Interactive comment on "Improving global paleogeography since the late Paleozoic using paleobiology" by Wenchao Cao et al.

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General Comments:

Reviewer: This is an interesting paper that does an excellent job combining two disjoint data sets (plate tectonic models & paleogeography) into a cohesive synthesis. The resulting discussion of the relationship of continental flooding to sea level and to the changing ratio of strontium isotopes in the oceans through time is clearly presented. All the figures are readable and well done. The writing is patchy, but I have made numerous suggestions for the authors. This study had four principle objectives: 1) to describe the process by which the paleogeography (Golonka) developed for one plate tectonic model (Scotese) could be reverse engineered and plotted on an alternate plate tectonic model (Matthews), 2) to improve the Golonka paleogeography by adding additional constraints from the Paleobiology Database, 3) to compare the resulting estimates of continental flooding though time with published sea level curves, and finally, 4) to explain the changing ratio of strontium isotopes in the ocean with the observed patterns of continental growth and emergence. Each of these objectives was successfully met, to varying degrees. Objective 1: The new set of paleogeographic maps produced in this paper, clear demonstrates that it is possible to transfer the paleogeographic information from one set of maps (Golonka, 2006) to another set (Matthews, 2016) – as long as plate tectonic models are available for both sets of maps. However, the methodology cannot be considered to be a universal solution. As pointed out by the authors, the paleogeography and plate models are inextricably joined, and moving the paleogeography from one plate model to a another plate model inevitably results in gaps and overlaps (see Figure 3c). Unfortunately this will always be the case. It will always be necessary to laboriously "hand edit" any attempt to transfer the paleogeography from one plate model to another.

Authors: We thank Christopher Scotese for his constructive review and detailed suggestions that will significantly help us to improve the manuscript. We agree with the four points he raised, to be addressed in the revision. In terms of objective 1, we agree that the methodology has some limitations and we will systematically discuss them in the revision.

Reviewer: Objective 2: There are several issues here that need to be discussed. My first major point is that I am not convinced that the "revised" coastlines are a significant improvement over the original coastlines. Though, I agree that the addition of information from the Paleobiology database can, in some areas, improve the location of the coastlines, it is not clear to me that the overall result is an improvement or merely a slight modification. There are two reasons for my skepticism. Firstly, I do not know what original data was used to draw the coastlines. Therefore I do not know how much "weight" to give the Paleobiology data with regard to the original data. For example is the original coastline is based on a dozens of coastline estimates from a variety of sources, then a few additional data points from the PBDB should not be given much weight. Conversely, if the original coastline position was an educated guess based on little or no data, then the extra information from the PBDB would be very welcomed. So, simply, we don't if the changes are an improvement or not. The second reason for doubting that any improvement has been made is to consider

what the coastline drawn on the original maps actually represents. In this case, I believe the error lies with the mapmaker, not the analysis.
Authors: The revised paleo-coastlines are significantly different, except for a few time-interval maps where there are few paleobiology data (Please see Fig. 1, 2, 3 below and a set of maps in the Supplement). Note that in the new tests carried out on the paleogeography with paleobiology, we only used marine fossil collections to improve paleo-coastline locations and the paleogeographic geometries because the coastlines on the paleo-maps used in this study represent maximum transgression surfaces. The paleogeographic atlas in the study is compiled based on gathered lithologic data, which is independent with paleobiology data. Since the original data that were used to estimate the coastlines are not available for us, it is difficult to give the weight to the paleobiology data. The coastlines drawn on the original maps represent maximum transgression surfaces and we do not know much about their errors. Instead, we will systematically estimate the errors of two key steps in the workflow, including filling gaps and modifying the coastline locations and the paleogeography (see Fig. 4 below) and add their discussion in the revision.

Reviewer: The 24 maps in this study cover ~400 million years. That means, on average, that each map represents an interval of 17 million years. It seems very unlikely that the coastline would have remained in one place for 17 million years. A more reasonable representation of the "coastline" for this long interval would have been to show it as a "zone" that was alternately marine or terrestrial. (see my Figure 1). One way to simulate this would have been to erect a 250- 500 km buffer around the coastline, and then test only the points that lied outside of the buffer. I am not suggesting that the authors do this, but rather I am suggesting that it is likely that the "discrepancies" they point out, may in fact, be perfectly OK, given the changing location of the coastline through time. In this regard, I think the manuscript would be improved if the author's pointed out this possibility and changed their wording so that it sounds less pejorative (i.e. You made mistake and now I'm going to fix it.) In fact what would be more valuable if the authors listed all the marine data points that plotted on mountain ranges or more than 500 km from the proposed coastlines, or conversely, terrestrial deposits that plotted in the deep sea (off the edges of the continents). In these cases, changes to the paleogeographic maps should certainly be made!
Authors: In the revised version of the maps, we only use marine fossil collections to improve coastline locations and paleogeographic geometries. We will flag all inconsistent marine fossil collections far more than 500 km inland from the nearest coastlines with red point symbology, on each time-interval map (see Supplement).

Reviewer: Objective 3: Everything here looks pretty good, however there was a little graphical confusion that needs to be fixed. It is hard to argue against a positive correlation between sea level rise and continental flooding, and I am happy to see that in Figure 9A both trends track each other well. However, it is not clear which units (y-axis) apply to which curve. This should be cleared up in the Figure caption. More problematic, however, is that the fact that the figure implies that these two very different units scale together. i.e. 40% flooding = 160m rise in sea level. This is certainly not true. The cleanest solution would be to separate these two graphs, but place them one above the other.
Authors: We will delete the comparison between continental flooding curves and published sea level fluctuation curves as there may be some circularity in this comparison. Instead, we will only compare our flooded continental area curve to previously published ones (see Fig. 5 below).

Reviewer: Objective 4. The same objection raised to Figure 9a also applies to 9b. It may be necessary to separate this figure into two diagrams.
Authors: We will delete the comparison between emerged land area, total land area and the strontium isotope ratio curve, so this figure will be replaced.

Additional General Comments:
Reviewer: The Methods Section consistently misuses verb tense. Lines 115 – 334. You are describing actions that you did in the past. You must use the past tense, not the present tense e.g. "They are first georeferenced" should be "They were first georeferenced. " Review all verb tenses in this section and correct.
Authors: Thank you. All verb tenses in this section will be corrected in the revision.

Reviewer: There is a confused an improper use of the terms "fossil" and "paleobiology". No fossils were used in this paper, only fossil collections that revealed paleoenvironmental conditions, i.e., marine or terrestrial.
Authors: We will correct this throughout the manuscript in the revision.

Reviewer: When listing ranges of dates, "Ma" should appear after each date if the dates are separated by a "and" or "to", e.g. 402 Ma and 2 Ma or 402 Ma to 2 Ma. This is not necessary if the dates are separated by a dash, as in 402-2 Ma.
Authors: We will amend this in the revision.

Reviewer: Other specific comments regarding the text, figures or tables are given in the following section. Specific Comments by line: 016 Delete "time-dependent global" and "Several"
Authors: We will delete them in the revision.

Reviewer: 018 The phrase "static maps with varying temporal resolution and fixed spatial resolution" is not clear and seems redundant and should be rewritten. Aren't all maps "static" and have a fixed "spatial resolution", i.e. "scale". So?
Authors: We will rewrite this in the revision.

Reviewer: 020 Though the authors were successful in "reverse engineering" the Golonka maps, the workflow they produced is not a general or universal solution. Because of the idiosyncrasies of various plate tectonic reconstructions, each reverse engineered set of maps requires extensive hand editing to fix the resulting gaps and overlaps. This will always be true. So the claim that this new workflow fixes that problem and is a universal solution is incorrect and therefore the claim must be withdrawn or modified.
Authors: We agree and will modify the claim in the revision. In addition, we will add the discussion of the limitations of the workflow developed in this study in the Discussions section.

Reviewer: 022 The sentence, "Published paleogeographic . . . datasets." is not informative and should be deleted.
Authors: We will delete this sentence in the revision.

Reviewer: 023 "fossil data" to "paleoenvironmental data".

Authors: We will amend this in the revision.

Reviewer: 023 I am not convinced that the maps were improved. See my comment above. There are some methodology problems here - both in the map making and analysis. The best I think you can say is that "the maps were modified to be more consistent with the paleoenvironmental data from the Paleobiology database." This statement does not imply that the resulting maps are "better". (I know this seems like nit-picking, but it actually is an important point!)
Authors: The paleo-maps are significantly different, except for a few time-interval maps where there have few paleobiology data (Please see Fig. 1, 2, 3 below and a set of maps in the Supplement).

Reviewer: 039 A definition of what you mean by "paleogeography" might be appropriate here. I favor this definition, "paleogeographic maps describe the ancient distribution of highlands, lowlands, shallow seas, and deep ocean basins". Of the list of examples, that would disqualify Scotese (2004), but Scotese (2001 and 2004) could be substituted (see list references cited at end of review).
Authors: We will add the definition of "paleogeography" here and correct the references in the revision.

Reviewer: 043 Here we go with that static .. fixed spatial resolution " business again.Why don't you just say that it is difficult to convert the maps into a digital format because of the varying map projection, different time intervals represented by the maps, and the different plate models that underlie the paleogeographic reconstructions. I agree that there is great power to having the paleogeographic data in a digital format so you can . . .. (examples). Yes, this is a worthwhile goal.
Authors: We will rewrite this part in the revision. Thank you.

Reviewer: 052 use "these issues"
Authors: We will amend this in the revision.

Reviewer: 054 not "any plate model" but a "different plate model". Your workflow is not a universal solution. It is likely that any change in the plate model will create new gaps and overlap that will have to be fixed by hand.
Authors: We will change "any plate model" to "different plate model" in the revision.

Reviewer: 055 Try rewriting this sentence without the jargon. "The first step was . . . "
Authors: We will rewrite this sentence in the revision.

Reviewer: 058 You didn't "reverse-engineer the global maps" (whatever that means). You "restored the ancient paleogeographic boundaries back to their modern coordinates by applying the inverse of the rotation that was used to make the ancient reconstruction." More words, but more clear.
Authors: We will amend this claim in the revision as suggested.

Reviewer: 060 -062 How about saying this, "Subsequently, we used information about marine and terrestrial paleoenvironments available from the Paleobiology Database to modify the location of the paleo-coastlines."

Authors: We will rewrite this in the revision as suggested.

Reviewer: 068 “modelled” should be “modeled”
Authors: Since we will delete the comparison between emerged land area, total land area and the evolution of strontium isotopes of marine carbonates, the whole sentence here will be deleted in the revision.

Reviewer: 073 “paleoenvironmental data” not “paleontological data”
Authors: We will modify this in the revision.

Reviewer: 077 see my comments about Table 1.
Authors: We will list three time scales of Sloss (1988), Golonka (2000) and ICS2016 in the table (see Table 1 below).

Reviewer: 084 change “a plate tectonic model” to “a mysterious plate tectonic model “ - just kidding! 089 not “reverse-engineer”, but “ restore these paleogeographies to their present-day coordinates”.
Authors: “reverse-engineer” will be modified to “restore” in the revision.

Reviewer: 091 in Figure 2 of this review I show that the plate model is identical to Scotese (1997) that was published in Scotese (2004). So the sentence should read, “are based on Scotese (1997, 2004)”. My plate models have been widely available – mostly through the paleomapping programs I have written (with students) – Terra Mobilis, PaleoMap-PC, PointTracker, & PaleoGIS. Jan probably obtained a copy from me directly, or by using one of my programs. In either case, I deserve credit for the plate model (but not the paleogeography).
Authors: Sorry for the improper claim and citation. “are similar to those in Scotese (2004)” will be revised to “are based on Scotese (1997, 2004)”.

Reviewer: 106 “fossil collections” rather than “documented fossils”
Authors: We will modify this in the revision.

Reviewer: 116 This is an important sentence. It must be clear. Try, “The methodology can divided into three steps: 1) the original paleogeographic boundaries were restored to present-day coordinates by applying the inverse of the rotations used to make the reconstruction, 2) these restored boundaries were then rotated to new locations using the plate tectonic model of Matthews et al. (2016), finally, 3) the location of the paleocoastlines were adjusted using paleoenvironmental data from the Paleobiology database.”
Authors: We will rewrite the sentence as suggested here.

Reviewer: 117 Figure 2 illustrates the generalized workflow.
Authors: “a generalized workflow” will be revised to “the generalized workflow”.

Reviewer: 126 “to refine the rotations and ensure that the paleogeographic boundaries are restored accurately to their present-day locations.”
Authors: We will modify the sentence in the revision.

Reviewer: 141 Emphasize how tedious and labor intensive this procedure is. “The gaps and overlaps were fixed, feature by feature, map by map, by extending or modifying the outlines of each mismatched polygon in order to make the boundaries connect in a similar fashion to the original paleogeographies.”
Authors: We will clarify this in the Discussions section in the revision.

Reviewer: 151 Try “Once the gaps and overlaps were fixed, the reconstructed paleocoastlines were compared with the data from the PaleoBiology Database that described the marine and terrestrial environments of the fossil collections. These comparisons were aimed at indentifying the differences between the mapped paleocoastlines and the marine and terrestrial environments in order to modify the location of the paleocoastlines.”
Authors: We will revise this part in the revision as suggested here.

Reviewer: 155 change “Only the fossils” to “Only the fossil collections”
Authors: We will replace “Only the fossils” by “Only the fossil collections” in the revision.

Reviewer: 157 change “fossils” to “collections” and “Fossils” to “Fossil collections”
Authors: We will modify this throughout the manuscript.

Reviewer: 161-165 The sentence starting with “Alternatively . . “ and everything after it, should be deleted. It is unnecessary. Makes things unnecessarily complex.
Authors: We will delete this part in the revision.

Reviewer: 169 ”collections were then attached” - delete “motion”
Authors: We will delete “motion” in the revision.

Reviewer: 170 Try, “Subsequently, a point-in-polygon test was used to determine whether the indicated terrestrial or marine fossil collection lied within the appropriate marine or terrestrial paleogeographic polygon. The results of these tests is discussed in the following section. (delete the rest of this paragraph).
Authors: We will modify this part in the revision as suggested.

Reviewer: 177-178. “In the next step, we modified the location of the paleocoastlines based on the differences between the paleoenvironments indicated by the fossil collections and the mapped paleogeography. Figures 4 & 5 illustrate how the paleocoastlines were modified. “
Authors: We will amend this part in the revision as suggested.

Reviewer: 184 “. . . taken into account. (3) The boundaries . . .”
Authors: We will delete “as valid proxies to improve marine-terrestrial boundaries” in the revision.

Reviewer: 192 “to maximize the use of the paleoenvironmental information from the fossil collection to improve . . “
Authors: We will change “paleobiology” to “the paleoenvironmental information from the marine fossil collection” in the revision.

Reviewer: 205 “ when using the fossil collections. . “

Authors: We will replace “paleobiology” by “the fossil collections” in the revision.

Reviewer: 208 “deceptive fossils, however, are rare.”
Authors: We will revise “deceptive fossils are rare.” to “deceptive fossils, however, are rare.”

Reviewer: 211 “4.1 Paleoevironmental Tests” - no Paleobiology used here.
Authors: We will modify “4.1 Paleobiology Tests” to “4.1 Paleo-evironmental Tests”.

Reviewer: 210 -254 I still think this “consistency/inconsistency ratio ” is somewhat dubious due to the changing location of the coastline (see previous discussion). Maybe if it were couched in terms of a “match ratio” , or “mixing ratio” rather than an ”inconsistency ratio”. A high mixing ratio (mixing of marine and terrestrial data) would indicate a widely fluctuating coastline. A low mixing ration would indicate relatively stable shorelines. Again, what should be flagged as anomalous are marine data points far removed inland from coastlines (>500 km) or terrestrial data points far removed, oceanward of coastlines. It seems nearly pointless to flag contrary indications that lie adjacent to the coastline.
Authors: Given that the coastlines on the paleo-maps used in this study represent maximum transgression surfaces, and we will only use marine fossil collections to improve the paleo-coastline locations and the paleogeographic geometries in the revision, this is not the case anymore. We will use the marine fossil collections less than 500 km from the nearest coastlines in the new tests and will flag all inconsistent marine fossil collections far removed inland from the coastlines (>500 km) with red point symbology on each time-interval map (see Supplement).

Reviewer: 254 ”scarce, the fossil collections were of limited . .”
Authors: We will revise “paleobiology data is” to “the fossil collections were”.

Reviewer: 261 “Methods”
Authors: We will revise “Method” to “Methods”.

Reviewer: 264-267 Rewrite this sentence.
Authors: We will rewrite the sentence in the revision.

Reviewer: 281-287 Rewrite, simplify, clarify. “380-285,81-58, and 37-2 Ma” should be “30-285 Ma, 81-58 Ma, and 37-2 Ma”
Authors: We will rewrite the sentence and modify “380-285, 81-58, and 37-2 Ma” to “30-285 Ma, 81-58 Ma, and 37-2 Ma” in the revision.

Reviewer: 313 NO. The sea level curves of Haq et al. 1987 & are not inferred from the flooding ratios. They have a completely separate derivation. I would delete this sentence.
Authors: As we will delete the comparison between continental flooding curves and published sea level fluctuations as there may be some circularity in this comparison, this sentence will be deleted accordingly.

Reviewer: 310 – 323 These values are in good agreement with the flooding curve I have independently produced.
Authors: We will delete the comparison between continental flooding curves and published sea level fluctuations as there may be some circularity in this comparison. Instead, we will

compare the flooded continental area curve generated from our amended paleogeography to previously published ones (see Fig. 5 below).

Reviewer: 326 A similar pattern of changing areas was published by Worsley et al (1984), Fig. 7.
Authors: We will delete the whole comparison between emerged land area, total land area and the evolution of strontium isotopes of marine carbonates in the revision.

Reviewer: 335 "402 Ma to 2 Ma"
Authors: We will delete the paragraph in the revision.

Reviewer: 343-345 I don't understand what you're trying to say here. Don't you mean "emerged", not "submerged"?.
Authors: We will delete the paragraph in the revision.

Reviewer: 368 "utility" rather than "flexibility"
Authors: We will delete the paragraph in the revision.

Reviewer: 372 "variable" rather than "flexible"
Authors: We will replace "flexible" by "variable" in the revision.

Reviewer: 375 "using paleoenvironmental data obtained from fossil collections"
Authors: We will change "using paleobiology data" to "using paleo-environmental data obtained from fossil collections" in the revision.

Reviewer: 397 Please include an acknowledgement to my help with the editing.
Authors: We sincerely thank the reviewer for his constructive reviews and suggestions, that we will acknowledge.

Comments about Tables
Reviewer: Table 1 Nearly all of the Sloss Sequence designations are incorrect. See Table 1 Revisions. Also the timescale for the maps is not the latest ICS timescale (2012). This means the ages may be off by as much as 4-6 million years.
Authors: We will correct the table in the revision (see Table 1 below).

Reviewer: Table 2 - OK
Authors: We will modify Table 2 in the revision (see Table 2 below).

Comments about Figures
Reviewer: Fig 1 I would arrange with oldest on bottom to match the timescale on the left.
Authors: We think the current arrangement in Fig .1 from old time to young time could better match the geological time scale.

Reviewer: Fig 2 change "Reverse Engineer" to " Restore to Present-day", change "Fix gaps" to "Fix gaps and overlaps"
Authors: We will change "Reverse Engineer" to "Restore to Present-day" (see Fig. 6 below). We only fixed the gaps.

Reviewer: Fig 3 Excellent Figure!
Fig 4 Nicely done, very clear.
Fig 5 Very clear – though I am not sue the changes are significant.
Authors: Thank you. The changes are significant and please see Fig. 1, 2 below and Supplement.

Reviewer: Fig 6 I would change it to "Match Ratio". Otherwise clear.
Authors: We will amend the explanation of "Consistency ratio" in the text to be clearer.

Reviewer: Fig 7 These area nice set of maps. Well done. I think the revised coastlines are fine, however the continental margins seem cartoonish and extend far beyond the COB. The size and placement of the mountains through time are very inconsistent.
Authors: Thank you. The paleogeographic geometries in this study were all originally obtained from Golonka et al. (2006)'s paleo-maps and we used the paleo-environmental data of the marine fossil collections from the Paleobiology Database to improve the paleo-coastline locations. Improving the continental margins or the size and placement of the mountains are beyond the scope of this study.

Reviewer: Fig 8 Clear.
Authors: Thank you.

Reviewer: Fig 9 Potentially misleading. Both 9a & 9b should be separate diagrams because the y-axis values are different, and not equivalent. See text comments for elaboration.
Authors: We will delete Figure 9a and b. Instead, we will compare the flooded continental area generated from our amended paleogeography to previously published ones (see Fig. 5 below).

Comments about References Cited
In good shape, only a few things
Reviewer: 41 Blakey, 2008, is Blakey, 2003 in References
Authors: Blakey (2008) was accidentally missing and we will add it to the reference list.

Reviewer: 95 Domeier and Torsvik, 2014 is missing, but there is a Domeier, 2016 that is not cited in the text.
Authors: We will add Domeier and Torsvik (2014) and delete Domeier (2016) in the References.

Reviewer: 311 & 312 There is no Haq et al., 2012 in the References; Haq et al, 2008?
Authors: We will delete the comparison between continental flooding curves and published sea level curves so they will be not cited anymore.

Comments about Supplementary Materials
Reviewer: Good to have a copy of Golonka (2006) included. It would have been nice to have the rotation model used by Golonka included as well. The link to the Supplement of Golonka (2007) is no longer active.
Authors: We will attach a copy of Golonka (2006)'s digitised paleogeographic maps and the rotation model in the Supplement.

Reviewer: I compared some of Golonka's original maps to the updated paleogeographies. In some cases I was not able to see any of the modifications (see Figure 3). It would be good to have a complete set of maps with the red and green symbols plotted as in Figures 4 & 5. That way we could see what was changed.
Authors: The paleo-coastlines are significantly different, except for a few time-interval maps where have few fossil data. We will attach a set of maps to demonstrate that (see Supplement).

Reviewer: When I loaded the Paleobiology data points in Gplates, I could not distinguish the "marine" from the "terrestrial" data points. The only attributes that I could discern were "plateid" and "end and start" times. The marine data and the terrestrial data should be in separate files.
Authors: We will supplement consistent and inconsistent marine fossil collection data in separate files (see Supplement) as only marine fossil data are used in the revision.

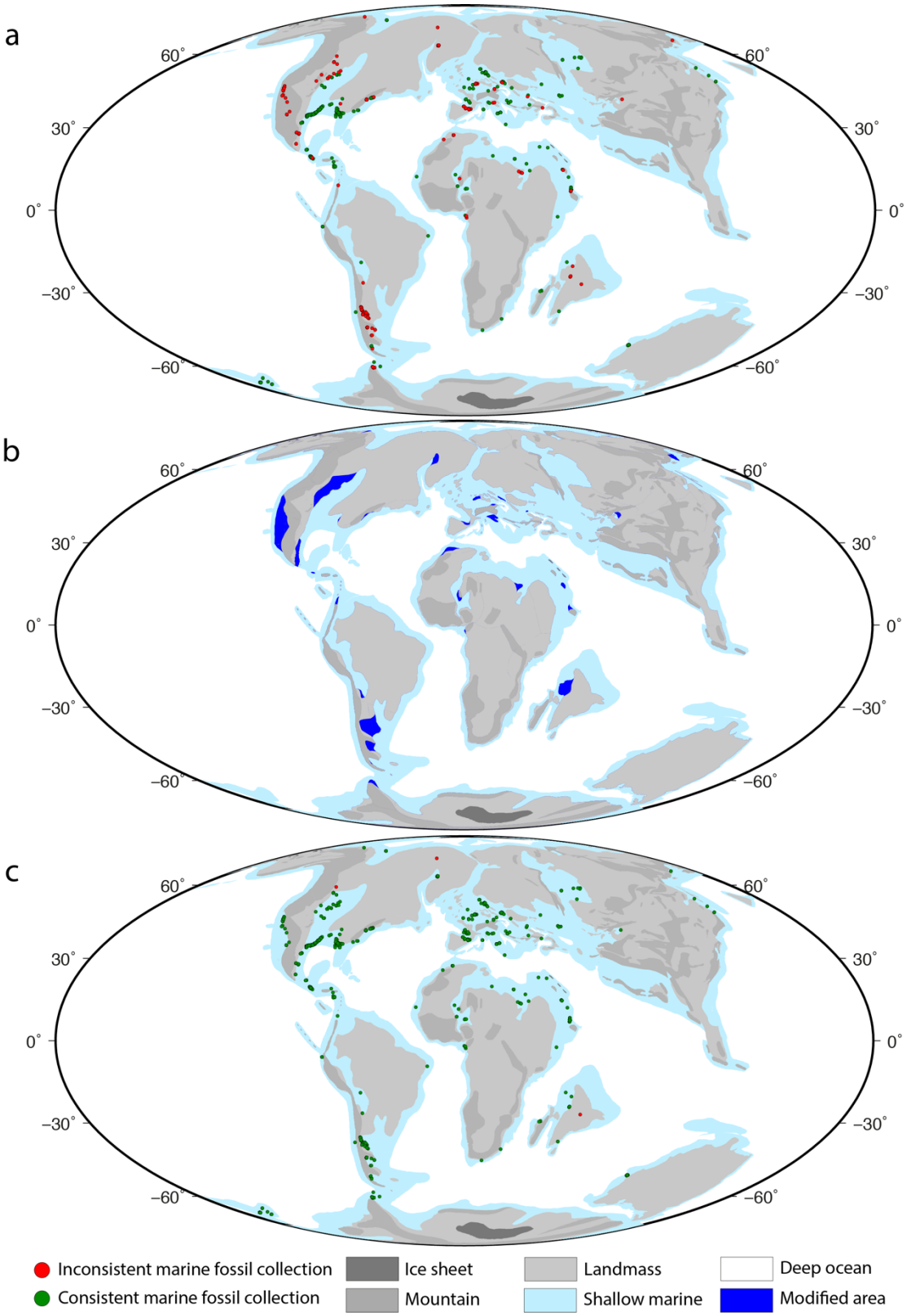

Fig. 1. (**a**) Test between the global paleogeography at 76 Ma reconstructed using the plate motion model of Matthews et al. (2016) with gaps fixed and the paleo-environments indicated by the marine fossil collections from the Paleobiology Database. (**b**) Areas modified (blue) to resolve the test inconsistencies. (**c**) Test between the revised paleogeography at 76 Ma and the same marine fossil collections. Mollweide projection with 0°E central meridian.

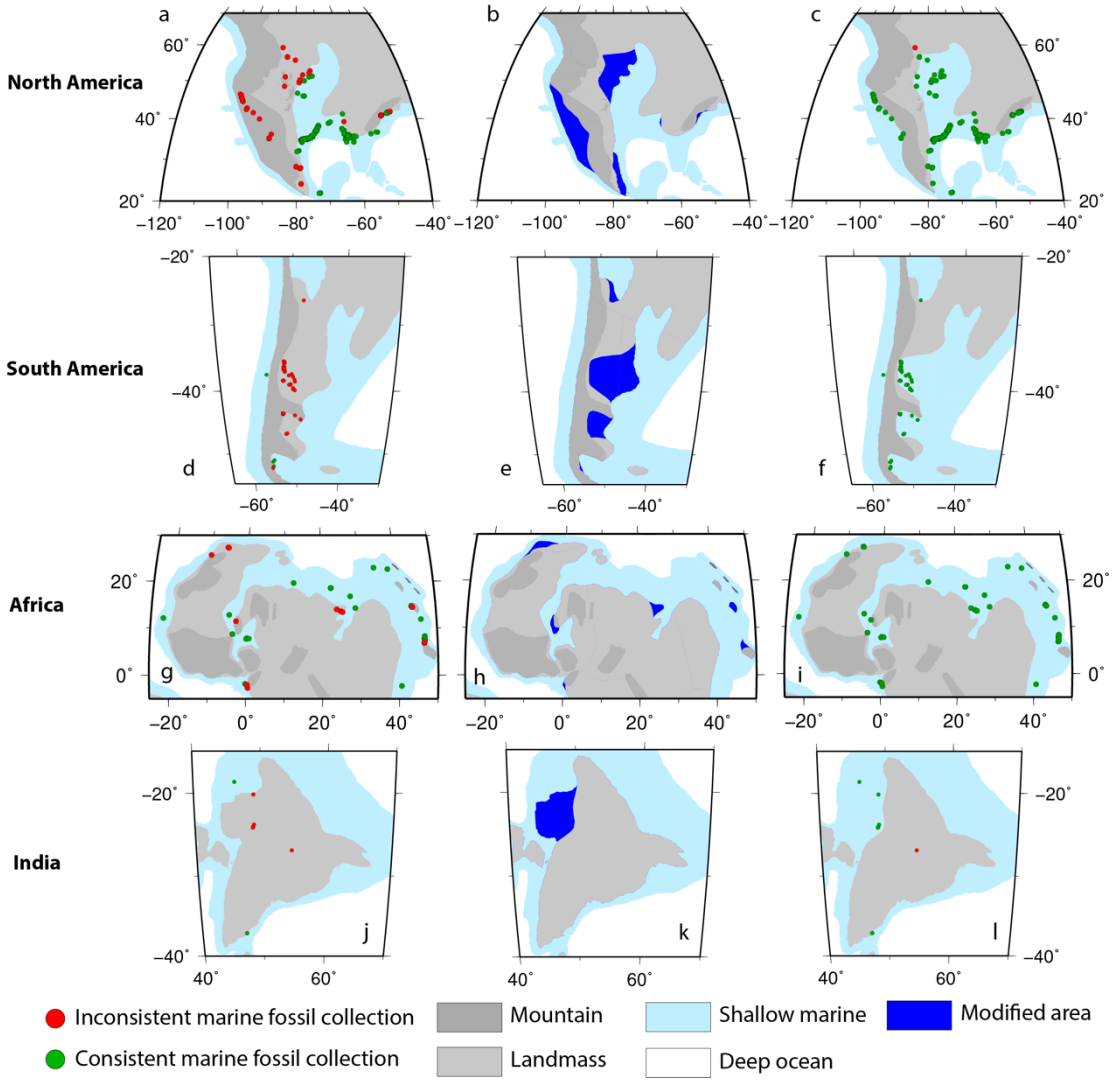

Fig. 2. Tests between unrevised and revised paleogeography at 76 Ma respectively and paleo-environments indicated by the marine fossil collections from the Paleobiology Database, and revision of paleo-coastlines and paleogeographic geometries based on the test results, for southern North America **(a, b, c)**, southern South America **(d, e, f)**, northern Africa **(g, h, i)** and India **(j, k, l)**. Mollweide projection.

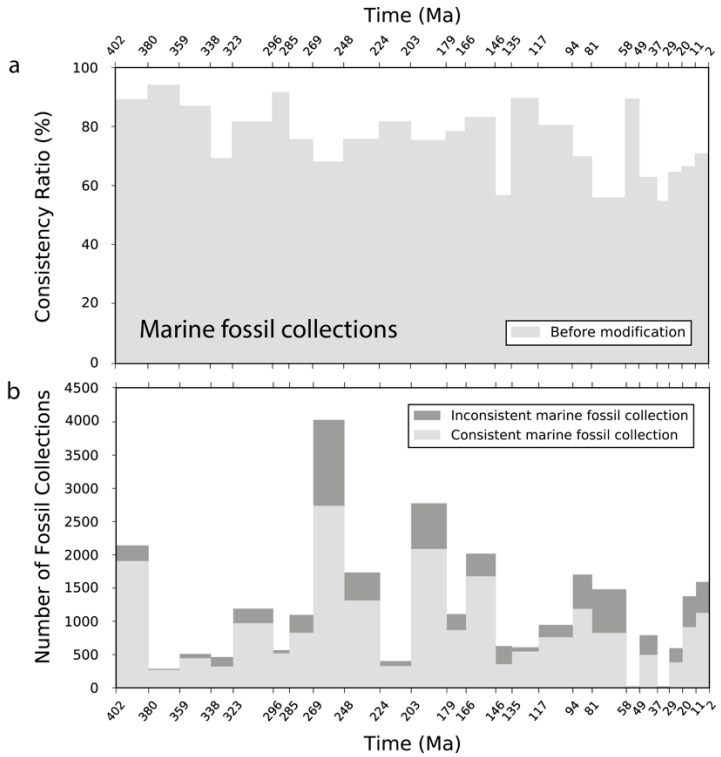

Fig. 3. (a) Consistency ratios between global paleogeography with gaps filled, but before PBDB test for the period 402-2 Ma, reconstructed using the plate motion model of Matthews et al. (2016) and the paleo-environments indicated by the marine fossil collections from the Paleobiology Database. **(b)** Numbers of consistent (light grey) and inconsistent (dark grey) marine fossil collections used in the tests for each time interval from 402 Ma and 2 Ma.

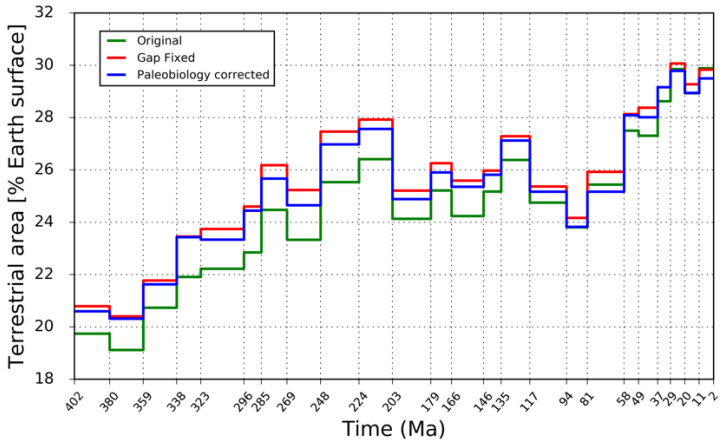

Fig. 4. Terrestrial areal change due to filling gaps and modifying the paleo-coastlines and paleogeographic geometries over time. Green: based on original paleogeographic maps of Golonka et al. (2006); Red: based on paleogeography reconstructed using a different plate motion model of Matthews et al. (2016) and gaps filled; Blue: based on paleogeography with gaps fixed and revised using the paleo-environments indicated by marine fossil collections from the Paleobiology Database.

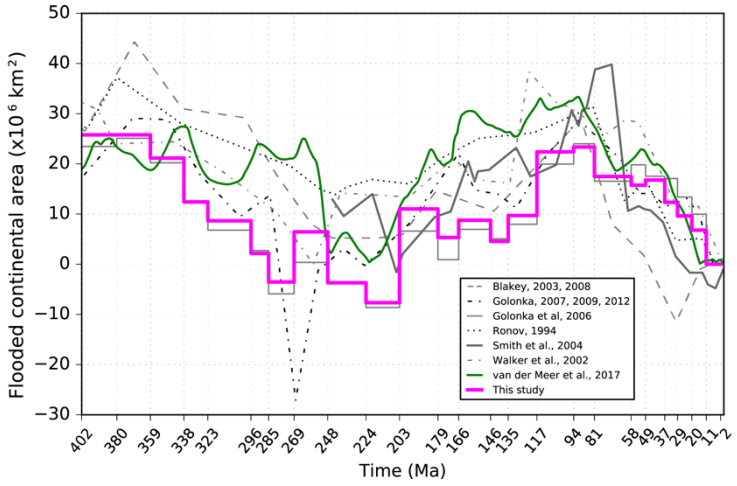

Fig. 5. Global flooded continental area since the Early Devonian Period from the original paleogeographic maps of Golonka et al. (2006) (grey solid line) and from the revised paleogeography in this study (pink line). Results for Blakey (2003, 2008), Golonka (2007b, 2009, 2012), Ronov (1994), Smith et al. (2004), Walker et al. (2002) are as in van der Meer et al. (2017). The van der Meer et al. (2017) curve (green line) represents an estimate of continental flooding derived from the Strontium isotope record.

Table 1. Time scale since Early Devonian times (Golonka, 2000) used in Golonka et al. (2006)'s paleo-maps, the original time scale of Sloss (1988), and 2016 time scale of the International Commission on Stratigraphy (ICS2016). Ages in italics are obtained by linear interpolation between subdivisions.

Era	Sloss (1988)			Golonka (2000)					ICS2016	
	Subsequence	Start (Ma)	End (Ma)	Time Slice	Epoch/Age	Start (Ma)	End (Ma)	Reconstruction Time (Ma)	Start (Ma)	End (Ma)
Cenozoic	Tejas III	29	0	Late Tejas III	Tortonian – Gelasian	11	2	6	11.63	1.80
				Late Tejas II	Burdigigalian – Serravallian	20	11	14	20.44	11.63
				Late Tejas I	Chattian – Aquitanian	29	20	22	28.1	20.44
	Tejas II	39	29	Early Tejas III	Priabonian – Rupelian	37	29	33	37.8	28.1
	Tejas I	60	39	Early Tejas II	Lutetian – Bartonian	49	37	45	47.8	37.8
				Early Tejas I	Thanetian – Ypresian	58	49	53	59.2	47.8
Mesozoic	Zuni III	96	60	Late Zuni IV	middle Campanian – Selandian (Late Cretaceous – earliest Paleogene)	81	58	76	*79.8*	59.2
				Late Zuni III	late Cenomanian – early Campanian (Late Cretaceous)	94	81	90	*96.1*	*79.8*
	Zuni II	134	96	Late Zuni II	late Aptian – middle Cenomanian (Early Cretaceous – earliest Late Cretaceous)	117	94	105	*119.0*	*96.1*
				Late Zuni I	late Valanginian – early Aptian (Early Cretaceous)	135	117	126	*136.4*	*119.0*
	Zuni I	186	134	Early Zuni III	late Tithonian – early Valanginian (latest Late Jurassic – earliest Early Cretaceous)	146	135	140	*147.4*	*136.4*
				Early Zuni II	late Bathonian – middle Tithonian (earliest Middle Jurassic – Late Jurassic)	166	146	152	*166.8*	*147.4*
				Early Zuni I	middle Aalenian – middle Bathonian (Middle Jurassic)	179	166	169	*172.8*	*166.8*
	Absorka III	245	186	Late Absaroka III	late Hettangian – early Aalenian (Early Jurassic – earliest Middle Jurassic)	203	179	195	*200.0*	*172.8*
				Late Absaroka II	late Carnian – middle Hettangian (Late Triassic – earliest Jurassic)	224	203	218	*232*	*200.0*
				Late Absaroka I	Induan – early Carnian (Early – earliest Late Triassic)	248	224	232	252.17	*232*
Paleozoic	Absorka II	268	245	Early Absaroka IV	Roadian – Changhsingian (Late Permian)	269	248	255	272.3	252.17
				Early Absaroka III	Sakmarian – Kungurian (Early Permian)	285	269	277	295.0	272.3
	Absorka I	330	268	Early Absaroka II	Gzhelian – Asselian (latest Carboniferous – earliest Permian)	296	285	287	303.7	295.0
				Early Absaroka I	Bashkirian – Kasimovian (Late Carboniferous)	323	296	302	323.2	303.7
	Kaskaskia II	362	330	Kaskaskia IV	middle Visean – Serpukhovian (Lower Carboniferous)	338	323	328	*341.4*	323.2
				Kaskaskia III	late Fammenian – early Visean (latest Devonian – Early Carboniferous)	359	338	348	*365.6*	*341.4*
	Kaskaski I	401	362	Kaskaskia II	Givetian – early Fammenian (Middle – Late Devonian)	380	359	368	387.7	*365.6*
				Kaskaskia I	late Pragian – Eifelian (Early – Middle Devonian)	402	380	396	*408.7*	387.7

Table 2. Lookup table to classify fossil data indicating different paleo-environments into marine or terrestrial settings and their corresponding paleogeographic types presented in Golonka et al. (2006). Terrestrial fossil paleo-environments correspond to paleogeographic features of landmasses, mountains or ice sheets, and marine fossil paleo-environments to shallow marine environments or deep oceans.

Marine			Terrestrial/Transitional Zone		
Paleogeography	**Fossil Paleo-environments**		**Paleogeography**	**Fossil Paleo-environments**	
Shallow marine environments/Deep oceans	marine indet.	slope	Landmasses/Mountains	terrestrial indet.	pond
	carbonate indet.	basinal (carbonate)		fluvial indet.	crater lake
	peritidal	basinal (siliceous)		alluvial fan	lacustrine delta plain
	shallow subtidal indet.	marginal marine indet.		channel lag	lacustrine interdistributary bay
	open shallow subtidal	coastal indet.		coarse channel fill	lacustrine delta front
	lagoonal/restricted shallow subtidal	estuary/bay		fine channel fill	lacustrine prodelta
	sand shoal	lagoonal		channel	lacustrine deltaic indet.
	reef, buildup or bioherm	paralic indet.		wet floodplain	lacustrine indet.
	perireef or subreef	interdistributary bay		dry floodplain	dune
	intrashelf/intraplatform reef	delta front		floodplain	interdune
	platform/shelf-margin reef	prodelta		crevasse splay	loess
	slope/ramp reef	deltaic indet.		levee	eolian indet.
	basin reef	foreshore		mire/swamp	cave
	deep subtidal ramp	shoreface		fluvial-lacustrine indet.	fissure fill
	deep subtidal shelf	transition zone/lower shoreface		delta plain	sinkhole
	deep subtidal indet.	offshore		fluvial-deltaic indet.	karst indet.
	offshore ramp	submarine fan		lacustrine - large	tar
	offshore shelf	basinal (siliciclastic)		lacustrine - small	spring
	offshore indet.	deep-water indet.	Ice sheets	glacial	

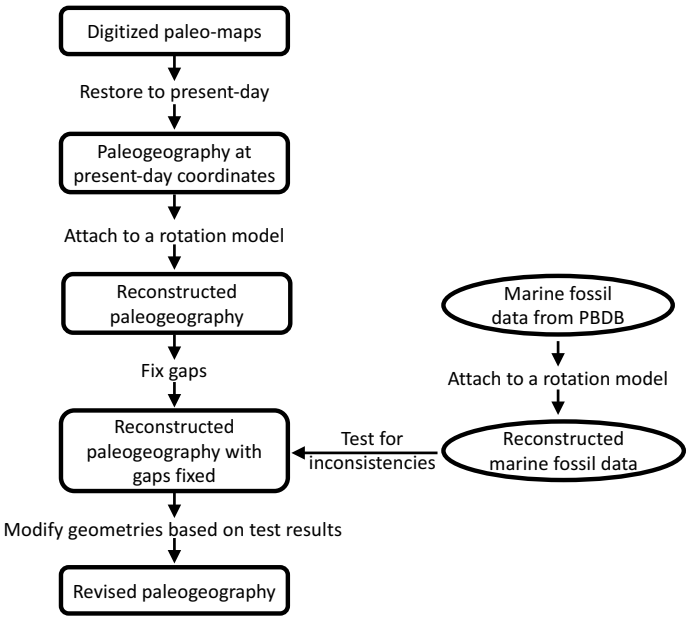

Fig. 6. Workflow used to transfer a set of paleogeographic geometries from one reconstruction to another, followed by revision using paleo-environmental information indicated by marine fossil collections from the Paleobiology Database (PBDB).