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Interactive comment on "Full-fit reconstruction of the Labrador Sea and Baffin Bay" *by* M. Hosseinpour et al.

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General comments

The discussion paper presents an interesting review of the controversially discussed opening of the Labrador Sea and BafïňĄn Bay region, embedded in a full-ïňĄt reconstruction for the area. The conclusions generally conïňĄrm the most recent seismic observations. Given the simpliïňĄcations that have to be made for such a large region with still relatively sparse seismic data coverage, the results present a good framework for future studies. Below, numbers in brackets refer to page and line number, e.g.

(919/20) line 20 on page 919.

SpeciïňĄc comments

1. The ïňĄgures, even when enlarged on the screen, are difïňĄcult to read. They contain a lot of information that is written in too small a font size. This destroys very much the ïňĆow of reading. Figures A1, B1, and C1 are so small that I was unable to review them.

Answer: Figures A1, B1 and C1 have been changed and made bigger.

2. (919/19) The time scale of Gradstein et al. 2004 is used. I would suggest using the most recent update (Gradstein et al. 2012).

Answer: The reference changed. All the given times in the text have been reviewed. As our work is in general using the magnetic anomaly time scale and not the relative geological time so the given times in text are not subjected to change.

3. (921/14-17) Rifting and extension most likely started before 160 or 140 Ma. Larsen et al. 2009 (J. Geol. Soc, 166: 999-1012) suggest initial stretching in the Late Triassic to Late Jurassic (223-150 Ma) based on the production of highly alkaline, volatile rich melts formed in small volumes in the deep lithosphere.

Answer: Larsen et al. (2009) study on Greenland margin refers to a dyke with the age 217 - 223 (Late Triassic) while it says other dykes are dated 166 to 150Ma that is in the range of what proposed in this paper for the beginning of rifting. They also mention that the magma amount was very small that indicates slight stretching. They also mention that the igneous rocks with the same age have not been reported from the Labrador margin and the oldest age of lamprophyre dykes on the Labrador margin is 142 Ma (Tappe et al., 2007). Furthermore, they mention that there is no evidence for Jurassic intrusions in the northern parts of the Baffin Bay. Taking in to account all of these facts, we can assume that the rate of extension and stretching and the following amount of magma generation up to the Late Jurassic-Early Cretaceous was

very slow and small and that the rifting starts from 140Ma by the formation of Alexis volcanic that has been traced in the wells onshore (e.g. Herjolf M-92 and Bjarni H-81) and as dykes offshore of the Labrador margin and formation of sedimentary basins (Figure 6. Tectonostratigraphic chart, Dickie et al., 2011). They also report a seismic unconformity between Palaeozoic basement rocks and the Early Cretaceous igneous formation in both margins

4. (926/20-24) A thickness grid for the high-velocity bodies has to be shown in a ïňĄgure. Otherwise it is impossible to decide if this step in the calculation was done correctly. High-velocity lower crustal bodies are probably widespread in the Davis Strait region based on the distribution of Palaeogene volcanics. Hence, it would be important to see how the volcanic distribution map (e.g. Skaarup et al. 2006) matches with the high velocity lower body grid.

Answer: It is a fair comment. We have added figure 8 that show the distribution and thickness of igneous crust in the region and its correlation with the previously existing volcanic maps. More detailed explanation about the process of eliminating of these igneous bodies and changes in full-fit rotation poles using this new thickness grid in COB restoration have been added to the section 4.2, Figure 14 and tables 1 and 2. The new crustal thickness grid without high velocity bodies has been added to the supplementary material.

5. (Section 4.2) It is unclear how tc was obtained in the compilation of the gamma factor in Fig. 9.

Answer: tc0 uses our preferred reference unstretched crustal thickness (37km) used to produce the crustal thickness grid.

6. (Fig. 9) The area of undisputed oceanic crust should be masked on the gamma grid, as oceanic crust was not thinned.

Answer: It was done.

7. (928/6-7) No reason is given for the choice of the reference crustal thickness. Why are different values used for Greenland and North America? At the time of rifting, the crustal thickness at the later COB should have been identical.

Answer: The choice of reference crustal thickness for gravity inversion has been explained in the Appendix 1 however more text has been added to the section 4.2 for more clarification. About setting the unstretched crustal thickness in both margins we modified the existing text and added more references in the section 4.3 to explain and correspond with our model.

8. (Section 4.3) No description is given how the location of the “UCCL” was chosen.

Answer: We added more explanation in the section 4.3

9. (930/1) The start of rifting is given here at 120 Ma, which contradicts the values presented in the tectonic setting (160 or 140 Ma).

Answer: First, It should be noted that the pole of rotation for full-fit reconstruction that is valid and remains the same regardless of the time of rifting. However, to investigate the effects of moving the initiation of relative motion back to 140Ma we tested changing the fit- reconstruction time for our preferred model 7 from 120 to 140Ma. If we assume the constant stretching rate from the beginning of rifting to the start of seafloor stretching, this change will move the break up time from 85Ma as our model predicts (Figure 15A) to about 95Ma. Accepting the average 120km amount of extension in both margins (Figure 11), the rate of extension for our best model will change from 3.42mm/y to 2.18mm/y. There are lots of uncertainties about the break up age and the stretching rate and whether it changes though time or not for this region and so it seems appropriate to consider a range of possibility for these factors. It also worth mentioning that as it was noted in comment 3 we considered that the magma production started at 140m Ma was so small that does not produce a recognisable relative motion. Referring to previous full-fit reconstruction in this area could further support this hypothesis as fit reconstruction for Rowley and Lottes (1988) is 130Ma and Srivastava and Roest (1989)

put their fit reconstruction at 118Ma that being followed by Torsvik et al (2008).

10. (929/9-21) Inaccurate terminology is used in the description of the geology. *First of all, all geological names mentioned in the text have to be labeled in Fig. 11.

Done.

*Second, there are some typos (correct spelling is Makkovik and Nordre Isortoq).

Done.

*Third, an “orogeny” is not a “line” that “separates” one region from another but is a geological process that results in the formation of an orogen. The region north of “line 1” in Fig. 9 is the “Committee-Melville Orogen”. “Line 1” would be the southern border of the CMO.

Done.

Similar with the “Makkovik and Ketilidian orogeny”: the border (“line 4”) is not the Makkovik and Ketilidian orogeny! South of “line 4” lies the Makkovik Province on the Canadian side and the Ketilidian fold belt on the Greenland side. The “line” (=structure) that separates the Makkovik Province and the Ketilidian fold belt from the North Atlantic craton would probably be the Kanairiktok shear zone on the Canadian side.

Done.

11. (931/24 - 932/5) I think you have to be slightly more cautious when saying that your models do not require internal deformation of Greenland and North America. First, I do not think that the resolution in the data is sufïňĄcient to exclude any such deformation. Second, some deformation should have occurred during the Eurekan orogeny (a major period of late Cretaceous-Paleogene tectonism in northern Canada and Greenland).

Answer: Your comment is fair and we agree about the possibility of existence of such motion but our data and the workflow was not aiming to disprove the possibility of such deformation. The fact that we concentrated on and tried to demonstrate in this

study is that achieving the best possible fit for beginning of rifting in the Labrador Sea and Baffin Bay is possible without considering any of North America or Greenland as non-rigid plates. Previous studies (cited in the text) had argued that large-scale deformation, either between Baffin Island and North America, or within Greenland, was required to arrive at a good fit. Our results suggest that, within the resolution of the available constraints, such deformation is not required. Regarding the Eurekan orogeny however, it worth mentioning that the region being affected by this tectonic deformation phase is Arctic Canada, Northern Greenland and Ellesmere Island that located further north of our study area and our reconstruction does not cover it.

12. No thoughts are given on the presence of exhumed mantle in the COT. In the preferred model (7), the COB lies seaward of the region where exhumed mantle is expected/interpreted. The gravity derived crustal thickness model for the COT would signiïňĄcantly overestimate the thickness of true continental crust as all serpentinized mantle would essentially be counted as crust. As consequence, the RCOB would be farther seaward. A quantitative estimate should be given, how large the error could be. As a general information, additional refraction seismic lines are published for the area. There are a number of lines onshore and offshore Labrador (references can be found in the summary of Hall et al. 2002, Can. J. Earth Sci., 39: 569-587; + Funck et al. 2008 (Can. J. Earth Sci. 45: 465-481)) and in the southern Nares Strait (Funck et al. C308 2006, Polarforschung 74: 97-112).

Answer: Some of these comments are fair. We referred to the existence of exhumed/serpentinized mantle within the COT at several places throughout the text as interpreted by many previous authors whose seismic lines we used. However we have modified the text to make this clearer. We tried to review different origins being proposed for the nature of COT in the section 3. As it is mentioned there, serpentinized and exhumed mantle has been considered as one of these alternatives explanations but the interpretation is not definitive. So, wherever we talk about the COT in the text, involving all our proposed models it will cover the possibility of exhumed mantle origin

for that area as well. For examining the effect of COT material on the reconstruction we put the COB landward of defined COT in models number 2 and 3. This uncertainty is the reason we test different COBs, and our approach and results for different COBs illustrates how this uncertainty maps to the full-fit poles of rotation, which is what we ultimately want to calculate. A further point of note is that, as pointed out by Dunbar and Sawyer (1989), large uncertainties in the position of the COB map to much smaller uncertainties in the RCOB, because the crust in this region is generally thin.

13. (Fig. 8) shows that the gravity grid systematically underestimates the crustal thickness for values >34 km when compared with the refraction seismic. If the parameters for the reference crustal thickness or the location of the UCCL are based on the gravity derived thickness grid, the results for the RCOB could potentially be biased.

Answer: This is a fair comment. The UCCL line is defined on the basis of where there is negligible crustal thinning within the continent, which should be apparent both from where the crustal thickness is not changing rapidly (compared to within the extended crust in the margin), and other criteria such as large areas of exposed basement or absence of thick sediments. So the UCCL used is consistent with a range of criteria, not just the crustal thickness contour alone, and had we drawn a UCCL based on only those criteria and ignored the crustal thickness from gravity, we would have defined the boundary in a similar location to what we used. Nonetheless, to investigate the effect of probable underestimating of crustal thickness and its effect on the position of UCCL and restored COB we restored the model 7 COBs using three different sets of UCCL located at 35, 37 and 40km crustal thickness boundaries. More information could be found in the sections 4.3 and 6.2. Figure 7 has been modified to demonstrate these three UCCL locations and Figure B3 has been added to illustrate and compare the full-fit rotation poles for these UCCL sets and their uncertainty ellipses.

14. (Fig. 7) no reference is given to the seismic lines shown.

Answer: references added.

There is also no reference for the receiver functions. All receiver functions onshore Greenland are published by DahlJensen et al. (2003, Earth Planet. Sci. Lett. 205: 379-393).

Answer: references added.

By the way, these receiver functions show crustal thicknesses exceeding the results from the gravity inversion that are stated in the ïňĄgure caption. Station SFJ has 47 km, station PAA 42 km, both are close to the coast. Even with some error, this is much more than the reference crustal thickness of 36 km that was used for the calculation of the RCOB in Greenland.

Answer: We discuss this in section 4.3.

Technical corrections

1. Different times for the cessation of seaïňĆoor spreading are mentioned: (920/15) states 34 Ma, while 49 Ma are mentioned in (920/25).

Answer: corrected.

2. Different times are mentioned for the age of chron 13: 35 Ma (921/3) , 34 Ma (920/15).

Answer: corrected.

3. (921/19) The cited paper by Sandwell and Smith (2009) does not say anything on sediments and volcanics in the study area and should therefore be deleted. Answer: corrected. 4. I noticed several references that are missing in the reference list (e.g. Reston 2009, Okulitch et al. 1990)

Answer: added.

5. (922/25) the UFZ is referred to in Fig. 3 but is not shown there.

Answer: UFZ is shown in Figure 3 as a polygon filled with dashed blue lined. The key

to it is in the Figure 2 as it is mentioned in the caption.

6. (926/17 and other occurrences) If spaces are to be added in the line numbers, this should not be done as 20 080 600 but as 2008 0600 as the ïňĄrst four digits correspond to the acquisition year. The full line name is actually AWI-20080600. This applies to other line names as well: (e.g. AWI-20080500, AWI-20080700, AWI-20100400)

Answer: Corrected as being advised.

7. C309 (928/4) The abbreviation “UCCL” is never explained in the entire paper.

Answer: corrected.

8. (928/7) Should be Fig. 10 and not 11.

Answer: corrected.

9. (929/8) Should be Fig. 11 and not 12.

Answer: corrected.

10. (931/1-2) There should be no paragraphs with just one sentence.

Answer: corrected.

11. (931/18) Please specify what exactly you mean by “channels” in this context.

Answer: added.

12. (931/18) delete “the” before Greenland

Answer: corrected.

13. (933/27) wrong spelling of “Døssing”

Answer: corrected.

14. (937/18) a word/noun is missing after the adjective “continental”

Answer: corrected.

15. (941/6-7) The reference given for Kusznir (2009) is not sufiňĄcient. Is it a book, journal article, report, conference contribution? Who is the publisher?

Answer: corrected.

16. (Table 2) Parameters a through f are not explained.

Answer: corrected.

17. All ïňĄgures with maps should have a scale bar.

Answer: done.

18. (Figure caption 1) “NUGGET” not “NAGGET”

Answer: corrected.

19. (Figure 1) a number of lines run under #16, which are referred to as Harrison et al. (2011). Many of these lines were already published earlier and proper reference should be given. I could for example identify the lines of Keen and Barrett (1972).

Answer: Done

20. (Figure 1) line #14 is a composite line consisting of AWI-20080500 and AWI-20100400.

Answer: corrected.

21. (Figure 1) line #12 is listed with the wrong name (should be AWI-20080700) and with a wrong reference (should be Suckro et al. 2013, which is also missing in the reference list)

Answer: corrected.

22. (Figure 5) ProïňĄle name for the model at the bottom of the left column is wrong (is the composite line consisting of AWI-20080500 and AWI-20100400). C310

Answer: corrected.

23. (Figure 6) some author names are misspelled, should be Louden and Müller

Answer: corrected.

24. (Figure 11) The ice shield in southernmost Greenland is shown in grey but should be in white.

Answer: corrected.

25. (Figure 14) The purple (?) lines are not explained (I assume UCCL and COB or RCOB?).

Answer: corrected.

The legend says that stretched continental crust is plotted in light blue. Why is then all continental crust shown in this color?

Answer: corrected.

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