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The interior of Enceladus one year after Cassini

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1. Introduction

While the observation of a large-scale plume emitted by Enceladus occurred early after the insertion of the Cassini spacecraft around Saturn, a coherent view on the interior processes that power and feed this activity started emerging only in the latest year of the mission. Thanks to a flexible payload as well as multiple flybys during the extended mission, analyses of Enceladus data (composition of materials originating from the moon's interior [7, 8], geophysical measurements and long series of surface images [5, 9, 1]) composed a view where a global salty ocean is present underneath an ice crust of very uneven thickness (20-25 km in average, less than 5 km beneath the south pole, more than 30 km in some equatorial regions). Density of the rock core implies a significant ($\sim$ 20-30 %), water-filled, porosity. Furthermore, several independent chemical clues indicate that high-temperature (>363 K) hydrothermal processes probably occur at present, deep in the moon [4, 12].

2. The vibrating hot sandy core [2]

These observations require a huge heat power and a mechanism to focus the release of heat in the South Polar Terrain (SPT), most probably related to tidal dissipation yet unexplained by previous models. Assuming the ice shell thickness is known locally, a conductive thermal equilibrium provides a rough estimate of the heat emanating from Enceladus' interior: while, in the SPT, tidal heating within the ice crust could match the local heat budget (3-5 GW) owing to an extremely thin shell and to the presence of faults [10], the considerable amount of heat extracted elsewhere (i.e. at moderate and northern latitudes) exceeds 20 GW, a figure that requires a deeper origin since a thicker ice shell is less dissipative.

Mechanical tests on water saturated unconsolidated rock materials subjected to cyclic deformation point to the likelihood that, at tidal frequency, a significant amount of energy can be dissipated in a rock core filled with interstitial liquid water. We show in 3D spherical simulations that thermal convection of interstitial water within such a tidally heated core leads to strongly focused hot upwellings, especially beneath the poles (Fig. 1). While the permeability of Enceladus' core is unknown and could vary within a range involving orders of magnitude, modeled temperatures obtained for a relatively limited interval within the admissible parameter space (typically 10^{-14}-10^{-13} m^2) agree with the estimate inferred from compositional measurements by Cassini that indicate water-rock interaction. Powerful hotspots (several GW) are thus predicted at the seafloor with maxima located beneath the poles and along the leading and trailing meridians.

3. Polar ocean Plumes

Ocean dynamics could partly filter this strongly heterogeneous heat flux at the seafloor, mostly if rotational effects overcome thermal convection. We have recently conducted 3D simulations dedicated to the buried ocean of Enceladus with a heterogeneous heat flux prescribed at the inner boundary (not shown in [2]): while the precise balance between the Coriolis and the buoyancy forces is not known, our first results demonstrate that although in some cases, the heat flux pattern at the seafloor can be significantly blurred at moderate latitudes bounded by the the tangent cylinder, it remains globally unaffected in polar regions where ocean plumes supply a significant amount of heat in regions coinciding with the lowest ice thickness (Fig. 1). Scaling relationships also indicate that the transport time of organic products by ocean thermal vents would match the constraints derived from Cassini measurements (typically a few months).

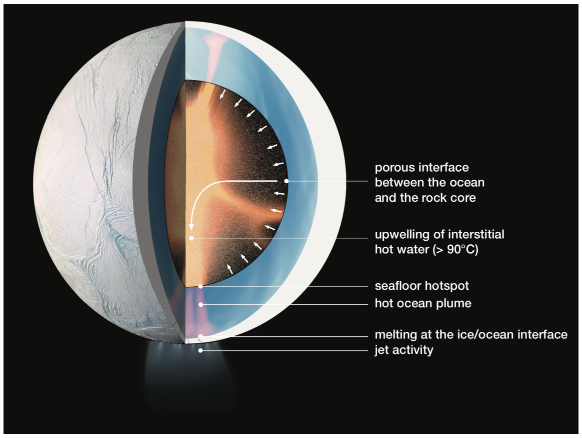

Figure 1: A general scheme describing our "vibrating hot sandy core" model for the interior of Enceladus and its relationship to the main properties inferred from Cassini observations: intense jet activity, uneven ice shell, buried global ocean and hydrothermal activity. *Credit: ESA-LPG*

4. The very uneven ice shell

We also refined our model for the ice shell thickness based on the shape data recently published by Tajeddine et al. (2017) [11] still considering the long-wavelength gravity model of Iess et al. (2014) [5] (again not described in [2]), globally confirming our earlier results [1]. Based on this new inversion, this presentation will briefly address the mechanical and thermal stability of the ice shell. We consider in particular how lateral heat flux variations delivered by the ocean at the base of the ice shell leads to melting/thinning and show that density anomalies caused by thermal convection in the porous core might affect the interpretation of the compensation mechanism.

5. Summary and conclusions

While the vibrating hot sandy core model for Enceladus (Fig. 1) accounts for the main features inferred from Cassini observations, a key question remains (especially with regard to habitability): since how long can such an intense activity have occurred ? The answer mostly relies on the dissipation mechanism within Saturn that controls the eccentricity of Enceladus and thus, ultimately, the power generated by tides in its core. Based on the latest estimates from astrometric data [6], we predict that hydrothermal activity can persist for several tens of millions of years. Assuming tidal evolution results from resonance locking as suggested by Fuller et al. [3], it could have lasted for billions of years.

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