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# *Interactive comment on* "3D numerical modelling of the re-distribution of partially molten lower crust rocks in relay zones between faults during transtension: Implications for the Sefwi terrane, SW Ghana" *by* Xiaojun Feng et al.

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There is certainly a paper in this submission, but much work has to be done.

The paper is poorly written, and poorly articulated. First, the study is not clearly framed. I suggest to the authors to choose between two options: Option 1: The motivation for the suite of 3D numerical experiments is to get insights into some peculiar or interesting features in the geology of the Sefwi terrane. The introduction should focus on the Sefwi terrane and should explain what is peculiar or interesting, and how numerical modelling



to help understand these interesting features. Option 2: The motivation of the suite of 3D numerical experiments is to understand the exhumation of the deep lower crust in the vicinity of strike-slip faults. The introduction should focus on explaining why this process is important, it should summarize what we know about this process and what are the knowledge gaps. The introduction should explain how numerical modelling can help, and what regions will be used to ground truth the models. The title suggests that option 2 was followed, by the structure of the article points to option 1.

The text and the figures should be carefully edited

Line 13: ". . . the normal component of velocity boundary conditions mainly controls the . . .": Normal component to which vertical wall? in 3D there are two sets of vertical walls on which a boundary condition must be applied.

Line 14: Please remove ". . . which occurred . . ."

Line 15a: " . . . is controlled by the ration of extension rate to shear rate . . . ": Could you say instead: ... is controlled by the obliquity between the applied extensional velocity vector and the vertical wall on which it is applied. Use "velocity" rather than "rate" to avoid confusion.

Line 15b: " . . . applied at the boundary . . . ": Which boundary? Again there are two sets of vertical walls.

Line 16: ". . . transtension direction . . .": I don't understand what is means. Is it the direction of extension? i.e. the direction of the horizontal velocity applied the two opposite vertical walls perpendicular to the direction of the faults?

Line 20: Please remove ". . . up to . . .".

General comment on the abstract: a/ This abstract lack clarity. The key point of the abstract ". . . the normal component of velocity boundary conditions mainly controls the exhumation of the lower crust ... " is particularly unclear as the reader is not informed about the nature of the boundary conditions. Besides, I suspect that – more simply

– exhumation of the lower crust is associated to regions of maximum thinning of the upper crust, which is hardly new. b/ There is a misalignment between the paper's title and the abstract in which the concept of " redistribution of partially melted lower crust " is ignored. To me, the exhumation of the partially molten lower crust is not the same as redistribution of partially melted lower crust. If the redistribution of partially melted lower crust is the main topic then one would expect a 3D mapping of the melt fraction through time. Instead, the documentation focuses on mapping the solidus, to capture the exhumation of the deep partially molten lower crust.

Line 28-29: The reference to Feng et al., 2016b doesn't seem to be appropriate or relevant to the claim that "A regional-scale fault commonly originates from a network of local pre-existing discontinuities. . ..". Please find a better set of references.

Page 2 line 1: " . . . interacting strike-slip fault systems . . ." interacting in which way? Is fault initiation and propagation relevant to the paper?

Page 2 line 5-8. The general statement that: ". . . The emplacement of partially molten rocks is dominantly driven by the contrasts in density and viscosity compared to surrounding rocks . . . " is wrong on several levels. 1/ emplacement of the partially molten rocks into what? 2/ The viscosity contrast is not a "driver" of exhumation; 3/ The density contrast can be a driver, however, when exhumation is driven by extension, the density contrast plays little role compared to the lateral pressure gradient induced by thinning. When extension is the main driver, exhumation occurs even when the lower crust is denser than the upper crust.

Line 8 to 10: What did we learn from the work of Tirel et al., 2008; Rey et al., 2009a, 2009b, 2011; Feng et al., 2017 . . . that is relevant to your own study?

Line 15: Here we are back on the subject of fault growth. Is this relevant to this paper?

Missing references (list definitively not exhaustive): Burg, J.-P., Kaus, B., and Podlachikov, Y.Y., 2004, Dome structures in collision orogens: Mechanical investigation



of the gravity/compression interplay, in Whitney, D.L., et al., eds., Gneiss domes in orogeny: Geological Society of America Special Paper 380, p. 47–66. Rey et al., 2017. The origin of contractional structures in extensional gneiss domes. Geology. This paper also shows the exhumation of the deep crust in between a set of strike-slip faults, also using Underworld . . . Román-Berdiel et al., Experiments on granite intrusion in transtension. Geol. Soc. London, Spe. Pub., 174, 21-42. Wdowinski, S., and Axen, G.J., 1992, Isostatic rebound due to tectonic denudation: A viscous flow model of a layered lithosphere: Tectonics, v. 11, p. 303–315, doi:10.1029/91TC02341. Weinberg, R., Sial, A.N., and Mariano, G., 2004. Close spatial relationship between plutons and shear zones. Geology, 32, 377-380. Wijns, C., Weinberg, R., Gessner, K., and Moresi, L., 2005, Mode of crustal extension determined by rheological layering: Earth and Planetary Science Letters, v. 236, p. 120–134, doi: 10.1016/ j.epsl.2005.05.030.

Line 26: Please consider "explored" instead of "constructed".

Line 28: Would "exhumation" instead of "re-distribution" be a better word in the context of your study?

General comments on the Introduction. This introduction is rather weak in the sense that very little effort is made to summarize the large body of work (from field geology, analogue experiments and numerical modelling) that has explored the relationship between faulting and exhumation of high-grade rocks and partially molten rocks. Very little effort is made to ground the present submission into the existing literature. What have we learn from pre-existing work, and which gaps do this new contribution fills? After reading the Introduction, the reader is left with little idea about the justification of this study, excepted that ". . . 3D numerical models including the processes of fault growth and lower crust exhumation driven by transtension boundary conditions have still not been completely explored." Tell us why this is important, what do we know about it, and what is left to understand.

Section 2: Geological settings. What is the purpose of this section? It is coming out

of nowhere and goes nowhere. It summarizes is the regional geology of the Sefwi terrane, but there is no attempt to pose a problem and define a knowledge gap. Is the purpose of this paper to understand a process or is it to understand the local geology of a particular region? At this stage, I suggest you choose between two approaches. Option 1: The motivation for doing a suite of 3D numerical experiment is to get insights into some peculiar or interesting features of the geology of the Sefwi terrane. The introduction should focus on the Sefwi terrane and should explain what is peculiar or interesting, and how numerical modelling to help understand these interesting features. Option 2: The motivation of doing a suite of 3D numerical experiment is to understand the exhumation of the deep lower crust in the vicinity of strike-slip faults. The introduction should focus on explaining why this process is important, it should summarize what we know about this process and what are the knowledge gaps. The introduction should explain how numerical modelling can help, and what regions will be used to ground truth the models.

Section 3: Method and model setup Please add a space before units: 300 km, not 300km; 2080 Ma, not 2080Ma, etc. Page 4 line 9-10. The intermediate crust is made of mafic rocks, but what is the lower crust made of? Page 4 line 10 remove ". . . place in . . .", " . . . that spatial relationship . . . ". Page 4 line 12-13 remove ". . . in this study . . ." Page 4 line 14: I do not understand ". . . extension rate to shear rate . . .", what is the extension rate? Do you mean the component of the velocity vector normal to the wall? Page 4 line 18: What is the point of these 450 tracers? Why not visualizing the top of the lower crust since the lower crust is a different material, or better how about mapping the solidus? Page 4 line 20: " . . . the upper surface of the upper mantle Z=-42 km . . . " why can't you say the Moho? Page 4 line 21: " . . . The mechanical boundaries are constrained by transtension (or extension) . . . " Do you mean that you are applying a kinematic boundary condition on two opposites vertical walls to drive extensional to transtensional deformation? If yes then re-write. Page 4 line 26: These references are unnecessary. Page 5 line 1: " The solid-deformation behaviour is modelled with a depth-dependent yielding . . ." does this mean that viscous flow is



not a "solid-deformation"? Can you please refrain inventing terminology when it is not necessary? Page 5 line 10 and 11: ". . . the mafic crust rocks start to melt (from 1% to 30%) at a solidus temperature of . . ." I don't understand the 1% to 30%. Do you that mean the solidus of the mafic rocks correspond to 836°C and the melt fraction is kept $\leq$30%? Since you give the solidus of the intermediate mafic crust (which doesn't melt), why don't you give the solidus of the lower crust (which actually melt)? Page 5 line 24: Please replace "In natural cases . . ." by "In nature . . .". Page 5 line 25: ". . . when the local temperature reaches the melting point of the lower crust. . . we model the effective viscosity by using a function of melt fraction . . . ", do you mean: When the lower crust reaches its solidus, its effective viscosity changes according to . . .

Is partial melting consuming heat? Are the densities in Table 2 at room temperature? Why is the density of the lower crust lower than that of the mid-crust and even the upper crust? Why is the density of the upper mantle so low?

Section 4: Results The first sentence (Page 5 line 8 to 10) is a repetition, please remove. The following sentence could be put in the acknowledgement.

Section 41: The upper surface of the partially molten lower crust Page 6 line 16: Is the comparison done at the same amount of extension? or the same time step? or what?

Page 6 line 16: ". . . the focus of exhumation in relay zones between faults in case A1 is higher than that in case B1 . . ." Perhaps this is because the panel in Fig.4-A1 shows the experiment at time 0.92 Ma, and Fig.4-B1 only at time 0.85 Ma? The caption of figure 4 does not help understand what this figure shows. What are A2, 3, 4, 5 various snapshots of the same experiment? Can you please draw the velocity vectors to scale and give the velocity ratio in each panel?

In figure 4, why don't you contour map the surface of the lower crust for elevation? This would result in more precise documentation of the exhumation of the lower crust. Similar comment for figure 5.

Page 6 line 19: Please replace: “In experiments A2 and B2, a tangential component of velocity boundary conditions was additionally introduced into the fault system.” By: In experiments A2 and B2, a tangential component of velocity boundary conditions is added.

Page 6 line 24: Ma is for time, e.g. 2085 Ma ago. Use “myr” for duration, e.g. after 0.80 myr of deformation . . ..

Page 7 line 10: “ . . . the branch of the red exhumation belt . . .”, ok I get what this means but really can you please make an effort. The snapshots shown in panel A4 and B4 show experiments run over a time period twice as long as previous cases (16 myr vs 0.8 myr), while the snapshot in A5 and B5 show experiments at time 1.24 myr. There is probably some good reason for these different durations, but no explanation is given. Please explain.

Page 7 line 18: “ . . . a relatively low concentration of the exhumation . . . ” what’s wrong with:. . . a relative low exhumation. . ..?

Page 7 line 21-25. This conclusion is not very convincing. There is no quantification of exhumation as a function of the normal velocity component. Would it be possible, as much as possible, to compare experiments for which the magnitude of the velocity is the same (only the ratio shear component vs normal component changes), and either same duration of deformation, or possible, the same amount of upper crustal thinning?

Section 4.2: Surface relief If properly document the relationship between surface topography and the obliquity of the velocity vector, you need to keep as much as possible everything constant but the angle between the velocity vector and the vertical walls. By comparing experiments at random time (0.8 myr, 1.6 myr, 1.2 myr) the various surface topography observed may be due to a different amount of deformation.

Section 4.3: Particle motion: extension versus transtension Page 8 line 16: “ . . . two groups of passive particles are initialized (Figures 6 and 7) in the upper surfaces of the



lower crust and the upper mantle, respectively.” What you mean by initialized? More importantly, say simply that a set of tracers is positioned at the surface of the lower crust, and another set at the Moho. Since section 4.1 and figure 4 already deal with the exhumation of the surface of the lower crust . . . Why don’t you combine this section with section 4.1?

Page 8 line 21: “ . . . the particles initialized in the relay zone . . . “ please remove “initialized”. Page8 line 24: “ . . . in the upper surface of the upper mantle . . .” this surface is known as the Moho. Page 8 line 26” “ . . . all the particles integrally move . . . “ please remove “integrally”.

Please, can one of the co-authors read the paper and edit the text? Can someone also look that the figures . . . e.g. the caption of figure 10 refers to black arrows “Black arrows represent the applied extension and shear rates, . . .”. The problem is that I can see many black arrows, and the most prominent one have probably nothing to do with boundary conditions.

At this stage, I feel I can stop. The paper is not ready.

Please also note the supplement to this comment:
https://www.solid-earth-discuss.net/se-2017-142/se-2017-142-RC1-supplement.pdf

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