

**LIMITS ON LITHOSPHERE EXTENSION AND MECHANISMS OF RIFTING ON GANYMEDE.** M.T. Zuber, E.M. Parmentier, and S. Joffe, Department of Geological Sciences, Brown University, Providence, R.I. 02912

It is generally accepted that bright terrain on Ganymede formed in an extensional tectonic regime, however the mechanism of formation remains uncertain. Various geologic evidence (1,2) is consistent with formation by finite lithospheric extension, in which case bright bands may be analogous to terrestrial rift zones. However, many outstanding questions remain regarding the structure of bands, the amount of extension associated with bright terrain formation, and the global mechanism of rifting.

Structural relationships between bright terrain units provide a basis for interpreting the style of global tectonics. Of particular interest is the geometry of intersections between bright bands. Such intersections are ubiquitous on the surface and may be classified into relationships where bands: 1)merge or bifurcate along strike; 2)cross-cut; and 3)form a terminating or *T* structure. The angle of intersection for mergers and bifurcations is difficult to measure precisely, but occurs at angles less than 50°. Cross-cutting and terminating relationships, which involve two discrete bright bands, intersect at a mean angle of about 70°, as shown in Fig. 1. The intersection of bands at high angles is consistent with bright terrain formation by the progressive accumulation of lithospheric stress. The older band relieves stress in a direction perpendicular to the strike of the band, and subsequent stress accumulation causes failure in a direction approximately normal to the first-formed band.

Constraints on the amount of extension associated with bright bands is of fundamental importance in understanding the mechanism of rifting. We propose two independent methods of estimating extension across regions of bright terrain. These include: 1)measurement of offset across cross-cutting bands; and 2)analysis of strain in craters around wedge-shaped band tips. Where bands cross-cut, the amount of offset *d* normal to the strike of the older band can be used to determine the amount of extension in the younger band by the simple relationship  $E = d/w \cos \psi$ , where *w* is the width of the younger band and  $\psi$  is the angle of intersection. For a given offset, the amount of extension can best be determined for intersecting bands with large *w* and small  $\psi$ . Since most bands intersect at high angles, it is often difficult to discern even moderately large amounts of extension. Measurements of cross-cutting bands in high resolution Voyager 2 images (approx. 1.3 km/lp) indicate negligible offset and therefore little extension. However for most cases at this resolution, it is not possible to recognize extension of less than several tens of percent. In order to identify modest amounts of extension in cross-cutting bands on a global basis, sub-kilometer resolution of surface features will be required.

An alternate estimate of the amount of extension associated with bright terrain formation can be obtained by examining wedge-shaped bands which penetrate into dark terrain regions. If these wedges formed in a manner similar to a mode I extension crack, then deformation should be concentrated near the crack tips within the dark terrain. Impact craters which predate the wedges can be used as a measure of this deformation. As shown in Fig. 2, the extension  $E = \alpha/\beta$  associated with a wedge of angular width  $\beta$  may cause initially circular impact craters surrounding band tips to deform into ellipses whose axial ratios and orientations characterize the strain field. The predicted ratio of the minor/major axes in a deformed crater can be obtained from a solution for an opening crack in a viscous layer. This yields

$$\frac{b}{a} = 1 - \frac{\sqrt{2}\alpha}{\pi} \left[ \left( 1 - \frac{\pi\sigma_n}{\alpha\mu} \right) (1 - \cos 2\theta) + \frac{1}{2} \left( \frac{\pi\sigma_n}{\alpha\mu} \right)^2 \right]^{1/2}$$

where  $\sigma_n$  is the normal stress on the crack face and  $\mu$  is the viscosity of the lithosphere. These results can be compared to the geometry of craters on the surface. The mean axial ratio of 29 craters around 6 wedge-shaped bands determined by the method of Zuber and Parmentier (3) is  $0.82 \pm 0.08$ . However the orientation of the major axes of almost every observed crater is aligned in the direction of the sun on the Voyager image and not in the direction predicted due to extension across the wedge. Hence the discernible non-circularity of craters around band tips at Voyager resolution is not a consequence of extension across the band, but is an artifact of the sun angle,

even after appropriate corrections have been made for the viewing geometry. Measurements from Voyager images show that the amount of extension beneath wedges with  $\beta > 16^\circ$  is less than 100%. However, higher resolution images with multiple phase angle coverage would be required to recognize smaller amounts of deformation.

Rifting on a planetary surface may be the result of localized extension of the lithosphere in response to global stresses (passive rifting) or of diapiric upwelling of less-dense material from depth (active rifting). Rifting due to localized extension is expected to form in a direction normal to the greatest tensional stress or in a direction of pre-existing linear structural weakness. Diapiric upwelling is expected to develop periodically in two directions and is characteristically accompanied by volcanic domes which mark the positions of initial lithosphere failure. On Ganymede, the distribution of bright terrain bands forms a non-regular pattern on the surface, and localized centers of volcanic activity along bright terrain bands are not observed. This raises question as to the importance of diapirism in controlling bright terrain formation.

Of considerable interest is the factor(s) which control the distribution of rift zones on the surface. One possibility is that rifts nucleate at pre-existing lithospheric thickness heterogeneities. For an extending plastic layer overlying a viscous substrate, the growth rate of small amplitude sinusoidal variations in layer thickness depends on wavelength (4), the fastest growth occurring near the dominant wavelength. An area of initially thinner lithosphere that is narrow compared to the dominant wavelength will grow wider until its width is comparable to this wavelength. The initial small amplitude stage of deformation may thus form a region of necking in which finite amplitude deformation concentrates with continuing horizontal extension. The dominant wavelength for small amplitude disturbances in this simple model depends primarily on the plastic layer (lithosphere) thickness; other factors such as buoyancy forces due to surface topography and rheological structure appear to be less important. However, the role of internal density and temperature stratification within the layer and substrate has not been previously considered. Bright terrain bands on Ganymede have a variety of widths that show no apparent systematic variation with sequence of emplacement. This may reflect global variations in lithosphere thickness, variations in the width of lithosphere thickness heterogeneities at which rift zones nucleate, or increases in the width of a region of lithospheric necking with increasing horizontal extension.

**References:** (1)Parmentier, E.M., et al., *Nature*, 295, 290-293, 1982. (2)Shoemaker, E.M., et al., *The Satellites of Jupiter*, Univ. Ariz. Press, 1982. (3)Zuber, M.T., and Parmentier, E.M., submitted to *Icarus*, 1981. (4)Fletcher, R.C., and Hallet, B., *J. Geophys. Res.*, 88, 7457-7466, 1983.

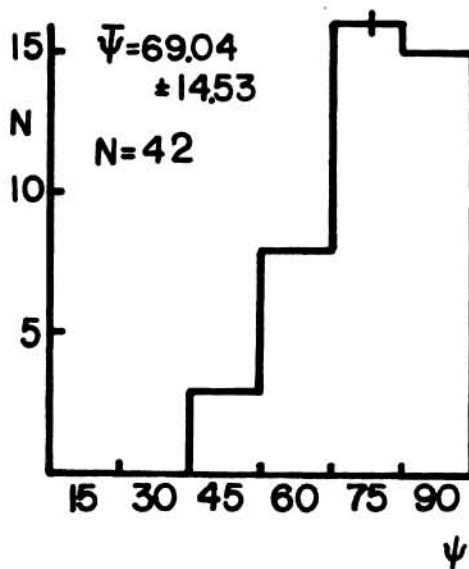


Figure 1. Histogram of intersection angles of cross-cutting and truncating bright bands.

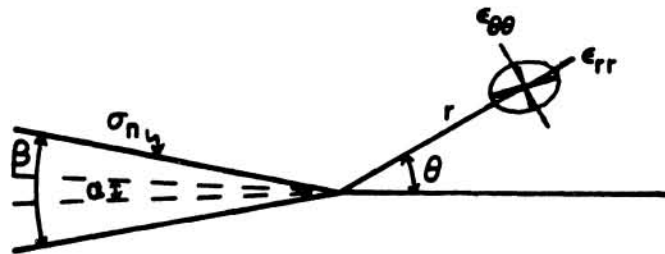


Figure 2. Geometry of an opening crack in a viscous layer. If the strain components at point  $(r, \theta)$  are known, then the amount of extension  $a/\beta$  beneath a wedge of angular width  $\beta$  can be determined.