On the onset of convection and differentiation in the hydrated cores of icy moons

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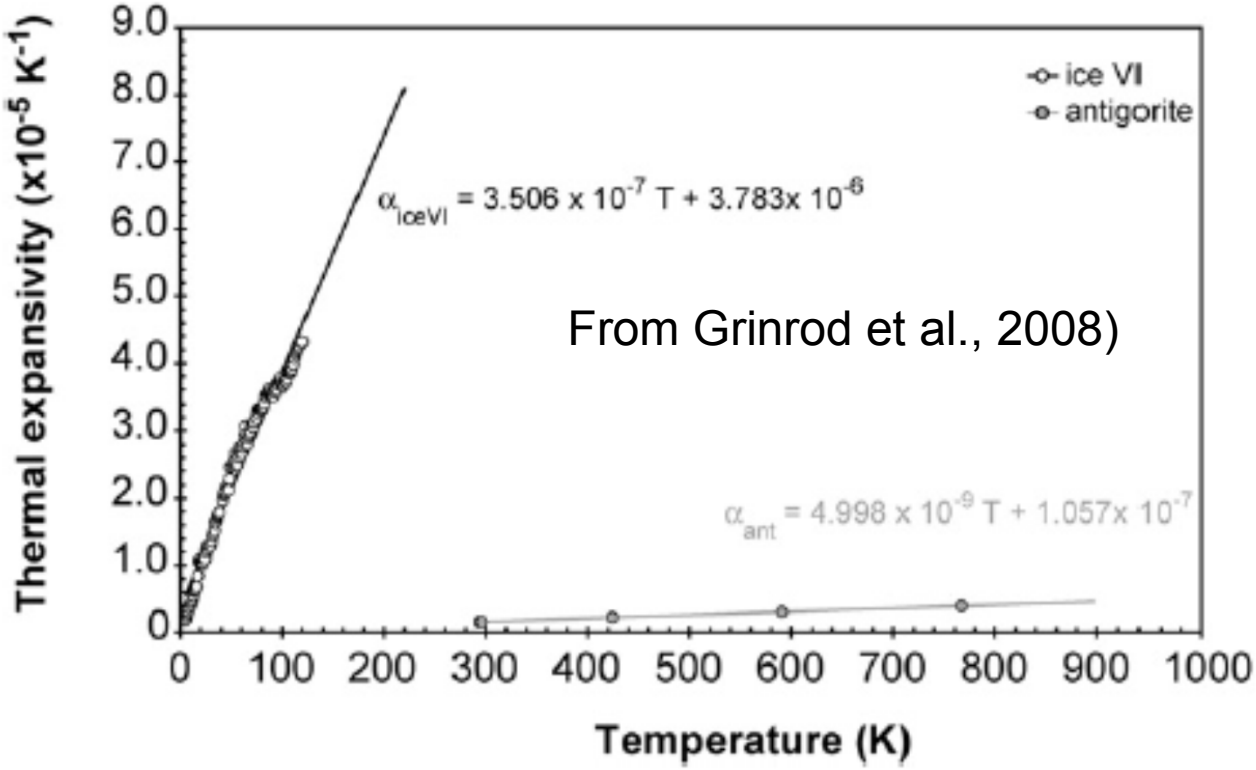
The core of icy satellites may be made of hydrated silicates (Grinrod et al., 2008; Castillo-Rogez and Lunine, 2010) – $MGO_{48}SIO2_{34}H2O_{31}$ –

Antigorite has physical properties that are well known (Hilairet et al., 2007; Osako et al, 2010)

- viscosity is very much pressure dependent
- previous studies used wrong values, which led to erroneous models of thermal evolution, specifically the dehydration process

We have revisited the simple thermal evolution model based on conduction
We have investigated the possibility of convection in the antigorite core

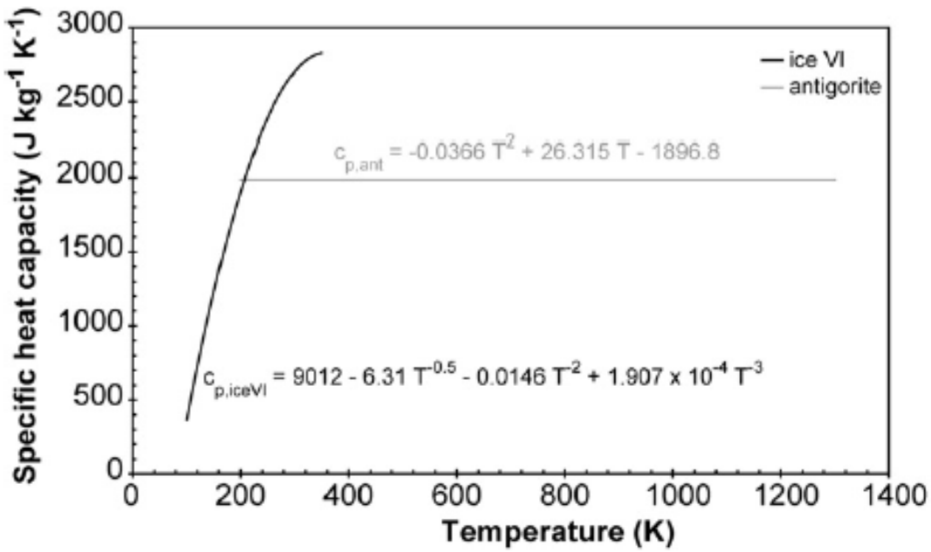
Example of thermal expansion



From Grinrod et al., 2008)

Values from Osako et al. (2010) are 10 times higher ~ 3 10^{-5} K^{-1} : obvious implications for volume change during thermal evolution

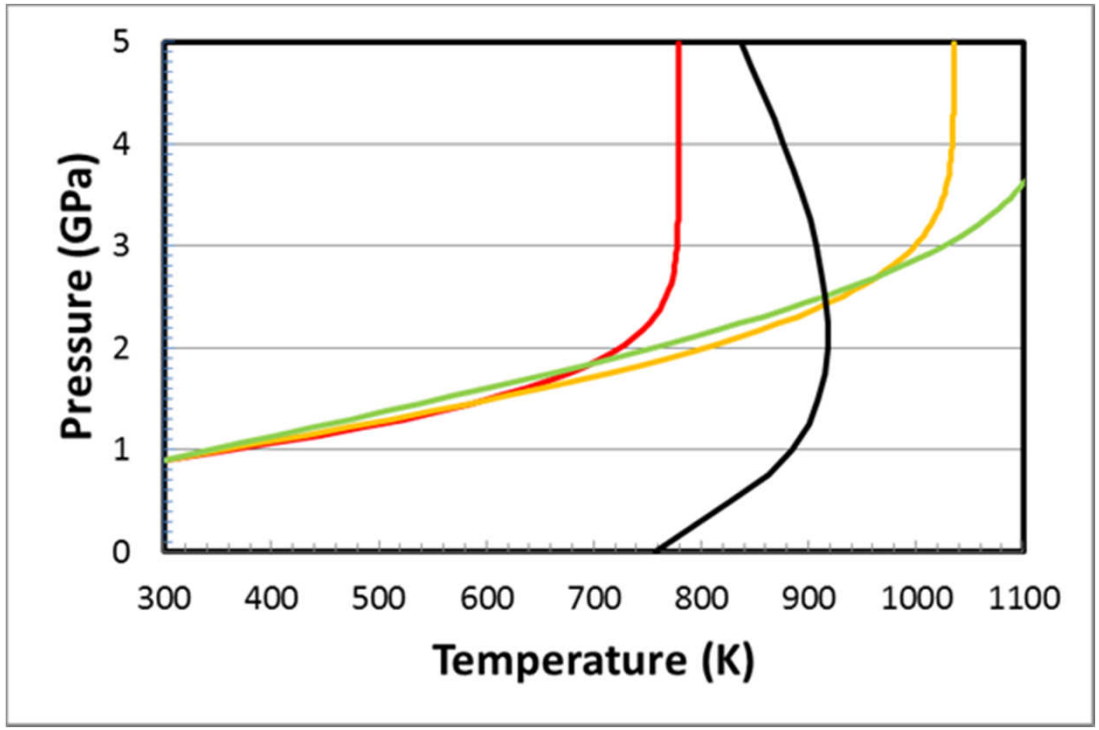
Example of specific heat



$$\frac{\partial\left(k\,\partial T/\partial r\right)}{\partial r}+\frac{2}{r}\left(k\,\partial T/\partial r\right)=\rho C_P\left(\frac{dT}{dt}\right)-H$$

Values from Osako et al. (2010) are 2 times smaller, which implies temperature increase 2 times larger and faster dehydration, everything else (H) being the same

Thermal evolution in the core

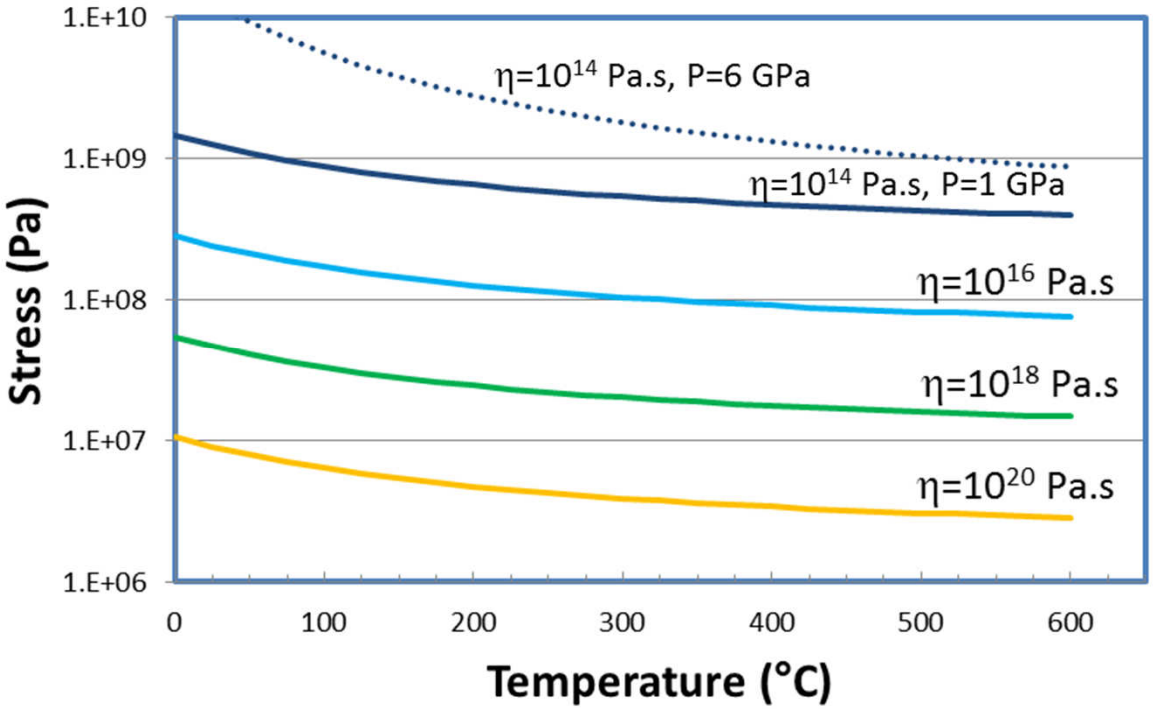


R: maximum heat flux
Y: Onset of convection
G: present time

Temperature profile in an antigorite core for the nominal case ($H0=2.10^{-11}$ W/kg) and a radius of 2000 km below a 500 km thick layer of ice and water.
The black line is the dehydration of antigorite. In this simulation, dehydration would start about 2 Myr after accretion. Since the inner part of the core does not participate in the convective process, a layer of liquid water may form at depth. Can this water be extracted?

Viscosity of antigorite

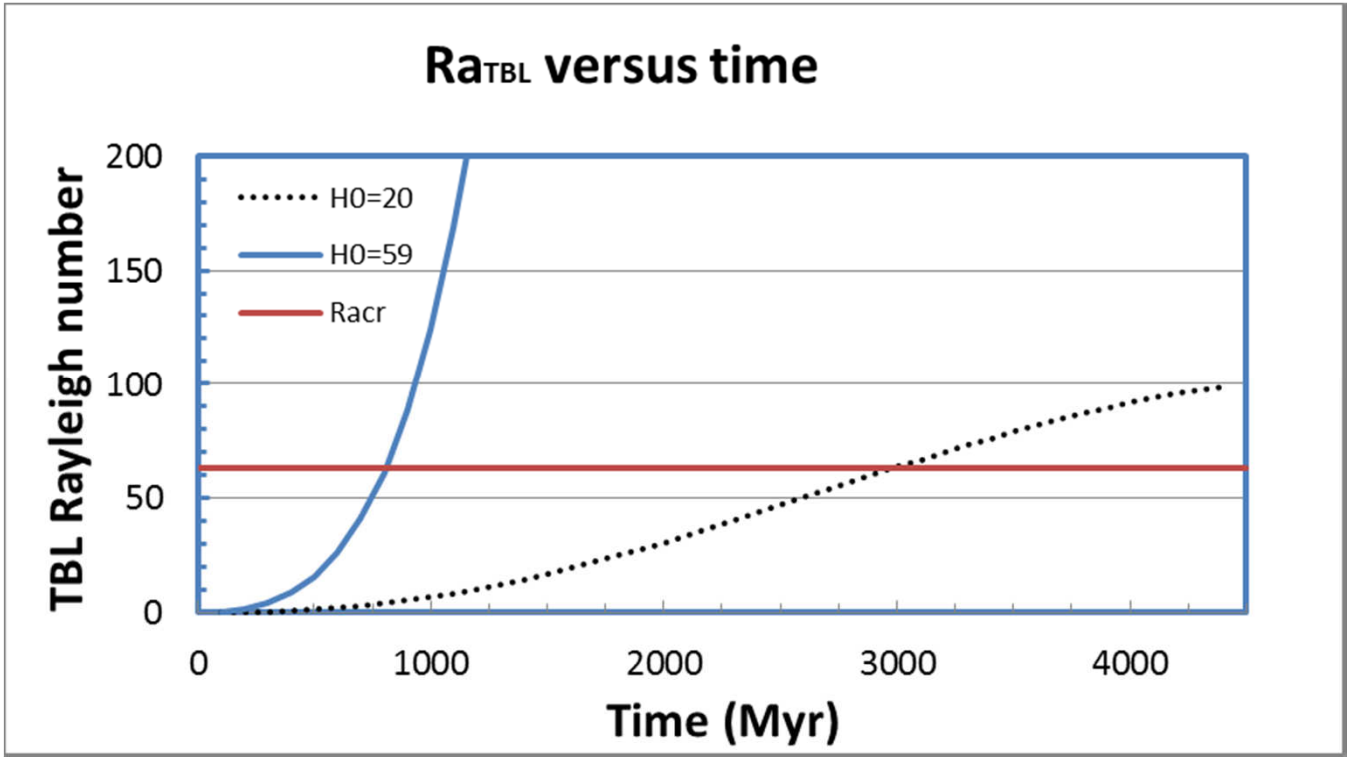
$$\eta = \frac{\tau}{\dot{\varepsilon}} = \frac{1}{A}\tau^{1-n} \cdot \exp\left(\frac{E + P \cdot \Delta V}{RT}\right)$$



Viscosity is mostly stress dependent with n=3.8 and is very little temperature dependent. E=8.9 kJ/mol

Onset of convection

$$Ra = \frac{\alpha \rho g \cdot \Delta T \cdot \delta_0^{n+2/n}}{\kappa^{1/n} \cdot b^{1/n} . \exp(-p/n)} = Ra_{cr}$$

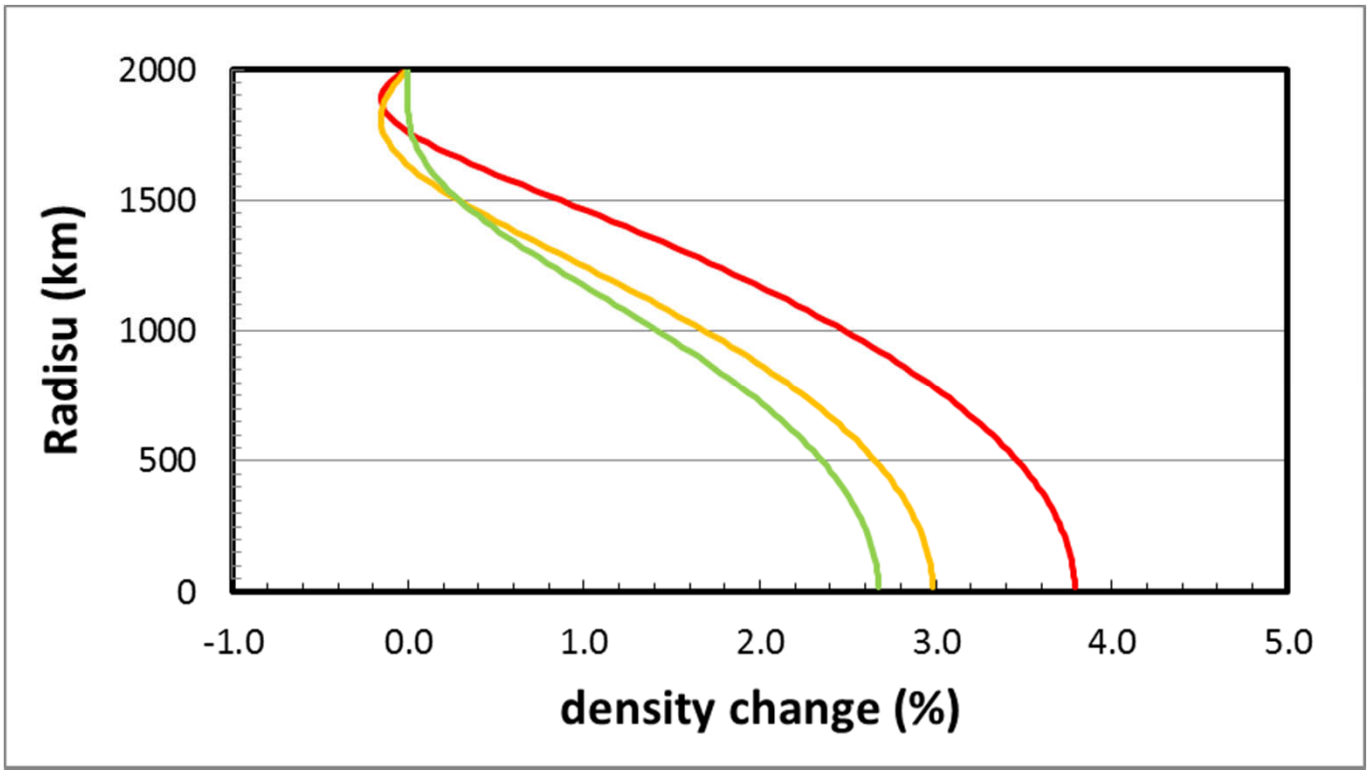


Onset of convection based on study by Solomatov (1995)
Convection would limit the temperature increase – dehydration process is less important

EoS

$$P = \frac{3K_0}{2}\left[\left(\frac{\rho}{\rho_0}\right)^{7/3} - \left(\frac{\rho}{\rho_0}\right)^{5/3}\right]$$

$$\rho = [2628 + 34.55 \cdot P] \cdot [1 - \alpha(T - T_0)]$$



Small amount of internal heating: density profile is very stable against convection

EoS

$$P = \frac{3K_0}{2}\left[\left(\frac{\rho}{\rho_0}\right)^{7/3} - \left(\frac{\rho}{\rho_0}\right)^{5/3}\right]$$

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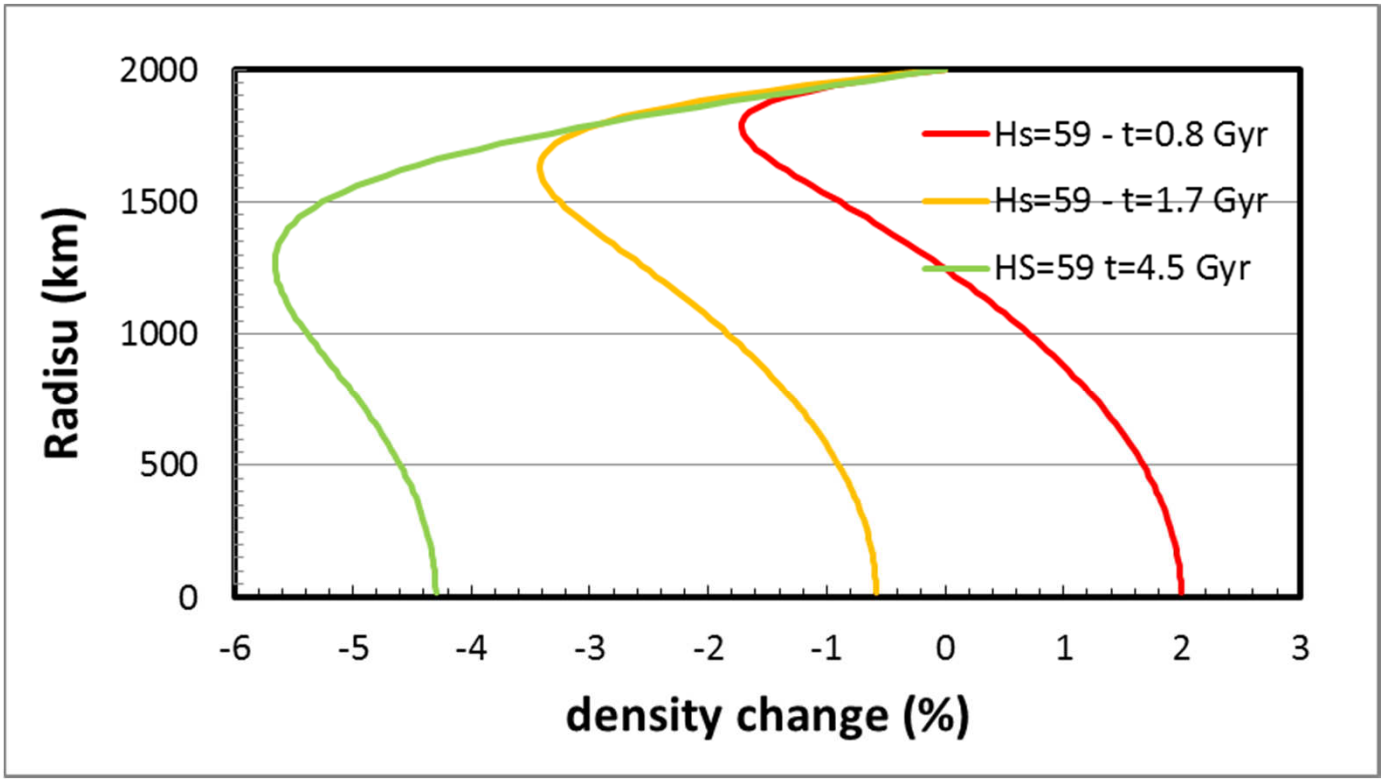

Larger amount of internal heating: density profile is unstable but convection affects the upper core only – future work with 3D numerical simulations

Conclusions

- Compared to previous studies, dehydration processes would start much earlier than previously reported if only conduction is taken into account
- Dehydration does not occur only if the amount of radiogenic heating is very low. Such low values do not seem realistic
- The viscosity of antigorite is very much stress dependent – The onset of convection is predicted for realistic values of internal heating rate.
- Convection processes limit the increase in temperature and the onset of dehydration
- These results can be applied to any icy satellite but has been limited so far to Titan