Obliquity-controlled lineament azimuth distributions on Europa. A.R. Rhoden[1] and T.A. Hurford, [1] NASA Goddard Space Flight Center, 8800 Greenbelt Rd., Greenbelt, MD 20771; alyssa.r.rhoden@nasa.gov.

Introduction: Lineaments are thought to form as tensile fractures, mainly in response to tidal stress generated by Europa's orbital eccentricity [1][2]. The influence of a small amount of stress built up during non-synchronous rotation of the ice shell has also been considered [2]. The fractures are predicted to form when the tensile stress reaches its daily maximum and at an azimuth perpendicular to the direction of the max tensile stress [1][2]. However, this formation model would only predict one lineament azimuth in any given region. In order to explain the wide variation in lineament azimuth observed in many regions of Europa [e.g. 3], the stresses that form lineaments must change over time. Potential mechanisms include spin pole precession changing the diurnal stress field over time and non-synchronous rotation (NSR) of the surface through the diurnal stress field. Here, we determine which mechanism is best supported by observed lineament azimuths in the Bright Plains region of Europa. We also revise previous predictions, in which the "max stress" failure criterion was incorrectly applied, and test an additional failure criterion in which lineaments form at a constant stress threshold.

Background: The azimuths of several young lineaments are well-explained by the stress field from eccentricity and 1° of NSR. The lineaments are assumed to have formed perpendicular to the maximum daily tensile stress, which occurs at 1/8th past apocenter at the current locations of the lineaments [2]. If the surface migrated in longitude due to NSR, older lineaments should have different azimuths, corresponding to the max stress at their formation locations.

To predict lineament azimuths at other longitudes, one first has to determine the time at which the max stress is reached, which varies considerably over Europa's surface. Unfortunately, previous authors used the stress field at 1/8th past apocenter to predict the azimuths of lineaments at all longitudes [2]. That would require the fractures to have formed at a variety of failure stresses rather than at the max daily stress. Hence, the predictions made by [2] are not based on a max stress condition, contrary to the formation model the authors describe. Addressing the inconsistency in their predictions is the first goal of this work.

In addition, there is now ample evidence that Europa's spin pole is titled by ~1° and may precess quickly with respect to the formation timescale of geologic features [3-6]. Hence, our second goal is to examine the influence of obliquity on lineament azimuths, which has not been considered previously.

The maximum daily tensile stress varies by a factor of two over the surface of Europa. This implies that the ice may fail at only 50 kPa in one region, but resist failure until 100 kPa in another region - solely because the two regions experience a different peak daily stress. Although one could envision spatial variations in the strength of the ice shell, they would likely be due to differences in shell structure rather than in the imposed stress. We thus expand our analysis to include predictions made at a constant failure stress.

Study region: Located near 15°N and 270°W, the Bright Plains region was imaged at 20 m/pix resolution, making it an ideal target for mapping. Tidal stresses do not vary appreciably across the imaged region, yet the Bright Plains region contains lineaments at a wide range of azimuths. Previous comparison between the observed lineaments and tidal stresses implied many non-synchronous rotations of the ice shell [7]. However, that work relied on the predictions in which time was held constant [2]. We thus revisit the Bright Plains region to determine the conditions under which the observed variations in lineament azimuth could be explained and identify the most likely stress conditions implied by their distribution.

Results: By holding the time of formation constant, which is akin to selecting an arbitrary failure stress for each lineament, all azimuths could be produced in this region [2]. However, when we correctly apply the max stress condition, we find that non-synchronous rotation through an eccentricity-driven stress field can only reproduce 22% of the observed lineaments. Using a constant failure threshold, we can account for 34% of lineament azimuths. Adding a small amount of stress from NSR (as in [2]), only improves the result to 37% with either failure condition.

The results change dramatically when we incorporate an obliquity of 1° into calculations of tidal stress. In this case, depending on the failure criterion, both non-synchronous rotation and spin pole precession can produce a wide variety of lineament azimuths in the Bright Plains region. However, when we attempt to reproduce the distribution of the observed azimuths, we can easily differentiate between these models.

We applied statistical tests to evaluate the predictive power of the precession and NSR models (as in [8]). As a reference, we also tested a model that assumes lineaments form at random azimuths. And, we investigated the possibility that the observations may be skewed in favor of younger cracks. These tests show that the random azimuth model outperforms the non-synchronous rotation model regardless of the failure condition or observational bias. Whereas, spin pole precession, combined with a threshold failure condition, is superior to both the random model and the NSR model at generating the observed distribution. The precession model is further improved by assuming that younger faults are more easily observed (Fig. 1).

Even with our best model, roughly half the lineaments are not well-explained (just as with strike-slip faults [5]). Potential contributing factors include: subsequent geologic activity reorienting lineaments, inclusion of lineaments that propagated through the region but formed elsewhere, or lineament formation modifying the stress field. Despite these complications, having the precession model account for half the lineaments outperforms a completely random model by 2 orders of magnitude – a robust result.

Conclusions: The lineament azimuth predictions presented by [2] are inconsistent with their reported failure assumption. The revised predictions are significantly different and cannot reproduce the azimuth variation observed in the Bright Plains region. In fact, without obliquity, longitude translation cannot account for the observations, regardless of the failure condition and with or without stress from NSR. If obliquity is included in the calculations of tidal stress, both non-synchronous rotation and spin pole precession can produce large variations in lineament azimuth, which adds to the body of evidence in favor of a small (~1°) obliquity during the most recent phase of tectonic activity on Europa [3-6]. The distribution of lineament azimuths in the Bright Plains region indicates that spin pole precession, not NSR, is the dominant process controlling changes in lineament azimuth over time.

In the precession model, we assume that lineaments have not moved in longitude since their formation. However, we cannot rule out non-synchronous rotation of Europa's surface based on this work. Rather, we interpret the weak signal of NSR in lineament azimuths and strike-slip faults [5] as an indication that these features are only diagnostic of very recent stress conditions. In contrast, cycloids do appear to retain a history of longitude migration [4], likely because their individual shapes are much more sensitive to the stress conditions in which they formed. It is also possible that slow NSR has contributed to the portion of lineaments that are not well-explained by either tidal model.

Several authors have used the predictions of [2] to derive rotation histories of Europa [e.g. 7-11]. Applying our revised predictions would likely yield very different results, as we have shown here for the Bright Plains. Examining lineament azimuths in other regions will help refine the parameters that control lineament azimuths as well as constrain Europa's rotation history.

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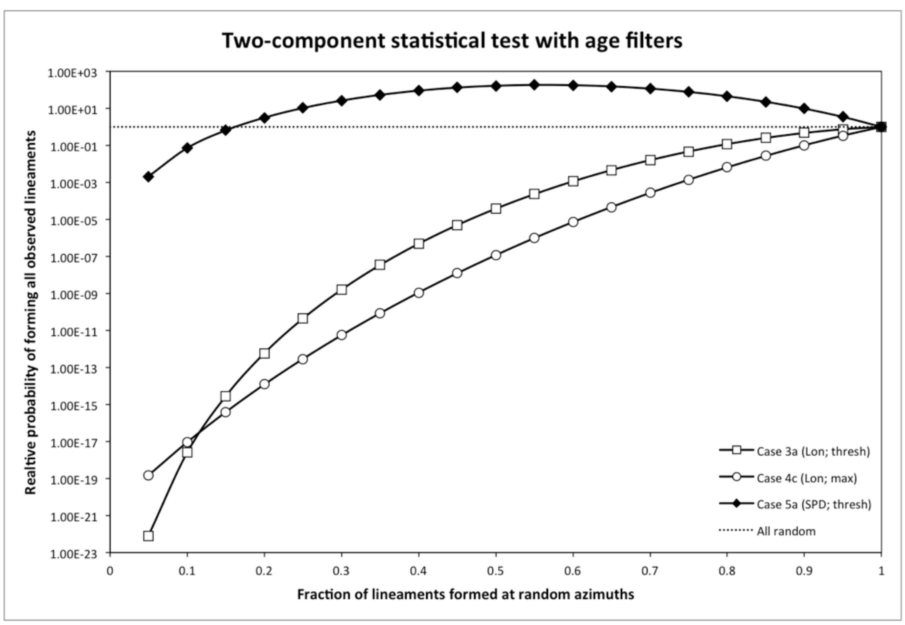

Figure 1: The probability of either NSR (open symbols) or spin pole precession (filled symbols) to produce the observed distribution, assuming some age bias in the data. The x-axis shows the fraction of randomly oriented lineaments included in the population. The y-axis shows the probability relative to forming all of the lineaments at random orientations. Neither of the NSR models can outperform the random model. Whereas, the precession model is two orders of magnitude more likely to produce the observations than a random model.