Dear Editor,

We would like to thank Reviewer 2 for his comments and his constructive remarks. Each comment or question has been considered. Please find below a point-by-point reply to all comments.

Line 162 : Constant P at the top, so the model is "open-top". Right? What is the T° conditions? constant T=T(top), or T=T(top) when the fluid moves down and dT/dz(top)=0 when it is moving up?

- ➔ Yes pressure is fixed at the top, the model is « open-top » . Temperature is fixed at the top boundary, as explicitely written line 160. Boundary conditions are exactly the same as those of Rabinowicz et al. (1998), as explained line 159.

Line 172 : When increasing the permeability (or equivalently Ra), the flow dynamics goes through a series of bifurcations starting from steady-state flow

- ➔ We agree with this remark which does not however require any change in the text.

Line 186 : One should consider plotting/giving the heat flux transported by these flows (e.g., the Nu at the base, or the mean flux at the top and/or the flux carried by the individual plumes). That would make sense for a geothermal exploration perspective, especially later in the paper, when more realistic (3D,fracture) geometries are considered.

- ➔ We partly agree with R2. Indeed, most of studies on hydrothermal convection in oceanic crust describe convective patterns and heat flux carried out by thermal plumes. However, in the context of geothermal studies, temperature is much more relevant than heat flux. For example, heat refraction effects could lead to anomalously high heat flux while temperature would not be affected (e.g. Guillou-Frottier et al., Geophys. Res. Lett., 1996). Nonetheless, in the frame of the benchmark tests of Fig. 1, the maximum heat flux carried by thermal plumes is now indicated. The obtained values are similar to the results published by Rabinowicz et al. (1998). Note that spatial evolution of surface heat flux has already been published by Garibaldi et al. (2010), their Fig. 10, and numerical values compared well with the results of Rabinowicz et al. (1998).

Line 194 : Are all these simulations steady-state? I would have thought that at least at 10-13m2, the flow is not steady anymore? How does this compare with other code (Rabinowicz, Fontaine, Coumou...)

- ➔ Yes, as indicated in the caption, these simulations are all steady-state, or show a steady-state pattern after a transient stage. As noted in the last sentence, « *Above 10^{-13} m², convection exhibits unsteady patterns, including typical Y-shaped and splitting plumes.* ». These results are identical to those of Rabinowicz et al. (1998), as written line 192.

Line 217 : I think that the reduction of the number of plumes have a lot to do with the fact that the local Ra at the base of the system is much smaller than at the top, and that accordingly less plumes arise in the thermal boundary layer at the base.

- ➔ We completely agree with R2's remark, which is another way to explain the physical mechanism. It is exactly the same as our explanations, but expressed with the local Rayleigh number instead of local permeability (our choice).

Line 240 : What is the heat flux (mean and /or individual/plumes) doing?

- ➔ We have added in the text the time evolution of surface heat flux carried out by thermal plumes (right before Fig. 3), but here again, in the frame of geothermics, temperature anomalies are more relevant for exploration. In addition, informations are given for the top surface and not at the base of the system since geothermal exploration is more interested in shallow thermal anomalies.

Line 258 : Again here, a plot showing the temporal variation of the mean heat flux (e.g., the Nu at the base of the system) would be useful to understand this pattern. When the permeability starts to increase is the flux decreasing, or increasing?

- ➔ When permeability starts to increase, the surface heat flux over the plume head increases from 5 to 35 $W.m^{-2}$ during the first 200 years. This is now specified in the text (lines 262-263).

Line 321 : I don't think this is actually, "plume splitting", more "plume pulsating". Plume splitting as described by Coumou and also by Fontaine, is a dynamical phenomena occuring when a hot rising plume meets a cold downwelling (or stagnant) front and the plume splits in several finger-like structures. Coumou has explained this phenomenum which requires a threshold plume velocity and a viscosity contrast. Coumou also explains that high-order in time and space numerical schemes (and low spatial resolution too) is necessary to see this. What I see on figure 7 here, is the pulsation of the plume because the lower thermal boundary become unstable (see the plumelets). In Fontaine&Wilcock 2007, we have highlighted and described this behavior (including periodicity) which is characteristics when the permeability exceeds c.a. 10-14 m2. The authors should distinguish carefully these 2 phenomena (i.e., pulsation vs. splitting). I am surprised to see that some of the models in figure 1 are steady, while the permeability is >10-14m2. So I have 2 questions: 1- how accurate is the scheme, and maybe it would be worth reproducing basics Ra-Nu relationships (see benchmark table in Fontaine&Wilcock 2007 for example); 2- Do you see actual "plume splitting"? I attached a figure from Coumou showing plume splitting.

- ➔ We thank R2 for this relevant remark. The word « pulsating » is indeed more appropriate and « splitting » is now changed by « pulsating ». Reference to Fontaine & Wilcock (2007) has been added and the obtained similar timescales are underlined. Details on the numerical procedure (accuracy, tolerances, type of solver) have already been given at the end of Appendix A. It is also well-known that different solutions can be obtained with different numerical codes, as discussed in Appendix B.
- ➔ Yes, actual plume splitting was also observed at permeability values exceeding 10^{-13} m^2, as indicated at the end of the caption of Figure 1 (we refer to this mechanism as « *Y-shaped and splitting* » plume).

Line 340 : What are the initial conditions in these models? In 2D you argue that the initial condition was important for the final flow geometry. Is it the case in 3D?

- ➔ We thank R2 for this question. Indeed, initial conditions may influence the following convecting pattern, as observed and demonstrated in 2D models. However, for all 3D models, the initial condition was a purely conductive regime, an information that was not clear. This is now specified line 384.

Line 363 : What if it does ?

- ➔ We did not investigate all possible configurations. We chose to look at non-outcropping fault zones. Tests on outcropping fault zones would correspond to another entire study.

Line 373 : How do you deal with the flow in the fracture and in the rocks around? Is the flow (i) 3D everywhere and you just have a permeability contrast between the fracture and the rocks or (ii) do you have "fracture flow" in 2D in the fracture and 3D in the rocks around. If you do (i) then you should discuss somewhere what is the limitations of that with respect to a more realistic "fracture flow". Maybe some insights in Mezon et al. 2018 (*Physical Review* E, 97(1), 013106.)

- ➔ Answer is (i) : the flow is 3D everywhere, but the low permeable host rocks do not involve significant fluid flow around the fault. We have added 2 sentences at the beginning of the discussion to not ignore the « fracture flow » approach, which is not necessarily more « realistic » than our approach in the case of crustal fault zones, whose thickness may reach hundreds of meters. This is now specified and reference to Mezon et al. 2018 has been added.

Line 385 : I can see that in all the inclined models, the temperature perturbation follows the dip of the fault. In the 2D models of Andersen et al. 2015 (Geology (2015) 43 (1): 51–54.) there is a discussion about the fact that there is a competition between the buoyancy of the fluid that tend to favor purely vertical flow, and the dip angle. For example sometimes in ANdersen et al 2015, the flow follows the fault plane at depth and then turn to vertical at shallow depth. You don't seem to observe that? Why (2D vs. 3D, boundary conditions?) It may have to do with the fact that your host rock is "impervious" with Kh=1e-18m2, but what if you consider an inclined fault models with depth-dependent permeability and for which the Kf/Kh ratio is "small" (i.e., the permeability of the host rock is not small at shallow depth, like in figure 14, but with an inclined fault).

- ➔ We thank Reviewer 2 for letting us know about this Andersen et al. Paper. Comment by R2 is interesting, and his answer is right : indeed, host rocks are almost impervious, preventing fluid flow to turn to the vertical at shallow depth. However, we could not test all possible kf/kh ratios, but we believe that Fig. 14 allows considering its effect on convective patterns. These tests would be worth to investigate in a future study.

Line 529 : « fluent-rich » ?

- ➔ These precision has been removed.

Line 598 : In your models in which this ratio is 20 (or 50), don't you get thermal instabilities in the host rock rather than only along the fault plane? I anticipate that in a 5.5km-deep system the effective Ra of the host rock could be supercritical if that ratio is "small" like 20. I guess it also depends on your depth-dependent permeability distribution, but you may have a completly different flow geometry if plumes start to arise in the host rock.

- ➔ We definitely agree with Reviewer 2. However, our objective was not to make a complete sensitivity study on all parameters. Many simulations would be needed to answer to this remark, and this was not the aim of our work, as underlined in the abstract (« *This study presents a non-exhaustive numerical investigation…* »).

Line 612 : Could you show a figure in which you calculate the volume (m3) of the thermal anomalies for the 3D models? as a function of DeltaT, or for a DeltaT greater than a predefine value that would have a geothermal meaning? This would be interesting to size the potential of geothermal energy.

- ➔ This is actually planned for the next step of our approach. We first presented « simplified models » to illustrate some mechanisms. Because a number of simplifications have been chosen, it would not be reasonable to « size the potential of geothermal energy ». However, such estimate is currently worked in the frame of Duwiquet's PhD thesis (second author), who applies this approach to the natural system of the Pontgibaud crustal fault zone, French Massif Central (Duwiquet et al., 2019).

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