COMSOL CONFERENCE 2011

Effect of Disintegration of Chemical Stratification on Time-dependent Behavior of the Earth's Mantle

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27. October 2011, Stuttgart.

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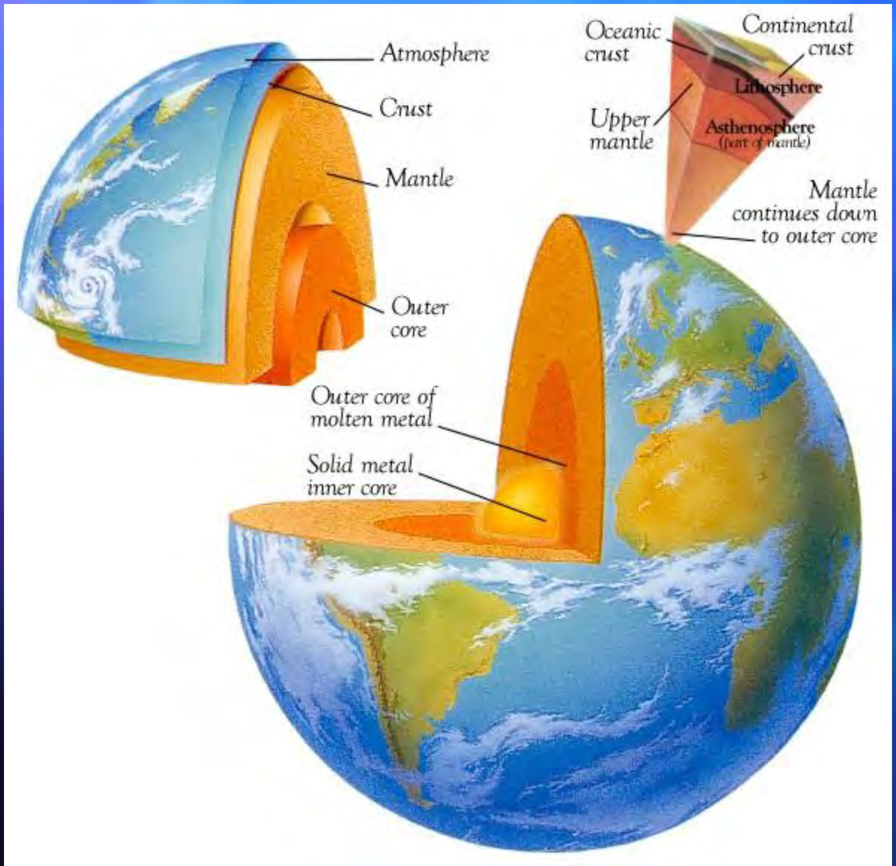
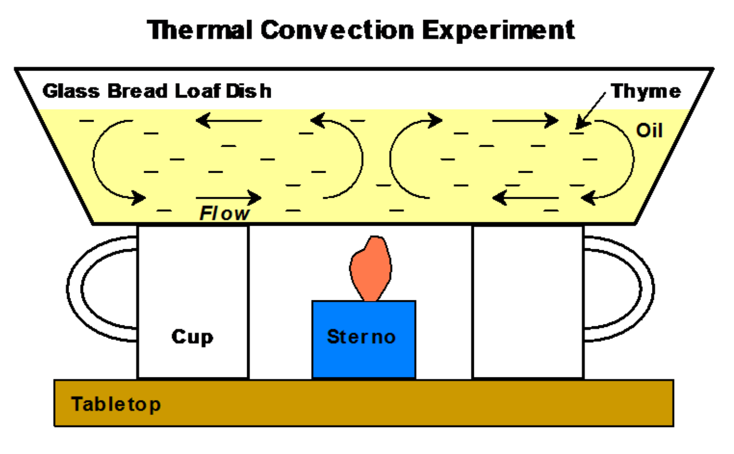
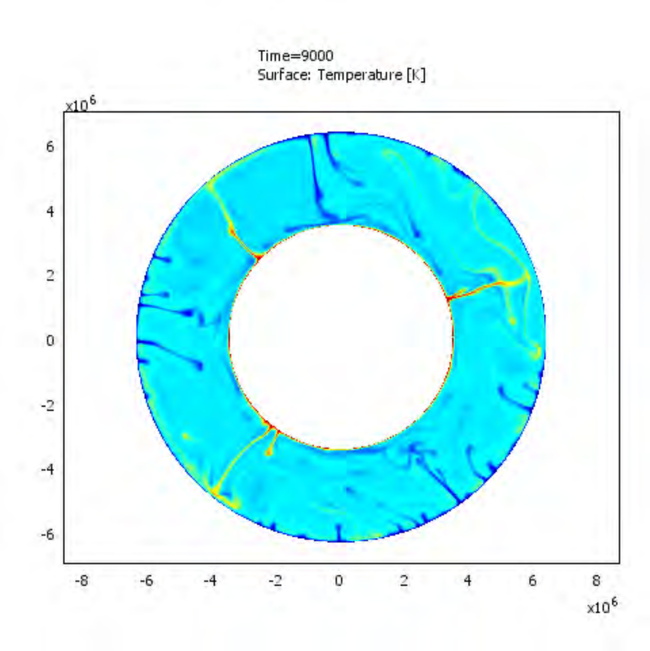
Introduction

Structure and thermal convection



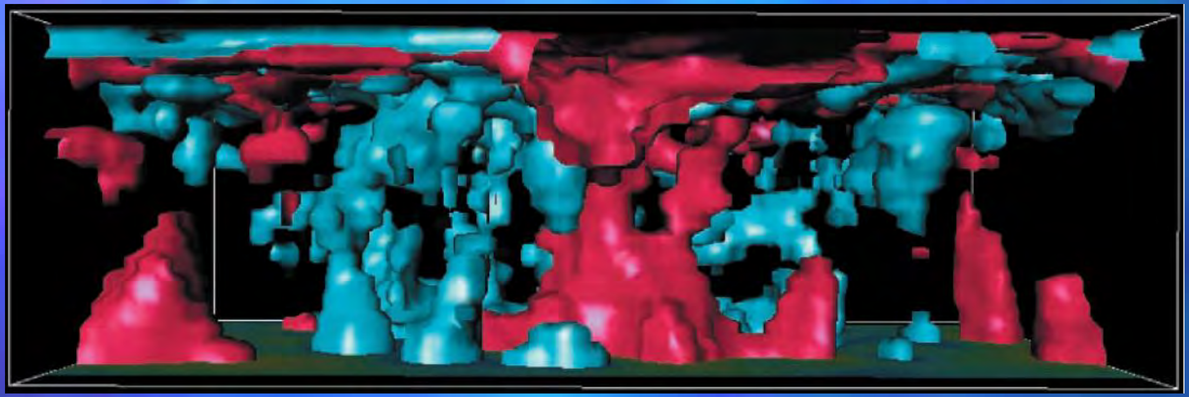
Structure of the Earth



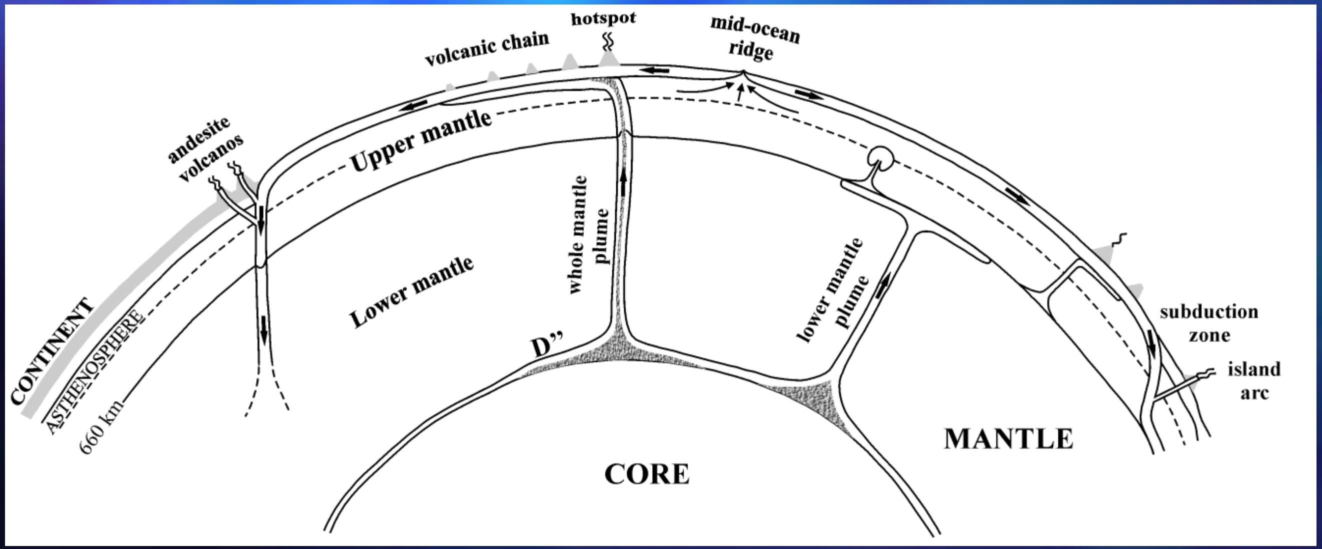


Thermal convection in a tank and in the Earth's mantle

Thermo-chemical convection (TCC)



Seismic tomography of the mantle, blue - fast, red – slow [Tackley 2000].



Conceptional model on the thermo-chemical convection in the Earth's mantle [Galsa et al. 2008].

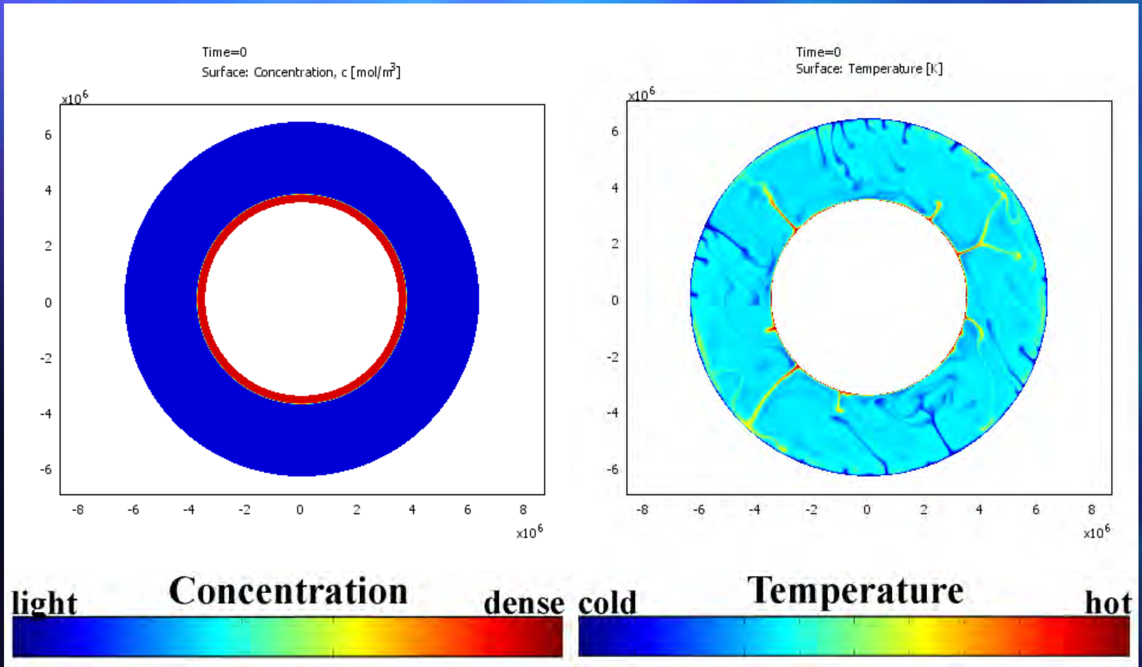
Comsol model

Chemical density difference:

β=0.1% - 2%, relative density difference between D” and the overlaying mantle

Buoyancy ratio:

$$B = \frac{\text{'chemical density difference'}}{\text{'thermal density difference'}} = \frac{\beta}{\alpha \cdot \Delta T}$$



Finite elements: 73772 (triangle advancing front)

Size: outer radius 6370 km
inner radius 3470 km

Subdomains: 2 (D”, overlaying mantle)

Thickness of D”: 300 km (flc1hs, 50 km)

Artificial diffusion: streamline, crosswind, isotropic

Boussinesq approximation:

Conservation of mass
$$\frac{\partial u_i}{\partial x_i} = 0$$

Conservation of momentum
$$\rho \frac{du_i}{dt} = \rho g e_i - \frac{\partial p}{\partial x_i} + \frac{\partial \sigma_{ij}}{\partial x_j}$$

Heat transport
$$\frac{\partial T}{\partial t} = \kappa \frac{\partial^2 T}{\partial x_i^{\,2}} - u_i \frac{\partial T}{\partial x_i}$$

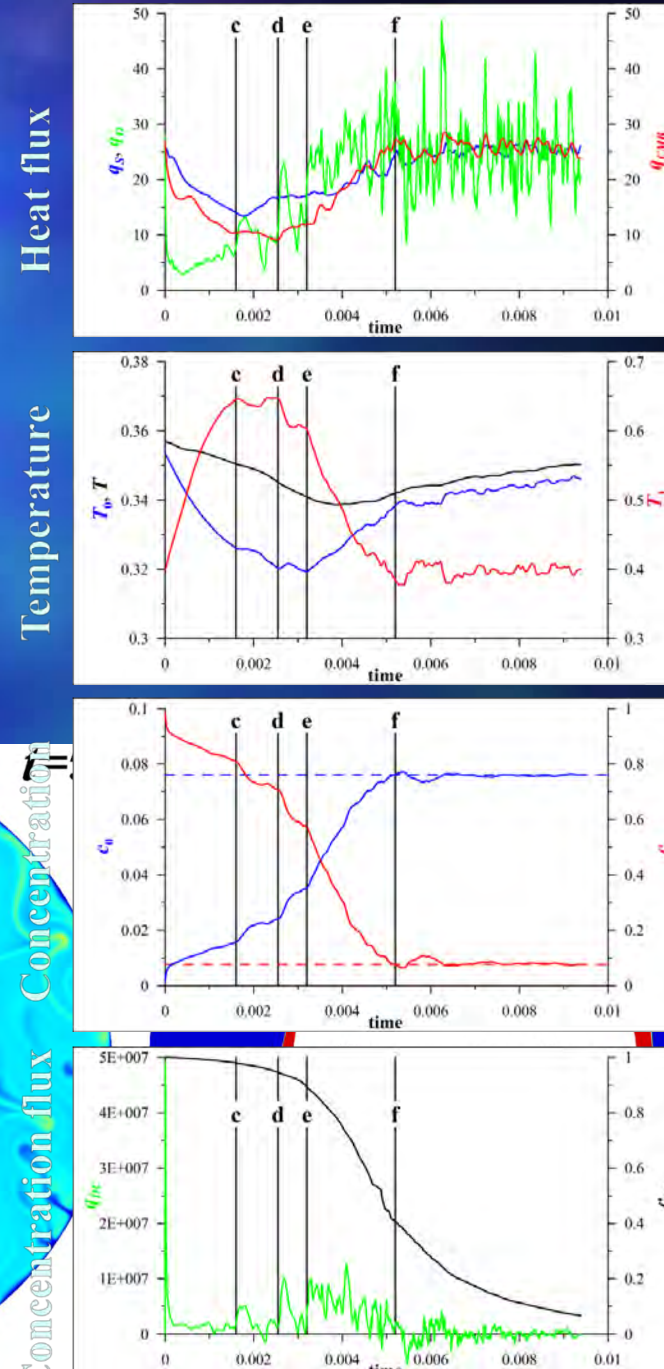
Mass transport
$$\frac{\partial c}{\partial t} = D \frac{\partial^2 c}{\partial x_i^{\,2}} - u_i \frac{\partial c}{\partial x_i}$$

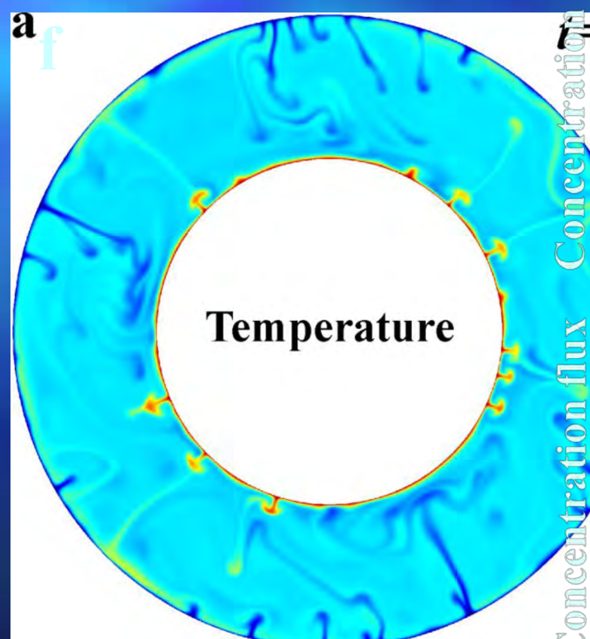
Thermo-chemical mantle convection at β=1% relative density contrast between the D” and the overlaying mantle.

Results

Seven stages of TCC

e





β=1%

a. deformation of D” layer

b. developed two-layer thermal convection

c. disintegration of D”

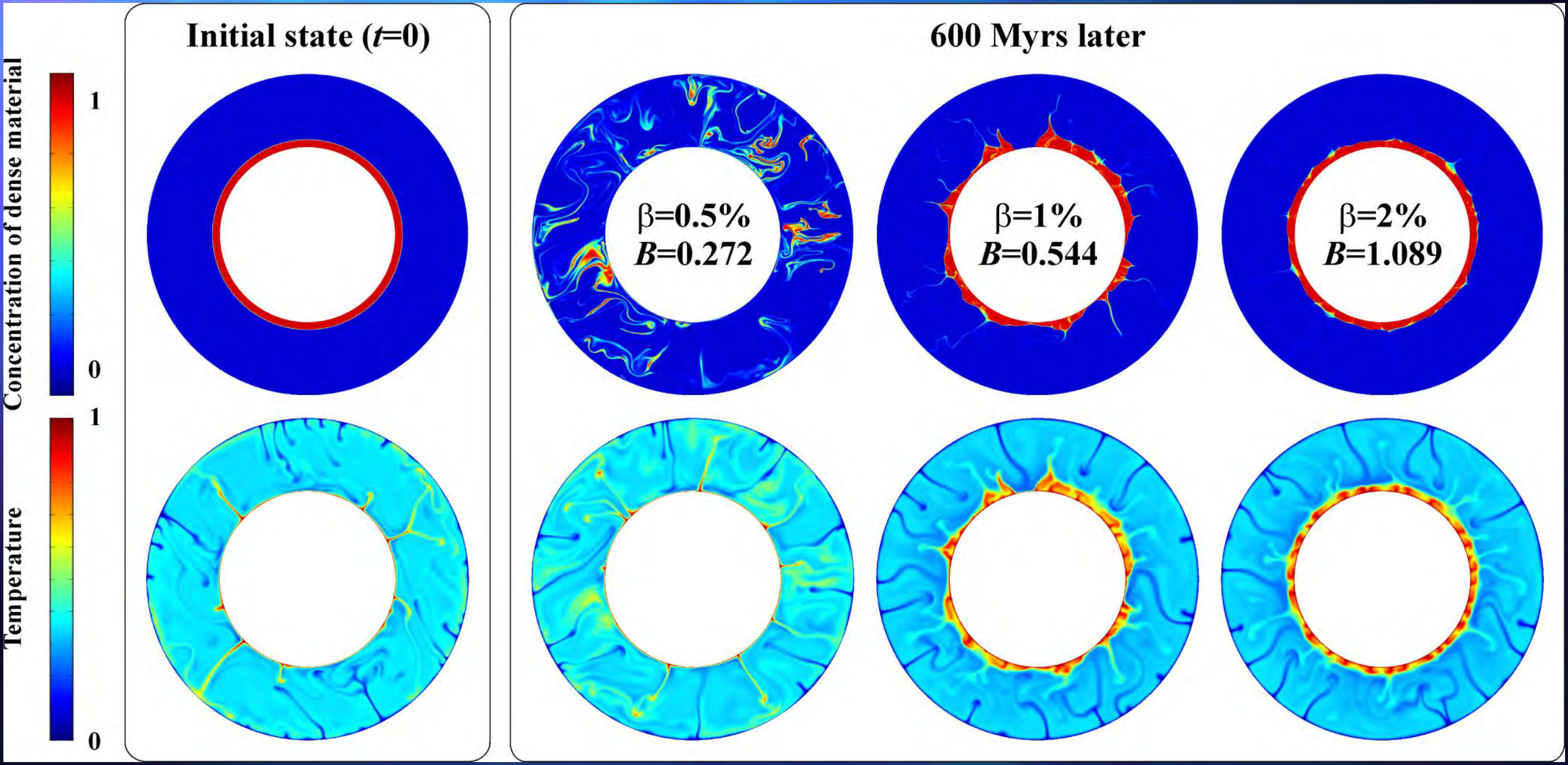
d. onset of one-layer TCC

e. first dome ceased

f. last dome ceased / mixed mantle

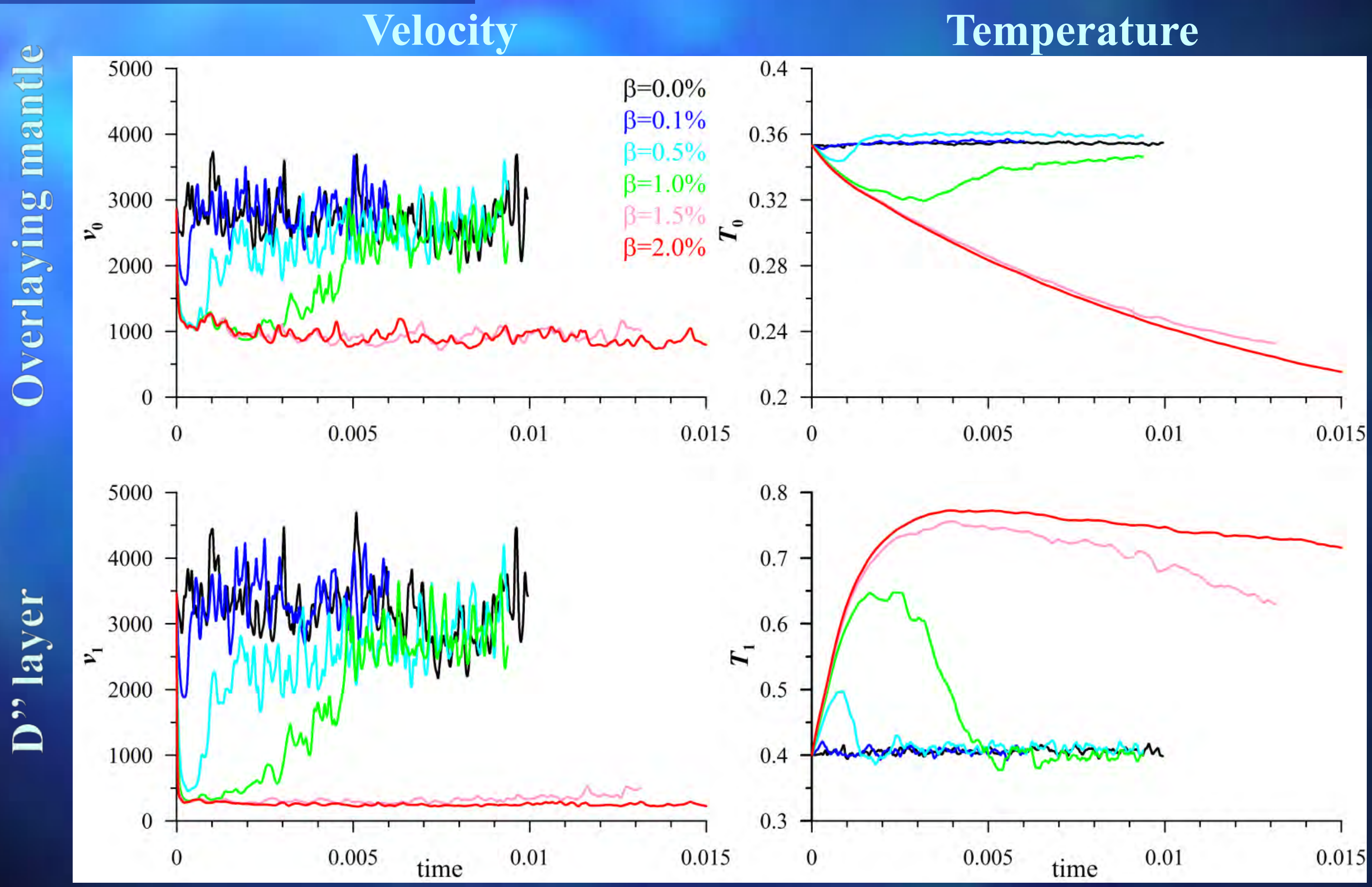
g. homogeneous mantle

Effect of density difference (β)



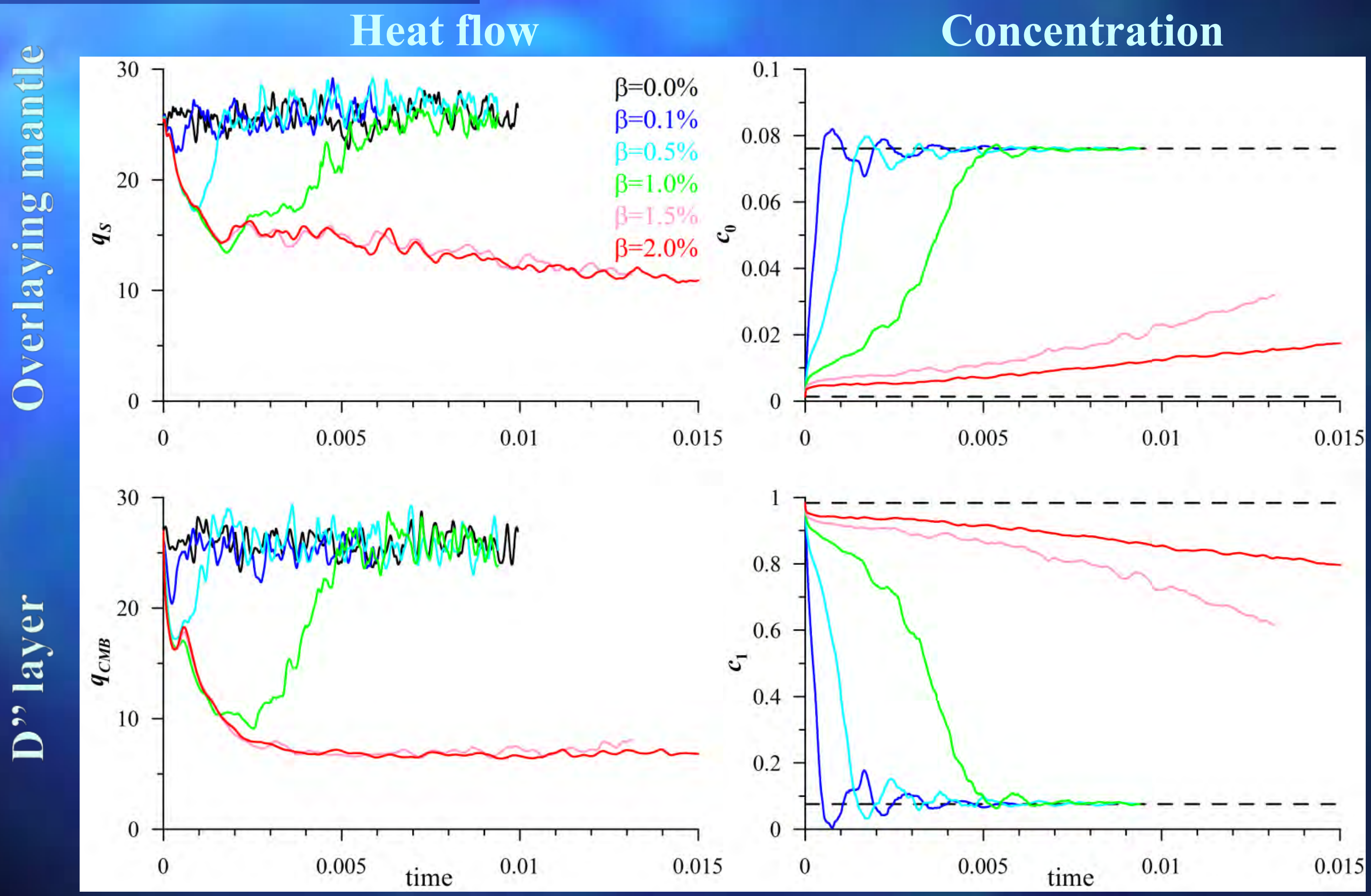
The concentration of the dense material and the temperature at the initial state (*t*=0) and 600 Myrs later at different density contrasts (β).

Effect of density difference (β) – Time series I



Velocity and temperature time series in the D'' layer and the overlaying mantle at different density contrasts (β).

Effect of density difference (β) – Time series II



Heat flow and concentration time series in the D” layer and the overlaying mantle at different density contrasts (β).

Time-dependent Buoyancy ratio

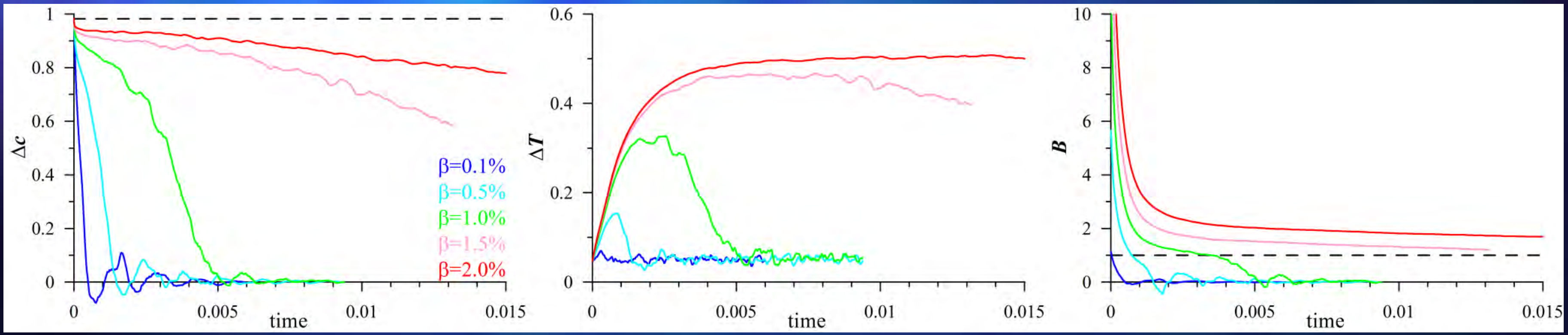
$$B = \frac{\text{'chemical density difference'}}{\text{'thermal density difference'}} = \frac{\beta}{\alpha \cdot \Delta T}$$

?

Traditional definition

$$B(t) = \frac{\text{'chemical density difference'}}{\text{'thermal density difference'}} = \frac{\beta \cdot \Delta c(t)}{\alpha \cdot \Delta T(t)} = \frac{\beta \cdot (c_1 - c_0)}{\alpha \cdot (T_1 - T_0)}$$

Reinterpreted definition



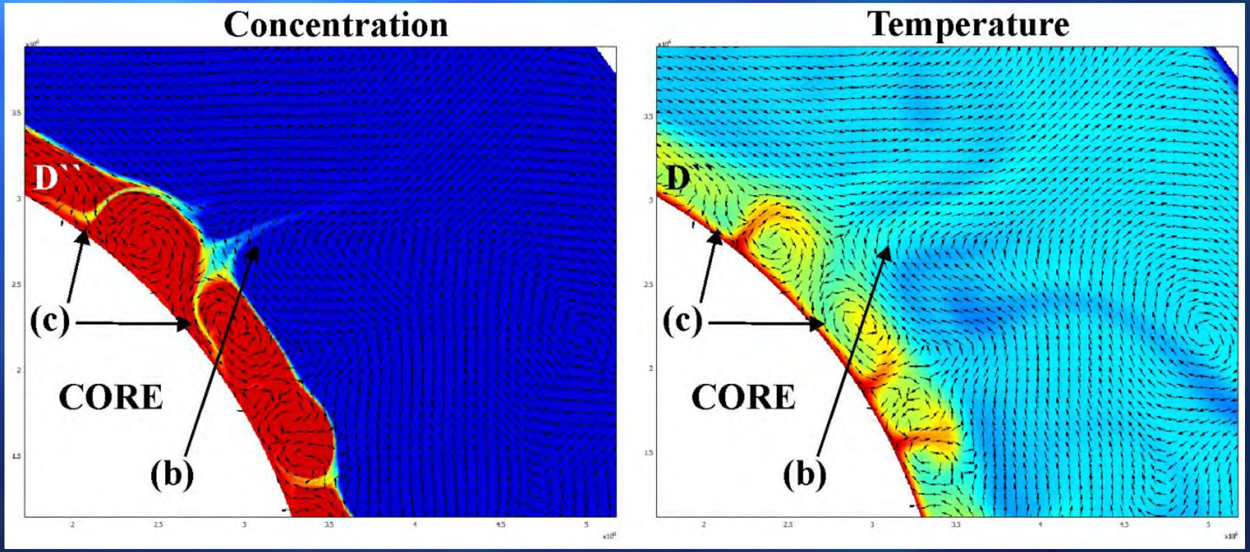
Time-dependent concentration and temperature difference between D” and the upper layer as well as the calculated Buoyancy ratio at different density contrasts (β).

Processes decreasing *B*

$$B = \frac{\beta \cdot \Delta c(t)}{\alpha \cdot \Delta T(t)}$$

Three main processes decrease *B* in time:

- a heat coming from the core warms up the dense layer reducing its density by thermal expansion;
- b thermal convection evolving in the upper layer erodes the surface of the dense layer;
- c thermal convection forming in the D” layer intermixes the light material from the overlaying zone.



Two processes decreasing the concentration difference between D” and the overlaying mantle.

Conclusions

- Existence of the dense D’’ layer around the core influences considerably the time-dependent parameters (heat flux, velocity, temperature, concentration) characterizing the flow regime.
- Good correlation was found between the evolution of D’’ layer and the time-series of the parameters monitored during the simulation.
- New interpretation of the buoyancy ratio was offered to help the understanding of the thermo-chemical processes in the mantle.

Thank you for the attention!