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Interactions between mantle convection and dense material accumulation on the core-mantle boundaries in large terrestrial planets

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Abstract

We consider interactions between mantle convection and dense material accumulation on the core-mantle boundaries in large terrestrial planets. We try to determine, using numerical simulations, how these accumulates and radioactive heat production in them may affect mantle convection. It is to further debate whether such systems can be the key to interactions between outer core and mantle convection for large terrestrial planets.

1. Introduction

The core-mantle boundary (CMB) is the most important boundary in the Earth's interior. It is an interface between geodynamo and mantle convection. Despite recent progress, it remains mysterious because of its' thermal and compositional diversity. The only ways of peeking inside deep Earth are seismological observations and numerical models combined with solid state physics dealing with materials at high pressures and temperatures. The CMB is probably a reservoir of material of density between the density of rocky mantle and outer core. Seismological observations and models concerning geological evolution of the Earth indicate existence of piles of enriched in iron, dense material on the CMB. These piles are referred as core-continents (c-continents) or BAM (basal mélange)[1,3] . On the boundaries of these bodies seismic velocities drop radically (5-10% anomaly) and Ultra Low Velocity Zones (ULVZs) are observed. Their edges correlate with rising of hot mantle plumes. We think that CMB is also probably the graveyard of cold subducted slabs. Taking everything into consideration, we see how complex and diverse this layer is. Its' composition (and thus viscosity) is strongly dependent on temperature (we may mention here the perovskite-post perovskite phase transition discovered in 2004 [2]).

In our research we consider CMB's influence on mantle convection – particularly, how it is affected by the deposits of dense material.

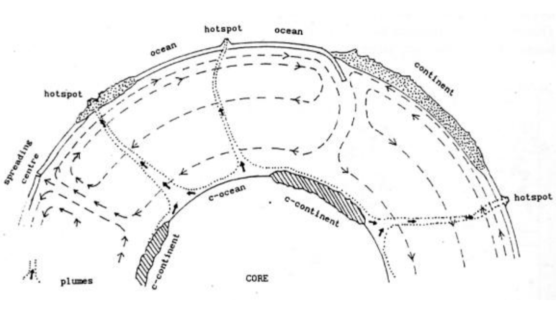

Figure 1: Interaction of c-continents with mantle convection, visible plumes rising from their edges [3]

2. Simulations

We are currently working on two-dimensional numerical model. It is based on the following equations:

$$\rho(T, Z_a, Z_b) = \rho_0 - \alpha\rho_0 T - \gamma_a Z_a + \gamma_b Z_b \quad (1)$$

$$\frac{DT}{Dt} = \nabla^2 T + f(Z_a, Z_b) \quad (2)$$

$$f(Z_a, Z_b) = (1 - Z_a - Z_b)Q_m + Z_a Q_a + Z_b Q_b \quad (3)$$

$$\nabla^2(\eta\nabla^2 S) = R_T \frac{\partial T}{\partial x} + R_{Z_a}\frac{\partial Z_a}{\partial x} + R_{Z_b}\frac{\partial Z_b}{\partial x} \quad (4)$$

$$\frac{DZ_{(a,b)}}{Dt} = C_{(a,b)}\left[\frac{\partial^2}{\partial x^2} + \frac{\partial}{\partial y}\left(\frac{\partial}{\partial y} - B_{(a,b)}\right)\right] Z_{(a,b)} \quad (5)$$

where $\frac{D}{Dt}$ denotes substantial derivative, η is viscosity, R_T corresponds to Rayleigh number in the case of internal heating and R_{Z_a}, R_{Z_b}, $C_{(a,b)}$ and $B_{(a,b)}$ are non-dimensional parameters characterizing gravitational differentiation. We use two different fractions of material: the crust, referred as Z_a, and c-continents, referred as Z_b. Assuming whole-mantle convection and given initial density distribution and initial temperature, we calculate temperature T, stream function S and distribution of both fractions. The function *f* in the temperature equation (2) describes radioactive heat production in each of the fractions considered (3), where Q_m and Q_a denote the concentration of heat sources in the mantle and in the crust respectively. The concentration of radiogenic heat sources in c-continental matter, Q_b, is virtually unknown. We plan to determine the role of this heat source. With increasing Q_b thermal isolation of the core is better, which results in lower heat flow from the core. In such a case the process of geodynamo needs to be more efficient in order to produce observed magnetic field. If Q_c is very high, the matter of c-continent could be partially molten and eventually differentiated. Lower Q_b means higher density of c-continents – in this case they have small influence on mantle convection.

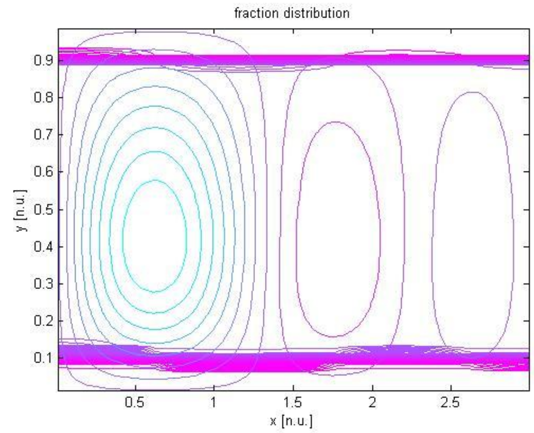

Figure 2: Result of our simulation for whole-mantle convection. The effect of thickening and thinning c-continents is visible (Natural units, 3:1)

3. Summary and Conclusions

The processes of convection, heat production and heat flow are crucial for planets with developed plate tectonics (Earth) as well as for the ones with present mantle plumes (Earth, Venus). Further investigation of core-mantle boundaries shall enlighten the processes of plume formation and heat flow control.

References

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