Solid Earth Discussions

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Comment on se-2022-20

Anonymous Referee #2

Referee comment on "Plume–ridge interactions: ridgeward versus plate-drag plume flow" by Fengping Pang et al., Solid Earth Discuss., https://doi.org/10.5194/se-2022-20-RC2, 2022

This manuscript by Pang et al. presents results of a series of 2D numerical simulations of plume ridge interaction. The goal of this study is to assess the role of ridge suction versus ridge drag on the flow of spreading plume material toward or away from the ridge axis. Below I post several comments and suggestions that I hope the authors will consider to improve their manuscript.

- Please revise the language using a professional editor or native speaker. There are many areas that may cause confusion as they are currently written.
- Definitions: one of the major problems with this work at the moment is the lack of a definition of "ridge suction". Plate drag is reasonably well explained as the frictional force imposed upon the sub-lithospheric plume material, but ridge suction seems to be simply anything that causes plume material to travel toward the ridge. Currently, I have to infer this definition since no clear description is given and the quantitative assessment of ridge suction is a fractional number looking at the volume of plume material flowing toward and away from the ridge. If ridge suction is only asseses in this way, then this is inconsistent with the literature and should be retermed as ridgeward flow or something similar. Better, I believe the authors need to reasses their model results with a more consistent definition of ridge suction that can be quantitatively assessed.
- In the abstract, the authors claim that plate drag has not been studied very much. However, I think this is perhaps an overly strong statement. There are several studies that incorporate the affect of plate motion (and the consequent drag) on plume spreading including Ribe et al. (1995); Ribe (1996); Ribe and Delattre (1998); Ito et al. (1997), Hall et al., 2003; 2004, etc. Each of these works (and others) incorporates the affects of plate drag on plume spreading in their calculations. I think the authors should be clear about what aspect of their work contributes something these other authors do not.
- Model Comments:
  - In my opinion, for the scope of this work, the model used is overly complicated and in some respects inaccurate for a mid-ocean ridge setting. For example, the authors are examining the flow of mantle material beneath a lithosphere and have included a 1.5 km thick sediment layer across the model, but near ridge (especially fast ridges)

there is little to no sediment. In fact, even along the slow-spreading MAR, 1.5 km of sediment does not occur along the ridge axis and, indeed not for a reasonable distance away.

  - Next, why is melting and heat flux useful for this study? Given the stated goal of the study to assess plume flow, I do not see (and it was not stated) why melting was useful or necessary. It is also unclear how the movement of melt throughout the system does or does not violate conservation of mass since you are working with an incompressible material and claming to add material beneath the crust after removing it from another location. Please justify the use of melting and melt movement/accumulation. Also, clearly state any affect this melt has on your model (viscosity? temperature structure?, density?, etc.)
  - Why do you need a plastic rheology? Given the scale of the problem you are workign on, is the added focusing of the ridge axis to a smaller number of grid cells necessary? I don't believe that the current models can answer this question given the problem I mention next.
  - Another issue is the lack of adjustment of the lithosphere for plate spreading rate. In other words, the ridge and lithosphere in the "fast spreading, ridge drag-dominated" cases do not appear to be in equilibrium before the plume is introduced. Looking that the compositional slices and temperature contours of the model in Figure 4, it appears that the sub-axial lithosphere is flattening out and a new, flatter lithosphere is forming without the initial half-space cooling structure (or with one that is in equilibrium with the faster spreading rate). This will alter the mantle flow field, the upslope topography of the ridge, and, potentially the location of the spreading ridge.
  - Thermal structure.
    - It is not clear to me how you arrive at a bottom boundary condition of 2513K when the base of the lithosphere has a Tmax = 1573. Since the base of the lithosphere is at ~100 km depth (Figure 1) and there is an imposed 0.5 K/km adiabatic temperature gradient, the max temperature at 660 km depth should be 1573 K + 560km*0.5K/km = 1853K. This is a big discrepancy that might imply a much hotter mantle than is realistic, which would likely have significant impacts on the results of this study.
    - How is the plume tail maintained? This is not clear or perhaps I missed it.
- Results/Interpretation
  - The images in Figure 4 demonstrate a factor that may explain the affect of plume head size on ridgeward flow – the erosion of the lithosphere by the plume head. As pointed out by Kincaid et al., 1995 in their laboratory experiments, the formation of lithospheric levees can act to block plume flow. This appears to be happening here. Small plume heads eat into the lithosphere a bit, effectively create ridges (or levees) that are the same thickness as the plume material and halt its motion. Then, as the plate moves the plume material has no choice but to flow with the plate. In constrat, large plume heads push the lithosphere out of the way all the way to the ridge. Despite the significant ridgeward flow, I would argue that this has nothing to do with ridge suction, but the lithosphere rheology and plume buoyancy forces.
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    The claim of "tension cracks" seems to be based on the stresses in the model. These stresses reach maximums of + or – 3x10^-7 Pa (Figure 5), much too small to actually fracture of rock - especially near the surface, which typically has yield strengths many orders of magnitude larger. Is this a typo? If this should be + or – 3x10^7 Pa (i.e., 30 MPa) that seems very large and so I am left to question how tension cracks are justified here. However, I would note that I don't think these are essential for the results of this paper and fall into the over complication of the model for the state purpose of the modeling.

- The role of ridge suction vs plate drag. I think the authors have glossed over some of the factors likely to contribute to the plume flow including the slope of the lithosphere and its role in guiding plume material up the slope, the buoyancy flux of the plume stem since this is not described by the plume radius definition here (which seems to describe the size of the plume head).
- Much of the interpretation of these results hinge around spreading of the plume head, not the plume after it has established itself beneath the lithosphere. Many plume have been active for 10 Myr or more and the plume head will have greatly diminished or completely spread away by that time. Yet, these plume tails can still interact with ridges since ridges migrate and often approach plumes. How does the long term interaction look - after the plume head has dissappeared?
- Related to 4., I don't think the authors should be claiming to assess plume radius, as this commonly is used to refer to the radius of the plume stem. Instead, I think the manuscript would be much clearer if the authors would state that they were varying the plume head radius.

Overall, I think the paper could use a significant overahaul and reassessment of the methodology and interpretation of the results. I hope that the authors will take the above as constructive criticisim and are able to improve their manuscript as plume spreading and its affect on the lithosphere is still a poorly understood topic. Below I add a few more specific comments.

- Line 47-48 – I'm not clear as to what this statement has to do with the EPR sucking in plumes so that they do not appear near the ridge.
- Line 52 – the use of the work "push" is inappropriate here and should be changed to "drag" or similar
- Line 53 – I don't think this sentence is needed as it is an opinion that does not bear on the rest of the paragraph.
- Line 58 - The authors should reconsider how they phrase things – for example, "slow-spreading rate, short distance (small plume-ridge distances??), and large plume radii promote ridge suction,…" is an inaccurate statement – really, I think what the authors are trying to say is that these factors favor plumes being pulled toward ridges by ridge suction
- Line 59 – maybe try a more careful wording – it is the fast plate motions associated with fast-spreading ridges that exert strong drag forces on plumes
- Figure 1B what do the percents in the insets indicate? Is that percent of the total number of plumes, percent of the total number of interacting plumes, something else?
- Figure 2 – this does not look like a half-space cooling model. Is this a plate cooling model or some modified half-space model? The half-space cooling model does not flatten like this.