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Interactive comment on "Effective buoyancy ratio: a new parameter to characterize thermo-chemical mixing in the Earth's mantle" *by* A. Galsa et al.

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Response to Anonymous Referee #1

We would like to thank Referee #1 his/her comments. Our response to the comments is as follows:

(1) The paper focuses on the disintegration and homogenization of the primordial dense layer above the core mantle boundary, so we applied a reference viscosity of 10ˆ22 Pas, one order of magnitude larger than the viscosity characterizing the upper mantle (10ˆ21 Pas) (e.g. Mitrovica and Forte, 2004; Kaufmann and Lambeck, 2000). The pressure-increased viscosity results in the thermal Rayleigh number in the order of magnitude of 10ˆ6 and a less vigorous convection in the deepest mantle. It is emphasized in line 108–111 of the revised manuscript. In the paper we use the conventional thermal diffusion time as the non-dimensional time. We clarify it in line 144.

(2) Buoyancy ratio or buoyancy parameter (B) (e.g. Davaille et al., 2002) is a constant and expresses the stabilizing effect of compositional/chemical density contrast related to the destabilizing effect of the thermal density contrast in thermo-chemical convection. This constant is appropriate to predict the resistance of the lower dense but hot layer against mixing. On the other hand, the effective buoyancy ratio (Beff) is a time-dependent parameter which represents the instantaneous stability of the thermo-chemical system. During the numerical modeling Beff decreases monotonically and when its value reaches one (the instability point, when stabilizing chemical and the destabilizing thermal buoyancy is balanced), the dynamics of the flow system changes considerably, the two-layer convection is replaced by a one-layer thermo-chemical mixing. Thus the effective buoyancy ratio is a good diagnostic tool to determine the actual state of two miscible fluid-like layers. Additionally, the time of Beff=0 might define the time when the two layers are mixed. The paper would like to inspire researchers to apply the effective buoyancy ratio both in numerical and laboratory modeling of thermo-chemical convection as a diagnostic tool to quantify the phase of mixing. In the 1st paragraph of Discussion and conclusions the physical implication of the effective buoyancy ratio is explained in detail.

(3) We do not have exact knowledge of the early stage of the mantle evolution that is the initial condition of such numerical and laboratory models is pending. Still, there are some hypotheses which make it plausible that the compositionally dense layer might have formed during the first 100–200 Myr of the 'Earth's history'. Deschamps and Tackley (2008) and Tackley (2012) detail this problem and mention that (1) mixing between the liquid iron of the outer core and silicate deep mantle; (2) early differentiation of the magmatic mantle; (3) crystallization of the basal magma ocean (BMO) forming iron-rich and therefore dense material would result in a compositionally dense layer above the core mantle boundary in the early phase of the Earth's evolution. On the contrary,

there are arguments for mechanisms that the dense material generates over time, e.g. by recycling and segregation of oceanic crust. Undoubtedly, there are arguments for and against the formation of a dense layer in the deepest mantle at the beginning of the Earth's evolution, though an indirect evidence might be the early differentiation that the oldest crusts were formed from an already depleted mantle 4.46 Gyr ago. Nevertheless, the dense material accumulated in the Archean deepest mantle is a geologically realistic initial condition, additionally, it is popular because it can be implemented easily both in numerical (e.g. Van Summeren et al., 2009) and laboratory models (e.g. Jellinek and Manga, 2002). Paragraph 2 in the part of Discussion and conclusions was devoted to the geological explanation of the applied initial condition.

The time of the disintegration of the primordial dense layer is very questionable. Dziewonski et al. (2010) suggest that the two, nearly antipodal dense piles are very stable features of the mantle structure. The degree-2 seismic anomalies generate mass excess in the equatorial plane and stabilize the rotation axis. They show that the Earth's rotation axis has moved above the seismically fast zone separating the dense piles (resulting in the maximum momentum of inertia) for the last 200 Myr that might be a lower limit of the lifetime of the piles. They propose that this 'Mantle Anchor Structure' formed in the early stage of the Earth's history and influences not only the Earth's rotation but also the global mantle flow system (position of subduction, hotspot location, thickness of transition zone etc.).

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