Solid Earth Discuss.,
https://doi.org/10.5194/se-2019-160-RC1, 2019

Solid Earth
Discussions
Open Access

Interactive comment on "On the self-regulating effect of grain size evolution in mantle convection models: Application to thermo-chemical piles" *by* Jana Schierjott et al.

Bradford Foley (Referee)

bjf5382@psu.edu

Received and published: 11 December 2019

Review of "On the self-regulating effect of grain size evolution in mantle convection models: Application to thermo-chemical piles" by Shierjott, Rozel, and Tackley

General comments:

This paper presents 2-D numerical convection models that include grain size evolution, to model the long term evolution of thermochemical piles at the base of Earth's mantle. In particular, the paper focuses on the effects of a composite rheology that includes dislocation and diffusion creep as well as a formulation for grain size evolution, to as-

Printer-friendly version

Discussion paper

sess how grain size evolution influences the dynamics of the piles. The main findings are that grain size in the piles is relatively self-regulating, following a long-term trend as a result of mantle cooling and changes in the typical stress & strain rate within the piles. Large episodic overturns lead to significant decreases in pile grain size and viscosity, but grain size quickly returns to the previous state once the overturn is over. Another important finding is that although warm temperatures in the piles lead to grain growth, this grain growth is limited by the background rate of deformational work in the piles, such that piles do not become very stiff and resistant to being pushed around the CMB by subducting slabs. I find the findings to be interesting and worthy of publication, and the science overall is sound. I do think some moderate revision is needed to more clearly highlight and demonstrate the main scientific findings, and address a few minor technical issues as well.

Specific comments:

1. This paper could be significantly improved by more clearly organizing it around central scientific questions being answered or hypotheses being tested. As of now it reads like more of a description of model results, without much direction beyond "what happens when we include grain size evolution." I have a couple suggestions for this:

A) Whether pile grain size can increase and allow the piles to become rheologically stiff, and therefore anchored at the CMB, is an interesting question, and could be looked into more thoroughly. The paper indicates that this is not the case, as the pile grain growth is limited and downwellings impacting the piles cause the piles to be rheologically weakened. This raises some questions that could be explored in more detail: What is it that prevents the piles from stiffening? Is there internal convection that supplies enough deformational work to keep grain size from growing too much? Is it downwellings hitting the piles that cause the stress/deformational work that keeps grain size from growing drastically? Likewise, during major overturns where there is significant weakening and grain size reduction of the piles, it would be useful to show the rate of deformational work in this instance

B) The fast pile grain size "recovery" is also interesting. How about using the model results to compare the recovery timescale seen from the numerical models to the theoretical prediction for recovery time, to demonstrate that the expected recover time scale indeed holds? Also, the authors should be able to work out what is stabilizing grain size and viscosity as the mantle cools (in particular for the cases shown in the appendix). There must be some trend in grain size (or viscosity) acting coupled to the change in pile temperature to keep grain size nearly constant over time. Finally, another interesting point is that grain size variations limit lateral viscosity variations; e.g. plumes have a similar viscosity to the surrounding mantle because the higher temperature is cancelled out by larger grain size. The authors could look into what conditions allow this to hold. For example, if the grain growth activation energy is much larger than the activation energy for diffusion creep, would plumes become more viscous than surrounding mantle? Or would deformation still limit the grain size?

2. Throughout this paper, the authors should be looking at the deformational work rate, not just stress. Work rate is what is controlling grain size reduction, and therefore the most relevant thing for the typical grain size in the piles and amount of grain size reduction seen when downwellings interact with the piles.

3. The authors should discuss whether the resetting of grain size at the post-perovskite phase change has any significant effect on the results, in particular for grain size evolution in the piles.

4. The results indicate diffusion creep generally dominates in the piles themselves, and dislocation creep can be active around downwellings or other high stress regions at the CMB. Given that we have observations of seismic anisotropy in some regions near the core-mantle boundary, the authors could do a more thorough comparison of their results to these observations. Comparing the settings where anisotropy is observed to where the models predict dislocation creep to be active would provide a good test to the model results.

5. Equation 7: What is the purpose of the "dislocation creep efficiency" parameter? A composite rheology formulation should be able to deal with this self-consistently, and have the temp, grain size, stress, pressure, etc dictate which mechanism dominates and controls the viscosity entirely on its own.

6. Below equation 14: "...where TCMB = 4000 K is the average temperature at the core-mantle boundary, ftop is the maximum (at 3000 K) and fbot the minimum damage fraction (at 4000 K). In order to set the damage fraction to zero at surface temperatures of 300 K, the term in (14) uses -300 in the exponent." Something's off here. By equation 14, f doesn't go to 0 at the surface, it just goes to f_top (the exponent goes to 0). Also f_top is the maximum at 300 K not 3000 K.

7. The calculation for the pile grain size recovery time for the Earth uses the typical stress and strain rate in the ambient mantle to calculate the deformational work rate. But stress and strain rate in the piles could be different. Better to analyze the flow patterns in the piles that determine the typical work rate in these regions, as I've suggested above, and use this in the estimate for the modern Earth.

Technical corrections:

Lines 42-43: I just don't follow what this sentence is trying to say

Line 101: "Intruda" likely a typo

Line 219: I think it is better to refer to this as a wattmeter since it is deformational work driving grain size reduction and not just the stress

Lines 252-253: Are the small grain sizes of 5 microns seen everywhere in the lithosphere or just at plate boundary areas?

Line 292: "This prevents the Earth to cool down more" should say prevents the Earth from cooling down more

Line 296-298: How is the second stagnant lid phase defined as stagnant lid, if surface velocities are nearly as high as in the mobile lid phase?

Line 324: “Vigorousness” should be “vigor”

Line 406: Here is a place where the authors could look into more detail at stress and strain rate in the piles, and what sets the typical level of deformational work in the piles and hence limits grain growth

Line 480: Saying that the models can and cannot confirm the idea that plumes form at the pile edges is very confusing. If the results don’t confirm this idea then they don’t confirm it! Please clarify the text here.

Lines 492-493: Larger grain sizes in the plumes not affecting the viscosity: Does this mean that the viscosity is not sensitive to grain size, or that the grain size just isn’t growing all that big? Confusing as written. As I suggest earlier, this issue of temperature vs. grain size tradeoffs for viscosity is something that should be looked at in more detail.

Appendix: I find this terminology of "continuous" versus "episodic" very confusing, as well as the further classification of “events, then constant,” “constant, then events,” etc. I’m not really sure what this classification is supposed to help the reader see. Maybe better to just show some example models individually and indicate where stagnant, mobile, and episodic overturning phases occur, so we can see how these effect the grain size evolution?

Lines 553-554: That basalt is not mixing in with the piles is an important point that needs to be explained further and compared with McNamara/Mingming Li work where they argue for basalt incorporation into piles

Appendix A3: Plotting density alone is not so useful. What really matters is the density difference between the pile and surrounding mantle. For example, the decrease in density seen due to the piles rising is not really dynamically meaningful as it is due to decompression. We need to know the density relative to surrounding mantle to see if the buoyancy has changed.

Interactive comment on Solid Earth Discuss., https://doi.org/10.5194/se-2019-160, 2019.