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Tidal dissipation in Dione's porous rocky core: implication for past geological activity and water-rock interactions

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The Cassini-Huygens mission revealed that Saturn's moon Dione exhibits convincing clues for past endogenic activity, suggestive of strong internal heating in the past [1,2]. Studies of craters relaxation enable heat flow estimates as high as 60 mW/m^2 relatively late in Dione's history [2]. Furthermore, contrasting terrains between heavily cratered surfaces (that supposedly underwent little relaxation) and lightly cratered surfaces (more relaxed) suggest long-lived planetary scale heterogeneity in the interior's thermal structure. This distribution suggests some similarity with Enceladus' pronounced north-south dichotomy [3]. However, while the spectacular activity of Enceladus attests to powerful heat sources at present, their persistence is not obvious in the case of Dione.

Combined analysis of gravity and topography indicates a differentiated interior (Fig. 1) and is consistent with the presence of a subsurface ocean estimated between 80 and 120 km below the surface [4,5]. Maintaining such an ocean would require a sufficient amount of energy coming from the interior in order to prevent crystallization. Even if the ocean is deeper in Dione than in Enceladus, as in the case of Enceladus, additional heat sources, most probably related to tidal dissipation, have to be envisioned besides the modest radiogenic content residing in the rocky materials (the rock fraction is similar for the two moons). This raises the question of the origin of an enhanced dissipative state, at least in the past.

The mechanisms leading to tidal dissipation in a differentiated body such as Dione (Fig. 1) still have to be explored in detail. A promising scenario proposed for Enceladus [6, 7, 8] locates most tidal heating in the unconsolidated rock core saturated with interstitial liquid water - the porous nature of Dione's core would be in line with a modest density inferred from Cassini's gravity and topography data [4]. Such a heat source is naturally expected to vary throughout the satellite's history in conjunction with its orbital evolution and possible core compaction.

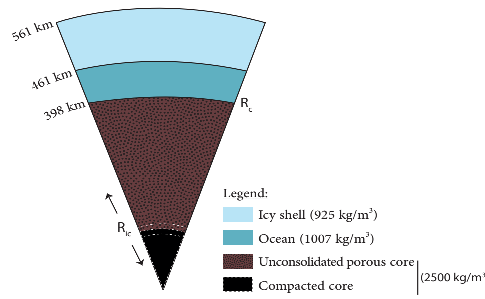

Figure 1: Model of Dione's internal structure used for our simulations.

In this context, the goal of this study is to investigate the tidal dissipation produced within Dione's core at present and in the past. We confront these results to the following observational constraints: (1) the possible preservation of a deep ocean up to the present-day, (2) the occurrence of past heat fluxes as high as several tens of mW/m^2. We also explore the patterns for porous convection of interstitial water and test the effect of a partially compacted core. These are briefly analyzed in the light of a hypothetical correlation with the evidence for spatial heterogeneity in the past surface heat flux.

1. Influence of rocky core structure

In order to evaluate heat generated by internal friction under the action of periodic tidal forces, the spatial distribution of the viscoelastic deformation has been computed following the approach of [9]. We have first computed the tidal heat budget that can be produced within the porous core of Dione for its present day orbital characteristics. In order to account for the possibility of partial compaction of the core (Dione's mass is 10 times that of Enceladus, and hence has higher confining pressure in the core), we investigate cases where an inner core with zero porosity within an inner sphere of radius R_{ic} corresponding to 0, 0.1, 0.3, 0.7 of the total radius of the core (R_c, see Fig. 1). The addition of a compacted inner core strongly affects the tidal heat flux pattern for $R_{ic}>0.1$, as well as the amplitude of dissipation, with a decrease in the core ability to dissipate as R_{ic} increases. For present day orbital conditions, the maximum total power that can be generated in Dione's porous core with our model does not exceed 10 GW. This is insufficient to prevent the ocean from freezing.

2. Influence of orbital characteristics

Tidal dissipation being strongly linked to the body dynamical evolution, the production of heat is likely to vary during the satellite history. In the light of the formation scenario by [10] where Saturn mid-sized moons migrate from the edge of the rings with a variety of possible resonances strongly affecting the moons' eccentricity [11], we computed the tidal power that can be generated in Dione's porous core for reasonable past values of the semi major axis and eccentricity (Fig. 2) and for several structures of the core (not shown here). This leads potentially to much larger values of tidal heat production in the past when the moon was closer to Saturn and/or its eccentricity was higher, solving the apparent paradox.

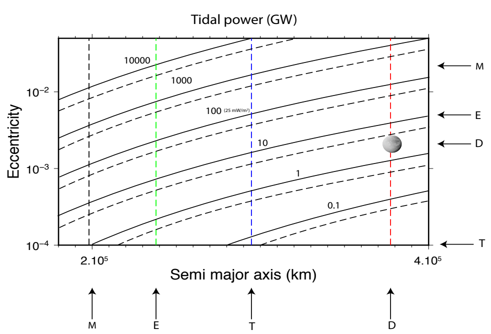

Figure 2: Tidal power generated in the porous core (no compacted inner core) as a function of orbital characteristics. Two typical values of dissipation function are considered: 0.2 (dashed lines) and 0.5 (solid lines). M, E, T and D respectively notice the present day orbital characteristics of Mimas, Enceladus, Tethys and Dione.

3. Past hydrothermal activity in Dione's porous core

In order to investigate the influence of past enhanced orbital characteristics on the heat transfer by thermal convection of interstitial water in the porous rock media, we follow the approach used by [8] for Enceladus. Our preliminary results show that the best spatial correlation between heat flux features at the seafloor and surface heat flux estimates from crater relaxation are obtained in the case of an entirely porous core, suggesting hydrothermal circulation in the whole core as on Enceladus. Heat flux maxima are located under the poles and along the leading and trailing meridians. If permeability is smaller than 10^{-13} m^2, temperatures as high as 300 to 500 K for past orbital conditions, favorable for efficient fluid/rock interactions are expected. This suggest that Dione's porous core experienced minor compaction and that Dione was probably formed late either due to late accretion [10] or due to late ice-rock segregation.

Acknowledgements

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