TIDAL STRESSES AT IAPETUS.

D. A. Patthoff[1], C. B. Beddingfield[2,3], R. J. Cartwright[2], [1]Planetary Science Institute, Tucson, AZ 85719, apatthoff@psi.edu, [2]The SETI Institute, Mountain View, CA 94043, [3]NASA Ames Research Center, Moffett Field, CA 94035

Introduction: Stresses at Saturn's moon Iapetus have been attributed to: contraction due to despinning [1, 2, 3], respinning [3], and folding of the lithosphere due to differential ice shell thickness [4]. While most studies have focused on stresses related to the creation of the spectacular equatorial ridge, some studies have explored the connection of stresses from despinning and respinning to observed fractures and tectonics (e.g. [3]). Those previous studies demonstrated that although the magnitude of the stress resulting from changes in the spin period are sufficient to fracture the ice shell, the orientations of observed tectonic features do not match the predicted trends of structures. However, additional fractures and faults may exist on Iapetus that have been buried by regolith, dust, or perhaps are too small to be observed [3]. Further complicating the dynamics, prior work [3] found some correlations between observed tectonic patterns and spin up stresses.

To help reveal that potential buried tectonic history and clarify the stress history, we turn to polygonal impact craters to create a more detailed map of Iapetus's tectonic features (see Beddingfield et al., this LPSC). Here we present preliminary results of other potential sources of ancient stress that may have left a tectonic signature on the icy world.

Other potential sources of stress: Presently, Iapetus orbits much farther (~3,561,000 km) from its parent planet than other similarly sized icy satellites. This distance results in relatively small (>5 kPa) present day diurnal tidal stresses. However, Iapetus also has a relatively high orbital inclination (~14.7˚) that can increase the resultant diurnal stresses. Along with the inclination, an additional stress may come from obliquity [5] which is effectively ~15˚ [6].

The alignment of the large basins Engelier, Falsaron, and Turgis with the axis of spin may preserve evidence for true polar wander (TPW) motion at Iapetus. Such a re-orientation of the ice shell early in Iapetus's history could result in significant stresses resulting in fracturing of the surface.

Stress models: We model various tidal stresses at Iapetus using SatStressGUI to evaluate if the magnitudes can be great enough to fracture the ice shell. Unless otherwise noted, we assume a 4-layer satellite with the parameters shown in Table 1. In the table, T is the thickness of the layer, ρ Is the density, E is the Young's modulus, ν is the Poisson's ratio, and μ is the viscosity. Except for the thickness and density, the values used for the core do not significantly affect the stresses. Each model was run to keep a bulk density of 1200 kg/m^3 and a radius of 746 km.

Table 1

Layer	T (km)	ρ (kg/m^3)	E (Pa)	ν	μ (Pa s)
Brittle	100	920	9x10^9	0.33	1x10^{19}
Ductile	100	920	9x10^9	0.33	1x10^{13}
Ocean	346	1000	0	0.30	0
Core	200	4000	9x10^9	0.30	1x10^{19}

Preliminary results: The first model we present here simulates an Iapetus with the properties from Table 1 and calculates the resultant diurnal tidal stresses the moon could have experienced if it was closer to Saturn at some point it its past. We maintain a, likely unrealistic, present day eccentricity of 0.0283. Recent work by [7] has demonstrated an outward migration of Saturn's moons. Although that work did not model migration for Iapetus, here we show what the expected tidal stress (Fig. 1) would be for a point (19˚ latitude, 65˚ longitude) on the surface that corresponds to an identified polygonal impact crater (see Beddingfield et al. this LPSC). The tidal stresses remain quite small (> 20 kPa) until you get closer to Saturn (~800,000 km).

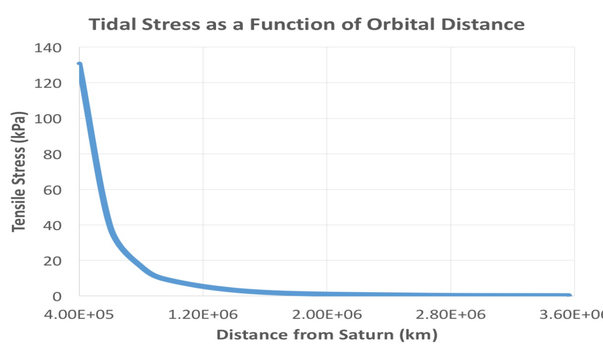

Figure 1: Diurnal tidal stress as a function of orbital distance at 19˚ lat., 65˚ lon. and a mean anomaly of 120˚ past periapsis. Tension is positive.

The second model (Fig. 2) combines obliquity with diurnal tidal stress. Using the same Iapetus configuration from before (Table 1) and an obliquity of

15˚ [6], we find much greater stresses, but again, not until Iapetus is moved much closer to Saturn than its present day location.

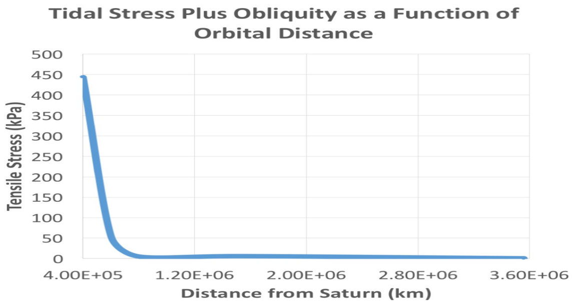

Figure 2: Diurnal tidal stress plus obliquity stresses as a function of orbital distance at a point located at 19˚ lat., 65˚ long. with a mean anomaly of 120˚ past periapsis. Tension is positive.

A third potential source of stress could come from true polar wander. Here we model an ice shell whose pole has moved 45˚ to the north along the 0˚ longitude axis. The aim for this modeling scenario is not to match observed features to the motion, only to determine if the magnitudes of the stresses are large enough to initiate failure. Here we show 2 models, one where Iapetus experienced TPW in its current orbit location (Fig. 3A), and a second where we move Iapetus to a distance of 1,561,000 km from Saturn (Fig 3B).

Another potential way to increase stresses at Iapetus is to change the thickness and viscosity of the ice shell. However, changing these values still results in relatively small stresses. In Fig. 4 we show combined obliquity and diurnal stresses at the present day orbit for Iapetus. However, here we shrink the brittle ice to just 5 km, the ductile ice to 30 km, and have a 511 km thick ocean. All other parameters remain the same as shown in Table 1.

Discussion: Present day diurnal, obliquity, and TPW stresses at Iapetus are all very small, even for relatively thin ice shells, due to Iapetus's large orbital distance from Saturn. If Iapetus orbited closer to Saturn in the past, the stresses increase, but only minimally except for orbits interior to Titan's current orbit, an unlikely scenario. However, Iapetus displays evidence for stress-induced tectonics [3, and Beddingfield et al. this LPSC], but the modeled stresses shown here are likely too small to result in the observed deformation. Future work will explore additional stressing mechanisms, e.g. ice shell thickening and despinning, to constrain if the resulting stresses are large enough to deform the surface. Alternatively, other substances, e.g., NH_3-hydrates and organics, [see Cartwright et al., this LPSC] could act to weaken Iapetus' ice shell.

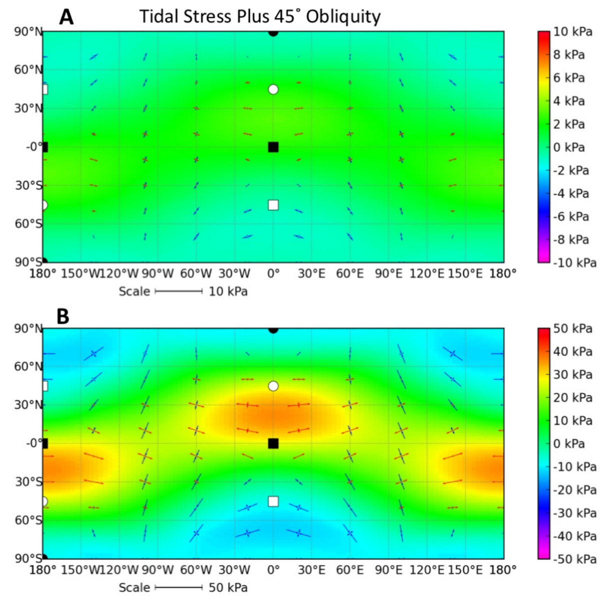

Figure 3: Diurnal tidal stress plus TPW. Part A shows the predicted stresses induced by 45˚ of TPW at the current orbit. Part B shows the predicted stresses induced by 45˚ of TPW at an orbital distance of 1,561,000 km. Note the different stress magnitude scales between the two figures. Tension is positive and both maps are cylindrical projections.

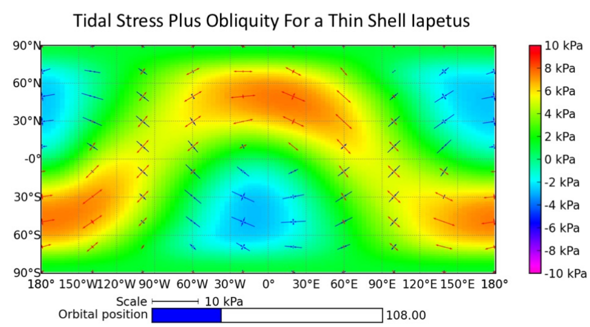

Figure 4: Cylindrical projection of the predicted stresses induced by diurnal tidal stress plus obliquity in a thin shelled Iapetus. Tension is positive.

References: [1] Matsuyama, I. and Bills, B. G. (2010) *Icarus, 209*, 271-279. [2] Castillo-Rogez, J. C., *et al*. (2011) *JGR, 116*, doi:10.1029/2010JE003664. [3] Singer, K. N. and McKinnon, W. B. (2011) *Icarus, 216*, 198-211. [4] Kay, J. P., and Dombard, A. J. (2018) *Icarus, 302*, 237-244. [5] Collins, G. C. et al. (2009) *Cambridge U. Press*, Planetary Tectonics. [6] Palmer, E. E. and Brown, R. H. (2008). *Icarus, 195*, 434-446. [7] Lainey, V. *et al.* (2020) *Nature Astronomy, 4*, 1053 – 1058.

Acknowledgments: This project is funded by NASA Cassini Data Analysis Program (CDAP) grant 80NSSC21K0537.