SHEAR HEATING AT THE "TIGER STRIPES" OF ENCELADUS?. F. Nimmo, *Dept. Earth & Planetary Sciences, U.C. Santa Cruz, Santa Cruz CA 95064 (fnimmo@es.ucsc.edu)*, J.R. Spencer, *Dept. Space Studies, SWRI, Boulder CO 80302*, R.T. Pappalardo, *Jet Propulsion Laboratory, M/S 183-301, Pasadena CA 91109*, M.E. Mullen, *Dept. Astrophysical & Planetary Science, Univ. Colorado, Boulder CO 80304*.

The "tiger stripes" of Enceladus are associated with locally high heat fluxes [1] and active plumes of water vapour and ice [2]. Here we investigate the ability of tidally driven (strike-slip) fault motions [2,3,4] with displacements of ∼10 cm over a tidal period to cause heating at the tiger stripes.

Lateral (strike-slip) motion has previously been inferred for Europa [5], and may result in localized heating due to friction or viscous dissipation [3]. Faults in the polar regions of Enceladus will experience stresses driving strike-slip motion for part of each tidal cycle, with the magnitude of the stresses increasing towards the pole [6,7]. Following [8], the mean shear velocity u on an individual fault driven by these tidal stresses is given by $\dot{\epsilon}d$=$7.2 \times 10^{-5} h_2 \ \ m\,s^{-1}$. Here d is the distance between faults (assumed 30 km for the tiger stripes [2]), h_2 is a dimensionless (Love) number which depends on the satellite's rigidity and density structure, $\dot{\epsilon}$ is the mean diurnal tidal strain rate and the second equality is obtained by scaling the strain rate on Enceladus to that of Europa. For a body which lacks significant rigidity (h_2 approaching 2.5), the shear velocity will be of order $10^{-4}\ m\,s^{-1}$. The presence of an elastic ice shell or silicate interior will reduce h_2 and the velocity by as much as several orders of magnitude [9].

To calculate the thermal consequences of this strike-slip motion, we use an approach [3,4] in which a single shear zone generates local heating in a conductive ice shell. We adopt a nominal conductive ice layer thickness of 24 km, comparable to the tiger stripe spacing, and assume that the ice shell is decoupled from the silicate core by an ocean. The shearing is accomplished by localized motion on a discrete vertical fault surface at shallow depths where the ice is cold and brittle, and by ductile motion across a broader shear zone at greater depths. The transition depth between brittle and ductile deformation is calculated in a self-consistent manner [4], and the resulting equilibrium temperature structure is derived. The vertically integrated heat production per unit length due to fault friction is given by $f\rho g z^2 u/2$, where f is the coefficient of friction, g is the acceleration due to gravity, z is the depth of the brittle zone and ρ is the ice density [3].

Figure 1 shows that the temperatures and temperature gradients near the strike-slip zone are significantly increased as a result of the brittle and viscous heating when the shear velocity is $3\times10^{-6}\ m\,s^{-1}$ (∼20 cm slip per tidal cycle; h_2=0.04). The depth of the brittle region is 1.4 km, comparable to the tiger stripe fracture width [2]. The resulting maximum surface heat flux is 0.4 $W\ m^{-2}$, while the surface temperature increases from 76.2 to 79.7 K. Assuming a total active shear zone length of 500 km [2] results in a total heat production rate of 1.2 GW; this rate is a factor of 2-6 smaller than the IR observations [1].

In reality, some fraction of the frictional dissipation will cause vapour sublimation, rather than shear heating, with the vapour escaping to the surface, generating the observed plume and redistributing heat from depth to the near-surface regions [10]. The brittle shear zone will thus be colder and deeper than shown in Fig. 1, resulting in a higher rate of heat production, likely enough to account for all the heat observed by Cassini. The near-surface heating by the plume vapor may also able to account for the high temperatures (at least 145 K) seen by Cassini [1]. Vertical cracks maintained at a constant temperature, for instance by plume vapor, may be able to explain the details of the tiger stripe thermal emission spectrum [11].

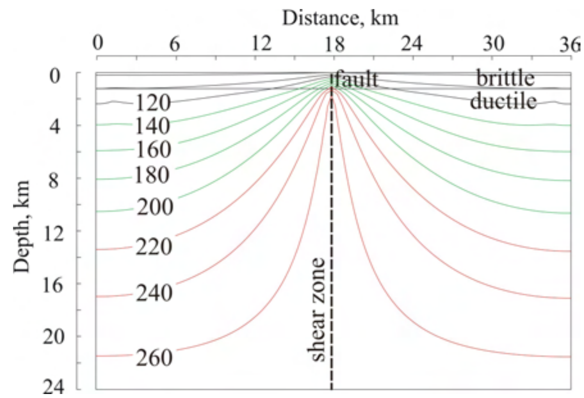

Figure 1: Cross-section of steady-state temperature structure (contours in K) for a shear velocity of $3 \times 10^{-6}\ m\,s^{-1}$ (implying a Love number h_2=0.04; see text). Bold dashed line represents a vertical fault along which lateral shear occurs (perpendicular to the page); thickness of the brittle zone is calculated self-consistently [4]. Calculations assume f=0.6, g=0.11 $m\ s^{-2}$, $\rho\ =\ 930\ kg\ m^{-3}$, ice reference viscosity 10^{14}Pa s, thermal conductivity 3 $W\ m^{-1}K^{-1}$, grid spacing 0.3 km (horizontal) & 0.2 km (vertical), background surface temperature = 75 K [1]; other parameters identical to [3].

Future Cassini observations may allow the shear-heating hypothesis to be tested. In particular, tidally-driven strike-slip motion is likely to result in permanent geological offsets [6], which should be detectable in images with sufficiently high resolution. Furthermore, the tidal heating varies in a predictable fashion with tiger stripe geometry and position.

References

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