Was the North Atlantic Ocean well-ventilated during Oceanic Anoxic Event 2 in the mid-Cretaceous?

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Supplementary Information

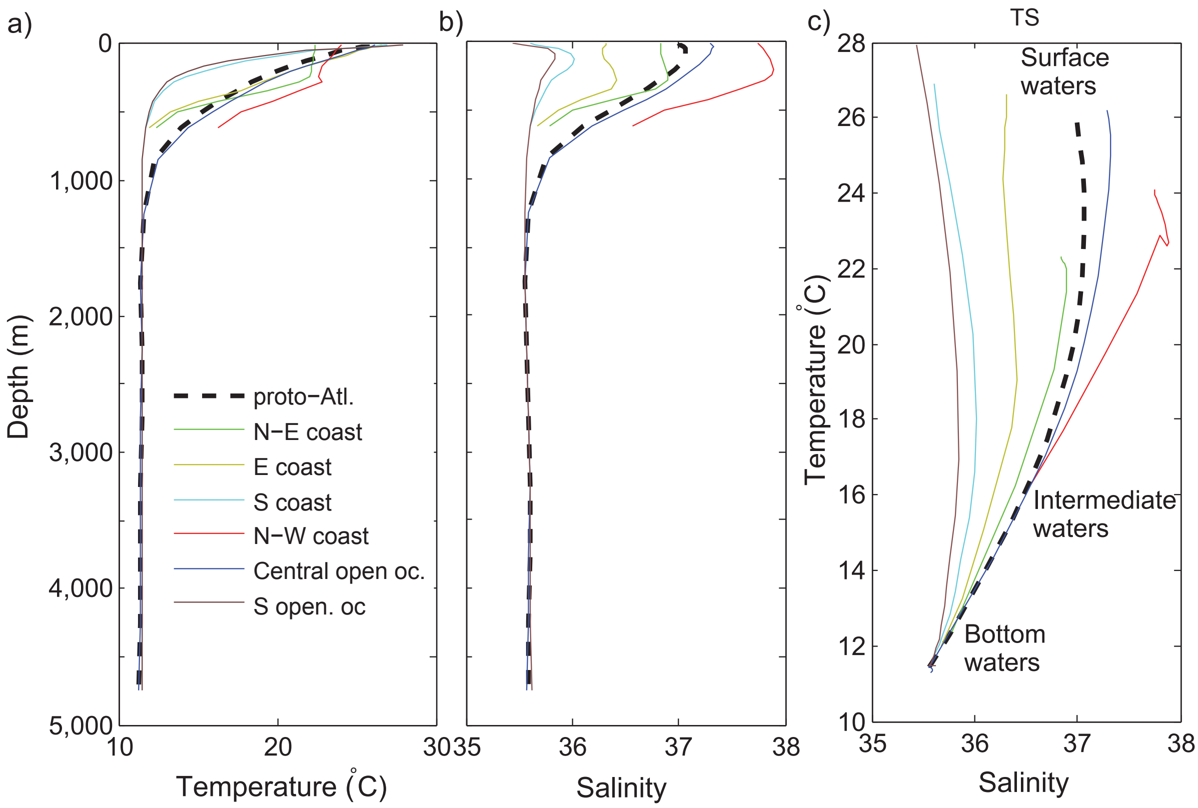

Figure S1: Profiles of a) mean temperature and b) salinity and c) a temperature (T)-salinity (S) diagram for several regions of the proto-North Atlantic, where the basin average is also shown with a dashed line (Topper et al., 2011). The TS diagram highlights that the proto-North Atlantic was poorly stratified. Note that the temperatures may be underestimated since the model uses yearly averaged air temperature as its forcing.

Table S1: Compilation of particulate organic carbon (POC) contents and various proxies for redox conditions such as POC/P_{TOT} ratios, biomarkers, trace metals (TM) and indicators for bioturbation for pre-OAE2 and OAE2 sediments in the proto-North Atlantic.

Sites	Location	Depth (m)	POC (wt%) pre-OAE2	POC (wt%) OAE2	POC/P_{TOT} pre-OAE2	POC/P_{TOT} OAE2	Biomarkers, TM pre-OAE2	Biomarkers, TM OAE2
	CENTRAL OPEN OCEAN							
105	Rise hill	4100	n.d.	9.5[3]	n.a.	n.a.	low Mo[30]	rise in Mo[30], bioturbation[8,25]
603	Cape Hatteras	4000	0.5-1[1]	3[2]	n.a.	330[2]	low Mo[30]	rise in Mo[30], bioturbation[8,25], low isoren.[25,32], TM enrich[25]
417	Hatteras Abyssal Plain	5500	n.d.	5.8 [3]	n.a.	n.a.		
638-641	Galicia Bank	>3000	<0.5[1]	11.3[4,1,26]	n.a.	n.a.		TM enrich[4]
551	Goban Spur	1500	n.d.	6.5[3]	n.a.	n.a.		
1276	Newfoundland basin	>2000	<0.5[5,6]	5[5,6]	n.a.	n.a.		low isoren.[31]
135		>2000	n.d.	7[7]	n.a.	n.a.		
138		>2000	n.d.	7[7,8]	n.a.	n.a.		
386	Bermuda Rise	<3200	∼1[33]	>5[33]	n.a.	n.a.		
398	Galicia Plateau	<700	∼0.5[1,22]	2.8[1,22]	n.a.	n.a.		
	AVERAGE		*∼0.5*	*∼6.7*		*330*		
	SOUTHERN OPEN OCEAN							
144		3000	5[4]	6[3]	n.a.	n.a.	low isoren.[4] high Mo[30]	high isoren./chlorobac.[3,4] high Mo[30]
367	Cape Verde Basin	3700	6.4[4]	21[3,4]	227[28]	552[28]	low isoren.[4] high Mo[30]	high isoren.[3,4,32]/chlorobac.[3,4] high Mo[30]
368	Cape Verde Rise	3700	n.d.	9.2[3]	n.a.	n.a.		high isoren.[3,32]
	AVERAGE		*∼5.7*	*∼12.3*	*227*	*552*		
	SOUTHERN COAST							
1258-1261	Demerara Rise	500-1500	7.6[18]	15.6[18]	114[2]	730[2]	low isoren., chlorobac. TM pick, high lyco./n-alkane[18], high Mo[30]	high isoren., chlorobac., TM enrich, high lyco./n-alkane[18] high Ti/Al[29], high Mo[30]
S_n	Tarfaya Basin	∼250	5.5[2,4,19,20]	8.5[2,4,19]	160[2,19]	458[2,27,19]	low isoren., chlorobac. TM pick, high lyco./n-alkane[20] mod. Mo, stable Fe_T/Al and $\delta^{56}Fe_T$[30]	high isoren., chlorobac. mod. Mo[30], TM enrich[20] stable Fe_T/Al and $\delta^{56}Fe_T$[30]
	Casamance Area	<100	1[8]	3.8[8]	n.a.	n.a.		
	Agadir Basin	<300	n.a.	4[8]	n.a.	n.a.		
	AVERAGE		*4.7*	*8*	*137*	*594*		
	WESTERN INTERIOR SEAWAY							
El pueblo	Colorado	<700	n.a.	1[9]	n.a.	250[9]		
USGS	Portland Colorado	<700	n.a.	2[10]	n.a.	n.a.		
	Rock Canyon	<700	n.a.	1.5[11]	n.a.	n.a.		
	AVERAGE			*1.5*		*250*		
	NORTHERN COAST							
627, 635	Bahamas	<500	<0.5[12]	1-5[12]	n.a.	n.a.		
1050, 1052	Blake Nose	∼500	<0.5[13,14]	1-5[13,14]	n.a.	n.a.		
	Bass River	30	0.6[15,16,17]	1.1[15,16,17]	45[17]	100[17]		

continuation

Sites	Location	Depth (m)	POC (wt%)		POC/P_{TOT}		Biomarkers, TM	
			pre-OAE2	OAE2	pre-OAE2	OAE2	pre-OAE2	OAE2
	AVERAGE		*~0.5*	*~1*	*45*	*100*		
	NORTH-EASTERN COAST							
	Wunstorf Germany	~100	<0.1[21,22]	0.7[21,22]	10[21,22]	33[21,22]		Si/Al, K/Al, Mn/Al rise[21]
	Eastborn England	~100	~0.1[23]	0.2[23]	n.a.	n.a.	low Mo[30]	fall of I/Ca[31]
							low Fe_T/Al[30]	and Mn, low Mo and Fe_T/Al[30]
	Vocontian Basin France	~200	~0.1[22,23]	0.5-1[22,23]	n.a.	n.a.		
549	Goban Spur	<700	<0.1[13,14]	<1[13,14]	n.a.	n.a.		
	AVERAGE		*~0.1*	*~1*	*10*	*33*		
	TETHYS GATEWAY							
El Chorro	Coast of Spain	<700	<0.5[24]	0.5-1[24]	n.a.	n.a.		
Hedionda	Coast of Spain	<700	<0.5[24]	1-5[24]	n.a.	n.a.		
Manilva	Coast of Spain	<700	0.5-1[9]	0.5-1[9]	n.a.	750[9]		
	Coast of N-Africa and Spain	<700	n.d.	0.31[8]	n.a.	n.a.		
	AVERAGE		*~0.5*	*~1*		*750*		

n.a. = not available; n.d. = not detected; [1]: Thurow et al., 1988; [2]: Kraal et al.,2010b; [3]: Sinninghe Damsté and Köster, 1998; [4]: Kuypers et al., 2002; [5]: Sinninghe Damsté et al., 2010; [6]: Urquhart et al., 2007; [7]: Lancelot et al., 1980; [8] Herbin et al., 1986; [9]: Mort et al., 2007; [10] Meyers et al., 2001; [11]: Snow et al., 2005; [12]: Austin et al., 1986; [13]: Norris et al., 2001; [14]: Barker et al., 2001; [15]: Sugarman et al., 1999; [16]: Bowman and Bralower, 2005; [17]: this study; [18]: van Bentum et al., 2009; [19]: Nederbragt et al., 2004; [20]: Kolonic et al., 2005; [21]: Hetzel et al., 2011; [22]: Arthur and Dean, 1988; [23]: Voigt, 2000; [24]: Rodríguez-Tovar et al., 2010; [25]: Kuypers et al., 2004; [26]: Kuhnt et al., 1990; [27]: Mort et al., 2008; [28]: M. M. M. Kuypers, personal communication; [29]: Hetzel et al.,2009; [30]: Owens et al., 2012; [31]: van Bentum et al., 2012; [32]: Pancost et al., 2004; [33]: Kuhnt and Wiedmann, 1995

Table S2: Water cycle: Reservoirs and fluxes for pre-OAE2 and OAE2 conditions as implemented in the multi-box model. Note that several fluxes change direction from pre-OAE2 to OAE2 conditions.

Box Name	Water reservoir pre-OAE2	OAE2	Description units in Tm^3
W1s	1522.11	1554.12	Surface water of the central open ocean
W1i	8623.65	8805.83	Intermediate water of the central open ocean
W1b	38518.87	40583.26	Bottom water of the central open ocean
W2s	254.6	259.51	Surface water of the southern open ocean
W2i	1527.58	1557.09	Intermediate water of the southern open ocean
W2b	7056.33	7408.83	Bottom water of the southern open ocean
W3s	53.47	227.61	Surface water of the Western Interior Seaway
W3b	139.12	387.49	Shallow bottom water of the Western Interior Seaway
W4s	129.37	202.61	Surface water of the northern coast
W4b	340.46	461.35	Shallow bottom water of the northern coast
W5s	129.17	202.41	Surface water of the southern coast
W5b	340.21	461.1	Shallow bottom water of the southern coast
W6s	47.75	76.25	Surface water of the north-eastern coast
W6b	128.28	180.06	Shallow bottom water of the north-eastern coast
W7s	35.66	34.29	Surface water of the Tethys gateway
W7b	91.35	125.63	Shallow bottom water of the Tethys gateway
Name	**Water flux (Sv) pre-OAE2**	**OAE2**	**Description ($x\ 3.1536\ for\ Tm^3\ y{-}1$)**
F1	4.91	7.09	Net surface water flux from W1s to the Pacific Ocean
F3	9.26	15.15	Net intermediate water flux from W1i to the Pacific Ocean
F6	13.75	21.98	Net bottom water flux from the Pacific Ocean to W1b
F7	1.3	6.67	Net surface water flux from the Tethys gateway to W7s
F10	0.88	6.47	Net bottom water flux from W7b to the Tethys gateway
F11	1.32	1.32	Evaporation in W1s
F12	0.81	0.81	Precipitation in W1s
F13	6.57	7.46	Surface water flux from W4s to W1s
F14	0.59	3.36	Surface water flux from W1s to W6s
F15	0.65	4.15	Surface water flux from W7s to W1s
F16	10.6	17.13	Downwelling from W1s to W1i
F17	2.89	7.83	Upwelling from W1i to W1s
F18	1.02	1.17	Surface water flux from W5s to W2s (Changes direction during OAE2)
F19	1.75	2.49	Surface water flux from W1s to W3s
F20	10.35	9.25	Intermediate water flux from W1i to W3b
F21	5.64	13.77	Shallow bottom water flux from W4b to W1i
F22	0.61	2.89	Intermediate water flux from W1i to W6b
F23	0.12	8.64	Intermediate water flux from W1i to W7b
F24	4.65	2.73	Shallow bottom water flux from W5b to W2i
F25	0.12	5.86	Deep bottom water flux from W1b to W7b
F26	1.71	1.75	Downwelling water flux from W7s to W7b
F27	2.12	3.44	Upwelling water flux from bottom W7b to W7s
F28	0.75	1.31	Downwelling water flux form W5s to W5b
F29	4.38	5.74	Upwelling water flux from W5b to W5s

continuation

Name	Water flux (Sv)		Description
	pre-OAE2	OAE2	(*x 3.1536 for Tm*^{3} *y*-1)
F30	0.3	0.3	River water flux to W5st
F31	5.21	6.05	Downwelling water flux from W3s to W3b
F32	6.9	7.38	Upwelling water flux from W3b to W3s
F33	5.39	3.83	Downwelling water flux from W4s to W4b
F34	8.24	4.62	Upwelling water flux from W4b to W4s
F35	1.1	3.17	Downwelling water flux from W6s to W6b
F36	0.43	1.15	Upwelling water flux from W6b to W6s
F37	8.38	19.16	Downwelling water flux from W1i to W1b
F38	21.23	33.31	Upwelling water flux from W1b to W1i
F39	3.53	3.97	Surface water flux from W3s to W4s
F40	0.08	2.61	Surface water flux from W6s to W4s
F41	0.15	1.25	Surface water flux from W7s to W6s
F42	0.91	2.95	Surface water flux from W7s to W5s
F43	0.41	4.62	Shallow bottom water flux from W7b to W5b
F44	1.46	1.73	Shallow bottom water flux from W6b to W7b (Changes direction during OAE2)
F45	0.18	6.63	Shallow bottom water flux from W4b to W6b (Changes direction during OAE2)
F46	8.67	7.93	Shallow bottom water flux from W3b to W4b
F47	3.85	4.59	Surface water flux from W1s to W2s
F48	8.27	6.87	Surface water flux from W2s to W1s
F49	8.34	2.1	Intermediate water flux from W1i to W5b
F50	9.92	11	Intermediate water flux from W1i to W2i
F51	12.42	11.79	Intermediate water flux from W2i to W1i
F52	15.37	17.73	Deep bottom water flux from W1b to W2b
F53	14.6	15.76	Deep bottom water flux from W2b to W1b
F54	3.82	8.85	Surface water flux from W5s to W1s
F55	0.12	0.15	Downwelling water flux from W2s to W2i
F56	3.51	3.6	Upwelling water flux from W2i to W2s
F57	0.37	0.37	Downwelling water flux from W2i to W2b
F58	1.62	1.9	Upwelling water flux from bottom W2b to W2i
F59	0.48	0.45	Shallow bottom water flux from W5b to W2b (Changes direction during OAE2)
R3	0.1	0.15	River water flux to W3s
R4	0.1	0.1	River water flux to W4s
R6	0.01	0.01	River water flux to W6s

Table S3: Carbon cycle: Reservoirs sizes and fluxes for pre-OAE2 and OAE2 conditions and pre-OAE2 biogeochemical fluxes as implemented in the multi-box model. Note that all OAE2 reservoirs, including the ones in Table S4 and S5, are the ones obtained after equilibrium.

Name	C reservoir pre-OAE2	OAE2	Description units in Tmol C
POC1s	4.84	4.54	Organic C in the surface water of the central open ocean
POC1i	9.14	8.58	Organic C in the intermediate water of the central open ocean
POC1b	8.17	7.67	Organic C in the bottom water of the central open ocean
POC2s	2.16	1.74	Organic C in the surface water of the southern open ocean
POC2i	6.48	5.23	Organic C in the intermediate water of the southern open ocean
POC2b	2.24	1.81	Organic C in the bottom water of the southern open ocean
POC3s	0.23	0.52	Organic C in the surface water of the Western Interior Seaway
POC3b	0.01	0.03	Organic C in the bottom water of the Western Interior Seaway
POC4s	0.69	0.49	Organic C in the surface water of the northern coast
POC4b	0.07	0.05	Organic C in the bottom water of the northern coast
POC5s	1.1	1.37	Organic C in the surface water of the southern coast
POC5b	0.29	0.36	Organic C in the bottom water of the southern coast
POC6s	0.05	0.07	Organic C in the surface water of the north-eastern coast
POC6b	0.01	0.02	Organic C in the bottom water of the north-eastern coast
POC7s	0.04	0.03	Organic C in the surface water of the Tethys gatway
POC7b	0.01	0.01	Organic C in the bottom water of the Tethys gatway
Name	**C flux pre-OAE2**	**OAE2**	**Description units in Tmol C $y-1$**
BCF1	163.79	153.79	Primary productivity in the central open ocean
BCF2	142.73	134.01	Remineralization in the surface water of the central open ocean
BCF3	16.38	15.28	Remineralization in the intermediate water of the central open ocean
BCF4	4.67	4.38	Remineralization in the bottom water of the central open ocean
BCF5	0.02	0.015	Organic C burial in the central open ocean
BCF6	224	180.89	Primary productivity in the southern open ocean
BCF7	195.2	157.62	Remineralization in the surface water of the southern open ocean
BCF8	22.4	18.09	Remineralization in the intermediate water of the southern open ocean
BCF9	6.38	5.15	Remineralization in the bottom water of the southern open ocean
BCF10	0.03	0.02	Organic C burial in the southern open ocean
BCF11	45.76	105.16	Primary productivity in the Western Interior Seaway
BCF12	39.81	91.49	Remineralization in the surface water of the Western Interior Seaway
BCF13	5.83	13.39	Remineralization in the shallow bottom water of the Western Interior Seaway
BCF14	0.16*	0.28	Organic C burial in the Western Interior Seaway
BCF15	104.64	75.16	Primary productivity in the northern coast
BCF16	91.04	65.39	Remineralization in the surface water of the northern coast
BCF17	13.31	9.57	Remineralization in the shallow bottom water of the northern coast
BCF18	0.29*	0.2	Organic C burial in the northern coast
BCF19	168.3	210.01	Primary productivity in the southern coast
BCF20	146.42	182.7	Remineralization in the surface water of the southern coast
BCF21	21.25	26.52	Remineralization in the shallow bottom water of the southern coast
BCF22	0.63*	0.77	Organic C burial in the southern coast
BCF23	4.25	6.14	Primary productivity in the north-eastern coast
BCF24	3.7	5.34	Remineralization in the surface water of the north-eastern coast

continuation

Name	C flux pre-OAE2	OAE2	Description units in Tmol C y−1
BCF25	0.54	0.78	Remineralization in the shallow bottom water of the north-eastern coast
BCF26	0.01	0.02	Organic C burial in the north-eastern coast
BCF27	24	22.19	Primary productivity in the Tethys gatewaygateway
BCF28	20.88	19.3	Remineralization in the surface water of the Tethys gatewaygateway
BCF29	3.06	2.83	Remineralization in the shallow bottom water of the Tethys gatewaygateway
BCF30	0.069	0.057	Organic C burial in the Tethys gatewaygateway
BCF31	21.06	19.78	Organic C export to the intermediate water in the central open ocean
BCF32	4.68	4.4	Organic C export to the bottom water in the central open ocean
BCF33	28.8	23.26	Organic C export to the intermediate water in the southern open ocean
BCF34	6.4	5.17	Organic C export to the bottom water in the southern open ocean
PCF35	5.95	13.67	Organic C export to the shallow bottom water in the Western Interior Seaway
BCF36	13.60	9.77	Organic C export to the shallow bottom water in the northern coast
BCF37	21.88	27.3	Organic C export to the shallow bottom water in the southern coast
BCF38	0.55	0.8	Organic C export to the shallow bottom water in the north-eastern coast
BCF39	3.12	2.89	Organic C export to the shallow bottom water in the Tethys gatewaygateway

Table S4: Phosphorus cycle: Reservoirs sizes and fluxes for pre-OAE2 and OAE2 conditions, and pre-OAE2 biogeochemical fluxes as implemented in the multi-box model.

Name	P reservoir pre-OAE2	OAE2	Description units in Tmol P
SRP1s	0.68	0.64	Soluble reactive P in the surface water of the open ocean
SRP1i	13.6	10.48	Soluble reactive P in the intermediate water of the open ocean
SRP1b	59.7	52.86	Soluble reactive P in the bottom water of the open ocean
SRP2s	0.04	0.03	Soluble reactive P in the surface water of the southern open ocean
SRP2i	3.29	2.64	Soluble reactive P in the intermediate water of the southern open ocean
SRP2b	11.98	10.34	Soluble reactive P in the bottom water of the southern open ocean
SRP3s	0.06	0.13	Soluble reactive P in the surface water of the Western Interior Seaway
SRP3b	0.21	0.47	Soluble reactive P in the bottom water of the Western Interior Seaway
SRP4s	0.15	0.1	Soluble reactive P in the surface water of the northern coast
SRP4b	0.56	0.52	Soluble reactive P in the shallow bottom water of the northern coast
SRP5s	0.08	0.1	Soluble reactive P in the surface water of the southern coast
SRP5b	0.73	0.95	Soluble reactive P in the shallow bottom water of the southern coast
SRP6s	0.02	0.04	Soluble reactive P in the surface water of the north-eastern coast
SRP6b	0.13	0.17	Soluble reactive P in the shallow bottom water of the north-eastern coast
SRP7s	0.01	0.01	Soluble reactive P in the surface water of the Tethys gatewaygateway
SRP7b	0.09	0.15	Soluble reactive P in the shallow bottom water of the Tethys gatewaygateway
POP1s	0.046	0.04	Organic P in the surface water of the open ocean
POP1i	0.086	0.08	Organic P in the intermediate water of the open ocean
POP1b	0.077	0.07	Organic P in the bottom water of the open ocean
POP2s	0.02	0.02	Organic P in the surface water of the southern open ocean
POP2i	0.06	0.05	Organic P in the intermediate water of the southern open ocean
POP2b	0.02	0.02	Organic P in the bottom water of the southern open ocean
POP3s	0.002	0.005	Organic P in the surface water of the Western Interior Seaway
POP3b	0.0001	0.0003	Organic P in the shallow bottom water of the Western Interior Seaway
POP4s	0.006	0.005	Organic P in the surface water of the northern coast
POP4b	0.0007	0.0005	Organic P in the shallow bottom water of the northern coast
POP5s	0.01	0.01	Organic P in the surface water of the southern coast
POP5b	0.003	0.003	Organic P in the shallow bottom water of the southern coast
POP6s	0.0005	0.0007	Organic P in the surface water of the north-eastern coast
POP6b	0.0001	0.0002	Organic P in the shallow bottom water of the north-eastern coast
POP7s	0.0004	0.0003	Organic P in the surface water of the Tethys gatewaygateway
POP7b	0.0001	0.0001	Organic P in the shallow bottom water of the Tethys gatewaygateway
Name	P flux pre-OAE2	OAE2	Description units in Tmol P y−1
			Fluxes coupled to the water cycle
PF1	0.07	0.09	Surface [SRP] of the central open ocean times F1
PF3	0.46	0.57	Intermediate [SRP] of the central open ocean times F3
PF6	0.55	0.88	Bottom [SRP] of the Pacific Ocean times F6
PF7	0.004	0.02	Surface [SRP] of the Tethys gateway times F7
PF10	0.03	0.24	Bottom [SRP] of the Tethys gateway times F10
PF13	0.23	0.12	Surface [SRP] of the Tethys gateway times F13
PF14	0.008	0.04	Surface [SRP] of central open ocean times F14
PF15	0.008	0.05	Surface [SRP] of the Tethys gateway times F15

continuation

Name	P flux		Description
	pre-OAE2	OAE2	units in Tmol P y−1
PF16	0.15	0.22	Surface [SRP] of the central open ocean times F16 (downwelling)
PF17	0.14	0.29	Intermediate [SRP] of the central open ocean times F17 (upwelling)
PF18	0.02	0.005	Surface [SRP] of the southern coast times F18 in pre-OAE2
			Surface [SRP] of the southern open ocean times F18 in OAE2
PF19	0.02	0.03	Surface [SRP] of the central open ocean times F19
PF20	0.51	0.35	Intermediate [SRP] of the central open ocean times F20
PF21	0.29	0.48	Bottom [SRP] of the northern coast times F21
PF22	0.03	0.11	Intermediate [SRP] of the central open ocean times F22
PF23	0.006	0.32	Intermediate [SRP] of th central open ocean times F23
PF24	0.32	0.18	Bottom [SRP] of the southern coast times F24
PF25	0.006	0.24	Bottom [SRP] of the central open ocean times F25
PF26	0.02	0.02	Surface [SRP] of the Tethys gateway times F26 (downwelling)
PF27	0.07	0.13	Bottom [SRP] of the Tethys gateway times F27 (upwelling)
PF28	0.02	0.02	Surface [SRP] of the southern coast times F28 (downwelling)
PF29	0.3	0.37	Bottom [SRP] of the southern coast times F29 (upwelling)
PF30	0.01	0.01	[SRP] of the South river times F30
PF31	0.18	0.11	Surface [SRP] of the Western Interior Seaway times F31 (downwelling)
PF32	0.33	0.28	Bottom [SRP] of the Western Interior Seaway times F32 (upwelling)
PF33	0.19	0.06	Surface [SRP] of the northern coast times F33 (downwelling)
PF34	0.43	0.16	Bottom [SRP] of the northern coast itmes F34 (upwelling)
PF35	0.02	0.05	Surface [SRP] of the north-eastern coast times F35 (downwelling)
PF36	0.01	0.03	Bottom [SRP] of the north-eastern coast times F36 (upwelling)
PF37	0.42	0.72	Intermediate [SRP] of the central open ocean times F37
PF38	1.04	1.37	Bottom [SRP] of the cental open ocean times F38
PF39	0.12	0.07	Surface [SRP] of the Western Interior Seaway times F39
PF40	0.001	0.04	Surface [SRP] of the north-eastern coast times F40
PF41	0.002	0.02	Surface [SRP] ot the Tethys gateway times F41
PF42	0.01	0.04	Surface [SRP] of the Tethys gateway times F42
PF43	0.01	0.17	Bottom [SRP] of the Tethys gateway times F43
PF44	0.05	0.07	Bottom [SRP] of the north-eastern coast times F44 in pre-OAE2
			Bottom [SRP] of the Tethys gateway times F44 in OAE2
PF45	0.01	0.19	Bottom [SRP] of the northern coast times F45
			Bottom [SRP] of the north-eastern coast times F45
PF46	0.42	0.3	Bottom [SRP] of the northern coast times F46
PF47	0.05	0.06	Surface [SRP] of the central open ocean times F47
PF48	0.04	0.03	Surface [SRP] of the southern open ocean times F48
PF49	0.41	0.08	Intermediate [SRP] of the central open ocean times F49
PF50	0.49	0.41	Intermediate [SRP] of the central open ocean times F50
PF51	0.84	0.63	Intermediate [SRP] of the southern open ocean times F51
PF52	0.75	0.73	Bottom [SRP] of the central open ocean times F52
PF53	0.78	0.69	Bottom [SRP] of the southern open ocean times F53
PF54	0.08	0.14	Surface [SRP] of the southern coast times F54
PF55	0.0006	0.0006	Surface [SRP] of the southern open ocean times F55 (downwelling)
PF56	0.24	0.19	Intermediate [SRP] of the southern open ocean times F56 (upwelling)
PF57	0.03	0.02	Intermediate [SRP] of the southern open ocean times F57
PF58	0.09	0.08	Bottom [SRP] of the southern open ocean times F58

continuation

Name	P flux pre-OAE2	OAE2	Description units in Tmol P y−1
PF59	0.03	0.02	Bottom [SRP] of the southern coast times F59 in pre-OAE2
			Bottom [SRP] of the southern open ocean times F59 in OAE2
PR3	0.0004	0.0006	[SRP] of the North-West river times R3
PR4	0.0018	0.0018	[SRP] of the North river times R4
PR6	0.00001	0.00001	[SRP] of the north-eastern river times R6
			Fluxes coupled to the C and O_2 cycles
BPF1	1.55	1.45	SRP uptake in the central open ocean
BPF2	1.35	1.26	SRP release in the surface water of the central open ocean
BPF3	0.155	0.15	SRP release in the intermediate water of the central open ocean
BPF4	0.04	0.04	SRP release in the bottom water of the central open ocean
BPF5	0.0001	0.0001	Organic P burial in the central open ocean
BPF6	2.11	1.71	SRP uptake in the southern open ocean
BPF7	1.84	1.49	SRP release in the surface water of the southern open ocean
BPF8	0.21	0.17	SRP release in the intermediate water of the southern open ocean
BPF9	0.06	0.05	SRP release in the bottom water of the southern open ocean
BPF10	0.0002	0.0002	Organic P burial in the southern open ocean
BPF11	0.43	0.99	SRP uptake in the Western Interior Seaway
BPF12	0.38	0.86	SRP release in the surface water of the Western Interior Seaway
BPF13	0.06	0.13	SRP release in the shallow bottom water of the Western Interior Seaway
BPF14	0.0005	0.001	Organic P burial in the Western Interior Seaway
BPF15	0.99	0.71	SRP uptake in the northern coast
BPF16	0.86	0.62	SRP release in the surface water of the northern coast
BPF17	0.13	0.09	SRP release in the shallow bottom water of the northern coast
BPF18	0.001	0.001	Organic P burial in the northern coast
BPF19	1.59	1.98	SRP uptake in the southern coast
BPF20	1.38	1.72	SRP release in the surface water of the southern coast
BPF21	0.20	0.26	SRP release in the shallow bottom water of the southern coast
BPF22	0.001	0.002	Organic P burial in the southern coast
BPF23	0.04	0.06	SRP uptake in the north-eastern coast
BPF24	0.03	0.05	SRP release in the surface water of the north-eastern coast
BPF25	0.005	0.007	SRP release in the shallow bottom water of the north-eastern coast
BPF26	0.00005	0.00007	Organic P burial in the north-eastern coast
BPF27	0.23	0.21	SRP uptake in the Tethys gateway
BPF28	0.2	0.18	SRP release in the surface water of the Tethys gateway
BPF29	0.03	0.03	SRP release in the shallow bottom water of the Tethys gateway
BPF30	0.0003	0.0003	Organic P burial in the Tethys gateway
BPF31	0.2	0.19	Organic P export to the intermediate water in the central open ocean
BPF32	0.04	0.04	Organic P export to the bottom water in the central open ocean
BPF33	0.27	0.22	Organic P export to the intermediate water in the southern open ocean
BPF34	0.06	0.05	Organic P export to the bottom water in the southern open ocean
PBF35	0.06	0.13	Organic P export to the shallow bottom water in the Western Interior Seaway
BPF36	0.13	0.09	Organic P export to the shallow bottom water in the northern coast
BPF37	0.21	0.26	Organic P export to the shallow bottom water in the southern coast
BPF38	0.005	0.008	Organic P export to the shallow bottom water in the north-eastern coast
BPF39	0.03	0.03	Organic P export to the shallow bottom water in the Tethys gateway
FePB1	0.00014	0.00016	Inorganic Fe-P burial in the central open ocean

continuation

Name	P flux		Description
	pre-OAE2	OAE2	units in Tmol P $y-1$
CaPB1	0.00029	0.00029	Inorganic Ca-P burial in the central open ocean
FePB2	0.00016	0.0002	Inorganic Fe-P burial in the southern open ocean
CaPB2	0.00037	0.00033	Inorganic Ca-P burial in the southern open ocean
FePB3	0.00043	0.00045	Inorganic Fe-P burial in the Western Interior Seaway
CaPB3	0.0009	0.0022	Inorganic Ca-P burial in the Western Interior Seaway
FePB4	0.0009	0.001	Inorganic Fe-P burial in the northern coast
CaPB4	0.0019	0.0018	Inorganic Ca-P burial in the northern coast
FePB5	0.0004	0.0004	Inorganic Fe-P burial in the southern coast
CaPB5	0.0017	0.0017	Inorganic Ca-P burial in the southern coast
FePB6	0.00005	0.00005	Inorganic Fe-P burial in the north-eastern coast
CaPB6	0.0001	0.00016	Inorganic Ca-P burial in the north-eastern coast
FePB7	0.0002	0.0003	Inorganic Fe-P burial in the Tethys gateway
CaPB7	0.0005	0.0005	Inorganic Ca-P burial in the Tethys gateway

Table S5: Oxygen cycle: Reservoir sizes and fluxes for pre-OAE2 and OAE2 conditions as implemented in the multi-box model.

Name	O_2 reservoir pre-OAE2		Description units Tmol O_2
OX1i	987.95	1323.70	Dissolved O_2 in the intermediate water of the central open ocean
OX1b	5777.83	6991.77	Dissolved O_2 in the bottom water of the central open ocean
OX2i	54.28	130.72	Dissolved O_2 in the intermediate water of the southern open ocean
OX2b	900.53	1175.8	Dissolved O_2 in the bottom water of the southern open ocean
OX3b	17.77	51.87	Dissolved O_2 in the shallow bottom water of the Western Interior Seaway
OX4b	39.6	64.38	Dissolved O_2 in the shallow bottom water of the northern coast
OX5b	10.11	14.64	Dissolved O_2 in the shallow bottom water of the southern coast
OX6b	20.18	30.8	Dissolved O_2 in the shallow bottom water of the north-eastern coast
OX7b	12.78	19.65	Dissolved O_2 in the shallow bottom water of the Tethys gateway
Name	O_2 flux pre-OAE2	OAE2	Description units in Tmol O_2 $y-1$
			Fluxes coupled to the water cycle
OF3	33.44	71.82	Intermediate [O_2] of the central open ocean times F3
OF6	90.76	145.14	Bottom [O_2] of the Pacific Ocean times F6
OF10	3.9	31.9	Shallow bottom [O_2] of the Tethys times F10
OF16	66.51	107.51	Intermediate [O_2] of the central open ocean times F16
OF17	10.46	37.11	Bottom [O_2] of the central open ocean times F17
OF20	37.4	43.86	Intermediate [O_2] of the central open ocean times F20
OF21	20.67	60.59	Bottom [O_2] of the northern coast times F21
OF22	2.2	13.67	Intermediate [O_2] of the central open ocean times F22
OF23	0.45	40.95	Intermediate [O_2] of the central open ocean times F23
OF24	4.37	2.73	Bottom [O_2] of the southern coast times F24
OF25	0.58	31.84	Bottom [O_2] of the central open ocean times F25
OF26	10.78	11.04	Surface [O_2] of the Tethys gateway times F26 (downwelling)
OF27	9.36	16.95	Bottom [O_2] of the Tethys gateway times F27 (upwelling)
OF28	4.62	8.07	Surface [O_2] of the southern coast times F28 (downwelling)
OF29	4.1	5.75	Bottom [O_2] of the southern coast times F29 (upwelling)
OF31	32.87	38.18	Surface [O_2] of the Western Interior Seaway times F31 (downwelling)
OF32	27.77	31.13	Bottom [O_2] of the Western Interior Seaway times F32 (upwelling)
OF33	33.97	24.17	Surface [O_2] of the northern coast times F33 (downwelling)
OF34	30.22	20.32	Bottom [O_2] of the northern coast times F34 (upwelling)
OF35	7.22	20.8	Surface [O_2] of the north-eastern coast times F35 (downwelling)
OF36	2.12	6.23	Bottom [O_2] of the north-eastern coat times F36 (upwelling)
OF37	30.27	90.81	Intermediate [O_2] of the central open ocean times F37
OF38	100.43	180.96	Bottom [O_2] of the central open ocean times F38
OF43	1.82	22.78	Bottom [O_2] of the Tethys gateway times F43
OF44	7.26	8.53	Bottom [O_2] of the north-eastern coast times F44 in pre-OAE2 Bottom [O_2] of the Tethys gateway times F44 in OAE2
OF45	0.66	35.73	Bottom [O_2] of the northern coast times F45 in pre-OAE2 Bottom [O_2] of the north-eastern coast times F45 in OAE2
OF46	34.92	33.47	Bottom [O_2] of the Western Interior Seaway times F46
OF49	30.14	9.94	Intermediate [O_2] of the central open ocean times F49
OF50	35.84	52.13	Intermediate [O_2] of the central open ocean times F50

continuation

Name	O_2 flux pre-OAE2	OAE2	Description units in Tmol O_2 y−1
OF51	13.91	31.22	Intermediate [O_2] of the southern open ocean times F51
OF52	72.71	96.31	Bottom [O_2] of the central open ocean times F52
OF53	58.76	78.86	Bottom [O_2] of the southern open ocean times F53
OF55	0.72	0.94	Surface [O_2] of the southern open ocean times F55 (downwelling)
OF56	3.94	9.5	Intermediate [O_2] of the southern open ocean times F56 (upwelling)
OF57	0.41	0.99	Intermediate [O_2] of the southern open ocean times F57
OF58	6.5	9.5	Bottom [O_2] of the southern open ocean times F58
OF59	0.45	2.23	Bottom [O_2] of the southern coast times F59 in pre-OAE2
			Bottom [O_2] of the southern open ocean times F59 in OAE2
			Fluxes coupled to the C and P cycles
BOF3	21.32	20.02	O_2 consumption in the intermediate water of the central open ocean
BOF4	6.07	5.7	O_2 consumption in the bottom water of the central open ocean
BOF8	29.16	23.55	O_2 consumption in the intermediate water of the southern open ocean
BOF9	8.3	6.71	O_2 consumption in the bottom water of the southern open ocean
BOF13	7.58	17.43	O_2 consumption in the shallow bottom water in the Western Interior Seaway
BOF17	17.33	12.46	O_2 consumption in the shallow bottom water in the northern coast
BOF21	27.67	34.54	O_2 consumption in the shallow bottom water in the southern coast
BOF25	0.71	1.02	O_2 consumption in the shallow bottom water in the north-eastern coast
BOF29	3.98	3.68	O_2 consumption in the shallow bottom water in the Tethys gateway

Table S6: Linear equations as implemented in the model for fluxes in oxic conditions. The k_* is a rate constant (y^{-1}). *SRP* is the reservoir of soluble reactive P, *POC* and *POP* are the reservoirs for particulate organic C and P, respectively. $_s$: surface water; $_i$: intermediate water; $_b$: bottom water.

Flux	Linear equations
C cycle	**(Tmol C y^{-1})**
Primary productivity in surface ocean	$PP = k_{PP} \cdot SRP_s \cdot 106$ [1]
Inorganic C release in surface ocean	$CREL_s = k_{CREL_s} \cdot POC_s$ [1]
Inorganic C release in intermediate open ocean	$CREL_i = k_{CREL_i} \cdot POC_i$ [1]
Inorganic C release in shallow/deep bottom ocean	$CREL_b = k_{CREL_b} \cdot POC_b$ [1]
POC Export in surface to intermediate/shallow bottom ocean	$CEXP_s = POPEXP_s * 106$ [1]
POC Export in intermediate to deep bottom open ocean	$CEXP_i = POPEXP_i * 106$ [1]
POC burial in coastal ocean	$CBUR = k_{CBUR} \cdot CEXP_s$ [1]
POC burial in open ocean	$CBUR = k_{CBUR} \cdot (CEXP_s + CEXP_i)$ [2]
P cycle	**(Tmol P y^{-1})**
SRP uptake in surface ocean	$SRPU = PP/106$ [1]
SRP release in surface ocean	$PREL_s = CREL_s/106$ [1]
SRP release in intermediate open ocean	$PREL_i = CREL_i/106$ [1]
SRP release in shallow/deep bottom ocean	$PREL_b = k_{PREL_b} \cdot POP_b$ [1]
POP Export from surface to intermediate/shallow bottom	$POPEXP_s = k_{POPEXP_s} * POP_s$ [1]
POP Export from intermediate to deep bottom ocean	$POPEXP_i = k_{POPEXP_i} * POP_i$ [1]
POP burial in coastal ocean	$POPBUR = CBUR/200$ [3]
POP burial in open ocean	$POPBUR = CBUR/106$ [1]
Ca-P burial in shallow/deep bottom ocean	$CaPBUR = k_{CaPBUR} \cdot PREL_b$ [1]
Fe-P burial in shallow/deep bottom ocean	$FePBUR = FePBUR_{oxic} \cdot \frac{[O_2]}{[O_2]_{crit}}$ [1]
O_2 cycle	**(Tmol O_2 y^{-1})**
O_2 consumption in intermediate open ocean	$OCON_i = CREL_i \cdot 138/106$ [1]
O_2 consumption in shallow/deep bottom ocean	$OCON_b = CREL_b \cdot 138/106$ [1]

[1]Slomp and Van Cappellen, 2007, [2] This study, [3]Van Cappellen and Ingall, 1994

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