Dear editor, dear reviewers, please find here a point by point answer to comments, questions and suggestions raised by the two reviewers.

R1: Sascha Brune

line 49 - "Whether transform faults originate pre- or syn-rifting or even post-continental break-up is still a matter of debate.": It would be a good addition here to mention that there are transform faults in the East Pacific Rise and at other mid-oceanic ridges, which never evolved from a continental rift. So it is clear that at least some of the transforms must have formed without any continental inheritance.

Yes, indeed, the formation of most of the oceanic transform faults may not emerge from any continental inheritance. That sentence was originally addressed to transform continental faults. We added: "However, some oceanic transform faults can form without any continental inheritances as showed by the presence of many transform faults along the mid-oceanic ridges due to the plate kinematics and oceanic lithosphere rheology (Langemeyer et al., 2021)" l. 52-54

line 75 - "models show that the onset of intra-continental deformation always localizes on structures closely orthogonal to the extension direction": This is not correct. In Brune (2014) I show that normal faults emerge at half the angle of obliquity (i.e. the angle between extension-perpendicular direction and rift trend). This is illustrated in Brune (2014), Figs. 5-9 in the upper left corner as the theoretical fault orientation perpendicular to the initial maximal horizontal stress. This orientation is computed following the idea illustrates in Fig.1 of the same paper and analytically based on Withjack & Jamison (1986). According to these theoretical considerations, faults are only perpendicular to far-field extension under zero-obliquity boundary conditions.

Ok indeed, we corrected for: "Except in experiments approaching pure strike-slip conditions, models show that the onset of intra-continental deformation localizes on structures at half the angle of obliquity (i.e. the angle between extension-perpendicular direction and rift trend)" l.80-82

line 390 - "[Modelling experiments] show that strain localization in the continental lithosphere always begins as extensional structures sub-perpendicular to the extension direction for angles between extension direction and the weak zones larger than ~30°.": this is not correct. See comment on line 75.

We corrected for: "show that strain localization in the continental lithosphere always begins as extensional structures approximately striking at half the angle of obliquity to the extension direction for angles between extension direction and the weak zones larger than ~30°." l.399-401

line 410 - "Brune et al., (2018)": I appreciate the many references, but the 2018 paper merely hypothesises about this point. Having said that, Heine & Brune (2014) actually provide complementary evidence in addition to my 2012 paper.

Ok, thank you for the reference, we added it l.419

line 420 - "shows that the deformation localizes to progressively form a unique straight shear zone and straight margins.": I was wondering about the same point. My feeling is that the numerical resolution might play a bigger role here than the setup of the weakness.

Yes, probably that the resolution plays a role since higher resolution allows forming more structures, and therefore increasing the resolution better partitions the deformation in oblique conditions. We added: "However, the resolution of these experiments was 3 times lower (in each spatial direction) than in our study, which also contributes to different strain localization patterns." L.430-432 *line 533 - "pull-apart basins": There is a very nice numerical study on pull-aparts that you might want to refer to (van Wijk et al., 2017).*

We added the reference l.554

Figure 1b: I am a bit confused by the half-headed arrows. Shouldn't they point in the opposite direction or be on the other side of the transform faults?

No, the displacement on these faults is sinistral.

Figure 2b: There should not be any red arrows on the left and right side of the box. They evoke the impression that you prescribe rift velocities there as well, but in fact you have a periodic boundary condition. Perhaps simply mention "Periodic BC" instead.

Figure 3: Mantle exhumation starts close to your periodic boundaries. Is that because your boundaries are only approximately periodic or because the distance between the neighbouring weak seeds across the periodic boundary is smaller than to the other neighbour?

Answer for the two comments above: The boundary conditions are imposed with Dirichlet BCs on all model sides. Therefore, it is indeed approximately periodic. Moreover, the weak zones located on each side are indeed closer to the boundaries (~200 km) than to the central weak zone (~400 km), which can explain why the mantle exhumation starts close to the borders before the central basin. We modified the text for: "On faces normal to the x-axis, we impose approximately periodic boundary conditions (Fig. 2b) where the velocity vectors flips 180° at the centre of the z axis." L.178-180

Figure 4: Is there a reason for the orientation of the cross sections? Wouldn't parallel to far-field extension be a logical direction?

Yes, indeed there is a reason. We choose to orient the cross-sections perpendicularly to the trend of the surface structures. But, parallel to the extension direction would be another logical option. We would prefer to keep them as they are. It is stated in the text: "We also display cross-sections oriented either perpendicularly to the strike-slip structures or to the extensional ones" l.193-194

title: "dynamic" is an adjective, the noun is "dynamics"

We modified the title accordingly to this comment

line 26 - "plates boundaries": replace with "plate boundaries"

Done

line 29- "Mélody Philippon & Corti, 2016": first name appearing in reference (please check throughout the manuscript)

Done

line 41 - "plate margins": I think you mean continental margins. The South African margin for instance does not coincide with the closest African plate boundary, which is a mid-ocean ridge.

We modified this l. 43

line 69: I would recommend to also include earlier analog models of oblique rifting. I find that notably Withjack & Jamison (1986) and Clifton et al., (2000) are excellent studies.

We added these studies l.73-75

line 91 - "rift basins segments": replace with "rift basin segments". This is similar to my comment on line 26. Please check entire manuscript for this little mistake.

Done

line 97 - "This highly oblique deformation regime is rarely simulated": I suggest to add "... except in setups with periodic boundary conditions." I fully agree that the highly oblique regime is where models with periodic boundary conditions like yours (or mine) are particularly useful.

We added this: "This highly oblique deformation regime is rarely simulated except in setup with periodic or open boundary conditions" l.103-104.

line 193 - "knowing": perhaps rather "known"?

Sentence has changed according to R2 comment l.200-202

line 397 - "For angles of obliquity lower than ~30° the models with oblique boundary conditions show that strike-slip deformation dominates": better refer to Withjack & Jamison (1986). They provided the analytical calculation for this statement.

We referred to this study, l.408

line 441 - "greater that": replace with "greater than".

Done l.451

line 491 - "Numerical models show that this is precisely during this intra-continental rifting phase that strike-slip": A relevant extreme case of this rotation, namely formation of a rotating continental microplate, has been very recently described in Neuharth et al., (2021).

We added the reference to this work l.511

Table 1 - "KJ/mol": tiny detail - for consistency it should be "kJ.mol^-1".

We corrected that in table 1

##

R2: Patricia Persaud

5) Line 35 – please clarify the meaning of non-cylindrical in this context. This would help clarify its meaning in other places in the text.

We do believe non-cylindrical is the appropriate term in the context of this study. Structures' cylindricity (especially used for folds and faults) relate to the 2.5D nature of their geometries. As such non-cylindrical means that the structures we observe in nature as well as in our models are truly 3D.

15) Line 67 – with "of normal and strike-slip faults" are the authors assuming that oblique-slip faults can be considered to be either mainly normal or mainly strike-slip faults? This is an important point to consider clarifying in the text.

It depends on the strain regime. If the strain regime shows mainly normal or strike-slip faults then their definition is straight forward. But if the strain regime is transtensional then it is difficult to say which regime is dominant. We added “and oblique-slip faults” in that statement. L.71

19) Line 101 - if free-slip is applied to a boundary with normal x, no deformation can occur in the x direction along this boundary (is this preserving the authors’ meaning?)

This is correct. If free-slip is applied to A boundary with normal x, deformation can only occur in the yz plane.

27) Line 175 – Can the authors provide some brief explanation for the choice of v=0.5 cm/yr

Yes of course. This velocity reaches to a total extension velocity of 1 cm/yr which is an averaged rifting velocity. The rifting velocity is generally very slow at the onset of extension and accelerates as the lithosphere thins to finally reach several cm/yr once the oceanic spreading starts. But since we are imposing a velocity and not a stress BC we choose a constant velocity that roughly averages the rifting velocity during its evolution. We added this precision in the text: “This velocity simulates a total extension rate of 1 cm/a corresponding to an average of the varying extension rate during the evolution of a rift system” l.182-183

28) Line 178 – “The basal boundary condition is defined as a constant inflow to compensate the outflow as:” – this means the bottom of the model is filled in with new mantle material, is that correct?

Yes indeed.

29) How do the authors deal with the topography that develops during the model evolution?

The topography evolves as a free surface. In these models there are no erosion-sedimentation processes. However, a remeshing routine avoids large mesh deformation at the surface.
The free surface is mentioned l.647-648

39) There are different velocity vectors used in the manuscript. Can the authors clarify the relationship between v and vb somewhere in the text?

vb is v, we replaced vb by v for consistency. Thank you for pointing this out. See l.228-229

46) Line 268 – Optional comment: can the authors provide a spatial dimension to quantify “diffuse” in this context? This would be helpful for real world comparisons.

Yes we can. The diffuse strike-slip deformation zone is about 200 km wide for a strain rate second invariant around 10^{-18} s^{-1}. This has been added in the text “(~200 km wide for a strain rate second invariant of 10^{-18} s^{-1})” l.276

48) Line 282 – what is meant with “ridge dynamics takes place in the basins”?

It means that the deformation is highly localized along two symmetrical shear zones accommodating the oceanic spreading. We added in the manuscript: “a ridge dynamics takes place in the basins (Fig. 5j and 6D) where the deformation is highly localized along two symmetrical shear zones accommodating the oceanic spreading.” l.290-292

67) The discussion and comparison to the Gulf of California is very interesting. For this section, please see the work of Persaud et al. (2017) where numerical models with obliquity are produced to explain active deformation in the northern Gulf of California. The active faults used in that study which are within the northern Gulf of California were mapped from high-resolution seismic profiles *presented in Persaud et al. (2003). There are also recent analog models for the northern Gulf of California by Farangitakis et al. (2021) that are relevant and the studies of Van Wijk et al. (2017) and (2019). The Van Wijk et al. (2019) study also discusses and proposes the existence of serpentinized mantle beneath the region that extends from the Salton Trough (Imperial Valley) to the northern Gulf of California through the modeling of different geophysical datasets.*

Thank you for these studies. We added the references in the manuscript l.538, l.539, l.553-554

68) Can the authors consider adding some brief wording on how the extension rates in the models relate to the natural rifts that are discussed?

Yes, for low to intermediate obliquity rifts the extension rates in the models represent a rough average of the natural rifting velocity during the evolution of the system. However, for high obliquity systems like the Gulf of California the extension rates in the models are clearly underrated (~5 times lower). As a consequence, the relatively cold temperatures showed in the high obliquity models might be higher in natural systems and could accelerate the strain localization processes. We added at the beginning of the section 6: "The numerical models presented in this study are not specifically designed for particular natural rifts, especially in terms of imposed velocities or tectonic inheritances. For low to intermediate obliquity rift, the extension rates in the models represent an average of the natural rifting velocity during the evolution of the system. However, for high obliquity systems like the Gulf of California, the extension rates in the models are ~5 times lower. As a consequence, the relatively cold temperature showed in the high obliquity models might be higher in natural systems and could accelerate the strain localization processes. However, they share first order similarities with natural oblique rift systems." L. 475-482

69) An important point to also note is that obliquity changes along the axis of the Gulf of California rift.

Yes indeed, this is expected in the case of propagating rift systems.

70) Please consider some modifications to Figure 1, particularly 1a. E.g., the thick black lines for the Gulf of California are described as strike-slip continental faults, this seems to be mislabeled. What are the blue lines and thick black arrows? Is "FZ" in some instances a fracture zone in 1a and 1b. The inactive subduction boundary in 1a should be labeled somewhere. There are no though-going active transform faults as drawn in the northern Gulf. Please provide references for the fault dataset shown in the maps wherever possible.

The blue lines represent the transition from continental crust to oceanic crust/exhumed mantle. The thick black arrows represent the shearing direction, but we can remove them. "FZ" is for fracture zones in the Atlantic Ocean because this how these faults are named. The faults are from a compilation of maps from Bonini et al., 2019; Ferrari et al., 2018; Fletcher et al., 2007, but we did not differentiate active and inactive faults. We modified the figure 1 to take into account these comments

71) Line 509 – This sounds as if the San Andreas fault is implied to not be active -- "In relation with the dextral San Andreas Fault system, the Gulf of California is an active plate boundary". Depending on what the authors mean here, they may consider: "Located south of the dextral San Andreas Fault system, the Gulf of California is an active plate boundary". This change would fit with the rest of the sentence.

Yes indeed. We did not want to mean that the San Andreas fault is not active. We corrected this l.528

73) Line 515 – The study of Bonini et al. was on the southwest margin of the Gulf of California. Is this what the authors mean: "The structural analysis performed on faults and shear zones in the southwest rift margin …"?

Yes indeed.

82) Figure 11 – what depths are shown, the surface of the model?

Yes. We added this information in the figure caption

1) In Line 19 and elsewhere, "extension direction" is used. It would help to define this somewhere close to the beginning of the manuscript (after the abstract) to avoid confusion particularly when the discussion also turns to oblique extension, e.g., on Line 81: "Low obliquity systems are close to orthogonal extension. For models with oblique extension or oblique weak zones it represents angles from 60° to 90° between extension direction …". To help with this, the extension direction can be labeled in Figure 2b.

We labeled the figure 2 with extension direction to help the reader understanding what we mean.

2) Lines 11-12. "Their formation and evolution have long been addressed through kinematic models that do not account for the mechanical behaviour of the lithosphere." Although it later becomes clear what is meant, this wording can be modified because dynamic models have also dealt with oblique rift formation and evolution as also noted by the authors. Consider: "… have traditionally been addressed …"

We modified this l.11

3) Line 19 – Suggest changing "the plates' motion" to "the plate motion vector"

Done l.20

4) Line 32 - Transform continental margins are comprised of transform faults that connect divergent margins…

Done l. 33-34

6) Line 36 - make it difficult to image them with seismic reflection methods.

Corrected l.36-37

7) Line 39 - from the interpretation of seismic reflection profiles

Corrected l. 40

8) Line 52 - and may reactivate

Corrected l.56

9) Line 55 – do not

Done l.59

10) Line 56 – structure reorientation (Comment: this will be understood as plural)

Corrected l.60-61

11) Line 58 - tectonic plate reconstructions (or "plate reconstructions")

Corrected l.62

12) Line 59 – a margin's progressive deformation history

Corrected l.63

13) Line 59 - during the intra-continental stage

Corrected l.63

14) Line 62 - it is therefore necessary to

Corrected l.67

16) Line 73 - See also Persaud et al. (2017) where boundary conditions were set in a similar way for northern Gulf of California numerical models. The citation listed here should potentially start with "(e.g., ...".

We added the citation l.78

17) Line 89 - once the continental lithosphere has thinned enough

Corrected l.95

18) Line 92 – I suggest changing "the obliquity" to "the strike-slip component of deformation"

Done l.98

20) Line 109 - allowing the viscosity in the weak zone to drop by 4 to 6

Corrected l.116

21) Line 113 – oblique velocity boundary conditions

Done l.117

22) Line 118 - for the formation of transform margins undergoing intermediate and highly

Corrected l.127

24) Line 154 – replace "and it allows to keep" with "it maintains"

Done l.160

25) Line 166 – Instead of "The geometry consists in three cubic damaged zone with a side length of 200 km" consider "The geometry consists of three cuboid damage zones with dimensions 200 km x ? km x ? km and centred at ..."

Corrected l.172-174

26) Line 174 - For every model,

Corrected l.181

30) Line 192 - is used to determine whether the dominant instantaneous deformation regime is extensional … , or compressional.

Corrected l.200-201

31) Line 196 – Modify "allows better interpreting the" to "facilitates the interpretation of"

Corrected l.203-204

32) Line 196 – Modify "well expressed" to "described"

Corrected l.204

33) Line 197 – Modify "in order to compute the regime stress ratio (RSR) giving a scalar" to "where the regime stress ratio (RSR) is computed as a scalar"

Corrected l.205

34) Line 199 – In Figures

Done l. 206

35) Line 200 - Table 2 shows

Corrected l.208

36) Line 203 - the mantle exhumation age, which is indicative of the time when the mantle starts to exhume.

Corrected l.212

37) Line 209 – "as" can be removed

Done

38) Line 225 - corresponds to the highest beta factor value (i.e. the location where the crust is the thinnest before the mantle starts to exhume) and the lines labelled "necking" is the beta equal two contour.

Corrected l.224-225

41) Line 234 – Should "individualise" be "form"? And on Line 241 – "basin formation" ?

Corrected l.243 and l.250

42) Line 244 – It seems "surface orientation" can be replaced with "strike"

Done l.252

43) Line 252 – Perhaps change "retrieves" to "resumes rigid behaviour" ("a" can be omitted)

Corrected l.261

44) Line 266 – Change "evidences" to "shows" or "is characterized by"

Corrected l.274

45) Line 266 - the variation in shear zones orientation

Corrected l.274

47) Line 270 – sigmoidal

Corrected l.279

49) Line 304 – Basins developed in these ….

Corrected l.313

50) Line 325 – "results" can be removed

Done

51) Line 327 - Although this model has only a small degree of obliquity,

Corrected l.336

52) Line 331 – in section ("the" can be removed)

Done

53) Line 339 - basins is essential in cases with low to intermediate obliquity. However, in high obliquity cases,

Corrected l.348-349

54) Line 348 - marks a significant change (in this sentence do you mean strain regime or stress regime?)

Corrected for "However, the second stage of deformation marks significant change in stress regime and strain localization" l.356-357

55) Line 371 – replace "Oppositely" with "In contrast"

Done l.380

56) Line 373 - progresses 2 to 4 times

Corrected l.382

57) Line 380 – as the strike-slip structures

Corrected l.389

58) Line 405 – in the presence

Corrected l.414

59) Line 413 – for producing

Corrected l.423

60) Line 427 – aligned with

Corrected l.438

61) Line 428 – whereas in basins … that form with an offset

Corrected l.439

62) Line 441 – for obliquity angles greater than

Corrected l.451

63) Line 456 – Change "no more" to "no longer"

Corrected l.466

64) Line 458 – also have very low extension rates

Corrected l.468

65) Line 460 – in the extension direction

Corrected l.470

66) Line 485 – changes in plate kinematics

Corrected l.502-503

72) Line 512 – This sentence and the subsequent one need some re-working: "Since ~12 Ma, the cessation of the Pacific plate's subduction beneath the Baja California led to a major change in plate kinematics." because the sentence may be understood as the end of subduction led to changes in plate motion. Since the Farallon plate was subducting and these plate fragments were subsequently transferred to the Pacific plate, one suggestion is: "At ~12 Ma, subduction beneath Baja California ceased. A major change in plate kinematics occurred and a system of highly oblique extension was established as the current plate boundary localized in the Gulf of California ~8-6 Ma." Atwater & Stock (1998) provide a nice synthesis of this plate boundary evolution.

We corrected this sentence: "At ~12 Ma, subduction beneath Baja California ceased. A major change in plate kinematics occurred and a system of highly oblique extension was established as the current plate boundary localized in the Gulf of California ~8-6 Ma" l.530-532

74) Line 519 - Several models were proposed to interpret changes in the surface geology through time

Corrected l.540

75) Line 520 - from ~12 Ma to the present

Corrected l.541

76) Line 526 – To establish context for the discussion of natural rifts, some wording similar to the sentence at the start of this paragraph should probably be added at the start of the section on natural *rifts: "The numerical models presented in this study are not specifically designed for particular natural rifts, especially in terms of imposed velocities or tectonic inheritances." This reviewer notes that the comparison to natural rifts is still valid and insightful.*

We moved this sentence to the beginning of the section 6 and added some details l.475-482

77) Line 537 – Modify "200 km while break-up did not occurred yet." to "200 km while break-up has still not occurred."

Corrected l.557

78) Line 537 – "In the Gulf of California the strike-slip motion since the Miocene (~12 Ma) represents 200 km to 300 km" can be modified to "In the Gulf of California, the oblique extension since ~8-6 Ma is about 300 km." This is rather complex because it depends on whether you are considering the northern or central Gulf and also including the Gulf of California Shear Zone in the slip budget. See Bonini et al. (2019) for a summary.

We modified the text for: "represents roughly 200 km to 300 km (DeMets & Merkouriev, 2016; Stock & Hodges, 1989) depending on whether the northern or central Gulf are considered, including also the Gulf of California Shear Zone in the slip budget (e.g. Bonini et al., 2019)" l.558-561

79) Figure 3 - please note in the caption what is shown in the inset plots of the left panel (same for Figure 7). Please check references to A5.

Done

80) For figures in which models are shown, please note in each caption which model set is being show as models at different resolutions as presented in the text.

Done l.623-624

81) Figure 10 – Line 593 and 595 lower crust models and different obliquities

Done

83) Figure 12 – Line 599 and intermediate to low obliquity

Done