ÉCOLE DOCTORALE SCIENCES DE LA TERRE

Subject offered for a contract starting in September 2012

SUBJECT TITLE: Numerical simulations of early mantle convection

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Presentation of the subject: (1 or 2 pages)

The compositional structure of the Earth's mantle after the crystallization of the magma ocean is unknown, but was probably characterized by a heterogeneous distribution of incompatible heat producing elements. This 'early structure' is important for the dynamical and thermal evolution of the Earth, and it depends on several key parameters, many of which are still a matter of debate. First of all, the composition of the Earth's mantle may not be the classical one, as inferred from carbonaceous chondrites, but might be closer to Enstatite chondrites. In such case, the lower mantle would be enriched in Si and Fe and depleted in U and Th (Javoy et al., 2010). Clearly, these elements have a profound effect on dynamics, since an iron enrichment increases the density, whereas U and Th affect the internal heat production. Geophysical, mainly seismological, constraints on the chemical composition of the Earth remain ambiguous and cannot fully resolve temperature vs compositional trend off. Direct modeling of thermo-chemical convection offers an alternative to thoughfully test the geodynamical consistency of compositional models of the mantle.

Here we propose to conduct three-dimensional numerical simulations of a compressible mantle, in spherical geometry, using the code kindly provided by Paul Tackley (Tackley, 2008). Our objective is to study solid state convection and mixing efficiency of the early mantle and to explore a variety of initial conditions.

The simulations will enable us to vary the bulk composition of the mantle and the conceptual scenarios for the crystallization of the magma ocean. The numerical model will include: (a) heterogeneous internal heat production, (b) compositional heterogeneities, e.g., Fe-enriched material. (c) Mantle phase transition, as detailed below. This study is technically challenging, since it requires to run high resolution simulations with millions of tracers tracking the composition. For several scenarios of early compositional stratification of the mantle, we will calculate the dynamical evolution of the system, paying attention to the conditions leading to the survival of hidden reservoirs, to the thermal evolution of the mantle, and to the resulting distribution of radiogenic elements (i.e., concentrated in an abyssal reservoir, uniformly distributed in the mantle, or concentrated at shallow depths?).

A novel aspect of our simulations will be to include the most recent mineral physics constraints on the physical properties of mantle minerals. In particular, we will include the spin state transition of iron (e.g., Badro et al., 2003; Badro et al., 2004 ; Lin and Tsuchiya 2008), which occurs gradually from 70 to 120 GPa (i.e. 1600-2600 km depth) in the dominant lower mantle components: ferromagnesium silicate perovskite and ferropericlase. This transition modifies important physical properties such as density (with an intrinsic density change of 2-4 %), and possibly, an increase in radiative thermal conductivity and viscosity. To find the density changes associated with the spin-transition, we propose to use Sthuran et al., (2005) method which calculates the number of unpaired electron by minimizing the Helmholtz free energy. We will also consider the experimentally observed change in iron proportion between magnesium perovskite and ferropericlase.

Although the spin state of iron can affect the efficiency of mantle convection, there are very few numerical simulations that explore its dynamic consequences. This part of the work will benefit from insightful discussions with James Badro.

Finally, we propose to couple analogue laboratory experiments of mantle dynamics conducted with microwave internal heating, to our three-dimensional simulations in cartesian geometry, specifically constructed to reproduce the experimental setup.This will provide a coupled verification and combined interpretation of numerical and experimental results.   Moreover, the Ph.D. student will have the opportunity to conduct laboratory experiments, in order to broaden his/her expertise besides numerical simulations.

References

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Lin J-F & Tsuchiya T., (2008) Spin transition of iron in the Earth's lower mantle, *PEPI*, 170, 248-259.
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