined valley. Devana Chasma and Ganis Chasma are clear examples of this morphology. Other rifts consist of several subparallel valleys and are classified as wide rifts. There is no evidence that all the branches of the rift must be active simultaneously, and, by analogy to well-studied wide rifts on Earth, especially the Basin-and-Range province [5], we consider that the center of activity may have switched over time. Therefore, these wide rifts are properly regarded as unstable rifts.

The strain estimated for these rifts is about 0.15 [6]. Therefore, there is no evidence that the different rift morphologies correspond to different development stages. Instead, we search for a mechanical explanation to the difference in rifting mode observed at different locations.

Rift Stability Model: Following [7], we evaluate rift stability by modeling the thermal evolution of a thinning lithosphere and the evolution of crustal thickness due to thinning and lower crustal flow. We compute the change in force needed to continue rifting, with contributions from 1) the integrated strength of the the lithosphere, 2) the buoyancy contrast due to the difference in crustal thickness inside and outside the rift, and 3) the buoyancy contrast due to the difference in temperature inside and outside the rift. If the total force increases upon extension, the nascent rift should be abandoned, a new branch may form, and the rift can be classified as a wide rift. Conversely, if the total force decreases, rifting continues where it was initiated and a narrow rift forms [7].

For application to Venus, we include the rheology of dry diabase for the crust [8] and dry olivine for the mantle [9]. We impose a strain of 10^{-17} s^{-1}, 10^{-16} s^{-1}, or 10^{-15} s^{-1}, over a width of 317 km (corresponding to velocities of 0.1, 1.0, or 10 mm/yr) while varying systematically crustal thickness and surface heat flow. We only consider parameter combinations for which the crust does not melt and the lithosphere is thicker than the crust but thinner than 400 km.

According to this analysis, narrow rifts should form when the crust is thin and/or the heat flow is low, in agreement with previous analyses conducted for Earth conditions [7]. However, strain rate dramatically changes the rift mode (Figure 1a): At 10^{-17} s^{-1}, most conditions lead to wide rifts, whereas at 10^{-15} s^{-1}, wide rifting is expected only for the hottest lower crust.

We also consider the possibility that rock strength decreases exponentially with strain, which is likely necessary to form faults and ductile shear zones [10]. We adopt an exponential weakening law with a critical weakening strain of 0.5, which approximates the actual behavior of a rock undergoing grain size reduction or infiltration by fluids such as melt [11]. Not surprisingly, it is easier to form a narrow rift when weakening processes are included. Including weakening in the ductile regime has the same effect on rift stability as increasing strain rate by an order of magnitude. Brittle weakening increases the crustal thickness for which narrow rifts form by 10 to 20 km (Figure 1b).

Application to Venus: Rift stability depends both on structural parameters (crustal thickness and heat flux) and on dynamic parameters such as strain rate. Strain weakening can be regarded as a fundamental aspect of rocks, especially in the ductile regime, where it is likely associated with grain size reduction. However, it can also be dynamically controlled: the reduction of brittle strength likely involves fluids, which, on Venus, are likely to correspond to magma.

Heat flow constraints only exist for six rifts [12]. Two of these, Devana Chasma and Ganis Chasma are
narrow rifts whereas the others, Hecate Chasma, Parga Chasma, and Dali Chasma are wide rifts. There is no significant difference in heat flux between these rifts.

Crustal thickness from these rifts can be evaluated from the global map of [13]. Crustal thickness varies along each rift and is usually between 15 and 20 km, with the thickest crust at Devana Chasma and the thinnest crust at Dali Chasma. A similar relation is seen in [14]. Everything else being equal, a thicker crust should favor wide rifts, which runs contrary to the observations. Therefore, we conclude that the control on rift mode on Venus does not reside in the structure of the lithosphere but in dynamical parameters.

The correct mode of rifting is predicted if the extension rate is $10^{-17}$ s$^{-1}$ at wide rifts and $10^{-15}$ s$^{-1}$ at narrow rifts. The narrow rifts are located at topographic highs, probably supported by a mantle plume [15]. Plume activity and gravitational collapse of regions of thickened crust [16] may add to the force available for rifting, increasing strain rate. The rift remains hot and the force necessary for extension decreases upon rifting, generating a narrow rift. By contrast, rifts for which extension is slow cool down efficiently, which increases the force necessary for rifting, leading to a wide rift.

**Geodynamical implications:** Stability of rifts on Venus does not depend on the structure of the lithosphere but on background strain rate. Therefore, whether deformation localizes or not depends on the available force. Local phenomena, such as mantle plumes or subduction zones, become important in the force balance and the stability of rifting.

The key difference between Earth and Venus is the low strain rate assumed for Venus: a strain rate of $10^{-17}$ s$^{-1}$ is so slow that conduction keeps the upwelling mantle cool, negating any potential thinning of the lithosphere. Such a strain rate, also low strain rate assumed for Venus: a strain rate of $10^{-17}$ s$^{-1}$ at wide rifts and $10^{-15}$ s$^{-1}$ at narrow rifts for which extension is slow cool down efficiently, which increases the force necessary for rifting, leading to a wide rift.

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Figure 1: Boundaries between rift modes predicted for extension rates of $10^{-17}$ s$^{-1}$ (red), $10^{-16}$ s$^{-1}$ (green), and $10^{-15}$ s$^{-1}$ (blue). Narrow rifts are expected on the thin crust/low heat flow side of the boundary. The thick black lines mark the limit of geologically realistic lithosphere structures. The colored boxes indicate the range of crustal thickness and heat flux for the rifts considered here, as labeled. **Top:** boundary for different strain rates and no strain weakening. **Bottom:** boundaries at $10^{-17}$ s$^{-1}$ with weakening in the ductile regime only, and with weakening in both ductile and brittle regimes.