DUCTILE LITHOSPHERE EXTENSION: IMPLICATIONS FOR RIFTING ON THE EARTH AND VENUS.

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Rift zones are areas of localized crustal extension characterized by a central depression bounded by flanking uplifts, and by thinning of the underlying crust. The topography of rift zones was first examined by Vening Meinesz (1), who suggested that the width of rifts was controlled by elastic flexure and that flanking uplifts formed by isostatic elastic upbending in response to graben subsidence. This model adequately explained the surface morphology of rifts, however, predicted crustal thickening beneath the rift. Bott (2) modified the Vening Meinesz model by considering a viscoelastic crust, in which crustal thinning occurs due to ductile flow in the lower crust. McKenzie (3) examined passive horizontal stretching of the lithosphere and proposed that isostatic rift subsidence occurred in response to crustal thinning and subsequent conductive cooling. This model explained the subsidence history of some sedimentary basins, but failed to account for uplifted flanks associated with the rifts. Artemjev and Artyushkov (4) qualitatively suggested that both crustal thinning and flanking uplifts could be explained by necking of a strong surface layer overlying a viscous substrate. In the present study we quantitatively test this hypothesis by considering rift initiation due to the growth of necking instabilities in an extending lithosphere. In particular, we examine how an initial, small perturbation in the thickness of a strong layer of thickness H overlying a weaker, viscous substrate is amplified by uniform horizontal extension. To assess the relative importance of buoyant upwelling and mechanical instability in rift formation, both density and strength stratification have been incorporated into the model.

Figure 1 shows that characteristic rift zone topography consisting of a central depression and flanking uplifts can result from uniform ductile stretching. The width of the rift zone is controlled by the layer thickness and by the growth rate spectrum, shown in Figure 1, which is a function of the layer/substrate strength contrast, the density stratification, and the stress exponent describing ductile flow. The width of the rift zone thus directly reflects the mechanical structure of the lithosphere. For an initial perturbation that is narrower than the dominant wavelength, surface extension concentrates in a zone comparable in width to the dominant wavelength, while if the initial thickness perturbation is wider than the dominant wavelength, the width of the rift zone is controlled by the width of the initial disturbance. The topography is relatively independent of the geometric form of the initial thickness perturbation. The amplitude of rift topography is directly related to the strength contrast, the mean extension, and to a lesser extent the stress exponent, while the morphology of the rift is most strongly a function of the ratios of buoyancy to strength at the free surface and the layer/substrate interface.

The continental lithosphere is thought to consist of a strong upper crust and mantle separated by a weak lower crust. To form terrestrial rift zones with a typical width of 50-60 km, the strong layer controlling the rift morphology must be about 20 km thick. This is a reasonable estimate of the thickness of a strong crustal layer based on continental geotherms and experimental flow laws. An extending lithosphere with this strength stratification may produce a growth rate spectrum with two maxima and thus two dominant wavelengths of instability (5). We suggest that the shorter wavelength instability may control the width of the rift zone while that at the longer wavelength may determine the horizontal scale of regional doming associated with many rifts.

A rift zone has recently been recognized in the Beta Regio region of Venus (6). Radar-bright lineaments, thought to be faults, and topographic profiles across the rift zone are shown in Figure 2. The rift depression, with a characteristic width of about 100 km, is bounded by flanking topographic highs that may represent uplifted flanks. Based on estimates of rock strength at the high surface temperature of Venus and on the spacing of features of presumed tectonic origin in the banded terrain, Solomon and Head (7) suggest that the elastic lithosphere may be only 1-10 km thick, and thus too thin to explain the width of this rift zone by elastic flexure. If the rift zone formed in response to a necking instability, as discussed above, its width would imply a ductile lithosphere thickness of about 30 km.

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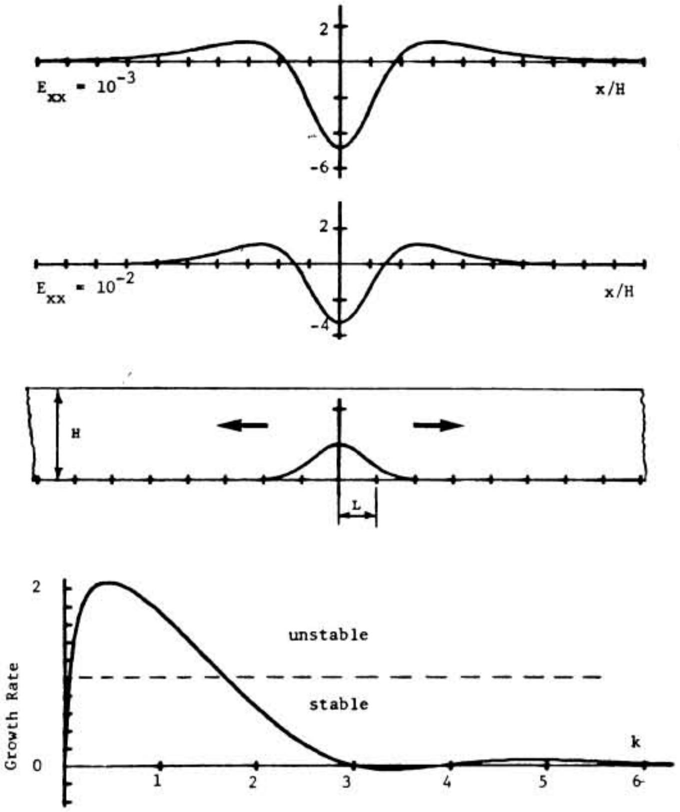

Figure 1. Rift zone topography for two values of the total mean extension E_{xx}, a layer/substrate strength contrast of 10, a stress exponent of 3, and no density contrast. Surface topography is normalized by the amplitude of the initial perturbation and the mean extension. The initial perturbation, presumed to be small in width (L<<H) and amplitude, is plotted with arbitrary size. The growth rate spectrum, q, plotted as a function of wavenumber, k, is normalized by the layer thickness H.

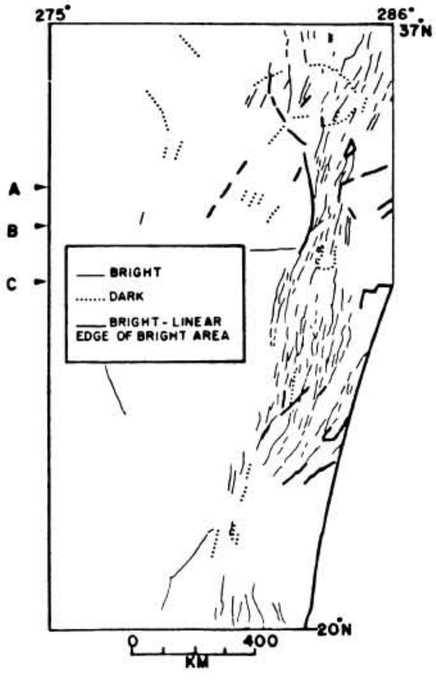

Figure 2. Map of linear features, interpreted as faults, and several topographic profiles of Beta Regio, Venus (6).