

Interactive comment on “Uncertainties in breakup markers along the Iberia-Newfoundland margins illustrated by new seismic data” by Annabel Causer et al.

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In their paper “Uncertainties in breakup markers along the Iberia-Newfoundland margins illustrated by new seismic data” Causer et al. use seismic data from offshore Newfoundland to assess the suitability of commonly used break-up markers along the Newfoundland margin for plate kinematic reconstructions. According to their results, basement associated with the younger M-Series magnetic anomalies is comprised of exhumed mantle and magmatic additions, and therefore most likely represents transitional domains rather than true oceanic lithosphere. This seems reasonable although some aspects of this are hard to assess with the materials currently provided with the

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manuscript. This has implications for plate tectonic modelling which is well demonstrated in the paper. The paper is on a worthwhile subject, and Solid Earth seems like an appropriate location for the results of this study. Plate reconstructions in the southern North Atlantic have been the focus of a number of recent publications, demonstrating that this is a very topical subject (Barnett-Moore et al., 2018; Nirrengarten et al., 2018; Peace et al., 2019). In addition, although the Newfoundland-Iberia margins are one of the most studied conjugate margin pairs in the world, there remains significant unknowns regarding the early aspects of separation (Eddy et al., 2017). Thus, the topic of the study addresses a very relevant subject.

Overall, the study seems to be generally well thought out and suitable for publication. However, there are several aspects that I think could be drastically improved, as outlined in detail below. I would therefore like to offer a largely supportive review on this paper, with a recommendation that this paper is published following major revisions.

1) Applying results beyond the data coverage

It is reasonable to extrapolate the finding of the study somewhat beyond the area investigated. However, further consideration, and justification, of how feasible this is would substantially improve the manuscript. Specifically, limited 2D seismic reflection data is interpreted on the continental margins and this is used to derive implications for plate models of the entire region. Although I think the approach is probably valid, it could potentially be problematic because it is well established that passive continental margins are highly variable along strike, so observations made in a region are not necessarily applicable elsewhere without consideration of the processes involved. For example, breakup of the southern North Atlantic occurred via a propagating rift (e.g., Nirrengarten et al., 2018), so timing of rifting and breakup is not the same right along the margin, and also the margin is highly structurally variable, with local complexities such as magmatism and reactivation. As such, the interpretation of magnetic anomalies source using the limited seismic data may not be valid for the entire anomaly. The authors should consider this aspect further in their justification of the approach, and

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also in the subsequent discussion section.

2) Location and orientation of the lines

The location and orientation of Lines A-C is currently difficult to discern with the current figure setup and description in the manuscript. For example, although the complete seismic grid is shown (Fig. 4), none of the figures show which line within the grid is Line A-C. As such, it is problematic to fully assess the validity of the results and outcomes. This links with the issue outlined above regarding the validity of the results over the entire region. This could in part be rectified by addressing the issues with the figures outlined below. In addition, although a sparse grid of 2D lines is shown on some of the figures only three lines are presented in detail in the paper. It would be beneficial if the authors could provide further description of what else is shown by the other lines in the grid of seismic data, and also describe why they have chosen lines A-C over others. Finally, the nature of the blue seismic grid shown on the Iberian margin is not well described in the manuscript.

3) Deformable models

The fundamental subject of the paper is about how current plate kinematic models of the Newfoundland-Iberia conjugate margins do not sufficiently describe the separation, and lead to problems when reconciled with regional observations. This aspect is well outlined in the paper. Recent work however, has sought a new solution to this issue through the use of deformable plate tectonic modelling, to reduce overlap in reconstructed conjugate margins and develop concepts of plate kinematics (Ady and Whitaker, 2018; Müller et al., 2019; Peace et al., 2019). These models are far from perfect but offer an alternative approach to the problem addressed in the paper. I think that discussion of the role of this new approach to plate modelling would also be beneficial in the manuscript.

4) Figures

In my opinion the figures are currently one of the weakest aspects of the manuscript. Overall, I felt that they were: 1) underutilised in the text, 2) difficult to interpret, and 3) at times ambiguous. Generally, on all figures making the text larger would substantially improve them. As outlined in the points below, the figures need substantial work to be of publication quality. In addition, I think adding an new figure showing a magnetic anomaly map of the region as a new Figure 2 would substantially improve the manuscript. This would be very beneficial to those working outside of the present study area as it could be used to label feature such as the J-Anomaly and M-Series. Something like the EMAG model (Maus et al., 2009) would suffice here.

Figure 1: I felt that figure 1 could have been used much more extensively throughout the manuscript. In particular, I think it could be used to show the locations of the other figures, and the data, as well as providing a better description of the geological setting such as the key magnetic anomalies. Also, many aspects of this figure are very problematic to see and interpret. For example, the red dots indicating drill sites are nearly impossible to find. In addition, although many of these are referred to in the text (e.g., DSDP site 398) there appear to be some wells in the Bay of Biscay without labels leaving me wondering what is the relevance of these? The green dashed line is not defined in the caption, and the “white envelopes” are difficult to see. Moreover, the red dashed lines do not show all the oceanic fracture zones, so why have these ones been chosen specifically?

Figure 2: Text is again too small. In addition, what is the small circle within ‘the maximum extent of the Continent-Ocean Transition Zone’ at 83 Ma offshore Newfoundland (under the ‘B’ of ‘Base’).

Figure 3: It is not immediately clear to the reader where the magnetic profiles shown in parts b and c are located. In addition, the text is again too small. Finally, what are the black dots shown on a, they are not described in the legend.

Figure 4: This figure is integral to the study as it shows the location of the data. How-

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ever, it is difficult to know which line presented in the paper (i.e. Lines A-C) corresponds which location shown on the figure. This information needs adding to the figure, otherwise the reader is unable to locate the data. Also the age of the isochrons quoted on the figure are according to which timescale?

Figure 5-7: Although the general interpretations shown look reasonable, there are several aspects of these figures that need substantial improvement. First, the labelling of subfigures (a-c) on these figures is a little strange as the seismic line and its interpretation are not given a subfigure letter. Another thing that struck me when I first saw the interpreted sections was that ages are provided for the sediment packages (e.g., Late Cretaceous), yet in the text it is stated that “sediments have been grouped into Synrift 1, Synrift 2, Breakup-sequence, and Post-Rift packages based on seismicstratigraphic observations”. Given this, where have these ages come from? In addition, it would help if the scale bars for TWT and distance were also present on the seismic data. Also, on some of the figures sills are labelled, how are these differentiated from other high amplitude reflectors? Finally, the difference between the grey and the black lines (in the key) is impossible to determine on the figure, the L-reflector symbol is too similar to the fault symbol, and the text on all of these figures is too small.

Figure 8: I like the approach to showing reconstruction using different models, however the text on this figure is again too small, particularly the age in Ma.

Figure 9: I think the concept behind figure 9 is good, particularly the description in the text acknowledging the limitations in this approach. However, all of the text on this figure either needs to be made substantially larger or removed. If all of the interpretation has been shown previously perhaps the text can be removed from this figure.

5) References

Throughout the manuscript there are multiple statements that require references. In particular, when the ‘literature’ is referred to or a statement like ‘broadly accepted’ is used, I think it is necessary to add additional references. Specific examples are of this

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are provided below. In addition, a few references are cited in the paper that do not occur in the reference list. For example, Eagles et al. (2015) is not in the reference list. Furthermore, the citation of 'in prep' works seems unnecessary given that the statement being supported could be supported with other published works. For example, at line 235 the compilation model of Matthews et al. (2016) could be cited as this also includes independent plates for Newfoundland (as part of North America), Iberia, Eurasia and Africa, as do other models (e.g., Nirrengarten et al., 2018). In addition, in plate modelling one can keep adding more and more plates, building increasingly complex models so what would be different about the model cited as 'in prep'? For example, Nirrengarten et al. (2018) use independent plates (with separate poles) for Flemish Cap, Rockall-Hatton Bank, Orphan Knoll and also parts of Iberia. Perhaps, this aspect is worthy of discussion in the paper.

Minor points:

Line 14: I suggest replacing 'on the belief' with another phrase such as 'based on the concept'.

Lines 14-15: What exactly differs between the models? The timing or the rotations? Inclusion of different plates? Essentially I found this statement a bit vague.

Line 23: I suggest replacing 'to' with 'with' after 'associated'.

Lines 34-38 (opening paragraph of introduction): All the statements in this paragraph need referencing.

Line 45: 'computer generated plate reconstructions' – I found this statement to be quite vague, surely most modern plate reconstructions are done on a computer?

Lines 48-49: 'alternative scenarios proposed in the literature' - Which alternative scenarios, and in what literature? This statements needs references and further description. I know this is described later on but I felt that without references here the statement feels out of place.

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Line 51: 'overlaps' – deformable plate modelling goes someway to address this, and I think it would be good to discuss this aspect of plate modelling (Ady and Whittaker, 2018; Müller et al., 2019; Peace et al., 2019).

Line 56: Why say 'West' here but nowhere else when referring to Iberia?

Line 66: 'heavily debated' – By who? This statement needs references, and explanation of what exactly is debatable about the aspects described in the sentence.

Lines 56-75: I felt that this was a really good description of the history and problems associated with studying the Newfoundland Iberia conjugate margins.

Lines 83-84: Slightly awkward phrasing.

Line 85: 'said studies' – which 'said studies'? You should cite them here.

Line 85: 'published rotation schemes'. Again, I think you should say which rotation schemes by citing the appropriate literature.

Line 89: Awkward phrasing. I suggest modifying this.

Line 90: Should the references be in chronological order in Solid Earth papers?

Line 94: Eagles et al. (2015) is not in the reference list.

Line 95: 'gradual' - Is it really gradual? I am just not sure that this is the best description. It is wide and structurally complex, but I don't think we can describe a change in crustal affinity as gradual.

Line 98: 'so-called' - according to whom? Add appropriate references here.

Line 99: I suggest inserting 'the' before 'literature'.

Line 100: Which 'literature' is being referred to in the sentence ending here. Add appropriate references.

Lines 101-112 (whole paragraph): I think this paragraph could be summarised to make

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it a bit simpler.

Line 108: 'age of seafloor spreading' - Eddy et al. (2017) discuss this. Also, this reference should probably be included generally as its quite recent and integral to the topic.

Lines 114-115: Add appropriate references regarding the complexity of reconstructing the kinematics of the Iberian plate.

Line 120: 'broadly accepted' – By who? Add references.

Line 127: I don't think the italics on the citation are necessary.

Lines 131-132: Cadenas et al. (2018) also conducted a recent study on compression along this boundary that might be of use. Also, the models in Peace et al. (2019) show this compression, and actually overestimate the extent and magnitude of thickening (based on published constraints) implying that the published models do not account well for Iberia's kinematics.

Line 133: I am not sure the italics on the citation are necessary here (and elsewhere).

Line 155: 'generally accepted' – this needs references to show who it is accepted by.

Line 164: Why are these references not at the end of the sentence? As it stands, it is confusing which statement the references are referring to.

Line 167: 'contradictory geological evidence' – you should expand on what this evidence is and provide references.

Line 167: 'Site 1070' – This is very difficult to see on figure 1.

Line 178: "old oceanic lithosphere" – How old? If you can provide an age here it would be better.

Line 186: 'The J-Anomaly' – See notes in section above regarding a figure showing the magnetic anomaly locations.

Line 196-200: Some references are in italics whilst others are not?

Line 201-208: Same as previous comment regarding italics.

Line 219-225: I found the tense of this paragraph quite strange. Essentially you are describing what you will do so why write it like this?

Line 235: The citation of 'in prep' works seems unnecessary given that the statement being supported could be supported with other published works. This point is expanded on in the points above.

Line 237: Remove 'some'.

Line 252-253: 'sediments have been grouped into Synrift 1, Synrift 2, Breakup-sequence, and Post-Rift packages based on seismic stratigraphic observations' - This statement appears to contradict what is shown on the figures as on the figures the sediments are also given ages? Also, where have these ages come from? I suggest providing the source of the information.

Line 263: 'DSDP, Site 298' - This is very hard to see on Figure 1. I suggest making this larger, along with all the other wells shown on the figure.

Line 274: 'variable offsets' – This is quite a vague phrase. Can these offsets be quantified on the data?

Line 275: 'seismic Moho' – refer to the figure showing this?

Line 289: 'Fig 5c' - This is good, I suggest referring to the subfigures more often when describing the interpretation.

Line 295: 'distorted seismic imaging' - This is quite vague terminology.

Line 299: Again, which line on the figure showing the seismic grid is line B?

Line 320: As with previous comment but for Line C.

Line 350 onwards (opening paragraph of the Discussion): I found the whole of this first

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paragraph of the discussion to be very vague, and question whether it is fully necessary as much of this information has already been provided in the introductory sections.

Line 350: ‘three seismic lines’ – why is a grid of seismic lines shown but only three are presented in the paper? Did you analyse the others, and how did you choose the ones presented?

Line 368: Yamasaki and Gernigon (2009) do not mention the origin of SDRs in their paper, so this citation does not make sense here.

Line 406-408: Opening statement on conjugate margins - This is good, I like that you state this.

References cited:

Ady, B.E., and Whittaker, R.C., 2018, Examining the influence of tectonic inheritance on the evolution of the North Atlantic using a palinspastic deformable plate reconstruction: Geological Society of London, Special Publications, v. 470, doi:10.1144/SP470.9.

Barnett-Moore, N., Müller, R.D., Williams, S., Skogseid, J., and Seton, M., 2018, A reconstruction of the North Atlantic since the earliest Jurassic: Basin Research, v. 30, p. 160–185, doi:10.1111/bre.12214.

Cadenas, P., Fernández-Viejo, G., Pulgar, J.A., Tugend, J., Manatschal, G., and Minshull, T.A., 2018, Constraints Imposed by Rift Inheritance on the Compressional Reactivation of a Hyperextended Margin: Mapping Rift Domains in the North Iberian Margin and in the Cantabrian Mountains: Tectonics, v. 37, p. 758–785, doi:10.1002/2016TC004454.

Eagles, G., Pérez-Díaz, L., and Scarselli, N., 2015, Getting over continent ocean boundaries: Earth-Science Reviews, v. 151, p. 244–265, doi:10.1016/j.earscirev.2015.10.009.

Eddy, M.P., Jagoutz, O., and Ibañez-Mejía, M., 2017, Timing of initial seafloor spreading

in the Newfoundland-Iberia rift: *Geology*, v. 45, p. G38766.1, doi:10.1130/G38766.1.

Matthews, K.J., Maloney, K.T., Zahirovic, S., Williams, S.E., Seton, M., and Müller, R.D., 2016, Global plate boundary evolution and kinematics since the late Paleozoic: *Global and Planetary Change*, v. 146, p. 226–250, doi:10.1016/j.gloplacha.2016.10.002.

Maus, S. et al., 2009, EMAG2: A 2-arc min resolution Earth Magnetic Anomaly Grid compiled from satellite, airborne, and marine magnetic measurements: *Geochemistry, Geophysics, Geosystems*, v. 10, doi:10.1029/2009GC002471.

Müller, R.D. et al., 2019, A global plate model including lithospheric deformation along major rifts and orogens since the Triassic: *Tectonics*, doi:10.1029/2018TC005462.

Nirrengarten, M., Manatschal, G., Tugend, J., Kusznir, N., and Sauter, D., 2018, Kinematic evolution of the southern North Atlantic: implications for the formation of hyper-extended rift systems: *Tectonics*, p. 2, doi:10.1002/2017TC004495.

Peace, A.L., Welford, J.K., Ball, P.J., and Nirrengarten, M., 2019, Deformable plate tectonic models of the southern North Atlantic: *Journal of Geodynamics*, doi:10.1016/j.jog.2019.05.005.

Yamasaki, T., and Gernigon, L., 2009, Styles of lithospheric extension controlled by underplated mafic bodies: *Tectonophysics*, v. 468, p. 169–184, doi:10.1016/j.tecto.2008.04.024.

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