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

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Reviewer: The authors attempt to produce a flexible, digital representation of Earth’s plates through most of the Phanerozoic. This representation should allow testing paleogeographic features of the original dataset against other datasets, adopting different rotation models as used in the original dataset, among other things. The authors then use a comparison of their original distributions of land and sea to that implied by the distribution of fossil organisms, to get a more accurate picture of the distributions of land and sea through Earth’s history. These ‘improved’ distributions are then used for various comparisons with eustatic sea level curves and measures for continental weathering. Although the attempt to build a flexible model of Earth’s plate movements through time is fine and useful, most of the subsequent comparisons are, in my view, redundant, insufficiently interpreted and discussed. Also the methods section needs improvements. In the present state I can only recommend to reject the manuscript, and to encourage the authors to focus on the core of their work (the model), to improve the methods section, and revamp their ‘testing’ and their discussion.
Authors: We thank the reviewer for his/her constructive review that will guide our revision of the manuscript. We will amend the paleogeographic model, give more detail in the Method section, and change the tests carried out on the paleogeographies using paleobiology. We will delete the comparison between continental flooding curves and published sea level fluctuations as there may be some circularity in this comparison, and the comparison between emerged land area, total land area and the evolution of strontium isotopes of marine carbonates. Instead, we will compare our flooded continental area curve to previously published ones (see Fig. 1 below). We will estimate the terrestrial and oceanic areal change due to filling gaps and modifying the coastline locations and the paleogeographic geometries over time (see Fig. 2 below), test the marine fossil collection dataset used in this study for fossil abundances over time with two different time scales (see Fig.3 below), and discuss the limitations of the workflow we developed in this study.

Reviewer: Detailed comments by line number: 106-108, there is another important bias in the PBDB: the uneven entry of fossil data.
Authors: We agree and will add this to the sentence in the revision.

Reviewer: 116-117, repetition
Authors: We will rewrite this sentence in the revision.

Reviewer: 145-147, I have the feeling that the authors are trying to explain here which environmental types have gone into the gaps and overlaps, but I failed to understand it.
Authors: We will delete this sentence to avoid any confusion.

Reviewer: 155-159, here the authors sometimes talk about ‘fossil collections’ and sometimes about ‘fossils’, though my impression is that they always mean ‘fossil collections’ – please be consistent here and throughout the ms in general.
Authors: Yes, they all mean ‘fossil collections’. This will be corrected throughout the manuscript.

Reviewer: 187-190, unclear how it was decided which ‘fossils’ (by which the authors presumably mean ‘fossil collection site’) are included in such a cluster and which aren’t. It is important to make clear how the boundaries of these clusters are drawn.
Authors: In our revised version of the maps, we will only use marine fossil collections to improve paleo-coastline locations and the paleogeographic geometries (see Fig. 4, 5, 6 below), because the coastlines on the paleo-maps used in this study represent maximum transgression surfaces, so this is not the case anymore.

Reviewer: 235-243, this entire test is redundant: if you’re adjusting the land-sea boundary in such a way that most inconsistencies are removed, of course does your ‘consistency index’ improve.
Authors: We will delete the test of modified paleogeography with paleobiology, and will only present the test of unmodified paleogeography (see Fig. 6 below).

Reviewer: Paragraph 245-257, it is not clear to me what the authors are getting at with this paragraph. They discuss various biases and inhomogeneities of the fossil data, but neither do they apply a coherent test to the problem, nor do they reach any conclusion (except perhaps for “fewer fossils = fewer possibilities for adjustments”, but this again is trivial).
Authors: We will apply a test on the marine fossil collection dataset used in this study for fossil abundances over time with two different time scales: ICS2016 and Golonka (2000) (see Table 1 below), and we will revise this paragraph, delete the trivial part, present the result (see Fig. 3 below) and discuss it in the Discussions section.

Reviewer: 245-249, as for lines 106-108, uneven entry of data is another potential bias.
Authors: We will add this in the revision.

Reviewer: 249-251, “shorter time spans contain fewer fossils” – it might be interesting to systematically test the fossil dataset for this.
Authors: We will test the dataset used in this study for fossil abundances over time with two different time scales: ICS2016 and Golonka (2000) (see Table 1 below), present the result (see Fig. 3 below) and discuss it in the Discussions section.

Reviewer: 253, “biological organisms” – organisms are biological by definition
Authors: We will remove “biological” in the revision.

Reviewer: 264-267, here I was wondering how much of the “areal change” might relate to the gap filling and overlap removal that the authors have done to fit the plate reconstructions. In their lines 144-145 they wrote that the total areal variations ranged from 5.8 to -2.7%. A comparison of these values through time to the extent of area change through time (or something along these lines) might provide valuable insights here.
Authors: We will estimate the areal change in two key steps of the methodology, including filling gaps and modifying the coastline locations and paleogeographic geometries, present the results (see Fig. 2 below) and explain it in the Discussions section.

Reviewer: 281ff, unless I’ve overlooked it, there is a step missing here in the explanation of the method. So far, the authors explained that in their adjustments, they exchanged ‘land’ for ‘sea’ and vice versa. But now they start discussing the quantification of different habitat

types (shallow vs. deep sea, mountains vs. low lands etc.). Does this mean that when the land-sea boundary was shifted, for example, the ‘new sea area’ was assigned the habitat type of the fossil collection that caused the change? For example, has an area previously classified as ‘mountain’ sometimes been replaced by ‘shallow marine’ and sometimes by ‘deep marine’? If so, this needs to be explained in the Methods section.
Authors: We will explain this in the Method section.

Reviewer: 310ff, this whole paragraph seems redundant. It is pretty obvious to any earth scientist that continental flooding and eustatic sea level changes are linked. Not only is it obvious that eustatic sealevel changes cause continental flooding (what else should it be?); to make matters worse, the eustatic sealevel curves are inferred from the continental flooding history as recorded in the sedimentary record so you might be looking at circularity here.
Authors: We will remove this entire paragraph as indeed there could be some degree of circularity.

Reviewer: 332, the difference between 27.7% and 27.5% isn’t really great, isn’t it? The authors should be a little more cautious about the errors in their own model. Could this difference of 0.2% again result from their gap filling procedure? Or could it be related to the inconsistencies in their ‘improved paleogeographies’? In their lines 238-241 they write that even their ‘improved paleogeographies’ are still 3-5% inconsistent, which is a lot more than the 0.2% difference mentioned above. I recommend that the authors assess these inherent errors in their model (gap filling and ‘consistency’ index) and then discuss only variations that exceed those errors.
Authors: Since we will delete the comparison between emerged land area, total land area and the evolution of strontium isotopes, this part will be removed accordingly. As suggested here, we will amend the paleogeographic model and update the test carried out on the paleogeographies using paleobiology. We will estimate the errors of two key steps in the workflow, including filling gaps and modifying the coastline locations and the paleogeography, on the terrestrial or oceanic areal change over time (see Fig. 2 below) and discuss them in the Discussions section.

Reviewer: 341, 3% of the world’s continental area has disappeared in the Neogene? Where did it go?
Authors: There is an increase in mountainous areas compensating the loss in non-elevated land.

Reviewer: 350-351, the abbreviation CGM is not explained (and perhaps not necessary?)
Authors: As we will delete this entire paragraph, this will be deleted in the revision accordingly.

Reviewer: 363, I find it dubious to ‘confirm that Sr isotope ratios have a good correlation with emerged land areas’ when there is no such correlation in the Paleozoic. Doesn’t this rather indicate that there may be something fundamentally wrong with this correlation? I have no solution to the problem, but it seems more scientifically to me to point out such inconsistencies rather than to uncritically reiterate some lukewarm ‘conventional wisdom’.
Authors: We will delete the comparison between emerged land area, total land area and the evolution of strontium isotopes of marine carbonates in the revision.

Reviewer: 366ff, the ‘Conclusions’ nicely sum up the good parts and the problems of this study. The first paragraph outlines the good part, the flexible, digital plate model that could surely be of use for a wide range of earth scientists. The second paragraph discusses the redundant correlation between emerged land and eustatic sea level changes, and the third paragraph again ‘confirms’ a correlation between Sr isotopes and emerged land, which apparently doesn’t exist in the Paleozoic.
Authors: Our conclusions will be amended in the revision. Thanks to the input from the reviewer.

Reviewer: Table 1. why is this awkward Sloss 1988 timetable used? As far as I can tell, it applies to the US only, and connecting it to the accepted ICS and GSA timescales and to the periods, series and stages that have been used by geologists for more than 100 years is confusing. Avoid this, it is of no use for geologists and paleontologists.
Authors: Sloss (1988) is the base of the time scale of Golonka (2000) applied to the paleogeography used in this study. We have converted the time scales of Sloss (1988) and Golonka (2000) to agree with the ICS2016 and will present them together in the table (See Table 1 below).

Reviewer: Table 2, I had difficulties relating this table to what’s written in the manuscript. The table distinguishes three paleogeographies (shallow marine, landmass/mountain, ice sheet), whereas in the text and fig 8 five distinctions are made (shallow marine, deep marine, land masses, mountains, ice sheets). Please be consistent here.
Authors: We will correct this in the revision (see Table 2 below).

Reviewer: Figure 5. colors and shapes are not explained; perhaps refer to fig. 4? And I presume you mean “fossil collection sites” rather than “fossils”? I don’t see any fossils in this figure.
Authors: We will replace Figure 5 by a new figure (see Fig. 5 below) in which the colours and shapes will be explained clearly. Yes, we refer to “fossil collection sites” rather than “fossils” and we will correct this throughout the manuscript.

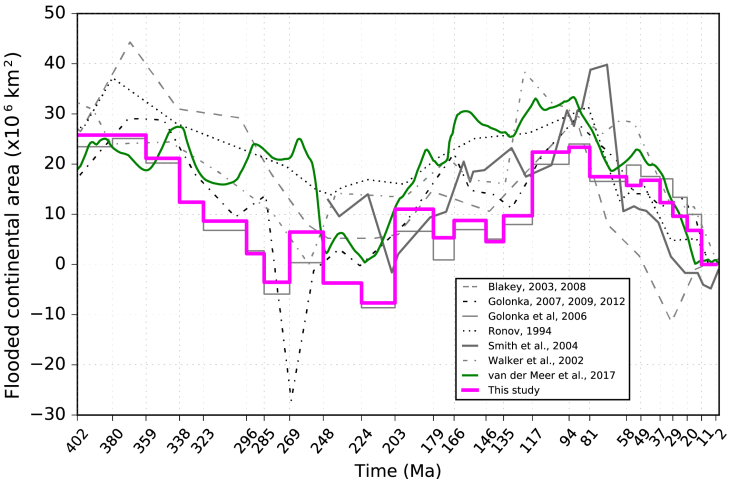

Fig. 1. Global flooded continental area since the Early Devonian Period from the original paleogeographic maps of Golonka et al. (2006) (grey solid line) and from the revised paleogeography in this study (pink line). Results for Blakey (2003, 2008), Golonka (2007b, 2009, 2012), Ronov (1994), Smith et 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.

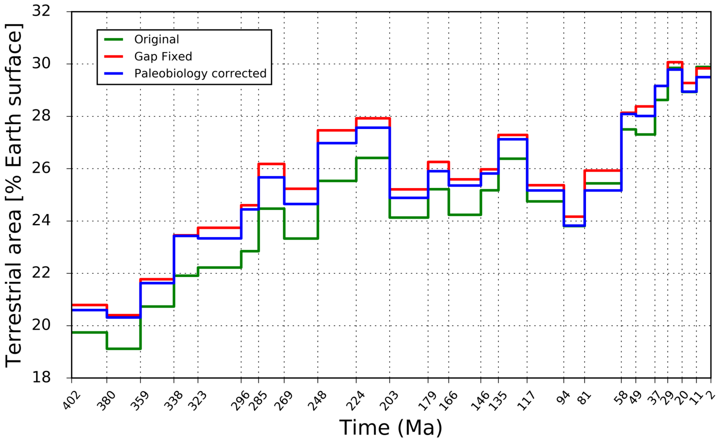

Fig. 2. Terrestrial areal change due to filling gaps and modifying the paleo-coastlines and paleogeographic geometries over time. Green: based on original paleogeographic maps of Golonka et al. (2006); Red: based on paleogeography reconstructed using a different plate motion model of Matthews et al. (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.

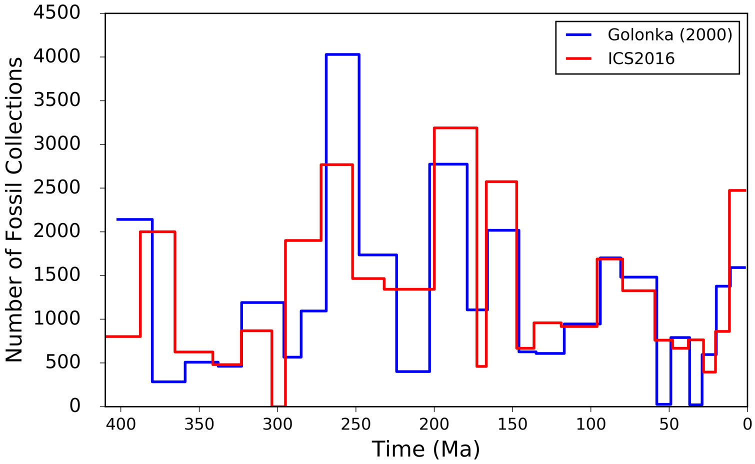

Fig. 3. Fossil abundance test on the marine fossil collection dataset used in this study with two different time scales: Golonka (2000) and ICS2016 (Table 1).

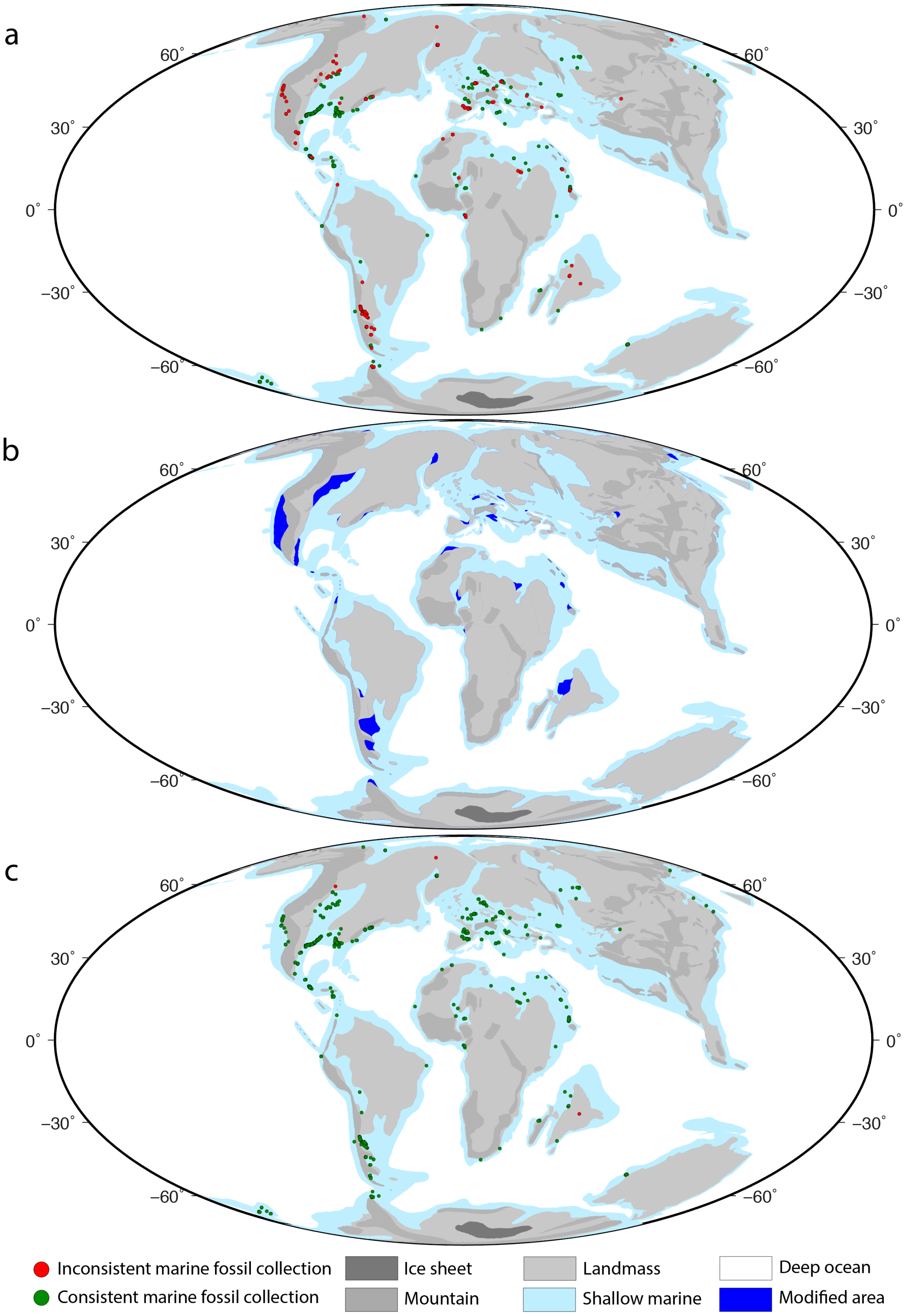

Fig. 4. (**a**) Test between the global paleogeography at 76 Ma reconstructed using the plate motion model of Matthews et al. (2016) with gaps fixed and the paleo-environments indicated by the marine fossil collections from the Paleobiology Database. (**b**) Areas modified (blue) to resolve the test inconsistencies. (**c**) Test between the revised paleogeography at 76 Ma and the same marine fossil collections. Mollweide projection with 0°E central meridian.

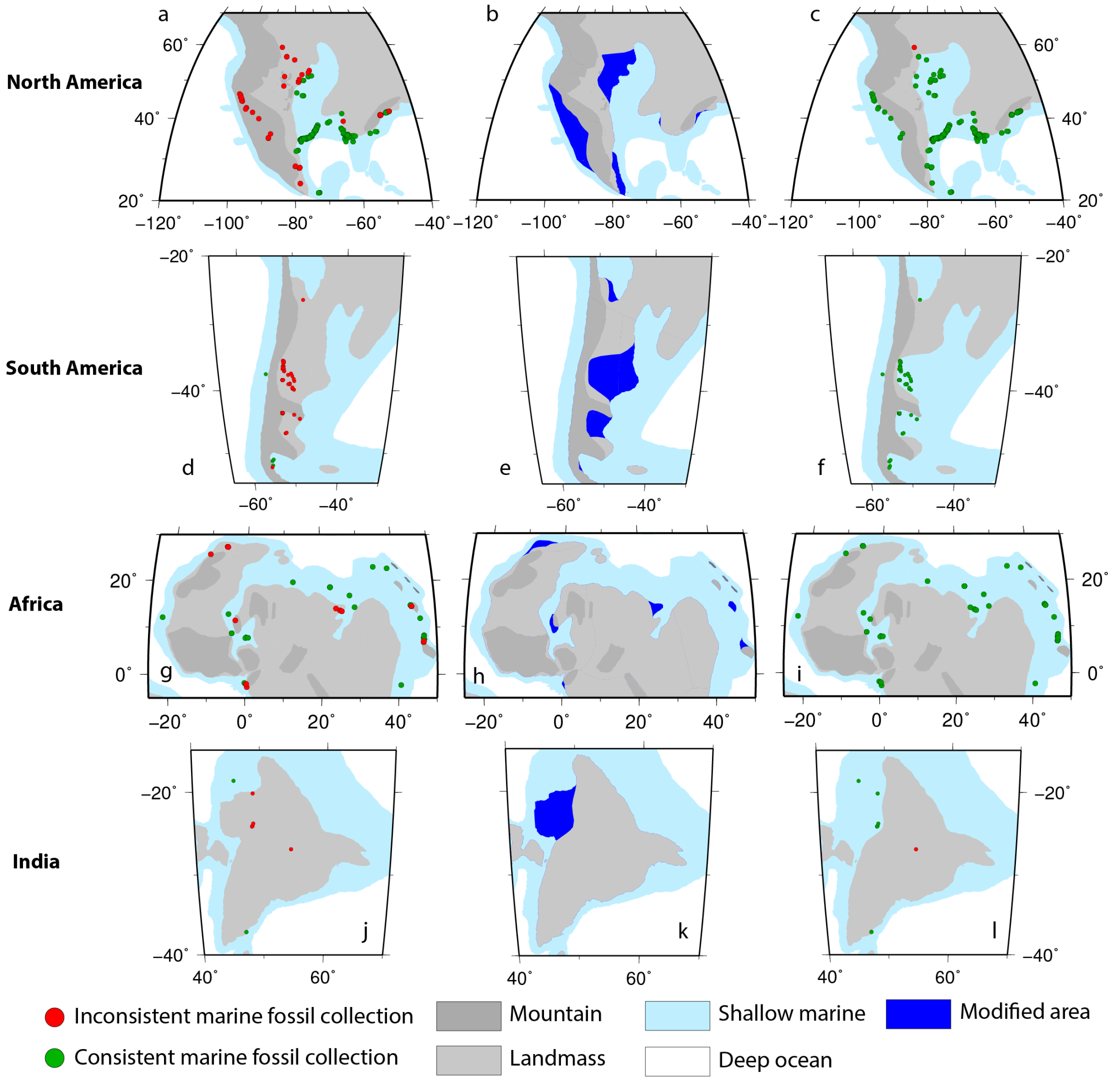

Fig. 5. Tests between unrevised and revised paleogeography at 76 Ma respectively and paleo-environments indicated by the marine fossil collections from the Paleobiology Database, and revision of paleo-coastlines and paleogeographic geometries based on the test results, for southern North America **(a, b, c)**, southern South America **(d, e, f)**, northern Africa **(g, h, i)** and India **(j, k, l)**. Mollweide projection.

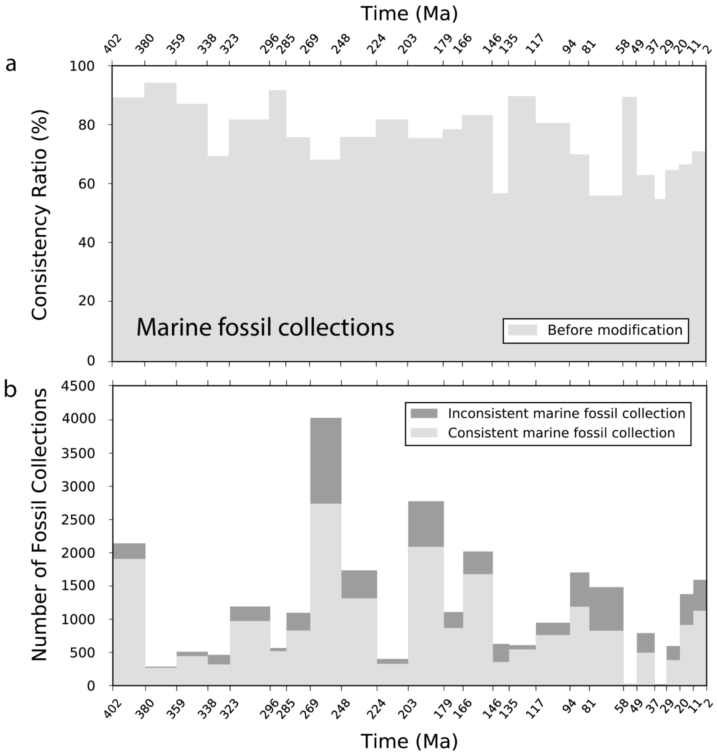

Fig. 6. (a) Consistency ratios between global paleogeography with gaps filled, but before PBDB test for the period 402-2 Ma, reconstructed using the plate motion model of Matthews et al. (2016) and the paleo-environments indicated by the marine fossil collections from the Paleobiology Database. **(b)** 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.

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	