SHEAR HEATING AND THE ORBITAL EVOLUTION OF ENCELADUS. F. Nimmo, *Dept. Earth & Planetary Sciences, U.C. Santa Cruz, Santa Cruz CA 95064 (fnimmo@es.ucsc.edu).*

Volumetric dissipation within satellites is typically assumed to be viscoelastic and is calculated using the Love number k_2 and quality factor Q [1]. However, observations of the plumes and "tiger stripes" at Enceladus [2] have led to suggestions that tidal dissipation may primarily be accomplished by shear-heating along individual faults [3]. This style of dissipation has a different functional form to the usual viscoelastic formula. In particular, the eccentricity damping timescale will differ, which may have important implications if Enceladus's eccentricity is time-dependent [4,5].

We assume that tidal stresses σ are capable of moving faults to a depth d. Here $d = \sigma/\rho g f$ where the denominator is the overburden pressure resisting fault motion, ρ is surface density, g is gravity and f is the coefficient of friction. The tidal strain rate $\dot{\epsilon}$ depends on orbital parameters and the Love number h_2 and is linearly proportional to σ. For active faults of total length L_{tot} and separated by an average distance w, the total frictional heating on the faults $\dot{W}$ depends on the fault depth and mean shear velocity, and is given by

$$\dot{W} = \frac{\dot{\epsilon}^3 L_{tot} w \mu'^2}{2\rho g f n^2} \quad (1)$$

where μ' (units: Pa) relates stress to strain and n is the mean motion of the satellite. Note that here we are neglecting the contribution from viscous shear heating, which is generally comparable to the frictional contribution [6], and any volumetric dissipation in the interior.

Substituting in for the tidal strain rate [7] we obtain

$$\dot{W} = n^7 e^3 h_2^3 \frac{L_{tot} w \mu'^2 c^3}{2\rho g f G^3 \bar{\rho}^3} \quad (2)$$

where c is a constant (1.55), G is the universal gravitational constant and $\bar{\rho}$ is the bulk density. This expression has a different functional form to the standard expression for tidal dissipation, which depends on k_2/Q, e^2 and n^5 [1].

In the absence of external torques, the rate of change of semi-major axis a and eccentricity e of a satellite are linked. Dissipation in the satellite results in a reduction in a; conservation of angular momentum then allows the change in eccentricity e to be determined:

$$\frac{de}{dt} = -\frac{1-e^2}{e} \frac{a}{G m_p m_s} \dot{W} \quad (3)$$

where m_p and m_s are the mass of the primary and satellite, respectively. This expression may be integrated if the functional form of $\dot{W}$ is known.

Figure 1 shows the effect of applying both the conventional dissipation (a) and the shear-heating (b) calculations to a body with present-day characteristics appropriate to Enceladus. The main difference of the latter approach is that the effective eccentricity damping timescale is larger by 70%. The dissipation thus falls off more slowly as a function of time (but more rapidly as a function of eccentricity). A lower rate of eccentricity reduction makes it more likely that oscillatory behaviour [4] can occur.

References

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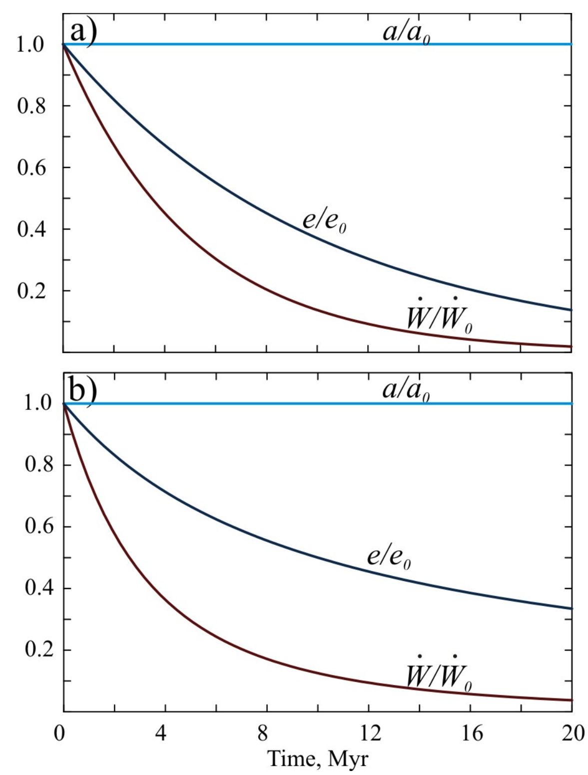

Figure 1: Evolution of a,e and heat production rate $\dot{W}$ with time, calculated using equation (3). Values are normalized to initial values (0.238×10^6 km, 0.0045 and 1 GW, respectively) appropriate to present-day Enceladus. Panel a) gives evolution using conventional tidal dissipation formula; panel b) gives evolution using shear-heating formula (equation 2). Effective eccentricity damping timescales are 10.2 Myr and 17.5 Myr, respectively. Here it is assumed that the characteristics of the satellite (especially h_2) do not vary in time.