A SEARCH FOR INFLUENCES OF TIDAL STRESSES ON SURFACE FEATURE FORMATION ON IO.
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Introduction: As the most volcanically active body in the Solar System, Io has a surface peppered with volcanic centers (paterae) and tectonic mountains that vary widely in morphologies. The spatial relationships between these surface features have long been a subject of interest in determining the relationship between volcanism and tectonic faulting on the body, which is strongly influenced by compressive stresses due to crustal subsidence [e.g.1, 2, 3]. Though they are orders of magnitude weaker than the crustal subsidence stresses, tidal stresses due to the Laplace resonance between Io, Europa, and Ganymede heat Io's interior, and possibly influence surface feature formation. Io's mountains generally occur as isolated linear massifs rising kilometers above the surrounding plains, while paterae are rounded, often elongate depressions; both have measurable orientations on the surface (Figure 1). In this study, we investigate global statistical trends in the orientations of surface features relative to tidal stresses to determine if tidal stresses have an influence on feature formation (the most intuitive relationship being mountain or patera formation perpendicular to stress direction at maximum compressive or extensional stress, respectively).

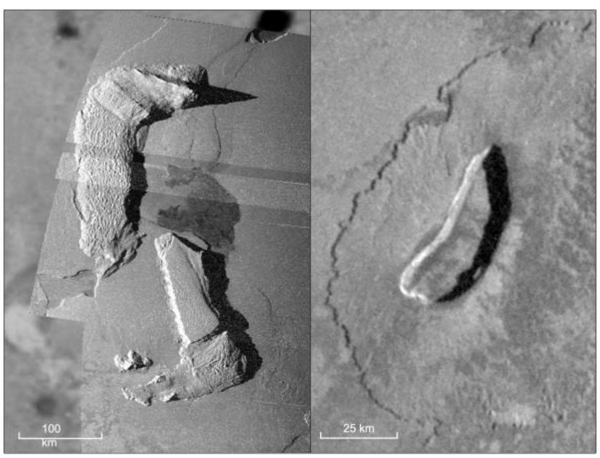

Figure 1. *Galileo* imagery of example mountain and volcano features on Io's surface where long axis of feature is measurable. (a) Mongibello Mons; (b) Thomagata Patera.

Dataset: We considered previously mapped features [4] with a clear long axis and measurable orientation from North. This dataset includes 93 mountains, which can be round and eroded but more often are isolated linear massifs, and 236 paterae, which can be circular or oblong. We further limited the paterae to the 178 features with an aspect ratio of 2/3 or lower, which served as our "elongate" cutoff.

The peak compressive and tensile stresses due to tides were calculated at each feature location using the SatStressGUI program (Kay & Kattenhorn, 2010). The model input parameters follow common assumptions about Io's interior structure and material properties, including the absence (this model) or presence of a magma ocean.

Results: We compared the measured orientation of mountain and patera features to the orientation of the modeled peak tidal stresses at their locations to determine if tidal stress may influence feature formation (Figure 2). For our full dataset, tensile and compressive tidal stresses both predominantly occur in the North-South direction (0° = N). Globally, paterae exhibit a strong preferential East-West orientation, and a statistically significant population is aligned perpendicular to the local peak extensional stress. Mountain orientations are more varied with one strong ~E-W population, but have a less defined relationship between compressive tidal stress and feature orientation (save one larger population oriented 60° from peak compressive tidal stress).

To test if the above relationships are statistically significant, we generated equivalently sized simulated datasets with randomly oriented features to compare to the mapped features. These show that the large population of measured paterae oriented within 10 degrees of East-West is indeed significant, as well as the population of mountains oriented 60° from peak tidal stress. These were extremely unlikely distributions in 10,000 random datasets.

Implications and Future Work: While the mechanisms surrounding tidal influence on mountain and patera formation are unclear, the spatial relationships between these features and the modeled tidal stress field are striking. Elongate paterae tend to form perpendicular to the peak extensional tidal stress, which could influence magma pathways. A population of mountains forms at a 60° angle to peak compressive tidal stress. Although this angle is measured in planview, it reminiscent of the cross-sectional characteristic angles of terrestrial fault planes according to Anderson's Fault Theory (1905). Given that the compressional mountain-building stresses are orders of magnitude larger than the tidal stresses modeled here, it is perhaps unsurprising that paterae may be more sensitive to these stresses than mountains.

Future work will continue to investigate the particular features that demonstrate preferential orientations, as well as investigate alignment trends of fissures and other features internal to paterae. This global survey demonstrates that there are significant feature orientation trends, and further exploration will illuminate how tidal stresses may influence the expressions of mountains and paterae on Io's surface.

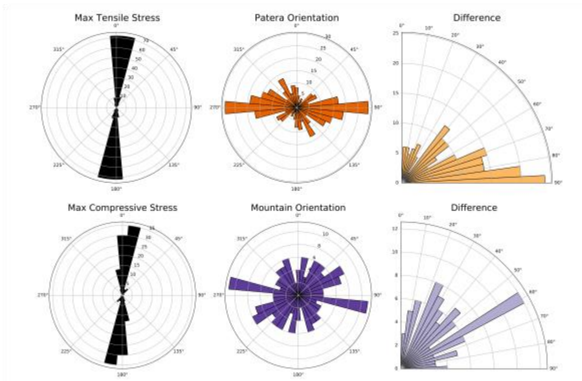

Figure 2. Distributions of measured patera and mountain orientations (middle), the corresponding modeled tidal stresses at those locations (left), and the relationship between those two angles (right), showing a statistically significant population of paterae forming perpendicular to max tensile stress.

References: [1] Schenk P. M. and Bulmer M. H. (1998) *Science*, 279(5356), 1514-1517. [2] Bland M. T. & McKinnon W. B. (2016) *Nature Geoscience*, 9(6), 429-432. [3] Kirchoff, M. R., McKinnon, W. B., & Bland, M. T. (2020) *Icarus*, *335*, 113326. [4] Williams D. A. et al. (2011) *USGS.* [5] Kay J. P., & Kattenhorn S. A. (2010) *41st LPSC* Abstract #1533. [6] Anderson E. M. (1905) *Transactions of the Edinburgh Geological Society*, 8(3), 387-402.