ONSET OF CONVECTION AND DIFFERENTIATION IN THE HYDRATED CORES OF ICY MOONS.

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Introduction: The Galileo mission to Jupiter and the Cassini/Huygens mission to Saturn have revealed that the three large Jovian icy moons and Titan, Saturn's largest satellite, are at least partly differentiated. Their normalized moments of inertia (C/Ma2 in Table 1) are smaller than 2/5, which is the value for undifferentiated moons. However, the value is quite different for Ganymede than for Callisto. The low value for Ganymede is consistent with a fully differentiated body consisting of an inner iron rich core, a silicate shell, a high-pressure ice shell, a liquid shell and an outer low pressure (ice I) layer [1]. The case of Europa is different since its lower mass and its large density imply a much thinner outer H_2O layer. One explanation for the larger values of the moment of inertia of Titan and Callisto is that they have not undergone complete differentiation and that their interior would be, at least partly, composed of hydrated silicates [2,3] which are much less dense than the silicates that compose the mantle of terrestrial planets. The present study models the thermal evolution of such cores. It investigates whether convection processes, that would prevent dehydration and differentiation, can happen

	Titan	Callisto	Ganymede	Europa
Mass (10^{23} kg)	1.345	1.076	1.485	0.481
Radius (km)	2575	2403	2634	1569
density	1881	1851	1940	2970
C/Ma2	0.342	0.358	0.311	0.347
Eccentricity (%)	2.92	0.7	0.15	1.01
Prot (days)	15.95	16.7	7.15	3.55

Table 1: characteristics of Europa, Ganymede, Callisto and Titan

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Thermal evolution model: A 1D spherical model is used to calculate the thermal profile in the silicate core as a function of time for a variety of initial conditions and parameters. The core is overlaid by a H_2O layer. In the nominal case, the initial amount of radioactive heat is $2x10^{-11}$ W/kg and the temperature and pressure at the H_2O/core interface are set to 300 K and 0.9 GPa, respectively. At each time step, the likelihood of convection is assessed (see below). The simulations start after the accretion phase during which temperatures were large enough to allow for partial melting and the formation of a hydrated core made of antigorite. The core heats up due to the decay of radioactive elements. The amount of ^{40}K is a free parameter because potassium is easily leached during processes involving circulation of water. The simulations use thermal parameters recently reviewed [4]. For example, the specific heat is about half the value used by [2], which means that the temperature increases much more rapidly with time for the same amount of internal heating. These values are based on several laboratories studies on antigorite whose properties play a key role in the geodynamics of subduction zones on Earth [5]. As the interior temperature increases, the inner part of the core can dehydrate (Fig. 1). Note that in the example shown in Fig. 1, the latent heat has not been incorporated. Also, the density change and the volume change related to the dehydration process have not yet been incorporated. The question on whether the water trapped at depth can migrate to the rock/H_2O interface has not been addressed.

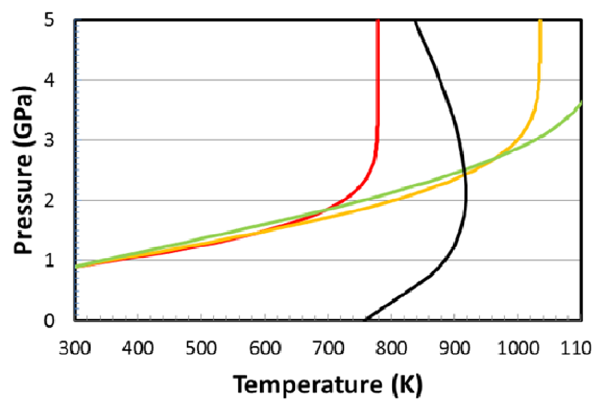

Figure 1: Temperature profile at three different time steps (Red: maximum of heat flux, Yellow: intermediate, Green: present time without convection). The dark curve is the dehydration curve of antigorite.

At each time step, the density profile is computed using an equation of state based on recent laboratory experiments [5, 6]. Using the parameters of their Birch-Murnagham equation, we determine a linear fit between pressure and density (correlation coefficient of 0.999) that provides a simple equation of state linking the density to temperature and pressure. The stability against convection is then assessed.

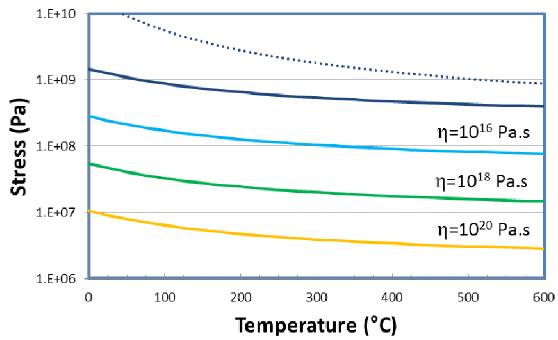

Figure 2: Viscosity of antigorite extrapolated from laboratory experiments [5]. It shows that the viscosity is strongly stress-dependent (non-Newtonian viscosity) and weakly temperature-dependent.

Onset of convection: Convection processes can start if the density profile is unstable (density decreases with pressure because of the temperature increase) and if the viscosity of the material is low enough for buoyancy forces to overcome viscous forces. It starts when the Rayleigh number becomes larger than a critical value that depends on the viscous behavior of the material [7]. The viscosity of antigorite is very strongly stress-dependent (Fig. 2). The value of the critical Rayleigh number for non-Newtonian viscosity with no temperature dependence has been estimated using both laboratory and numerical data [7]. It must be noted that in such fluids, the meaning of the boundary between conductive and convective regimes is that if the Rayleigh number is below some critical value, no convective motion is possible with any initial conditions; if it is above this critical value, convection is possible but initiation of convection requires sufficiently large initial perturbations. In the icy moons Europa, Ganymede, Titan or Callisto, the perturbations may be the tidal forces acting on the core. If the amount of ^{40}K is large (CI chondrites) the critical value can be reached in less than 1 Gyr (Fig. 3). With an Earth-like amount of ^{40}K, the critical value is reached much later. In both cases, convection would only affect the outer layer of the core while the inner core would be subject to dehydration. The implications for the evolution of the interior structure are being investigated

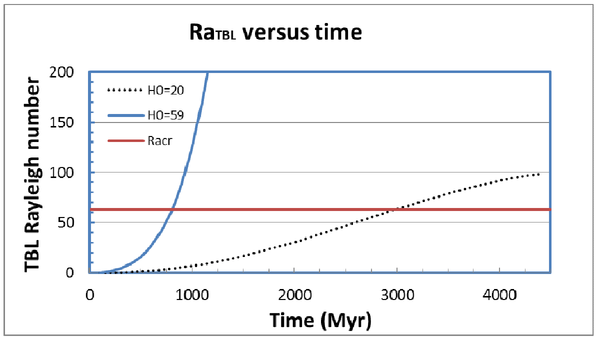

Figure 3: Evolution of the Rayleigh number with time for the chondritic case (blue curve) and Earth-like case (dotted line).

Conclusions: The numerical simulations presented in this study suggest that the inner part of the hydrated core of icy moons would dehydrate for a large range of parameters, the most important of which is the amount of ^{40}K. The outer core would remain hydrated. The onset of convection has been investigated for antigorite whose viscosity is mostly stress-dependent. It is shown that convection could start in the outer core for large values of internal heating. Implications for subsequent thermal evolution are being investigated.

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