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Fe-snow in Ganymede's core

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Abstract

In the low pressure range of Ganymede's core the melting temperature of the Fe-FeS eutectic has a negative slope. As a consequence, on the iron rich side of the eutectic solid iron first forms close to the core mantle boundary, snows down and eventually remelts at deeper levels. This process produces a stable chemical gradient before inner core formation and may prevent convection by thermal bouyancy; thus possibly influence the dynamo action. In the present study, we focus on the determination of the chemical gradient that depends on the initial sulfur content and the adiabatic temperature gradient.

1. Introduction

One of the most startling discoveries of the Galileo Mission was the self-sustained magnetic field of the Jovian moon Ganymede. The favored explanation is a compositionally driven dynamo inside the core [1,2]. Due to the negative slope of the Fe-FeS eutectic melting temperature [3,4], chemical convection driven by compositional buoyancy can differ from convection in the typical Earth-like dynamo. On the left side of the eutectic, iron solids snow down from the core-mantle boundary and possibly remelt at deeper levels (Fe-snow). This process produces a stable chemical gradient before an inner core starts to form. This chemical layer remains stable in the liquid outer core also when an inner core starts to grow. Hauck et al. [1] propose that Fe-snow can provide the driving force for the today self-sustained magnetic field of Ganymede. On the contrary, Bland et. al. [2] suggests that a production of Ganymede's magnetic field can not be met with the Fe-snow regime. In the present work, we examine the Fe-snow regime and in particular the development of the chemical layering.

2. Model

For modeling the scenario of the Fe-snow regime we divide a liquid Fe-FeS core into 100 core shells of constant volume. Considering local pressure and temperature conditions in the core, precipitation of Fe, the descent and remelting of Fe as well as the consequential growth of an inner iron core are calculated. The initial sulfur composition in the core is assumed to be homogeneous. The melting temperature of Fe-FeS has been obtained assuming a linear change of the melting temperature between pure Fe [5] and the eutectic Fe-FeS [3, 4]. We calculate the local temperature with

$$T_c = T_{cmb} \cdot exp\left(\frac{\alpha_c \cdot (P(r) - P_{cmb})}{\rho_c \cdot c_{c,p}}\right) \qquad (1)$$

assuming an adiabatic temperature profile. In case of $T_c \leq T_{liq}$ part of the iron solidifies in the corresponding core shell and sinks down towards the core center due to its higher density. For calculating the fraction of solid iron we use the lever rule, assuming the core to be in thermo-chemical equilibrium. The densities are calculated with a third order Birch-Murnaghan equation of state for $\gamma - Fe$ and $FeS - V$. In the case of liquids the correction factor of Van Hoolst [6] is used. At deeper levels, where $T_c \leq T_{liq}$ the iron remelts and causes a change in T_{liq}. The output of the model is the total temperature decrease until an inner core starts to grow (ΔT), the radius of the inner core (R_{ic}), the sulfur decrease (Δx_s) and the density increase ($\Delta \rho$) from the core-mantle boundary to the center.

3. Results and Conclusions

The sulfur (density) gradient in the core and the size of the solid inner iron core have been calculated for a fixed temperature decrease. For the onset of inner core growing we find a temperature decrease of $40 - 65K$ for initial sulfur contents x_s from 10% to 20% and a thermal expansion coefficient of $\alpha = 10^{-4} K^{-1}$ (table 1). Models with a reduced thermal expansion coefficient of $\alpha = 5 \cdot 10^{-5} K^{-1}$ and the same initial sulfur contents as above yield temperature differences of $20 - 50K$ (table 2).

Associated density increases are 200-350 kg/m^3 for the higher thermal expansion coefficient and 150-230 kg/m^3 for the lower one. The associated chemical gradient seems to be strongly dependent on the initial sulfur content as well as on the assumed adiabatic temperature gradient. The obtained temperature decrease suggests a time scale of the Fe-snow regime (until an inner core grows) in Ganymede's core of about 0.5-1 Ga. This time scale is estimated from thermal evolution models that suggest a core cooling rate of about 50 K per one billion year [1].

The chemical gradient which arises during that time may prevent thermal convection in the core - possibly only convection by sedimentation exists. Whether a dynamo can be sustained by sediment convection alone is not known.

If sediment convection is insufficient for magnetic field generation, dynamo action may stop when the outer core becomes enriched in sulfur due to inner core growth and the chemical gradient too large to allow thermal convection. The presented model does not account for latent heat and gravitational energy during the core forming process. Both contributions may influence the local temperature, i.e. the temperature increase can deviate from the assumed adiabate, and therefore have an impact on the whole core growing process.

Table 1: $\alpha_c = 10^{-4} K^{-1}$

$x_s[\%]$	$\Delta T[K]$	$\Delta x_s[\%]$	$\Delta\rho[kg/m^3]$
10	40	2.6	213
13	48	3.4	257
15	52	3.5	271
18	56	3.6	304
20	66	4.4	340

Table 2: $\alpha_c = 5 \cdot 10^{-5} K^{-1}$

$x_s[\%]$	$\Delta T[K]$	$\Delta x_s[\%]$	$\Delta\rho[kg/m^3]$
10	22	1.4	146
13	30	1.8	163
15	36	2.5	215
18	44	2.9	221
20	48	3.3	233

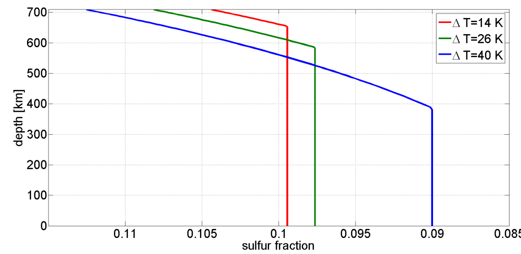

Figure 1: Sulfur concentration in a liquid Fe-FeS core as a function of depth for a temperature reduction of $\Delta T = 14K$, $\Delta T = 26K$ and $\Delta T = 40K$, $x_s = 10\%$ and $\alpha_c = 10^{-4}K^{-1}$. In the upper core a layer with a stable chemical gradient evolves. Its thickness increases with cooling of the core - below this layer the core is homogeneously mixed. Temperature decrease greater than $40K$ will lead to the growth of an inner core.

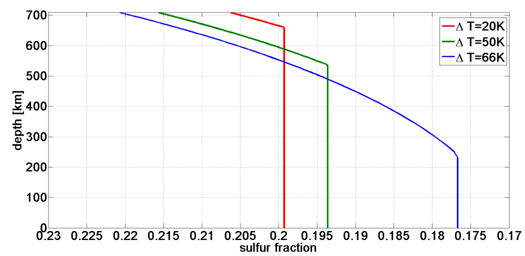

Figure 2: Sulfur concentration in a liquid Fe-FeS core as a function of depth for a temperature reduction $\Delta T = 20K$, $\Delta T = 50K$ and $\Delta T = 66K$, $x_s = 20\%$ and $\alpha_c = 10^{-4}K^{-1}$. In the upper core a layer with a stable chemical gradient evolves. Its thickness increases with cooling of the core - below this layer the core is homogeneously mixed. Temperature decrease greater than $66K$ will lead to the growth of an inner core.

References

[1] Hauck, S. A., Aurnou, J. M. and Dombard, A. J., 2006. J. Geophys. Res., 111.

[2] Bland M.T., Showman A.P., Tobie G., 2008. Icarus, 198, 384-399.

[3] Fei, Y., Bertka, C.M., Finger, L.W., 1997. Science 275, 1621-1623.

[4] Fei, Y., Li, J., Bertka, C.M., and Prewitt, C.T., 2000. Am. Mineral. 85, 1830-1833.

[5] Boehler, R., 1993. Nature, 363, 534-536.

[6] Van Holst T. and Jacobs, JGR, 2003.