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The Effects of the Spinel-Perovskite Phase Transition in The Martian Mantle

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Introduction

The importance of the high pressure phase transitions on the mantle dynamics has been illustrated for Mars both with 2D and 3D simulations. Phase transitions in the Martian mantle, the exothermic Olivine to Spinel transition and in particular the endothermic Spinel to Perovskite transition, are assumed to influence significantly the convective flow field of Mars and the dynamo of the planet, [1]. To apprehend the past of the Martian dynamo, Breuer et al., [2], invoke the presence of an initial hot core. This core is thus cooling and crossing a threshold where the dynamo can't be active anymore.
We investigate the role played by the Spinel-Perovskite phase transition on the thermal evolution of Mars. Indeed, we will analyse, with the numerical simulation code CITCOM2D, [3, 4], the consequences of the motion in depth and, eventually, the disappearance, of the endothermic phase transition during the planet cooling.

Numerical simulation

As the Clapeyron slope is negative for an endothermic phase transition, this transition moves downward, at higher pressure as the planet is cooling: the thickness of the Perovskite layer decreases with the planet cooling. Two consequences are link to this behaviour: (1) The Perovskite layer can go up from a convective state to a conductive state (2) the Perovskite layer can disappear.

We used the CITCOM2D numerical code, [3, 4] that we modified in order to take the cooling of the core into account. Fixed parameters values are resumed in table 1. In particular, we used the values of 16 ppb U and the ratios of the concentrations K/U of 10^4 and Th/U of 3 [5, 6] for the heat sources in the mantle. Using the radioactive decay constants and the rate of heat release of these elements an initial heat production density of the primitive mantle after core formation of $Q_0 = 1.18\ 10^{-8}$ W/m^3 is obtained.

We focus on the motion of the endothermic phase transition and the effects on the heat flux from the core, when the core is cooling, with a temperature dependant viscosity in the mantle. We choose to study the case of a small core (a radius equal to 1360 km), which permits the presence of the Spinel to Perovskite phase transition [7].

Property	Units	Values
Planetary radius	km	3400
Core radius	km	1360
Mantle density	kg.m^{-3}	3500
Rayleigh number	-	3,7 10^7
Viscosity reference	Pa.s^{-1}	2,0 10^{20}
Surface temperature	K	220
CMB temperature	K	2500
Initial mantle heat sources	W.m^{-3}	1,18 10^{-8}
Endothermic phase transition		
Clapeyron slope	Mpa.K^{-1}	-3
Temperature	K	2200
Density difference	kg.m^{-3}	400
Exothermic phase transition		
Position	km	2140
Clapeyron slope	Mpa.K^{-1}	+3
Temperature	K	1000
Density difference	kg.m^{-3}	250

Table 1: Fixed parameters for each case in the Martian mantle

Variable parameters are the viscosity contrast and the position of the endothermic transition. We have six cases. In three cases we place the endothermic transition at 50 km from the core. The viscosity is constant in a first case, thus it is temperature dependent with a contrast viscosity of

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10^3 in a second case and 10^7 in the third case. In the three other cases we use the same variation of the viscosity, but with an endothermic transition at 100 km from the core.

Results

When there is a viscosity contrast equal to 10^7, the mantle is warmer and the endothermic transition doesn't move downward significantly. As the exothermic transition tends to enhance the convection, the cooling is more efficient when it's added to the model. The exothermic phase transition favours the core cooling even when the viscosity contrast is 10^7 but not so efficiently than with any viscosity contrast.
The disappearance of the endothermic Spinel to Perovskite transition has an influence on the heat flow from the core. The flux decreases upon the core cooling, and when the endothermic transition disappeared, the flux becomes constant for a while, then decreases again, as on the figure 2.

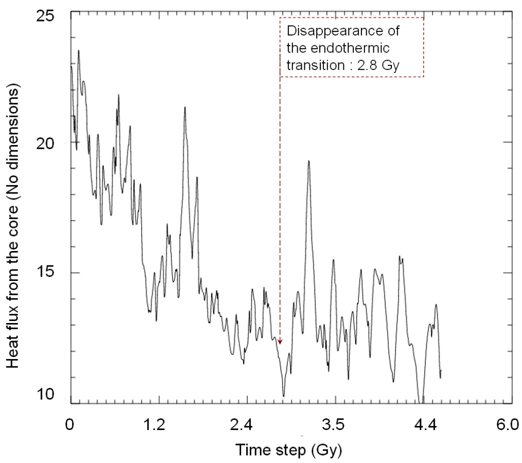

Figure 2: Heat flux at the base of the mantle, from 0Gy to 6 Gy, in the case with constant viscosity and the endothermic phase transition at 50 km from the core (small core).

Conclusion

In the first cases where the endothermic phase is at 50 km from the core, we have two different scenarios. With a constant viscosity in the mantle and a small core, the endothermic phase disappears after a few billion years and this disappearance has an effect on the flux from the core who could explain the past dynamo of Mars. But in the more realistic case with a high viscosity contrast, the endothermic phase does not have similar effects on the heat flux from the core. It does not have effects too on the heat flux from the core in cases where the endothermic phase transition is at 100 km from the core.

As the size of the Martian core is not well known, we will consider a larger core (1700 km radius). In this case the endothermic phase transition cannot be present in the mantle. In our future work we will compare the effects of the exothermic phase transition on the heat flux from the core (in case of a larger core) with the precedent case of a small core and an endothermic phase transition presents in the mantle and will also add the Martian crust into the model.

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