Solid Earth

Discussions

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comment

# *Interactive comment on* "Timescales of chemical equilibrium between the convecting solid mantle and over-/underlying magma oceans" *by* Daniela Paz Bolrão et al.

**Anonymous Referee #2**

This paper provides a numerical model of solid mantle convection below, above or sandwiched between magma ocean(s) with phase change boundaries. The latter allows material transport between the solid mantle and the magma ocean and is used instead of the commonly used free-slip boundary condition. At the boundary between a solid mantle and a liquid of similar composition, a flow through the phase change can take place, depending on how fast latent heat is transferred in the liquid region. Due to convection in the solid mantle a dynamic topography is generated which can be eroded by melting around topographic highs and is 'filled' by freezing, around topography depression. This process requires that the latent heat released in regions of freezing is transferred efficiently to regions where it is consumed for melting. The

critical parameter for the efficiency of material exchange is the phase change number Phi, the ratio between phase-change timescale for transferring latent heat from region where it is released to places where it is consumed and the timescale for producing a dynamic topography. The authors find that a small value of the phase change boundary (Phi <100) allows efficient chemical equilibration before the end of magma ocean crystallization of about 1 Ma even in case of fractional crystallization. This material exchange may prevent strong chemical stratification of the solid mantle and enforce chemical homogenization – a finding in contrast to classical models of fractional crystallization. This is an interesting model and expands on previous work of this group related to the interaction between solid mantle and top or basal magma oceans. In the present study, the focus is on the timescales of chemical equilibrium between the solid mantle and magma ocean(s). Similar to previous studies on the interaction between the solid mantle and the magma ocean, the most unknown but important parameter is Phi, and its value is highly speculative because the model is in part very simple and important physical processes may not be captured - most of them were mentioned on paper. For example, for silicate material there is no sharp boundary between liquid and solid phase. The partial melting zone could be responsible for inefficient heat transport of latent heat and may lead to significantly higher Phi. This heat transport is possibly even more inefficient if the phase boundary moves (solid mantle grows) through cooling. The authors therefore investigate a large range of Phi, which is certainly positive, but unfortunately does not make it easier to classify the results. However, at this stage one has to accept this uncertainty, but there are some aspects of this work that could be better explained and/or discussed in more detail.

Points that should be considered / discussed:

Specific comments

1. Thermo-chemical convection: The number of buoyancy is set to 1 without further explanation. Why was this value taken and how does the choice of B influence the results? With the present values it seems that the chemical density variation has no

significant influence.

2. In the initial setup a homogeneous FeO content of solid mantle and magma ocean is assumed. As the authors themselves write, this is not a realistic initial state but it also not clear how sensible are the obtained time scales depending on initial conditions? In the current setup, the material that forms in the topography depression is depleted in FeO, this would not be the case for a more realistic start condition. An initial unstable gradient in the solid mantle can trigger convection but may also result is a stable configuration after overturn, depending on B (see above). This can be important for the time scale of chemical equilibrium - if in this case a chemical equilibrium can be established.

3. Two effects have been neglected, but they can also result in chemical equilibration and compositional mixing before final magma ocean crystallization: 1) When the solid mantle grows and has no fixed boundaries, as is assumed here, convection causes the new top crystallized layer, which should have a different FeO content, to sink and mix continuously with the solid mantle. 2) If convection in the solid mantle starts before the solidification of MO, partial melting of the cumulates and 'feeding' of the MO with this melt is very likely. Both effects change the chemical equilibrium considerably and do not necessarily require the material to be able to flow through by phase change. However, the latter may further reduce the time scale of chemical equilibrium.

4. Steady-state simulations, i.e. delta T is constant, but also no internal heat sources and a constant viscosity are used – all these effects can influence the strength of convection (and chemical equilibration) and possibly the convection pattern. In particular the influence of internal heat and a temperature dependent viscosity could be tested fast.

5. A new phase change boundary condition for convection has been investigated, are there benchmark studies also for sufficient resolution or how do the authors ensure that the calculations are correct?

6. A table should be added for all parameters used.

7. Line 255: It is not clear to me why with small Phi the volume of the solid mantle has no effect on the time scale of chemical equilibration. Do the authors have an explanation? I think this also indicates that the material flow is extremely large - is this really realistic? One could estimate the value.

minor comments

8. Line 310: In the discussion, the crustal dichotomies of Mars and the Moon are mentioned and associated with the present process. I don't find this so obvious, because according to the model low degree convection is postulated at the beginning of the MO crystallization, but the crustal dichotomy is more likely to occur at the end of the MO phase, when the pattern becomes small scale.

9. Line 370: It is stated that smaller planets cool faster. This is not generally true, for example if a blanketing crust is formed during MO crystallization before the mantle is entirely solid and the cooling and crystallization of the MO slows down considerably - as postulated for the Moon.

10. Line 380: "for realistic values for the phase change number Phi+ smaller than $\sim$ 100". I doubt that we really know the realistic value in view of the simplification of the process and the unknown parameters.

technical comment

11. Figure 7 is difficult to read with the different symbols and lines.

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