BUOYANCY AND EXTENSION IN RIFTING: IMPLICATIONS FOR THE ALONG-AXIS DISTRIBUTION OF VOLCANISM; E.M. Parmentier, Department of Geological Sciences, Brown University, Providence, RI 02912

The relationship of volcanism and tectonism is important to understanding the formation of rift zones. As in terrestrial rift zones, volcanism along the Beta Regio rift, Venus, appears to be contemporaneous with extension: some radar lineaments interpreted as faults clearly transect constructional volcanic features (cf. 1) while what may be earlier formed faults appear to be covered by unfaulted volcanic deposits (2). Along the Beta Regio rift, volcanism appears to localize in two large volcanic centers, Rhea and Thea Mons, rather than being uniformly distributed along the rift. In contrast bright terrain bands on Ganymede, also thought to be rifts where both extension and volcanic resurfacing has occurred (3), show no obvious evidence for the localization of bright terrain emplacement. This study examines the implications of the along-axis localization of volcanism during extension.

Volcanism is a result of partial melting and the buoyant rise of magma. Previous models of buoyancy-driven flow beneath rift zones have all been two dimensional (e.g. 4) or have considered the consequences of buoyancy only after necking of lithosphere by extension has already occurred (5). These models do not consider how the buoyant rise of magma may be distributed along the rift axis to produce volcanic centers. If a low density, low viscosity mantle layer forms beneath the lithosphere, the distribution of rising diapirs and their spacing along the rift axis will be controlled by the dominant Rayleigh-Taylor instability wavelength. This has been suggested as an explanation for the volcanic segmentation length of terrestrial spreading centers (6,7,8). However, earlier studies have neglected the effect of plate extension which is a fundamental characteristic of rifting.

To examine the combined effects of plate extension and buoyant instability, consider a strong surface layer of density ρ, viscosity μ, and thickness d, representing the lithosphere, overlying a much weaker layer of density $\rho-\Delta\rho$, representing accumulated magma or partially molten mantle beneath the lithosphere as shown in Figure 1. Horizontal extension occurs at a prescribed rate E_{xx}, and the growth of small amplitude harmonic disturbances, with a given wavelength and direction of wavenumber vector, is characterized by a growth rate q. Disturbances grow, that is diapirs will form, only if $q>0$. In the absence of horizontal extension, the growth rate depends on wavelength but is independent of the direction of the wavenumber vector. In the presence of horizontal extension, harmonics of the same wavelength but with wavenumber vectors parallel and perpendicular to the extension direction have different growth rates. In Figure 2, growth rates normalized by E_{xx} are plotted as a function of wavelength for a range of $\Delta\rho/\rho$ values and for specific values of $G=\rho gd/\mu E_{xx}$ and R, the ratio of the viscosity of the low density layer to that of the surface layer. The growth rate can be represented as the sum of contributions from horizontal extension and buoyancy acting separately. In the absence of both buoyancy ($\Delta\rho/\rho=0$) and a viscosity contrast (R=1), $q=-E_{xx}$ in both the extension and along axis directions reflecting the effect of vertical shortening associated with horizontal extension. In the extension direction, the strength contrast between the surface layer and its weak substrate layer result in a necking contribution to the growth rate so that the maximum growth rate in the absence of buoyancy approaches zero for small values of R. For a linearly viscous material with a stress exponent of unity, as considered here, necking alone is not unstable. For stress exponents n greater than unity, as expected for dislocation creep (n=3) or perfectly plastic behavior representing deformation on distributed faults ($n\rightarrow\infty$), necking instabilities in addition to buoyant instabilities will increase the growth rate of disturbances in the extension direction. Buoyancy increases growth rates relative to their values with $\Delta\rho/\rho=0$. The growth rate, maximized with respect to wavelength, is given in Figure 3 as a function G for $\Delta\rho/\rho=0.1$ and a range of R values. The growth rate is given for wavenumber vectors parallel and perpendicular to the direction of extension.

These results show that periodic disturbances along the rift axis always grow more slowly than those perpendicular to the axis. For a very weak low density layer (e.g. $R\leq0.1$), along-axis disturbances are unstable only if G exceeds a minimum value that depends on $\Delta\rho/\rho$: for localized diapiric upwelling to develop along the axis $G>4\rho/\Delta\rho$. If values of μ, $\Delta\rho/\rho$, and d are prescribed or can be estimated, the existence of volcanic centers along a rift zone due to diapirs which develop during extension may place an upper buond on the extension rate of rifting. Extension must occur slowly enough to allow the growth of along-axis disturbances.

References: (1) Campbell, D.B., et al., Science 226, 167-170, 1984. (2) Parmentier, E.M.,et al., Lunar Planet. Sci. 18, 764-765, 1987. (3) Parmentier, E.M., et al., Nature 295, 290-293, 1982. (4) Keen, C.E., Geophys. J. Roy. Astr. Soc. 80, 96-120, 1985. (5) Buck, W.R., Earth Planet. Sci. Lett. 77, 362-372, 1986. (6) Bonatti, E., Nature 316, 33-37, 1985. (7)Crane, K., Earth Planet. Sci. Lett. 72, 405-414, 1985. (8) Schouten, H., et al., Nature 317, 225-229,1985.

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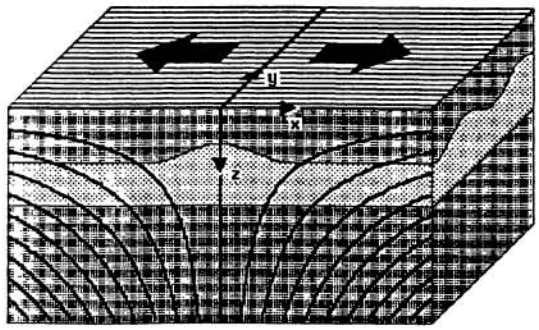

Figure 1. Horizontal extension of a viscosity and density stratified halfspace. A strong layer (dark shading) representing the lithosphere overlies weaker, lower density material (light shading) representing a layer of melt or partially molten mantle. Horizontal extension occurs in the x-direction as shown by arrows.

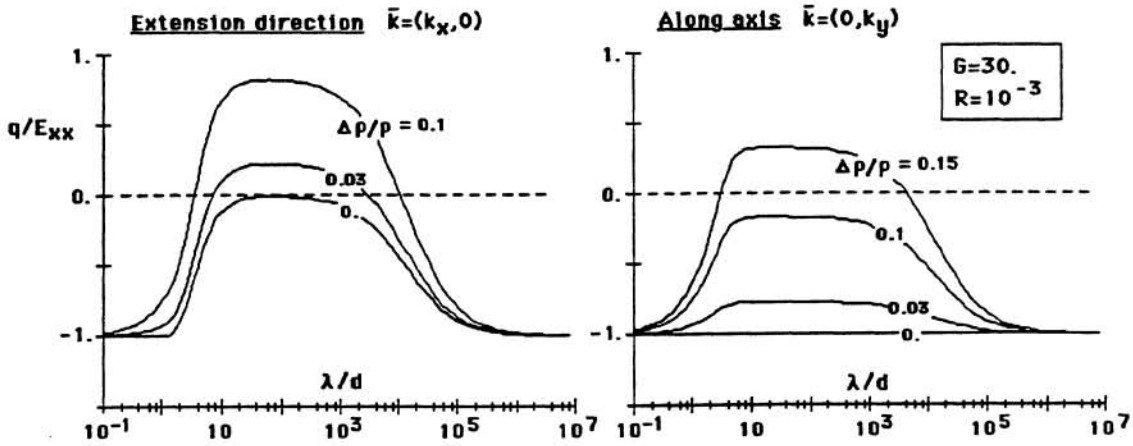

Figure 2. Growth rate q of harmonic disturbances as a function of wavelength with wavenumber vectors in the extension and along-axis directions. See text for further discussion.

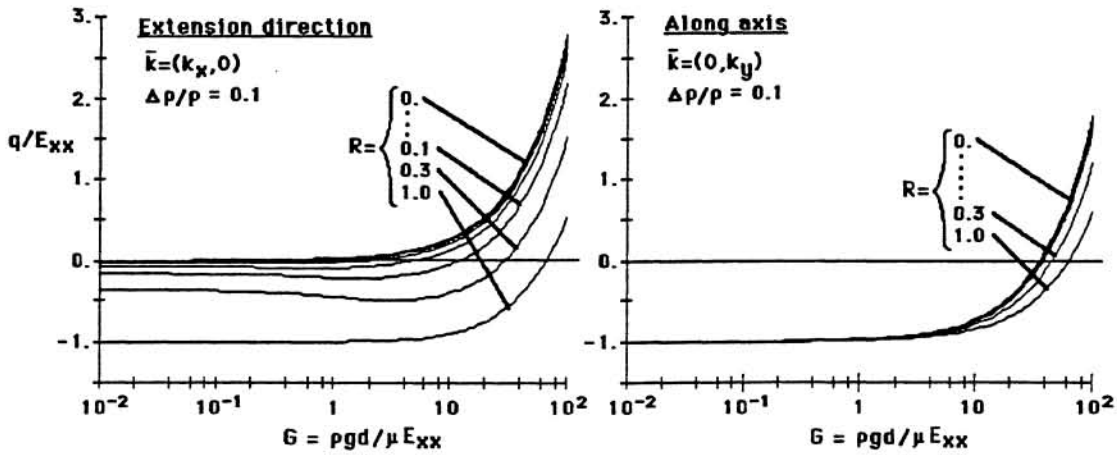

Figure 3. Growth rate of harmonic disturbances, maximized with respect to wavelength (see Figure 2), as a function of the dimensionless parameter G for a range of R values. The growth rate of along axis disturbances is always less than that for disturbances in the extension direction. For small R, disturbances in the extension direction are unstable for all values of G. The value of G must exceed a minimum value for along axis disturbances to be unstable.