Author comment to RC1 (Merce Corbella)

We thank the reviewer for carefully reading our manuscript and providing us with valuable feedback for improving the manuscript. We copy below the reviewer comments (in italic) and a point-by-point response (in plain text).

a. *A justification of caprock porosity and permeability, as well as basement permeability would help in accepting the simplified model as realistic. The values used seem to be rather high.*

Response to a: We acknowledge the reviewer's comment. As now explained in the Methods section in the revised manuscript we use "caprock" and "basement" as generic terms indicating layers of lower permeability relative to the reactive carbonate aquifer which are overlying and underlying the aquifer respectively and behave effectively as semi-confining units. As our model simply demonstrates hydrothermal dolomitisation by seawater convection within a generic faulted heterogeneous system, not a specific case or area, we deliberately keep the variation in rock properties to a minimum. The initial fractional porosity (0.2) and permeability of the caprock (1 mD) represent fractured rock or semi-consolidated sediment where the porosity is quite high due to the lesser effect of compaction and diagenetic alteration. The critical value is that for permeability, which at 1 mD is comparable to values assigned for a shallow shaley layer overlying the carbonate reservoir of the Barremian Toca Fm in the Lower Congo Basin (Consonni et al., 2018). Although the porosity of 0.2 for caprock is quite high, several prior studies show that the influence of changing porosity on the flow field and convection cell patterns is negligible (Gow et al., 2002; Kühn et al., 2006; Zhao et al., 2003). However, it is still important to note that porosity affects the difference between the average pore velocity and the Darcy velocity.

The reviewer is correct that in some situations the shallow permeability may be lower and we now include the results of additional simulations with smaller caprock permeabilities of 0.5 mD and 0.1 mD. These suggest that within the range investigated this parameter has very little effect on the behavious of the system relative to the base case. To further investigate the sensitivity to basement permeability in controlling heat and fluid flux from deep sources, we have also included an additional simulation with lower basement permeability i.e. 0.1 mD within the revised manuscript (section 3.4).

b. *Also, an explanation for the chemical composition of the basement fluid would be nice, as a quite alkaline and dilute fluid is being used for the simulations, which do not correspond to a usual warm and acidic brine.*

Response to b: Basement fluid is high-temperature modern seawater at equilibrium with calcite and dolomite and thus has a higher Ca^{2+} concentration, lower Mg^{2+} concentration and alkalinity, and slightly acidic. The basement fluid has been explained in the Methods section (line 153–155) and Table 2 in the revised manuscript. Further simulations of alternate basement fluid chemistries are the subject of ongoing investigations.

c. *Figure 1 illustrates very well most of the parameters of the system simulations. However, consider adding a figure 1b with the initial and boundary conditions of the simulations (temperature, fluxes, etc) so that we can easily visualize their influence over the simulation results.*

Response to c: We have modified figure 1, adding an initial plot (figure 1b) to show the initial and boundary conditions. No boundary flux has been imposed in this system to avoid an uncertainty from specifying the flux. Rather fluxes across the boundaries are determined by density contrasts and permeability enabling us to show the effect of how these evolve over time.

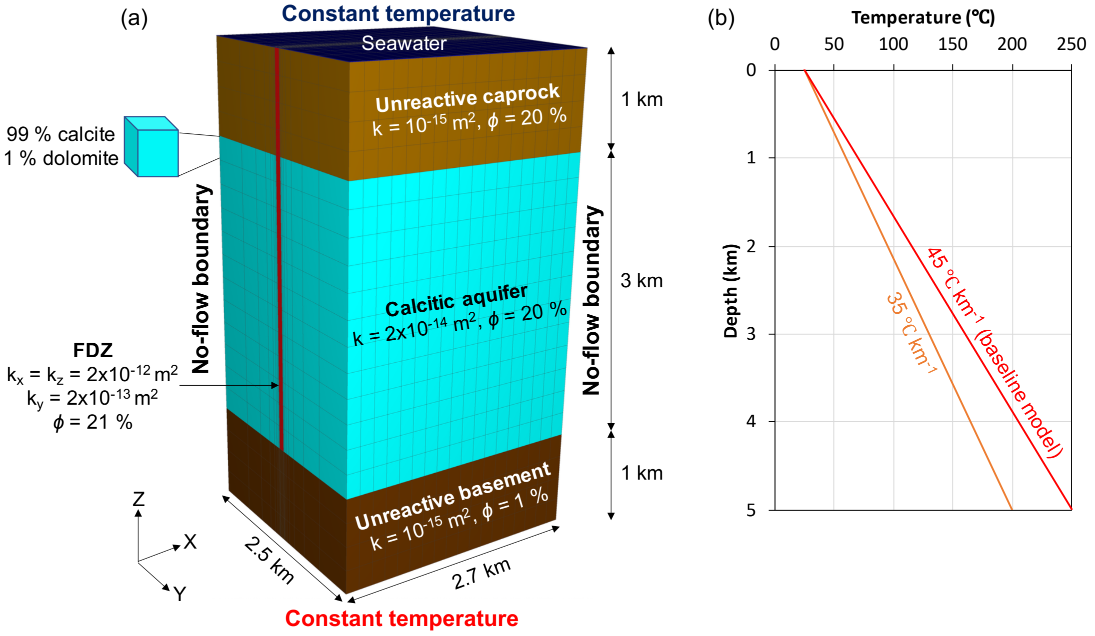

Figure 1. (a) Model dimensions, material properties, and simulation grid. The permeable fault damage zone (FDZ) is displayed in red. Parallel to the FDZ the grid is regularly discretized with dimension of 150 x 250 m (width x height), but perpendicular to the fault cells thickness varies from 500 m at the edge of the model to 10 m within the FDZ. The caprock and basement are unreactive, and the aquifer is calcitic, with 1% "seed" dolomite. The side boundaries are no-flow, and the top and bottom boundaries are constant temperature. (b) The initial conditions of the simulations. Top boundary is open to exchange with overlying seawater at 25 °C and the base of the model is set at 200 and 250 °C, giving an initial geothermal gradient of 35 and 45 °C km^{-1}, respectively.

d. *The modelled system has a tall prismatic shape, which, together with the no-flow boundaries used, forces convection to form narrow vertical cells. I'm afraid this also constraints the shape and size of the resulting dolostone bodies.*

Response to d: The dimensions of the model are one of a number of uncertainties in 3D RTM simulation of complex HTD system, which also include boundary conditions and petrophysical properties as discussed above. Although we agree that the shape and size of dolostone bodies could be influenced by our model setting, model width is only one of the minor controls on fluid circulation. These are already well explained by the classic studies such as those of Bethke (1989). In real systems the permeability structure within the fault damage zone will be complex distribution and will likely dominate the pattern of hydrothermal convection (Guillou-Frottier et al., 2020; Harcouët-Menou et al., 2009). We thank the reviewers for raising this point and have incorporated statements in the second paragraph of section 4.2 in the revised manuscript which clarifies these issues.

Again, our main point of this study is to demonstrate that the proposed mechanism is a viable means of forming HTD, and can explain the apparent incongruity between geological observations (in particular fluid inclusion temperatures and salinities of the dolomites) and challenges in satisfying Mg^{2+} mass balance requirements worthy of consideration. We hope this paper will act as a jumping-off point for further studies applying this concept to specific outcrop or subsurface case studies.

e. Check figures 2b, f and j, which show vertical Darcy velocity fields, for the arrows superimposed. The arrows must correctly reflect the flow directions but are quite confusing where they appear to 'crash' (cap rock flow with convection in aquifer, basement flow with convective flow). Consider using flow lines or small velocity vectors instead.

f. The 3D model results of Fig 2 can hardly be observed in the plane perpendicular to the fault. The temperature variations, velocity field or dolomite formed cannot be appreciated there. Consider adding a 2D cross-cut of it or modifying the orientation of the 3D prism or enlarging the figure.

Response to e and f: We have modified Figure 2 by using velocity vectors of each individual cell to represent flow direction. The 3D diagrams are revised in Figure 3 for a better presentation with enlarged 3D solids.

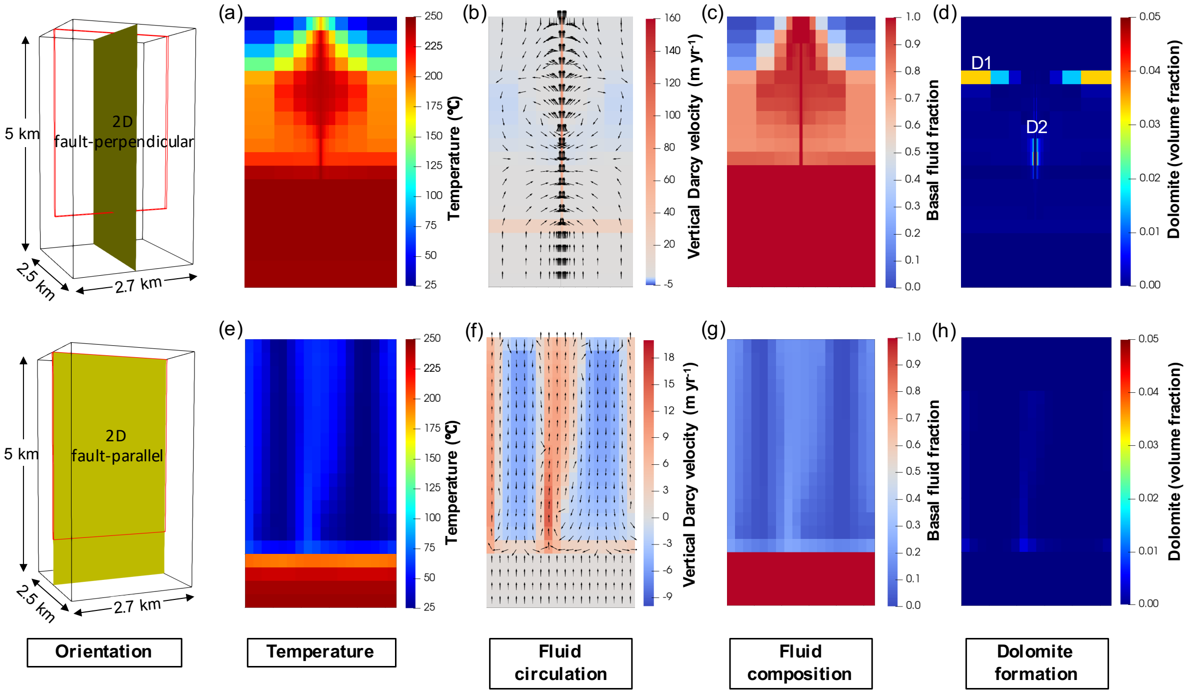

Figure 2. Simulation results for 2D fault-perpendicular (a–d) and fault-parallel (e–h) models showing heat transfer, fluid flow (with representative streamlines), basal fluid fraction, and dolomite distribution at 30 kyr. The yellow planes on the left of each row represent the orientation of 2D displays and the red outlines highlight the FDZ. Darcy velocities are positive when flow is upward and negative when flow is downward. Note the difference in scale for Darcy velocity between the 2D fault-perpendicular and fault-parallel models.

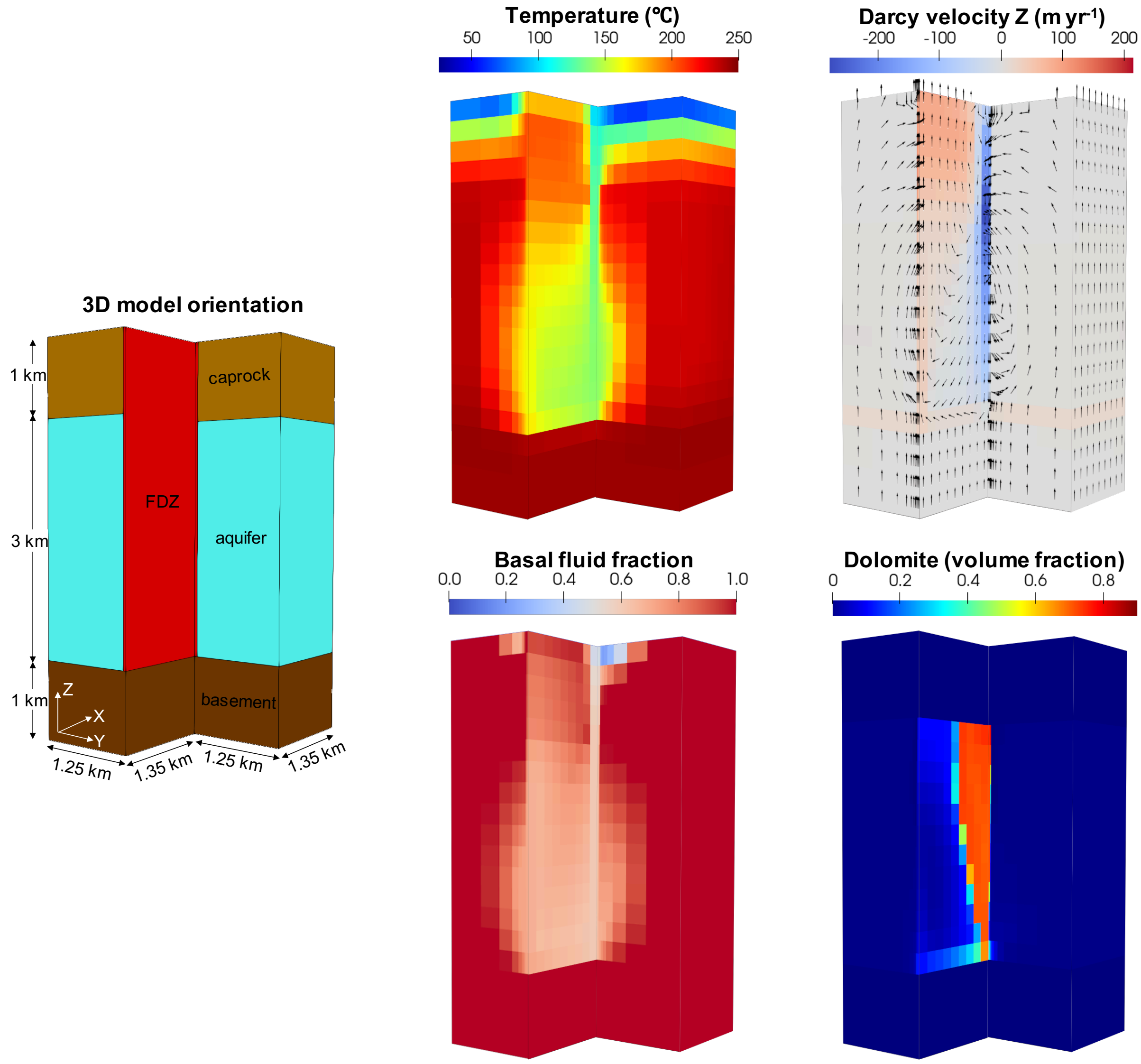

Figure 3. Three-dimensional baseline simulation illustrating heat transfer, fluid flow, basal fluid fraction, and dolomite distribution at 30 kyr. Note Darcy velocities are positive when flow is upward and negative when flow is downward. The 3D volume on the left represent the orientation and dimensions of the displays. The dolomitisation is focussed along the plane of the fault which the temporal evolution of the system is presented in Fig. 5.

g. *A thorough sensitivity analysis is important. I would like to see the results of simulations with lower basal temperature, an acidic brine as basal fluid, smaller permeabilities for caprock and basement and a much wider system.*

Response to g: These points are addressed in responses to reviewer's comments a and b above. With reference to the lower basal temperature, we have included an additional simulation illustrating sensitivity to this parameter by reducing the temperature at the base of the model from 250 to 200 °C. We also now include further simulations investigating (separately) the influence of a lower permeability of basement (0.1 mD) and caprock (0.5 mD and 0.1 mD) in the revised manuscript. However, a simulation of much wider system is omitted but explained above in our response to comment d and also discussed in the revised manuscript. We agree that the fluid chemistries are interesting and alternative investigations of more acidic brines are underway as part of a subsequent study.

However, we would like to clarify that the main purpose of this manuscript is a generic evaluation of the new conceptual model of hydrothermal dolomitisation by top-down circulation of seawater, which is successfully demonstrated by our 3D RTM simulations and represents a significant advance on those for HTD previously published which have been exclusively 2D perpendicular to the plane of the fault and simulate the response to injection of fluids at specified locations and rates. As mentioned in section 4.2 (Model limitations) in the manuscript, a more fully developed sensitivity analysis on rock properties, fluid compositions, model dimension etc. are important as areas for further work.

List of technical corrections

1. *Order the citations to references in the same sentence time-wise. Normally, the cites are organized from older to more recent. E.g. Introduction, lines 35-40, Discussion lines 350, 480, etc).*

Response to 1: We acknowledge the reviewer's comment. However, the order of in-text citations herein is based on relevance and alphabetical listing with response to the manuscript preparation guideline.

2. *Consider not to include references that cannot be found by many researchers, such as Breislin et al., Robertson et al. 2015.*

Response to 2: We have updated the reference of Breislin et al. which now is accepted by the Journal of Sedimentary Research, though it is currently still in press. However, we decline to remove the study of Robertson et al., 2015 as it is one of key studies pointing out a limited dolomitisation potential of fluids in deep aquifers. The abstract of this work can be accessed via the following link: https://www.cspg.org/common/Uploaded%20files/pdfs/documents/conference_website/carbonates/Abstract_BookV2.pdf

3. *Correct the reference Almandine Les Landes et al. 2019, line 565: there's no volume number.*
4. *Some references are missing from the list, like Gòmez-Rivas et al. 2014.*

Response to 3 and 4: We have crossed checked all references and corrected that.

5. *First sentence of paragraph in lines 420: spare 'and'.*

Response to 5: Sorry, we cannot find that.

6. *In paragraph of lines 245, is "mineral density" appropriate, or should it rather be 'molar volume"?*

Response to 6: Yes, it should be molar volume. We have replaced the word "mineral density" by "molar volume" in the revised manuscript.

References:

Bethke, C. M.: Modeling subsurface flow in sedimentary basins, Geol Rundsch, 78(1), 129–154, doi:10.1007/BF01988357, 1989.

Breislin, C., Crowley, S. F., Banks, V., Marshall, J., Millar, I., Riding, J. and Hollis, C.: Controls on dolomitization within extensional basins: an example from the Derbyshire Platform, UK, J. Sediment. Res., in press.

Consonni, A., Frixa, A. and Maragliulo, C.: Hydrothermal dolomitization: simulation by reaction transport modelling, J. Geol. Soc. London Spec. Publ., 435(1), 235–244, doi:10.1144/SP435.13, 2018.

Gow, P. A., Upton, P., Zhao, C. and Hill, K. C.: Copper-gold mineralisation in New Guinea: Numerical modelling of collision, fluid flow and intrusion-related hydrothermal systems, Aust. J. Earth Sci., 49(4), 753–771, doi:10.1046/j.1440-0952.2002.00945.x, 2002.

Guillou-Frottier, L., Duwiquet, H., Launay, G., Taillefer, A., Roche, V. and Link, G.: On the morphology and amplitude of 2D and 3D thermal anomalies induced by buoyancy-driven flow within and around fault zones, Solid Earth, 11(4), 1571–1595, doi:https://doi.org/10.5194/se-11-1571-2020, 2020.

Harcouët-Menou, V., Guillou-Frottier, L., Bonneville, A., Adler, P. M. and Mourzenko, V.: Hydrothermal convection in and around mineralized fault zones: insights from two- and three-dimensional numerical modeling applied to the Ashanti belt, Ghana, Geofluids, 9(2), 116–137, doi:10.1111/j.1468-8123.2009.00247.x, 2009.

Kühn, M., Dobert, F. and Gessner, K.: Numerical investigation of the effect of heterogeneous permeability distributions on free convection in the hydrothermal system at Mount Isa, Australia, Earth Planet. Sci. Lett., 244(3), 655–671, doi:10.1016/j.epsl.2006.02.041, 2006.

Robertson, H., Whitaker, F. F., Palmer, T. and Gabellone, T.: The Search for Fluids with HTD Potential, CSPG-SEPM Mountjoy carbonate meeting, Banff, Alberta, 23-28 August 2015, 2015

Zhao, C., Hobbs, B. E., Mühlhaus, H. B., Ord, A. and Lin, G.: Convective instability of 3-D fluid-saturated geological fault zones heated from below, Geophys. J. Int., 155(1), 213–220, doi:10.1046/j.1365-246X.2003.02032.x, 2003.