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Differentiation and mineralogy of Rhea

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Abstract

We considered thermal evolution and differentiation of Rhea (a satellite of Saturn). We have found that chemical reactions could be an important source of heat.

1. Introduction

Rhea is a medium sized icy satellite (MIS) of Saturn. It is built of mixtures of rocks and ices. The rocky component is believed to be of chondritic composition. The main component of ices is frozen H_2O. Initially the interior was built from homogenous mixture of both components. The separation of rocky component from the ices is known as differentiation. It is possible if the icy component is molten in the large part of the satellite interior. During this differentiation the high density silicate grains sink in the liquid eventually forming the central core. The low density matter forms an upper layer.

Analysis of the Doppler data acquired by the Cassini spacecraft on November 26, 2005 yields the mass of Rhea and its gravity field with unprecedented accuracy [3]. It was found that Rhea is in hydrostatic equilibrium. Moreover, models with a constant silicate mass fraction throughout the body cannot account for the determined quadrupole coefficients of the gravity. Eventually, [3] conclude: "The one model that fits the gravity data and is self-consistent […] is an "almost undifferentiated" Rhea, in which a very large uniform core is surrounded by a relatively thin ice shell containing no rock at all".

In the present paper we try to find explanation of these observations using thermal model of evolution. Comparing to our previous models, we include here also the heat of chemical reactions.

2. Numerical method

The parameterized theory of convection combined with FDM (Finite Difference Method) approach is chosen for the present research [1, 2]. The approach is based on the 1 dimensional equation of the heat transfer in spherical coordinates:

$$\rho\, c_p \frac{\partial T(r,t)}{\partial t} = \mathrm{div}(k(r,T)\,\mathrm{grad}T(r,t)) + Q(r,T) \quad , (1)$$

where r is the radial distance (spherical coordinate), ρ is the density [kg m^{-3}], c_p [J kg^{-1} K^{-1}] is the specific heat, Q [W kg^{-1}] is the heat rate, and k [W m^{-1} K^{-1}] is the thermal conductivity. Note that Q(r, t) includes sources and sinks of the heat: radiogenic heat resulting from the decay of isotopes, latent heat of melting, latent heat of solidification, and chemical reactions. The heat of accretion is included as initial temperature of the accreted layer.

The heat transported by convection is included by multiplying the coefficient of the heat con duction in the considered layer by the Nusselt number Nu:

$$k_{conv} = Nu\, k, \qquad (2)$$

where for Nu we use the formula given by [4] for temperature dependent viscosity and for the medium viscosity contrast.

3. Basic results

We found that partial differentiation followed by uprising of light component is consistent with observations of gravity and surface of Rhea. Our calculations indicate that partial melting is possible only for narrow range of parameters. It makes possible to determine approximately the time of accretion of Rhea. Without consideration of chemical reaction the time from forming CAI to the end of accretion is probably from 2 to 4 My. Including chemical reaction reduces further this range to 2-2.6 My. However, the other possible model includes full differentiation into water ice and less dense silicates that include mainly serpentine and probably other silicate minerals. In this case the time of accretion cannot be determined.

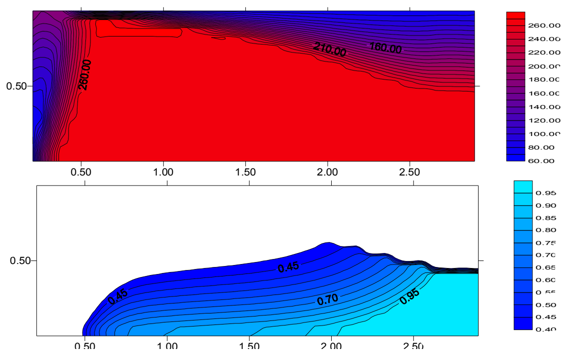

Figure 1: Thermal and melting history in Rhea according to our model for accretion starting 0.4 My after formation of CAI and lasting for 1 My. The reference viscosity of ice at melting temperature is $\eta_m=10^{12}$ Pa s. The vertical axes give r/R_{sat}, the horizontal axes give $\log_{10}(t$ [My]), where t is the time from the beginning of accretion. The upper panel presents isotherms in Kelvin, the isolines in lower panel give supplied fraction of latent heat of melting (1 means fully molten matter). Note substantial phase shift between temperature distribution and melting distribution and that the melting starts after 100 My only [2]. No chemical reactions are included in this calculation.

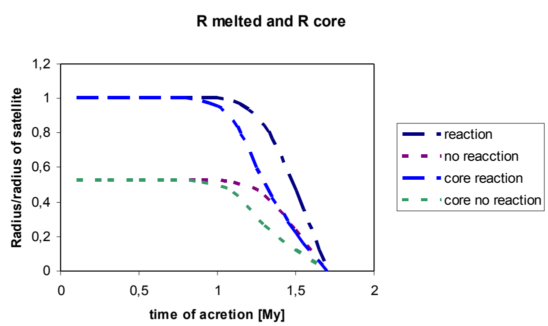

Figure 2. Radius of melted part and radius of core as a function of time of beginning of accretion with, and without heat of chemical reactions. The partial differentiation is possible for very limited range of time of accretion (1-1.6). The accretion lasts additionally 1 My, so time from formation of CAI to end of accretion is in the range from 2 to 2.6 My.

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