Review by: Patricia Persaud (ppersaud@lsu.edu)

The authors, Anthony Jourdon, Charlie Kergaravat, Guillaume Duclaux and Caroline Huguen present an in-depth 3-D numerical study of the evolution in space and time of oblique rifting. They consider weak and strong lower crust and the structural evolution of the faults, basins and linkages within the model rift. They also compare their main model features to two natural rifts.

The study has a number of interesting and compelling findings that are important and will advance our understanding of rifting such as the changes in the stress regime within the rift and how this is manifested in rift structures, the importance of weak zones and their geometry, details of spatial and temporal patterns of crustal thinning, and a change in local stress conditions within the rift without a need for a change in plate kinematics. I support the publication of this well-presented manuscript and provide a list of minor suggestions/comments below to help clarify some points.

Suggestions/comments:

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.
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 …”
3) Line 19 – Suggest changing “the plates’ motion” to “the plate motion vector”
4) Line 32 - Transform continental margins are comprised of transform faults that connect divergent margins…
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.
6) Line 36 - make it difficult to image them with seismic reflection methods.
7) Line 39 - from the interpretation of seismic reflection profiles
8) Line 52 - and may reactivate
9) Line 55 – do not
10) Line 56 – structure reorientation (Comment: this will be understood as plural)
11) Line 58 - tectonic plate reconstructions (or “plate reconstructions”)
12) Line 59 – a margin’s progressive deformation history
13) Line 59 - during the intra-continental stage
14) Line 62 - it is therefore necessary to
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.
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.,…”.
17) Line 89 - once the continental lithosphere has thinned enough

18) Line 92 – I suggest changing “the obliquity” to “the strike-slip component of deformation”
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?)
20) Line 109 - allowing the viscosity in the weak zone to drop by 4 to 6
21) Line 113 – oblique velocity boundary conditions
22) Line 118 - for the formation of transform margins undergoing intermediate and highly
23) Line 124 – replace A5 with A6
24) Line 154 – replace “and it allows to keep” with “it maintains”
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 …”
26) Line 174 - For every model,
27) Line 175 – Can the authors provide some brief explanation for the choice of v=0.5 cm/yr
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?
29) How do the authors deal with the topography that develops during the model evolution?
30) Line 192 - is used to determine whether the dominant instantaneous deformation regime is extensional … , or compressional.
31) Line 196 – Modify “allows better interpreting the” to “facilitates the interpretation of”
32) Line 196 – Modify “well expressed” to “described”
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”
34) Line 199 – In Figures
35) Line 200 - Table 2 shows
36) Line 203 - the mantle exhumation age, which is indicative of the time when the mantle starts to exhume.
37) Line 209 – “as” can be removed
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.
39) There are different velocity vectors used in the manuscript. Can the authors clarify the relationship between v and vb somewhere in the text?
40) Line 231 – in detail
41) Line 234 – Should “individualise” be “form”? And on Line 241 – “basin formation” ?
42) Line 244 – It seems “surface orientation” can be replaced with “strike”
43) Line 252 – Perhaps change “retrieves” to “resumes rigid behaviour” (“a” can be omitted)
44) Line 266 – Change “evidences” to “shows” or “is characterized by”
45) Line 266 - the variation in shear zones orientation
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.
47) Line 270 – sigmoidal
48) Line 282 – what is meant with “ridge dynamics takes place in the basins”?
49) Line 304 – Basins developed in these ….
50) Line 325 – “results” can be removed
51) Line 327 - Although this model has only a small degree of obliquity,
52) Line 331 – in section (“the” can be removed)

53) Line 339 - basins is essential in cases with low to intermediate obliquity. However, in high obliquity cases,
54) Line 348 - marks a significant change (in this sentence do you mean strain regime or stress regime?)
55) Line 371 – replace “Oppositely” with “In contrast”
56) Line 373 - progresses 2 to 4 times
57) Line 380 – as the strike-slip structures
58) Line 405 – in the presence
59) Line 413 – for producing
60) Line 427 – aligned with
61) Line 428 – whereas in basins … that form with an offset
62) Line 441 – for obliquity angles greater than
63) Line 456 – Change “no more” to “no longer”
64) Line 458 – also have very low extension rates
65) Line 460 – in the extension direction
66) Line 485 – changes in plate kinematics
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.
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?
69) An important point to also note is that obliquity changes along the axis of the Gulf of California rift.
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.
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.
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.

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 …"?
74) Line 519 - Several models were proposed to interpret changes in the surface geology through time
75) Line 520 - from ~12 Ma to the present
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.
77) Line 537 – Modify "200 km while break-up did not occurred yet." to "200 km while break-up has still not occurred."
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.
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.
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.
81) Figure 10 – Line 593 and 595 lower crust models and different obliquities
82) Figure 11 – what depths are shown, the surface of the model?
83) Figure 12 – Line 599 and intermediate to low obliquity

References

Farangitakis, G, McCaffrey, KJW, Willingshofer, E, et al. (2021) The structural evolution of pull-apart basins in response to changes in plate motion. *Basin Res*.; 33: 1603– 1625.0

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