Simulating Spatial Variations of Lithospheric Folding on Enceladus

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Introduction:

- A consequence of this tectonics may be the formation of short-wavelength, low-amplitude topography via folding of the lithosphere within regions of compression [1-3]
- Elevated heat flow has been observed within the region and profiles taken between the tiger stripes has shown periodic topography (Figure 1)
  - The wavelength of the observed features has been estimated to be nearly 1.1 km with an amplitude of ~100 m [3, 4]
- Another set of potential folds exist along the periphery of the SPT
  - These features have a wavelength of 5km and an amplitude of 100s of meters [5]
- Here, we test this idea using a finite element approach than employs a more realistic elastic-viscous-plastic rheological model and extend to terrain along the periphery of the SPT.
- We test a range of wavelengths in order to identify the fastest-growing, dominant wavelength

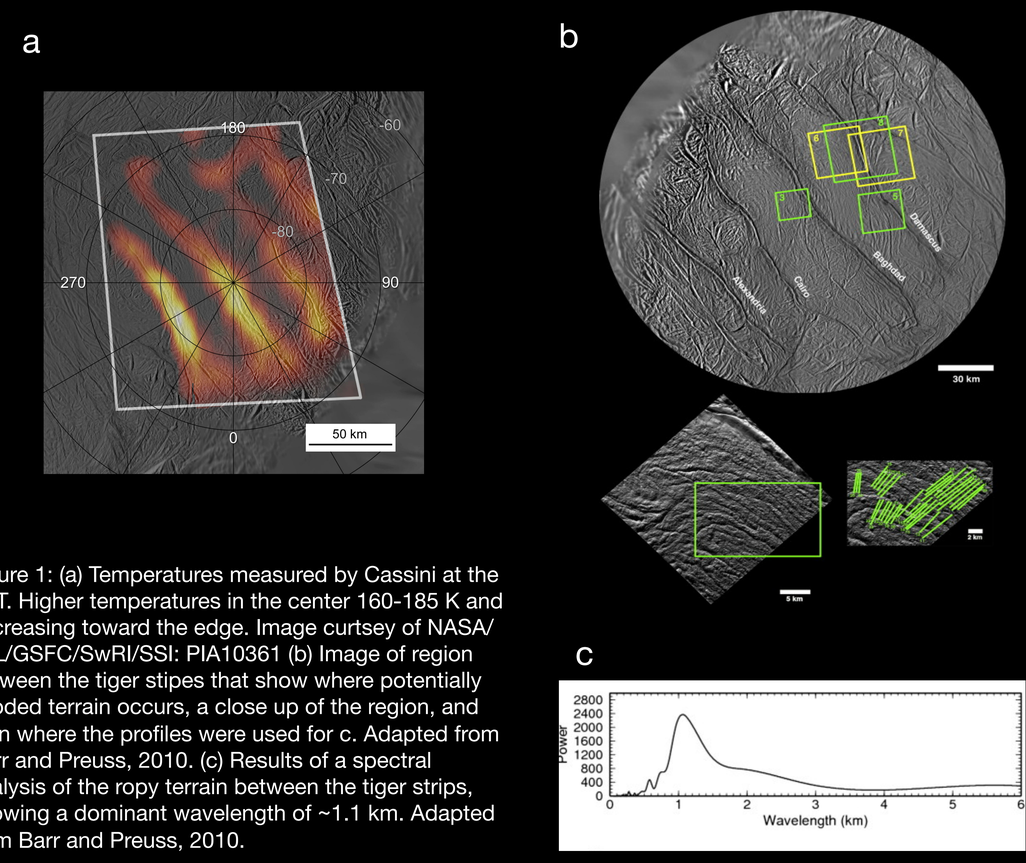

Figure 1: (a) Temperatures measured by Cassini at the SPT. Higher temperatures in the center 160-185 K and decreasing toward the edge. Image curtsey of NASA/JPL/GSFC/SwRI/SSI: PIA10361 (b) Image of region between the tiger stipes that show where potentially foloded terrain occurs, a close up of the region, and then where the profiles were used for c. Adapted from Barr and Preuss, 2010. (c) Results of a spectral analysis of the ropy terrain between the tiger strips, showing a dominant wavelength of ~1.1 km. Adapted from Barr and Preuss, 2010.

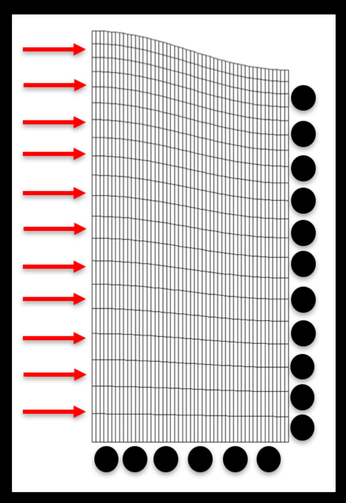

Figure 2: Sample mesh with forced displacement arrows and black circles are free slip surfaces

Methods:

- Planar mesh (Figure 2)
- Mesh varied in size based on wavelength being tested
  - 2:1 depth to width ratio
  - 600 – 9000 m
  - Mesh contains between 5000 and 15000 elements
- Forced lateral displacement at constant rate
  - 1 m perturbation
- Tested a broad range of values for heat flow and surface temperature
  - 90 K – 185 K (assumed to be effective surface temperature)
  - 100 mW m-2 – 400 mW m-2

Conclusions:

- Need warm conditions to get to 1 km range for funiscular terrain
- The 5km features have a significantly cooler regimes in which can form
- This shows significant spatial variations of heat flow/ temperature within the SPT
- Need further work to constrain the amount of strain within the SPT

Results:

- Use thermal state as proxy for lithospheric thickness (Figure 3)
- Different amplification scenarios for the two sets of folds (Figure 4)
- For short wavelength features high thermal state required to produce observed folds
  - 185 K/400 mW m^{-2}
  - Lithosphere is very thin
- Larger wavelength folds can be produced under a larger range of conditions (Table 1)
- Strain becomes proxy for thermal conditions
  - Lager amounts of shortening
    - Cooler thermal state
  - Small amounts of shortening
    - Warmer thermal state

Table 1: Reference table for results of simulation for producing the dominant amplification wavelength

Temperature (K)	Heat Flow (mW m^{-2})	Peak Half wavelength (km)	Fold Length (km)	Ropy Terrain Strain (%)	Peripheral Fold Strain (%)
150	300	8	16	93	68
150	350	7	14	92	65
150	400	6.5	13	91	60
170	125	8	16	93	68
170	200	6	12	90	60
170	400	5	10	90	50
185	200	5	10	90	50
185	300	4	8	85	37.5
185	400	1.1	2.2	50	N/A

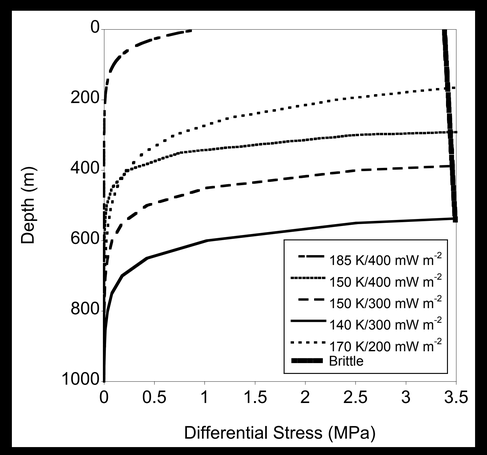

Figure 3: Differential stress as a function of depth, where each line corresponds to a specific thermal state.

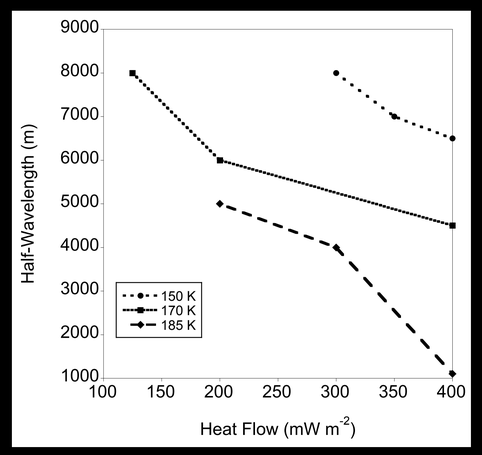

Figure 4: Heat flow and surface temperature combinations and the dominant amplification wavelength.

References: [1] Porco et al., (2006) Science 311, 1393-1401. [2] Spencer et al., (2016) Science 1401-1405. [3] Barr and Preuss, (2010) Icarus, 208, 499-503. [4] Bland et al., 2015 Icarus, 260 232-245. [5] Beddingfield et al., 2013 LPS XLIV, Abs. #1254.