Reply on RC1
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The authors appreciate the comments made by R1 and we address each below. We have decided to expand the introduction and rearrange the results section so that the manuscript is easier to follow.

General Comments
- Yes, the mantle convection model set-up we consider is intended to be Earth-like. However, we do not intend on reproducing the Earth mantle's history. Within this framework we have been able to examine the effect of the thermal conductivity model on the evolution of the primordial layer at the bottom of the mantle.

- We agree with R1 that the introduction can be expanded. Regarding the thermal conductivity, each of the component (dependency) of the conductivity model will be discussed. In addition, we will now address why conductivity is relevant for compressible mantle convection.

- We consider the suggestions that R1 outlines for reorganizing the results section. As the manuscript stands, introducing the reference case \( K_D = 2.5 \) first is too much too quickly for the reader. We now separate all the effects so that the progression of the results is easier to digest. The subsections of the results are now:

1) Effect of a purely depth-dependent conductivity
2) Effect of a temperature- and depth-dependent conductivity
3) Including the effect of composition-dependent conductivity
4) Long-term stability of thermochemical reservoirs featuring mineral physics derived conductivities

Specific Comments
- The heat conservation equation will now be added to the Methods section to help the reader understand where the conductivity model influences mantle dynamics.

- A new figure with a plot of the initial thermal conductivity profiles for cases featuring...
mineral physics defined conductivities are now included so that the conductivity reductions from different temperature- and composition- dependencies is clarified.

-The simulation time is long (~11 Gyr) to allow the system to reach a statistically steady state and to investigate how the heterogeneous conductivity will affect the long-term evolution of the primordial layer. The simulation averages are taken towards the start of simulations' statistically steady state (approximately 4.5 Gyr). Again, we do not intend to model the exact evolution of the Earth's mantle. The conditions for simulating Earth's history (i.e., initial conditions, decaying heat sources, and cooling bottom boundary) are not included in our model setup. In the current version of the manuscript, the averaged values were inset within the annulus snapshots and their trends were discussed within the results subsections. Specific values were not used often so that the text would not be inundated with numbers. We now incorporate more references to the Table 1 averages into the manuscript.

-The values presented in the manuscript will be presented as dimensional.

Technical Comments:
-L. 48: for clarity, "composition- dependent" will now be used throughout the manuscript.
-L. 84: inserted the word 'curve'.
-Figure 1: markers for "< 200 ppm water" are changed to bright green to be more contrasting with the background.
-L. 118: The case with a purely depth- dependent thermal conductivity and K_D = 2.5 is considered as an analogue for models that already account for the combined depth- and temperature- dependences. In the latter (hypothetical) model of thermal conductivity, the depth- dependent component would have conductivity values that are much greater than those defined by K_D = 2.5. To clarify, the sentence has been changed to "As an analogue for a thermal conductivity model that accounts for depth- and temperature- dependence, we first consider a purely depth- dependent reference case characterized by depth- dependence, K_D = 2.5. Our reference case produces lower mantle conductivities that are comparable to current estimates (e.g., Deschamps & Hsieh, 2019; Geballe et al., 2020)."
-L. 121: "by approximately 75%", this refers to a comparison of heat flow values averaged about 4.5 Gyr for cases #4 and #8. This comparison is between a purely depth- dependent conductivity case (#4) and heterogeneous conductivity case (#8). The sentence has now been revised to read: "Comparing the purely depth- dependent conductivity model to the completely heterogeneous conductivity model, the latter greatly reduced both CMB and surface heat flows (by approximately 76% and 22%, respectively), as less heat can be extracted from the base."
*The subsection including the timeseries figure has now been moved to the final subsection of the results section. It has now been updated so that the cases are relevant to the mineral physics derived conductivity profile.
-L. 122: fixed the citation to read "... Li et al., (2022)'s findings".
The mean temperature of primordial material is indicated by \( T_{\text{prim}} \) (not to be confused with the global mean temperature of the system \( <T> \)). \( T_{\text{prim}} \) is inset within the annulus and is indicated for each case. \( T_{\text{prim}} \) can be seen decreasing for cases with the same \( K_D \) value as \( n \) is increased. In addition, the temperature field is offset with respect to the CMB temperature so that the differences in hotter temperatures within the piles is easier to see. The boundary between regular mantle material and primordial material is indicated by a green contour. When \( n \) is increased, the red colour within these contours becomes more saturated.

- Snapshot figures have been revised so that superfluous conductivity model labels are omitted.
- Figure 5: The colormaps for each different field are now alternated.
- L. 172: inserted the word ‘which’.
- Figure 6: The colormap is changed. The onset of instability is now indicated by a dashed cyan line.
- L. 189: The parantheses has been moved.

Supplemental Materials:
- L. 43: "imply" -> "implies".
- L. 176: "is" -> "are".
- Figure S1: "depth" -> "height".
- Figure S4: The case numbers have been added to the legend so that the line styles are now clear.