DOES EUROPA'S SURFACE MANIFEST EVIDENCE OF POLAR WANDER?

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Previous studies have compared the orientation of the lineaments on Europa's surface with the global stress fields set up by orbital eccentricity, orbital recession, and non-synchronous rotation [1–4]. Of these orbital and rotational effects, non-synchronous rotation, combined with an offsetting of the tidal bulge, has come closest to providing agreement between the stress field generated and the lineament orientations [4]. However, inferred minimum stress directions for a zone of wedge shaped bands near the anti-Jove point cannot satisfactorily be accounted for by any of the above mentioned effects, but are consistent with a clockwise rotation (as seen at the anti-Jove point) of Europa's shell about an axis through the sub and anti-Jove points [5,6]. Calculations of the thermal state of Europa's ice shell indicate that spatial variations in the thickness of the shell may cause it to undergo a reorientation which would produce the stress field inferred from the wedge shaped bands [7,8]. We investigate whether a reorientation of the shell about an axis through the sub and anti-Jove points produces a stress field consistent with the lineament orientations over large regions of Europa's surface, rather than merely in a zone near the anti-Jove point.

To calculate the stress directions and magnitudes caused by reorientation we consider a thin elastic shell of uniform thickness, decoupled from the interior. For the thin shell approximation, stresses normal to the shell are very small and are assumed to be zero. The tidally distorted figure of Europa is a triaxial ellipsoid, which can be treated as the superposition of two biaxial deformations [1]. For a reorientation about the tidal axis, one of the biaxial deformations remains constant, and the problem becomes that of the reorientation of a rotationally distorted body. This problem has already been investigated [9]. The elastic properties of the shell do not affect the shape of the tidal bulge, thus the directions of the principal stresses are independent of the elastic properties of the shell and of the Love number that characterises the size of the tidal distortion. However, the magnitude of the bulge and the elastic properties do affect the stress magnitudes. For a reorientation through 90° we calculate maximum stress differences on the order of 5 MPa at the sub and anti-Jove points, and maximum tensional stresses of about –4 MPa at the leading and trailing apices.

A digital mosaic of Europa was compiled from Voyager images and 62 of the most prominent lineaments were digitized. The azimuths of the lineaments were calculated at approximately 50 km intervals. At each point that a lineament azimuth was measured, the direction of the maximum horizontal stress due to reorientation was also calculated, and the angle between the two recorded. Histograms of the angle between the lineaments and the maximum horizontal stress for reorientations of 1/2° clockwise and anti-clockwise (when looking down onto the anti-Jove point), and 90° are shown in Figs. 1, 2, and 3 respectively. The 1/2° rotations represent the instantaneous stresses set up by reorientation. Figure 4 shows a histogram of the angle between the lineaments and the maximum horizontal stress direction for non-synchronous rotation, assuming that the tidal bulge was located 25° east of its present position, this being the combination chosen by McEwen [4] as best explaining the lineaments.

If the lineaments formed as tension or extension cracks, they should be oriented perpendicular to the most tensional (minimum) stress direction, which means that in most cases they should be parallel to the maximum horizontal stress direction. Figs. 1 and 2 each show some preferential orientation of lineaments at about 55° and 35° respectively to the maximum horizontal stress, but the general trend in both cases is for uniform (random) orientation. Although in the anti-clockwise case (Fig. 2) the 35° peak is close to that which would be expected for shear fractures, the magnitude of the stresses involved is less than 0.1 Mpa, and is well below the expected shear strength of the shell.

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There is a definite trend in the data for the case of a 90° rotation (Fig. 3); however, it is towards a prefered orientation perpendicular to the maximum horizontal stress. Because the fractures are most unlikely to be the result of thrusting, there is no obvious physical explanation for the trend seen in Fig. 3. Figure 4 shows the strong prefered orientation expected for lineaments formed as tension or extension cracks, and provides strong support for non-synchronous rotation as the fracturing mechanism on Europa. This confirms the results of McEwen [4], even though we analyzed a similar but not identical set of lineaments.

Reorientation about the tidal axis is not precluded because the time scale for reorientation may be significantly shorter than the time scale for non-synchronous rotation [8], so reorientation may only occur episodically. With the exception of the anti-Jove point, which does show evidence for reorientation, the points where reorientation stresses are most likely to be manifest (the apices and sub-Jove point) are poorly imaged. However, there is no compelling evidence that shell reorientation has taken place, and non-synchronous rotation of the shell still seems to be the most likely cause of the fracturing of Europa's surface.

References. [1] Helfenstein, P. and E.M. Parmentier (1980) *Proc. Lunar Sci. Conf.* 11th, 1987-1998; [2] Helfenstein, P. and E.M. Parmentier (1983) *Icarus* **53**, 415-430; [3] Helfenstein, P. and E.M. Parmentier (1985) *Icarus* **61**, 175-184; [4] McEwen A.S. *Nature* **321**, 49-51; [5] Schenk, P. and W.B. McKinnon *Icarus* **79**, 75-100; [6] Golombek, M. and W.B. Banerdt (1990) *Icarus* **83**, 441-452; [7] Ojakangas, G. and D.J. Stevenson (1989) *Icarus* **81**, 220-241; [8] Ojakangas, G. and D.J. Stevenson (1989) *Icarus* **81**, 242-270; [9] Melosh, H.J. (1980) *Icarus* **44**, 745-751.

Figure 1

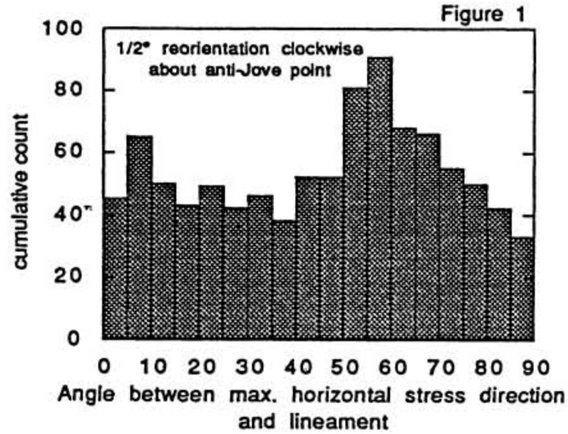

Figure 2

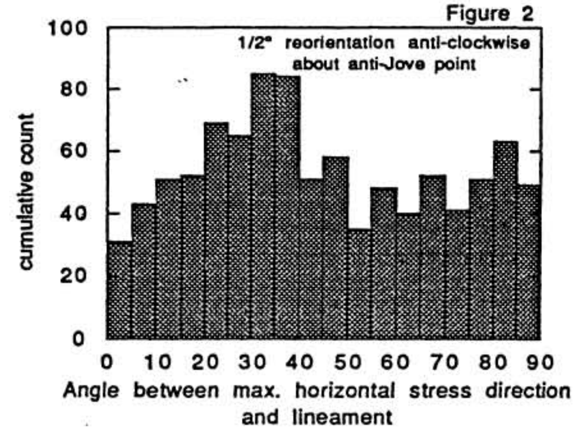

Figure 3

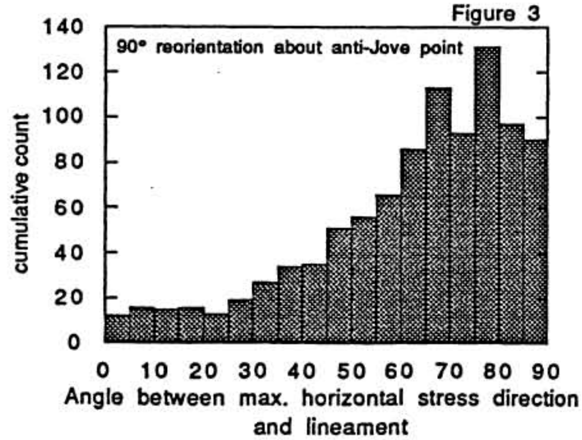

Figure 4