EVIDENCE FOR EPISODIC FORMATION OF EUROPA'S GLOBAL LINEAMENTS VIA NON-SYNCHRONOUS ROTATION. Zane A. Crawford[1] and Robert T. Pappalardo[1], [1]Laboratory for Atmospheric and Space Physics and the NASA Astrobiology Institute, University of Colorado, Boulder, CO 80309-0392, zane.crawford@colorado.edu.

Introduction: Many global-scale linear features on the surface of Europa appear, when translated to the west, to trace paths on the moon's surface roughly orthogonal to the most tensile stresses generated by non-synchronous rotation (NSR) of the ice shell. To best match the entire set of observed global lineaments simultaneously to the global non-synchronous stress field, the features must be translated westward between 25° and 30° [1-3]. Thus, it has been suggested that these features have been forming continuously for the last 50° to 60° of shell rotation. We show that a variety of scenarios in which lineaments form in several discrete episodes can produce fits to the NSR stress field that are as good or better than fits produced by a continuous formation scenario. These analyses do not yet take into account the apparent cross-cutting relationships between global lineaments.

Model Setup: Our model of Europa's surface stresses is derived directly from the gravitational potential [4,5]. The internal structure of the satellite is described using the degree two Love numbers h_2 and l_2. The ice shell is taken to be ~20 km thick, decoupled from the rocky interior by a global ocean, and elastic on the timescale of NSR [cf. 6].

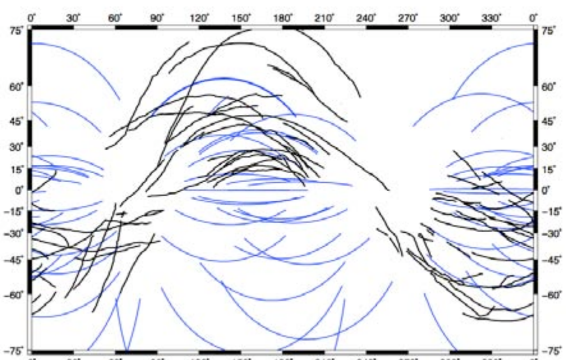

Fig. 1. Comparison of mapped lineaments on Europa (black) to synthetic lineaments (blue) formed in a near-continuous manner.

We produce sets of synthetic global lineaments (blue and red curves of Figs. 1 and 2) by assuming tensile failure orthogonal to the greatest tensile principal component of the stress field. For each synthetic dataset, a number of random locations are chosen on the surface of Europa, and synthetic lineaments are allowed to propagate away from those points until they naturally terminate in regions with insufficient tensile stresses to cause failure. Note that this approach excludes consideration of equatorial regions in which both horizontal stresses are compressional.

In order to compare a given modeled stress field to a given set of mapped or synthetic lineaments, we calculate the stresses at the midpoint of each of the many small line segments making up the lineament, and measure the difference between the expected direction of tensile failure and the observed orientation of the lineament segment. These differences in orientation are used to calculate an RMS error between the observed and predicted lineament orientations, weighted according to the lengths of each line segment.

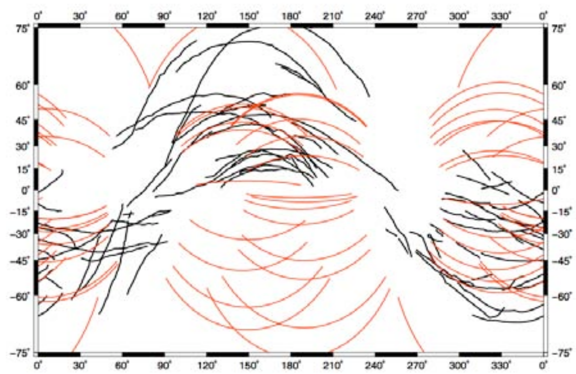

Fig. 2. Comparison of mapped lineaments on Europa (black) to synthetic lineaments (red) that represent episodic lineament formation.

The actual global lineaments are digitally mapped from the USGS coordinate-controlled basemap of Europa [7] using GIS software (black curves of Figs. 1 and 2). Only those features spanning several hundred km are included. Those that are grossly inconsistent with the hypothesis of tensile failure in a NSR stress field (e.g. those oriented nearly north-south) are removed. The remainder are compared to the NSR stress field at a variety of westward translations.

For the mapped global lineaments, the RMS difference between observed lineament orientation and expected tensile failure direction is minimized with a westward translation of 33°. The minimum

RMS difference in orientation between the mapped lineaments and the local tensile stress direction is 27°. The unfiltered set of global lineaments also has a minimum RMS difference in orientation at 33° westward translation, suggesting that no bias was introduced in the selection process. The difference in orientation is fairly large because the global lineaments probably were not formed simultaneously, but rather probably formed over a long period of time during which the ice shell underwent NSR. Thus, this value of 33° presumably represents the average amount of westward translation required to best match the individual global lineaments.

We determine the RMS difference in orientation between the NSR stress field and a given set of mapped or synthetic lineaments for a variety of westward translations. In this way, the formation histories of the different lineament sets can be assessed. In Fig. 3, we compare the RMS difference plot for the actual mapped global lineaments to that for three different sets of ~50 synthetic lineaments. (1) The first synthetic set (red curves of Fig. 1) represents the hypothesis of near-continuous formation over the last 66° of ice shell rotation, modeled as 4 lineaments formed at each 5° interval of shell rotation (4 at 65° of backrotation, 4 at 60°, 4 at 55°, etc.). (2) The second represents a more episodic formation history, in which 8 lineaments are formed at each 11° interval of backrotation up to 66° (not pictured). (3) The third represents an episodic formation hypothesis (blue curves of Fig. 2) composed of four sets of 12 lineaments formed at 11°, 15°, 51° and 55° of backrotation. Each of these scenarios is symmetric about 33° of back rotation of the shell, and thus will minimize their RMS differences in orientation at a similar amount of westward translation as the mapped lineaments (33°).

Results: The fits from the mapped global lineaments and the synthetic dataset representing continuous formation dataset are noticeably different (Fig. 3). The plot of RMS difference in orientation versus the amount of back rotation for the synthetic, continuously formed lineaments is very nearly linear, increasing to a maximum 90° of shell rotation away from the 33° westward translation, whereas the mapped lineaments produce a more sinusoidal curve (Fig. 3). Both of the more episodic formation scenarios produce plots that are more nearly sinusoidal. Additionally, the minimum RMS difference in orientation for continuous formation is less than 10°, versus ~25° for the mapped lineaments and both of the episodic formation scenarios.

These results might be taken as evidence that elastic stress builds up until an episode of tensile failure relieves stress, followed by another episode of stress buildup and tensile failure. Alternatively, perhaps periodic variation in the rate of NSR [8] may cause episodes of more intense failure at greater NSR rate.

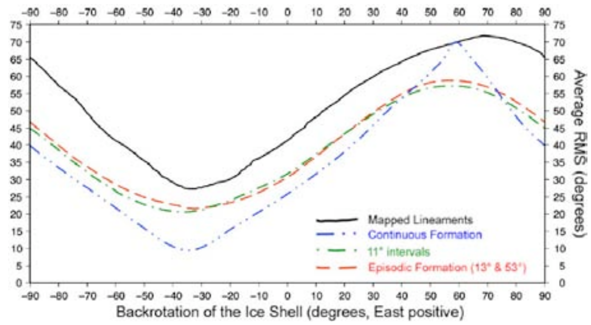

Fig. 3. Average RMS difference between observed and predicted lineaments orientation as a function of the amount of backrotation of Europa's ice shell.

We are presently conducting a more detailed analysis of the set of mapped global lineaments, in which we measure the amount of back rotation required to best fit each individual lineament to the NSR stress field. This should give us explicit information about the variation in lineament formation rate with shell rotation. We are also experimenting with allowing the diurnal variations in the stress field to alter the trajectories of the global lineaments as they form. Additionally we are working to incorporate the apparent stratigraphic relationships between the global lineaments, using a computer assisted stratigraphic sorting method [9].

References: [1] McEwen, A. (1986) *Nature, 321*, 49-51. [2] Leith A. C. and McKinnon W. B. (1996) *Icarus 120*, 387-398; [3] Greenberg R. et al. (1998) *Icarus, 135*, 65-78; [4] Stempel M. M. et al. (2004) *LPSC XXXV*, Abstract #2061. [5] Wahr, J. et al., in preparation. [6] Mullen, M. et al. (2006) this meeting; [7] Becker, T. L. et al. (2001) *LPSC XXXII*, Abstract #2009 [8] Nimmo, F. et al. (2005), *Eos*, *86(52)*, Abstract P22A-05. [9] Crawford Z. A. and Pappalardo R. T. (2004) *Astrobiology 4(2)*, 245-246.