INTERNAL STRESSES OF IO ARE REVEALED BY SURFACE LINEATIONS.

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Introduction: Jupiter's closest Galilean satellite Io undergoes a tremendous amount of tidal stress and resultant deformation [1]. Several prominent surface features of Io have associated lineations, many of which stretch for tens of kilometers and likely indicate lithospheric fracturing resulting from internal tectonic stresses. We analyze lineations on paterae, mountains, and chains of volcanoes to determine stress directions in Io's lithosphere and the effects of tidal stresses on the surface features of Io.

Lineations on Mountains, Paterae, and Hotspot chains: Io's mountains are generally isolated, not in long chains, and appear to be uplifted and tilted blocks [2,3,4,5,6]. Many of the mountains are fractured, are bounded by fault scarps, or have linear summit traces [4]. Paterae, depressions similar to calderas, likely have a tectonic component to their formation revealed in linear portions of many of their margins [7]. Some of these lineations connect to adjacent mountains or lie along obvious fault lines that extend away from the patera, while others are isolated and only form the patera margin. The linear features seen in mountains and paterae were traced in ArcGIS, using the Io Arc project (to 65° N and S latitude) of combined *Voyager* and *Galileo* images, most at 1-2 km/pixel, produced by the USGS Astrogeology division [8]. In addition, six larger lineations in the form of volcanic chains, or strings of seemingly related volcanoes, were traced. These include the Chaac-Camaxtli string of volcanoes that may be the surface expression of a large, lithospheric fracture system [9].

Lineation Lengths: Lineations measured on Io's surface total 331, with 113 being mountain-related lineations and 212 being patera-related. If linear features such as mountain fractures were parallel and adjacent, they were not measured twice. The resolution limitations of the images meant that only features longer than 9 km were measured. Measured mountain lineations are longer than for paterae, having a mean of 148 km compared to a mean of 48 km. The mean for patera lineations is similar to that of patera diameters [7,10], indicating lineations on paterae often extend across the entire feature and likely help control their size.

Lineation Orientations: Azimuths (orientations from north) of all lineations show a minimum at 90°, or E-W, and perhaps a lesser minimum at 180°, or N-S oriented. This is apparent in both the rose diagram (Fig. 1) and histogram (Fig. 2) of these data. These minima are apparent in data for the Anti- and Subjovian quadrants, but not conclusively in the leading and trailing quadrants (Fig. 3). The troughs at 90° and 180° are evident in data for paterae alone, and are much less evident in data for mountains alone (Fig. 4).

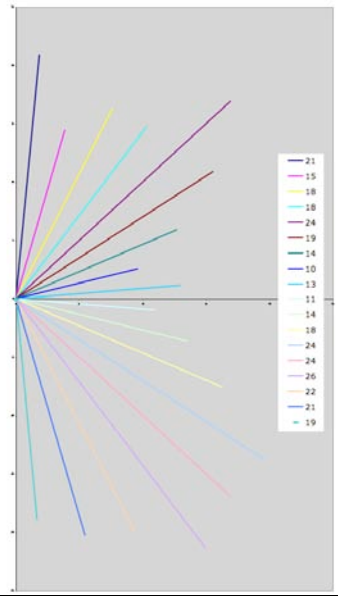

Fig. 1. Rose diagram of all lineations on Io. Numbers in legend indicate numbers of features at the orientation indicated.

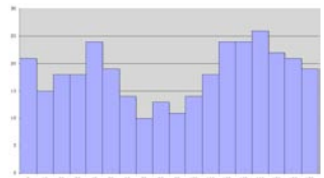

Fig. 2. Azimuths of all lineations - mountains, paterae, and volcano chains - on Io in degrees from north. Maximum is 30.

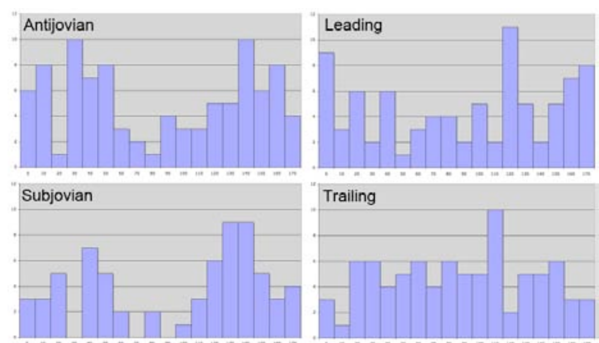

Fig. 3. Azimuths of all lineations broken out by hemisphere. Antijovian: 135°-225°, Trailing: 225°-315°, Subjovian: 315°-45°, Leading: 45°-135° W longitudes.

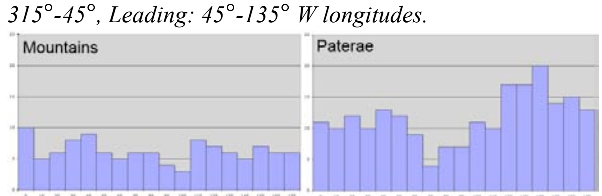

Fig. 4. Azimuths of all lineations broken out by feature, mountains and paterae, same relative vertical scale (maximum is 25).

Stress Orientations: The minima in the azimuths of lineations on Io reveal that stresses, if they are extensional, are not typically N-S or E-W, especially in the sub- and anti-jovian hemispheres and for paterae in general. Favored orientations are seen at 45° and 135°, indicating the orientation of extension. If stresses are compressional, they are parallel to these lineations, indicating stress orientations of 135° and 45°.

Fracturing in Io's lithosphere is thought to result from magmatic processes indirectly resulting from tidal stresses [5,11]. Magmatic upwellings related to asthenospheric tidal heating occur, causing lithospheric thinning and extension and increased volcanism (and patera formation). These are predicted by models and are observed in increased numbers of paterae in the sub- and anti-jovian quadrants [7]. Corresponding downwellings, compressive stresses, and resulting uplift and mountain formation occur in the leading and trailing quadrants [3,12]. In these models, generally extension leads to patera formation and compression to mountain formation [11]. Our data for lineation orientations in the sub- and anti-jovian quadrants, where higher concentrations of paterae are found, show more prominent peaks at 45° and 135° than do orientations in the leading and trailing quadrants (and mountains alone). Perhaps these peaks are perpendicular to the dominant extensional stresses on Io.

Conclusions: The first global study of lineations on Io reveals that lineations, and therefore internal stresses, occur at all orientations on Io, however, there are some orientations that are favored (or more prominent). Lineations with N-S and E-W directions, especially at the sub- and anti-jovian hemispheres, are less common. That there is a difference in orientations of lineations by hemisphere indicates nonsynchronous rotation must not be occurring at rate greater than the erosion or burial of the fractures, or we would see a more uniform distribution.

Further analysis of these data will reveal global and regional stress directions, and analyzing them locally could help illuminate the formation processes of individual features. Although paterae and mountains are globally anticorrelated, locally some paterae are adjacent to mountains. Studying the lineations in regions where paterae are found in proximity to mountains will be especially valuable, as the stresses here likely led to the formation of both features.

References: [1] Thomas et al. (1998) *Icarus* 135, 175-180. [2] Turtle, E.P. et al. (2001) *JGR* 106, 33175-33199. [3] Schenk, P.M. et al. (2001) *JGR* 106, 33201-33222. [4] Turtle et al. (2009) *Io After Galileo*. [5] Schenk P.M. and M.H. Bulmer (1998) *Science* 279, 1514-1517. [6] Jaeger W.L. et al. (2003) *JGR* 108. [7] Radebaugh J. et al. (2001) *JGR* 106, 33005-33020. [8] Becker, T. et al. (2005) *LPSC*. [9] Williams D.A. et al. (2002) *JGR* 107. [10] Barth B. et al. (2010) *LPSC*. [11] McKinnon et al. (2001) *Geology* 29, 103-106. [12] Tackley et al. (2001) *Icarus* 149,79-93.

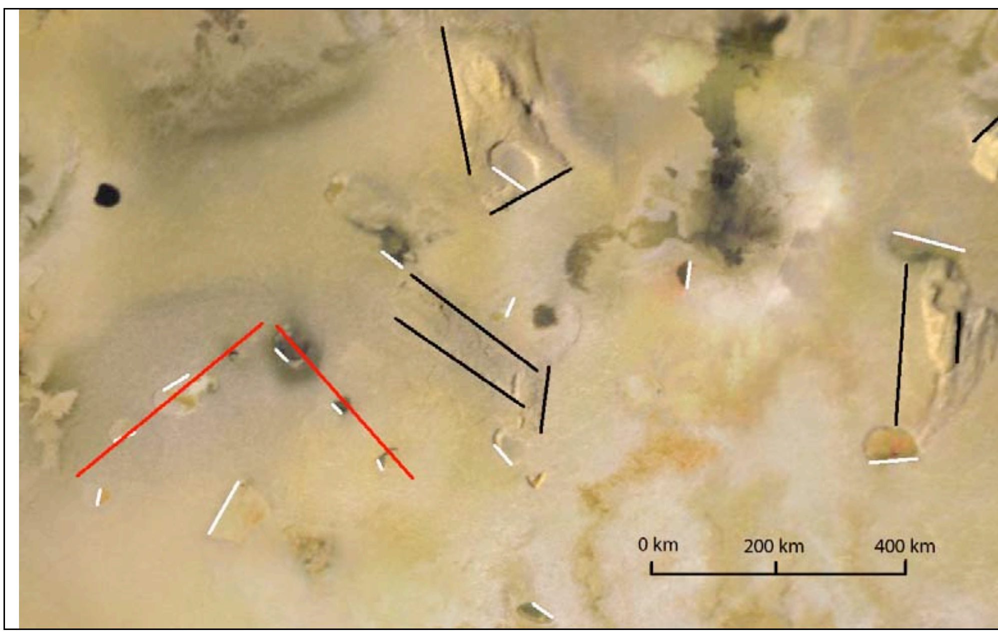

Fig. 5. Lineations on Io as measured in ArcGIS on Galileo basemap. Black = mountain-related lineations, white = patera lineations, and red = volcanic chains.