Responses to comments on egusphere-2023-1388

Title: The role of continental lithospheric thermal structure in the evolution of orogenic systems: Application to the Himalayan-Tibetan collision zone

Referee #1 Lin Chen:

In this manuscript, the authors used 2D thermomechanical models to investigate the role of plate thermal state in the continental collision. Through systematic parameter testing, they found that a cold pro-plate favors continuous subduction, whereas a hot pro-plate prefers slab break-off. On this basis, they attributed the along-strike variations, including subducting angle and crustal faulting style, in the India-Asia collision zone to the inherited lateral inhomogeneity of the Indian plate's thermal state. This is an interesting study, which brings us some novel insights (thermal state of the subducting plate) about the factors controlling on the deformation style of continental collision zone. I think this paper is suitable for Solid Earth after some revision.

My main comments are as follows:

1. *The authors systematically tested variations in temperature at moho and heat production in the crust, but I think the two types of parameters are not independent. Given that the temperature structure of the continental plate is defined by the steady-state heat conduction equation (i.e., Eqs. 11-13), the moho temperature is determined by the heat production distribution and surface heat flow. Thus, it is more reasonable to treat heat flow and crustal heat production as two independent parameters. Similar treatment can be found in Beaumont et al. (2004, JGR), Chen et al. (2019, Tectonophysics).*

R1: Thanks for pointing this out. According to Eqs. (11) - (13), the moho temperature and radioactive heat production are not independent. However, as we focus on the influence of each of these two parameters, when we test crustal radioactive heat production, we fix the corresponding moho temperature. More Specifically, the procedure to define a continental geothermal structure is as follows: (1) Choosing the surface temperature (T_T), moho temperature (T_B), and radioactive heat production (H), calculating the surface heat flow q_T on the basis of Eq. (12); (2) Based on the above known quantities and Eq. (11), we then get the temperature at an arbitrary depth in the crust. Thus, when we take parameter H as a variation, the moho temperature is fixed,

and the crustal temperature gradient then increases with increasing H (see Figure 1 below). We've added a detailed description to the paper (lines 117-120):

"According to these equations, Tmoho and Hr are not independent parameters, we thus fixed Tmoho when investigating the influence of Hr. Specially, we first choose a surface (TT), moho temperature (TB), and radioactive heat production (H), then calculate the surface heat flow (qT) based on Eq. (12). After that, we substitute the above TT, qT, and H into Eq. (11) to get the continental crustal temperature structure."

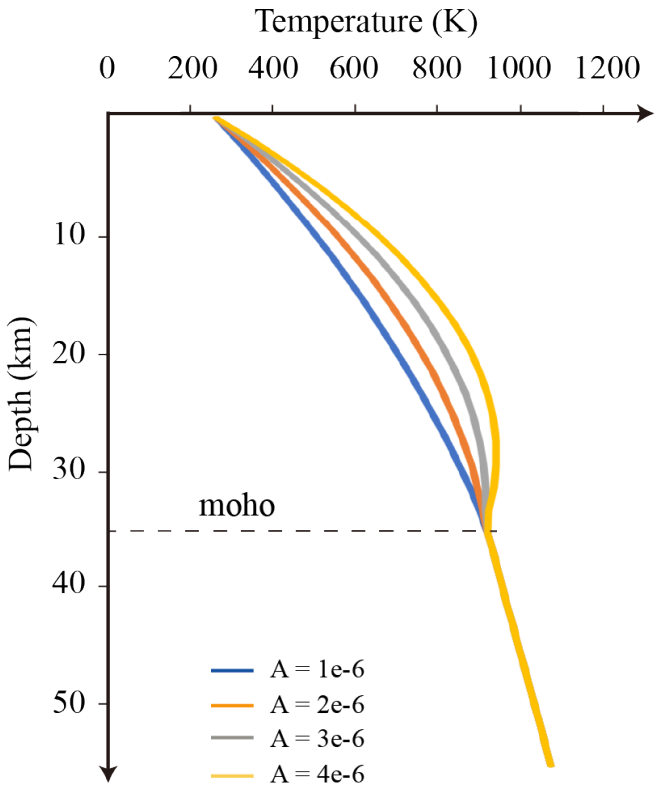

Figure 1. Continental temperature profile with different crustal radioactive heat productions and a fixed moho temperature of 600 ˚C.

Besides, we agree with the reviewer that surface heat flow is also an important parameter that is worth further study. We may test it in the future.

2: There are a number of factors controlling whether a slab breaks off or not. The thermal state of subducting continental plate was probably not mentioned in the previous studies. I suggest the authors to add some discussions about the factors controlling slab break off, comparing with previous studies, including Duretz et al. (2011) and others.

R2: Thanks for the suggestion. We've added a part discussing the factors controlling slab break-off and comparing them with previous studies in Section 4.1, lines 205-222:

"As to mode II, models with hot procontinental Tmoho (≥ 500˚C) always evolve into continental subduction following a slab break-off. In these models, when the retrocontinental Tmoho is determined, (1) as the procontinental Tmoho decreases, the procontinental lithosphere becomes cold, which results in a rheologically strong lithosphere that can be subjected to greater deformation; the slab thus breaks off much latter (Fig. 5e). This is consistent with many of the previous numerical studies (van de Zedde and Wortel, 2001; van Hunen and Allen, 2011; Duretz et al., 2011). However, it appears that Duretz and Gerya (2013) proposed an apparent opposite tendency. It may come from the fact that these models do not use a layered crust. In consequence, a strong crust is more likely to result in strong crust-mantle coupling and a deeper slab break-off under slower convergence, while a weak crust leads to crust-mantle decoupling that may evolve into delamination. (2) The depth of slab break-off in our models is between 30 ~ 60 km, which has also been indicated by Davies and von Blanckenburg (1995), Li et al. (2002), Duretz et al. (2011), and Duretz and Gerya (2012). (3) After slab break-off, the buoyant continental lithosphere experiences a rebound accompanied by strong surface uplift within a short duration (Fig. 3c), which coincides with Duretz and Gerya (2013) and Magni et al. (2017). Slab break-off is often considered an early process of continental collision, and numerous numerical simulations have been conducted to investigate it. Comparing their results with our models, we suggest that slab break-off is closely related to the rheological strength of the lithospheres. Therefore, the parameters that have prominent impacts on it, such as oceanic plate age, convergence velocity, continental crustal structure, layered crustal rheological strength, the strength of the interface between the subducting and overriding plates, etc. (Gerya et al., 2004; Burov, 2011; Duretz et al., 2011; Magni et al., 2017; Koptev et al., 2022), may significantly influence the evolutionary path of slab break-off. "

3: The language needs improving. I sensed a lot of writing or grammar issues, some of which are marked in the annotated pdf file, but they only represent a fraction of the language problems, not all.

R3: Thanks for the suggestions, we've modified the paper accordingly. All the modifications are shown in the revised manuscript attached here.

1) Lines 6-8, "Continental collision is a crucial process in plate tectonics, whereas our understanding regarding the tectonic complexities at such convergent plate boundary remains largely unclear in terms of the evolution and the controlling parameters of its lateral heterogeneity." Rephrase this statement using short sentences.

R3-1: Thanks for the suggestions, we've modified the sentence (lines 7-9):

"Continental collision is a crucial process in plate tectonics. However, in terms of the evolution and the controlling parameters of its lateral heterogeneity, our understanding of the tectonic complexities at such a convergent plate boundary remains largely unclear."

2) Line 13, modify "relative".

R3-2: We've modified it to "relatively", line 14.

3) Line 14, delete "In contrast".

R3-3: We've deleted "In contrast" here, line 15.

4) Line 14, what is Hr?

R3-4: We've changed it into "Radioactive heat production", line 15.

5) Line 16, "geoscience" -> "geological"?

R3-5: We've modified it to "geological", line 18.

6) Line 19, add "most".

R3-6: We've added "most" here, line 21.

7) Line 22, "Continental collision following the closure of the ocean is…". Since the second half of this statement is specific, I suggest to specify which continent collided and which ocean closed."

R3-7: We've modified it, line 23:

"The collision between the Indian and Asian continents following the closure of the Neo-Tethys Ocean."

8) Line 25, delete "geoscience".

R3-8: We've modified it, line 27.

9) Line 27, "slding" -> "underthrusting"?

R3-9: We've modified it, line 29.

10) Line 28, "vary laterally from west to east", Be specific. How do them vary from west to east?

R3-10: We've modified it, line 28-29:

"Specifically, the horizontal underthrusting distance of the Indian lithosphere decreases and the subducting angle increases laterally from west to east."

11) Line 34, "manifested", change a word.

R3-11: We've modified it to "suggested", line 36.

12) Line 57, delete "Otherwise".

R3-12: We've modified it, line 59.

13) Line 61, "varies" -> "influences".

R3-13: We've modified it, line 63.

14) Line 63-64, "our model results are applied to draw some parallels with the Indian-Asian collision zone.", rephrase this statement.

R3-14: We've modified it, lines 65-66:

"the results of our models are used to draw comparisons with some first-order characters of the Indian-Asian collision zone."

15) Line 63, No mention of Table S1 before Table S2.

R3-15: We've modified it, line 65.

16) Line 71, delete "and we quoted directly from these publications".

R3-16: We've modified it, line 72.

17) Line 81, "friction" -> "frictional".

R3-17: We've modified it, line 82.

18) Line 107, "consists" -> "consisting".

R3-18: We've modified it, line 109.

19) Line 111, what about the resolution in the horizontal direction?

R3-19: The resolutions in horizontal and vertical direction are the same, we've modified it, lines 113-114:

… from 2 km × 2 km to 8 km × 8 km

20) Line 116, "plate" -> "half-space".

R3-20: We've modified it, line 121.

21) Line 134, "crustal Hr", *this parameter seems confusing. What does it really mean? Upper crust heat production, lower crust heat production, or the whole crust heat production?*

R3-21: We've modified it, we define continental upper crust heat production as H_{r_uc}, while lower crust heat production as H_{r_lc}, lines 141-142.

22) Line 134, "mimic" -> "capture".

R3-22: We've modified it, line 142.

23) Line 138, "it takes the Model m2", a conjunction is missing here.

R3-23: We've modified it, line 146, "and it takes the Model m2…"

24) Line 141, "at shallow"?

R3-24: We've modified it, line 149, "at surface".

25) Line 142, "under" -> "due to"?

R3-25: We've modified it, line 150.

26) Line 143, "fully" -> "full".

R3-26: We've modified it, line 151.

27) Line 147, "shallow"?

R3-27: We've modified it to "scraped off", line 155.

28) Line 149, "initiated to"?

R3-28: We've modified it to "began", line 157.

29) Line 150, "broke the neighboring retrolithopheric", it is not clear.

R3-29: We've modified it, line 158.

30) Line 169, "relative" -> "relatively"

R3-30: We've modified it, line 175.

31) Lines 182-183, "(b) upper and (c) lower crustal radioactive heat production (Table S2)", I suggest to use different symbols to denote the upper and lower crustal heat production. It is not a good idea to use Hr to stand for everything.

R3-31: We've modified it, we define continental upper crust heat production as H_{r_uc}, while lower crust heat production as H_{r_lc} (lines 141-142), Figures 4b, 4c, line 187-188.

32) Line 226, "on" -> "for".

R3-32: We've modified it, line 249.

33) Line 226, "heterogeneous" -> "heterogeneity"?

R3-33: We've modified it, line 249.

34) Line 232, "extend" -> "end"?

R3-34: We've modified it, line 255.

35) Line 270, "relative" -> "relatively".

R3-35: We've modified it, line 294.

36) Line 276, "inhomogeneous" -> "variation".

R3-36: We've modified it, line 300.

37) Line 351, “feformation” -> “formation”.

R3-37: We’ve modified it, line 397.