A FINITE AMPLITUDE NECKING MODEL FOR THE FORMATION AND EVOLUTION OF RIFT ZONES: APPLICATION TO THE BETA REGIO RIFT; E.M. Parmentier, E.R. Stofan, and J.W. Head, Department of Geological Sciences, Brown University, Providence, RI 02912

Models for the formation of rift zones which examine mechanisms controlling the width of the region of surface extension and the surface topography can provide important insight into the rifting process. In terrestrial rifts, extension associated with rifting begins in a wide region which narrows as the rift develops. This has been described for the East African rift based on the age and distribution of faults (1), and for the Gulf of Suez rift based on sediment thicknesses from well data (2,3). A similar evolution may occur for the Beta Regio rift. First, the width of the region of faulting, as seen in radar bright and dark lineaments, is much broader than the current rift trough. Radar bright lavas of Rhea Mons may cover some of the more widely distributed faults. Since Rhea Mons is dissected by the current rift trough and in this region faulting appears to occur only within the trough, this suggests that faulting has progressively localized toward the center of an initially broader zone of extension. Faults within the rift trough on Rhea Mons are also more closely spaced (5 km) than the older more broadly distributed faults (10-20 km) (4).

Previous models of rifting do not describe this behavior. Elastic flexure (5) has been suggested to explain the initial width of a rift but does not account for the pervasive faulting that occurs within a rift as it develops. A model which treats the lithosphere as a deforming plastic or viscous continuum (6) suggests that the width of rift zones may be related to the dominant wavelength of necking. A perfectly plastic material is adopted as a continuum description of deformation on distributed faults. This model can explain the observed width and morphology of terrestrial continental rift zones and may explain the width of the Beta Regio rift trough without the need for a thick elastic lithosphere. While, this linearized, small amplitude model correctly treats the rift as a zone of faulting, extension is not restricted to the rift zone itself, and the model does not predict the time evolution of the rift.

Results of a finite amplitude necking model which examines the structural evolution of rift zones are shown in Figure 1. Initial deformation within the rift zone occurs within a region about four layer thicknesses wide as predicted by the small amplitude necking model (6). However as the layer in the necking region extends and thins, stresses in the strong layer outside the region of initial localization (dot shading) fall below the yield stress and horizontal extension due to faulting in this region ceases. The width of the region of active necking (diagonal shading), bounded by a yield surface separating rigid and plastic material, decreases as the lithosphere in this region thins. At any stage of the rifting process, this behavior results in a region out side the region of active necking where the strong layer has thinned and extended, but in which extension no longer occurs.

This finite amplitude extension model is based on a one dimensional approximation for plastic flow in the necking region that is valid for small layer thickness variations. The horizontal force balance on a thin vertical slice of material is given by

\[(2K - \sigma_{xx}^{(s)}) \partial H/\partial x + \sigma_{xz}^{(s)} + \rho g H - \sigma_{xx}^{(s)} \partial D/\partial x = 0\]  

(1)

where x and z are the horizontal and vertical coordinates, respectively, K is yield stress, H(x,t) is the layer thickness, D(x,t) is the surface topography, \(\rho\) is the density of the layer, g is the gravitational acceleration, and \(\sigma_{ij}^{(s)}\) is the stress in the substrate at the base the layer. The evolution of the layer thickness is governed by the incompressibility condition

\[\partial H/\partial t + u \partial H/\partial x = -H \partial u/\partial x\]  

(2)

where u(x,t) is the horizontal velocity of the layer. The left side of this equation is the time rate of change of layer thickness following a material column, and the right side is the rate of thinning of that column due to horizontal extension.

For simplicity, a thin viscous layer is adopted as the substrate of the strong plastic layer so that \(\sigma_{xz}^{(s)}=\mu u/d\) where \(\mu\) and \(d\) are the viscosity and thickness of the viscous layer. This leads to a single equation which describes the evolution of \(H(x,t)\) as an inverse diffusion process with a diffusivity \(2KdH/\mu\). Layer thickness within the zone of yielding, as shown in Figure 1, is described by the same solution as that for the temperature in a cooling, solidifying dike (7) but with time running backwards. In this simple approximate model, short wavelengths of deformation are rapidly and unrealistically amplified in the inverse diffusion process. This is a consequence of neglecting terms in equation (1) related viscous normal stresses in the substrate and to the shear stress-velocity relationship in the viscous substrate layer that is valid only at long wavelengths. Numerical solutions required to alleviate the need for these approximations are being formulated. However, the simple approximations leading to the results in Figure 1 suggest that the more complete model will describe important characteristics of the evolution of rift zones that have not been predicted by earlier models and which are observed both in terrestrial rift zones and in the Beta Regio rift on Venus.
Finite Amplitude Neaking Model for Rift Zones

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Figure 1. Finite amplitude necking of a strong rigid-plastic layer. The width of the region of necking (diagonal shading) decreases as the layer in this region thins. The distribution of extension rate within the necking region is controlled by shear stresses in the viscous substrate of the layer. The resulting surface topography is due to a combination of plastic flow in the necking region and isostatic compensation by elastic flexure (5) of the layer outside this region.