Geophysical Research Abstracts,
Vol. 10, EGU2008-A-04481, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-04481
EGU General Assembly 2008

Tidal heating of Enceladus: Is there a subsurface ocean?

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Tidal dissipation has been suggested as the heat source for the south polar thermal anomaly on Enceladus. Under reasonable rheologic conditions, we find that tidal dissipation is only significant in the ice shell if it is decoupled from the silicate core by a subsurface ocean, suggeting the presence of such an ocean in order to explain the observed surface activity. However, dissipation in the core is negligible; radioactive decay is the only significant heat source in that region (secular cooling is probably very small). We have run a series of convection and conduction models in two-dimensional axisymmetric and three-dimensional spherical geometry in which we include the spatially-variable tidal heat distribution. In general, we find that more heat must be removed from the core than can be produced by radioactive decay in order to maintain the ocean at the melting point of water. Under likely conditions, the ocean would freeze solid on timescale of order tens of Myr (depending on the initial thickness of the ice shell).

This does not preclude the existence of an ocean, only that it is not in steady-state. Our results are based on the present-day orbital parameters. If the eccentricity of Enceladus were higher (≥ 0.015) in the past, the increased dissipation in the ice shell would have been sufficient to maintain a liquid layer. The surface heat flux is further evidence that Enceladus may not be in steady-state. A heat flow of 4-7 GW is observed in the south polar region alone [Spencer et al., 2006]; the global heat flux is likely to be much higher. It is difficult for either the conductive or convective models with viscoelastic rheologies to generate even this heat flux at the surface globally. This is supported by models of orbital dynamics which suggest that the current heat flux of cannot be sustained, given the current orbital environment of Enceladus [Meyer and Wisdom, 2007]. However, a subsurface ocean may exist today as the relic of an earlier era of greater heating. If the eccentricity has been periodically pumped up, then the variations in tidal heating may have caused the ocean thickness to vary on the same timescale as for the orbital evolution, provided that this timescale is faster than the time required for the ocean to freeze completely. The freezing point of the ocean may be lowered if it is not pure water, e.g. it contains significant amounts of ammonia. However, chemistry alone cannot prevent the ocean from freezing, it can only delay it. Even the H_20-NH_3 peritectic temperature is too high to be maintained by tidal dissipation under present-day conditions. We conclude that any global subsurface ocean on Enceladus cannot be in long-term thermal equilibrium.