TIDAL DISSIPATION IN A FROZEN ENCELADUS. J. H. Roberts[1], [1]Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Rd., Laurel, MD 20723, James.Roberts@jhuapl.edu

Introduction: Enceladus is perhaps best known for its young south polar terrain [1], which is scored by the four large "tiger-stripes". These lineations have been observed to emit several GW of heat [2,3] as well as plumes of vapor and ice [4]. The origin of this south polar thermal anomaly is not completely understood. The likelist source of energy is from tidal dissipation. Howe

ver, the observed thermal radiation detected by the Composite Infrared Spectrometer (CIRS) on Cassini [3] far exceeds the long-term level of dissipation that is sustainable by orbital dynamics [5]. Moreover, models of the internal dynamics suggest that this tidal heating is removed from the interior faster than it is produced, resulting in the geologically rapid freezing of any global subsurface ocean [6,7], although a regional sea may be longer-lived under appropriate conditions [8]. Tidal dissipation in the ice shell is severely restricted if it is mechanically coupled to the rigid silicate core. In such a scenario, if the ocean freezes entirely, tidal heating has been predicted to drop precipitously.

Here, I propose that the silicate core may not be monolithic, and that the tidal deformation of the core may be partially controlled by interstitial ice. The strength of the core may therefore be relatively low, and an ocean may not be required in order to sustain siginificant dissipation of tidal energy in the interior.

Core Consolidation: The interior structure of Enceladus is not well constrained. The satellite has a mean radius, R_0=252 km, and a bulk density of ρ_0=1.61 g cm^{-3}, suggesting a silicate fraction of at least 50%. It is most likely differentiated due to long-lived radioactive heating [9], although the size and density of the core are not well known. Here, I assume a silicate density ρ_s=2.71 g cm^{-3} consistent with the grain density of CM chondrites [10], a plausible source of the silicate component [11]. I assume the ice shell is pure water with a mean density of ρ_i=0.925 g cm^{-3}.

The degree of consolidation of the core of Enceladus is highly dependent upon the time of accretion and the amount of ^{26}Al available [9,10]. If Enceladus forms more than 1.6 My after CAI formation, then the core reaches peak temperatures below 1000°C, and will not melt. Furthermore, the central pressure on Enceladus is only ≈20 MPa, well below the compressive strength of most rocks. This is roughly equivalent to the pressure 1 km below the surface of the Earth. In this case the core will be a rubble pile with pore space filled by water or ice (Figure 1a) rather than a monolith (Figure 1b). I consider interior models consistent with the observed R_0 and ρ_0 between the following two end members: 1) a competent core of radius R_c=183 km, and 2) a rubble-pile core with 30% porosity filled by water ice with R_c=206 km.

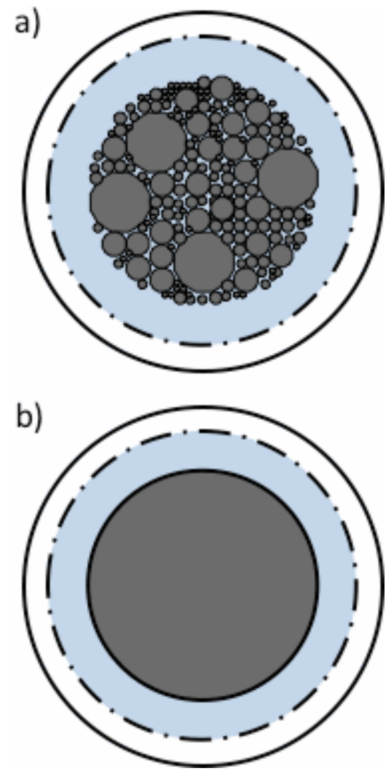

Figure 1: Possible interior structures for a differentiated Enceladus with a rocky core overlain by an ice shell (with a possible subsurface ocean in between; this layer may also be frozen). a) Unconsolidated "rubble-pile"core (fragments are not necessarily regular as show here). b) Monolithic core.

Tidal Heating: I compute the tidal dissipation in the interiors using the propagator-matrix code TiRADE [6] for a spherically symmetric body with an arbitrary number of visco-elastic layers [14,15]. I set the rigidity μ to 1 GPa for ice, and 100 GPa for rock. Viscosity η is 10^{20} Pa s for rock, and 10^{14} Pa s for ice near the melting point. The rock viscosity may be higher, but the value chosen here is sufficiently hight that dissipation in a solid rock layer is minimal. The core may either be a solid monolith, or a rubble-pile with porosity values of up to 30%, and ice filling the pore space. The mechanical properties of the core vary between those of rock for the monolithic and those of ice for the most unconsolidated end member, under the assumption that such a high degree of interstitial ice will dominate the deformation as the rock fragments slide past each other with minimal contact. I consider higher values of porosity implausible, as this would imply a lack of contact between rock fragments, which is incompatible with a differentiated body.

I find that the tidal dissipation increases by a factor of ~20 between the end member cases. With $\eta_i=10^{14}$ Pa s, only 85 MW of heat are dissipated in the ice shell if it is coupled to a rigid silicate core. With increasing porosity, the size of the core increases. The dissipation initially decreases, as the mechanical properties of the core are still dominated by those of the silicate. The ice shell above is thinner, and its movement is still restricted by the core. Once the porosity reaches ~20%, the core becomes sufficiently weak that dissipation in the core becomes significant. At even higher porosities, the core becomes more dissipative and the ice shell has greater freedom. At 30% porosity, 1.7 GW are dissipated in the interior, the bulk of it in the core itself. Figure 2 shows radial profiles of the volumetric heating rates for cores with varying amounts of ice-filled pore space.

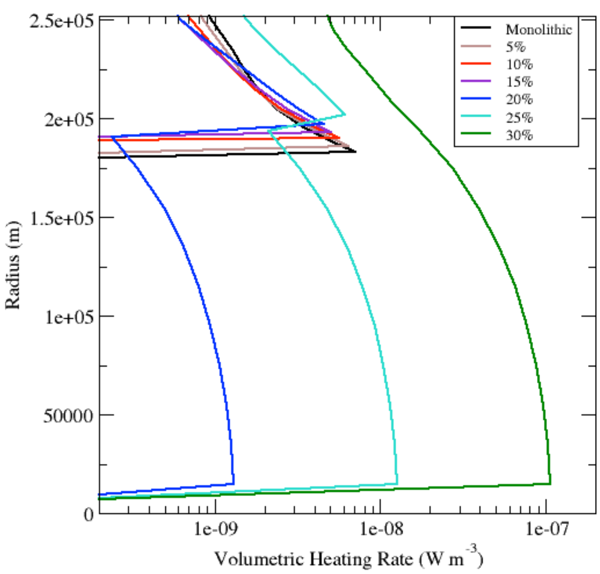

Figure 2: Rates of tidal dissipation in Enceladus for monolithic core, and for disaggretaged cores with ice-filled porosity of up to 30%.

Preliminary Conclusions and Future Work: I find that significant amounts of tidal dissipation can occur in a completely frozen Enceladus if the silicate core is unconsolidated, and lubricated by interstitial ice. The heating rates obtained for the more unconsolidated cases are broadly consistent with the long-term sustainable level of tidal dissipation [6]. Although this level is short of the observed infrared flux [3], the models here apply to the rate of heat production rather than the observable rate of heat loss. Heat may be produced at a lower rate and released episodically [e.g. 16] without violating constraints of orbital mechanics.

The next step is to include these tidal heating results into corresponding models of thermal convection and conduction (as for [6]) in order to determine the rates of heat loss and to compare these to the observations. While the existence of a subsurface ocean is no longer a requirement for continued tidal dissipation, the ability of a frozen Enceladus to dissipate heat may permit the formation of such an ocean at later times.

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