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Solid Earth
Discussions

Interactive comment on "Kinematics of the South Atlantic rift" *by* C. Heine et al.

C. Heine et al.

christian.heine@sydney.edu.au

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We would like to thank Dieter Franke for his thorough and encouraging review.

Response to comments by Reviewer 2 (Dieter Franke)

1. Time scale issues:

> *"[...] the authors have converted the estimates given by Gradstein et al. (1994) and Gradstein et al. (2004) to polarity chron ages which places base Aptian (Base M0r old) at 121 Ma. The difference of about 5 Ma is substantial. The most recent time-scale places base Aptian at 126 Ma.[...] Only He et al., 2008 (not cited) provided age determinations for supposedly M0 anomalies in Yixian, China, indicating younger ages. Maybe this is absolutely clear for a plate modeler, personally I would like to see much more written on the "extensive review of global spreading velocities""*

Dieter Franke is right that we have not cited He et al. (2008) in the manuscript as one of the best constraints correlating M0r/Base Aptian with an absolute age of 121.2±0.5 Ma.

Considerable debate is ongoing about the absolute age of M0r and thus the base Aptian (e.g. He et al., 2008; Gee and Kent, 2007), but a detailed review of the issues related to the time scale is beyond the scope of this (already extensive) paper. We prefer to use the He et al. (2008) correlation of M0r with an absolute age of 121.2±0.5 Ma (we use Gee and Kent, 2007, 's 121.0 Ma) and subsequent ties of stratigraphic ages to magnetic polarity chrons using the GTS 2004 timescale as presented in our Fig. 2. More support for an M0r age of around 121 Ma comes from recent dating of Cretaceous-aged, North-South striking dykes on the Falkland Islands which show evidence for reversed magnetic polarity(Stone et al., 2008). The GTS 2004/2012 absolute age for anomaly M0 is based on a hypothetical linearily decreasing seafloor spreading rate *model* for the M-anomaly sequence in the Pacific (Ogg, 2012, ;compare their Fig. 5.5). We have added the reference to the manuscript and extended our discussion on the time scale problem.

2. *"Formation of the volcanic seaward-dipping reflectors (SDRs). . . "*

   and following paragraph in his review.

   The geometries and ages of the SDRs in the South Atlantic in the initial version of the paper have been used from the UTIG PLATES Large igneous provice data compilation with slight modifications to geometry and emplacement age. Dieter Franke is of course right in saying that the SDRs were emplaced symmetrically on both margins prior to the generation of oceanic crust. During the review process he kindly supplied us with mapped SDR data from the Argentinian South Atlantic margin which we have now included in our revised reconstructions, along with updated and checked geometries for the African SDRs based on published literature. Along with this we have further refined the definition of the LaLOC and extended continental crust along the volcanic margin segments of the South Atlantic.

3. *“Offshore the Tristan da Cunha hot-spot (if it is a hot-spot at all) did emplace much more material to the African plate. This typically explains the “plume tail”, the Walvis Ridge. However, in the models it is placed consistently below the S-American plate.”*

   The plume location assumes fixed hot spots as stated in the caption of Fig. 12 in combination with a . We have not “placed” the hotspot deliberately under the South American plate.

4. *“There are a numbers of studies available on the evolution of the Falkland Islands area and if those did rotate or not and where these islands”*

   The paper is focussing on providing a quantiative framework for the evolution of the South Atlantic rift system as a function of plate interaction between the African and main South American plates. The southernmost South Atlantic region is heavily influced by plate motions and kinematics of Antarctica relative to Africa and the Patagonian extensional domain, especially in the complex junction around the Malvinas/Falkland islands. While the larger scale evolution of the region should be captured by our plate model we apologise that we cannot go into much greater detail in this paper. However, our reconstructions for the post-150 Ma history of the Malvinas/Falkland Islands region do not involve a major rotation and –while attempting to integrate reasonable crustal stretching scenarios based on crustal thickness and sediment thickness estimates – only allow to restore the

   Falkland Islands to a position directly south of the Aghulas Arch/Outeniqua Basin region (compare our Fig. 11). We accordindingly added a short comment on this in the revised manuscript.

5. *“4.1 Kinematic reconstructions I suggest a reorganization of this chapter. The main issue should be to convince the reader about the consistency of your preferred model PM1. ”*

   Done.

6. *“[...] but how to explain that the N Falkland Basin is N-S while the other two are E-W directed? In my view we need to attribute the N Falkland Basin to the latest E-W extension like the Orange Basin. If so we have to assume older ages for the first oceanic crust and the seafloor spreading anomalies?”*

   Subsidence data from Jones et al. (2004) indicates peak strain rates in the North Falkland basin around 140-145 Ma with the youngest faulted sediments around 125 Ma. We hence attribute the formation of the North Falkland basin to the early resulting motion of southern South America away from Africa, related to the opening of the South Atlantic rift, while Colorado and Salado basins are opened by an overall rotation of the Patagonian and Salado platelets in a counterclockwise fashion away from South America.

7. *“Extensional deformation started much earlier, admittedly it is not well understood. A summary of known ages of the onset of rifting around South Africa is given by Jackson et al. (2000). Estimations for the southern African basins are: Cape Basin, 220-200 Ma; Orange Basin, 160 Ma to 144 Ma; LuÌĹderitz-Walvis Basins, 126 Ma . The ages should be handled with caution, because the earliest rift fill was rarely drilled and these estimations may vary by as much as 20 Ma for any particular basin (Jackson et al., 2000). However, at least two phases of*

rifting, as suggested by Keeley and Light (1993), occurred in the Late Triassic-Early Jurassic and in the Mid-Jurassic - before the major Late Jurassic to Early Cretaceous rift phase that subsequently resulted in seafloor spreading. There is discussion about Triassic rifting, however, as you state above evidence for Jurassic rifting is widespread. (“This is recorded by Oxfordian-aged syn-rift sediments in the Outeniqua Basin in South Africa as well as subsidence and crustal stretching in the North Falkland Basin and the Maurice Ewing Bank region”)”

We acknowledge that many of the basins experienced –possibly multiple– episodes of extension prior to the start of the main extension phase that is related to the onset of relative motions between the main South American and African plates culminating into the formation of the South Atlantic basin. We have based our model for the rifting in the Orange and North Falkland Basins on the work by Jones et al. (2004) who describe peak strain and rifting based on strain rate inversion from exploration well data for the Orange Basin at 140-120 Ma and for the North Falkland for the time between 150-130 Ma. We have attempted to achieve a fit reconstruction of the Patagonian extensional domain and southern Africa which should resemble the Latest Jurassic/Earliest Cretaceous and thus *include prior* stretching events, such as the formation of the Triassic San Julian basin. This is now clarified in the manuscript.

8. *“ All this depends on your proposition that extension starts in ?Late Jurassic times. If there was a Triassic rift phase these numbers were wrong. I suggest writing this more carefully. I did not get the arguments for the proposed E-W direction from 143 Ma to 127 Ma. Please explain in a bit more detail what this proposition is based on. What is the relation to the opening of the Weddel Sea (starting at 155 Ma), which maybe count for more N-S extension?”*

As mentioned above, we consider only extension of latest Jurassic to Early Cretaceous in our current plate model and assume that the older Patagonian basins already do exist at this time – we’re starting our model with a snapshot at 140 Ma. The E-W directed extension between Africa and Patagonia is a result of the clockwise rotation of the Patagonian domain away from South America. We have changed the text accordingly.

9. *“I agree with those absolute ages because these fit nicely with reported ages for the breakup unconformity in the basins around the S Atlantic (see Franke, 2012 MPG). However it became not fully clear to me how you constrain such ages.”*

These ages are simply derived (or “predicted”) from our plate model and defined by the time the present-day LaLOC (or COBs) start to diverge, indicating seafloor spreading. We have added a sentence to clarify this in the manuscript.

10. *“Lots of abbreviations make the manuscript difficult to follow”*

Changed.

11. *“Given the uncertainties in the timing I suggest avoiding ages like 126.57 Ma. 127 Ma is fully sufficient.”*

The ages are based on the mapping of magnetic polarity chrons to absolute time. While we agree that the uncertainties are large enough to avoid such “über-”exact ages, the plate model is nevertheless tied to these ages for stage poles.

12. *“P49: L22ff: “we use anomaly M4n old as our oldest oceanic isochron to constrain the motion of South America relative to Africa.” Please explain the resulting effect of this limitation”*

Changed. We have now included M7 in our model.

13. *“ I suggest assuming an earlier age for the initial formation of these basins. Please see also PaÌĄngaro and Ramos (2012).”*

We are now using 150 Ma for the onset of rifting in the Colorado Basin and 145 Ma for the onset of rifing in the Salado basin.

14. *"Case insensitivity is widespread "*

    This was introduced in the technical editing part on the publishers side. Fixed.

15. *"Now there are more than ten plate reconstructions at hand for the South Atlantic. It is typically left to the reader to evaluate the limitations or to the follow-up authors to point to the problematic parts. Wouldn't it be a good idea to write a few lines about the regions, structures and times where you do not feel too well with? Just a thought."*

    And a very good one. We have added a concluding statement in the revised version.

16. *"Fig. 1 I suggest sorting the description and abbreviations in alphabetic order"*

    Changed.

17. *"Fig. 9: Please explain the two lines in the NW corner."*

    These are flowlines from a another flowline pair further north and have been deleted.

18. *"Fig. 13 It would be nice seeing the full extent of the South Atlantic region here"*

    Map extended as requested.

19. *"Fig 14 lower panel could be limited to the western hemisphere only"*

    Changed.

References

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