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New insights on black carbon in pelagic Atlantic sediments

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Supporting Information for

New insights on black carbon in pelagic Atlantic sediments

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Contents of this file

Additional Supporting Information (Files uploaded separately)

None

Introduction

This supporting information includes additional details for the Materials and Methods for the petrographic analysis, carbonates, organochloride pesticides, polycyclic aromatic hydrocarbons, and definitions; Results and Discussion for the petrographic black carbon concentrations and organic carbon extrapolation; 6 Tables and 4 Figures with all collected black carbon, total organic carbon, and stable carbon data from 5 geographical regions in the Subtropical Atlantic Ocean.

Text S1. Methodology

S.1.1 Petrographic analysis

Select sediments were analyzed at the Laboratories for Applied Organic Petrology at the University of Tübingen, Germany. Briefly, polished sediments were observed under a Leitz DMRX-MPVSP microscope photometer using a total magnification up to 500X with reflected white light, uv fluorescence, plane-polarized light, and cross-polarized light (Taylor et al., 1998; Crelling et al., 2006). Various anthropogenic and natural organic matter fragments were observed including char, soot, coal, plastic, pollen, and fungal spores.

S.1.2 Carbonate abundance

The percentage of inorganic carbon, as carbonate, was estimated for each study subregion using a loss on ignition where 550°C (4 hours) was presumed to evolve off the organic carbon and a second treatment at 950°C (2 hours) to evolve the carbonate fraction (Heiri et al., 2001). Average carbonate percentages were as follows: Amazon Delta (21%), Sierra Leone Rise (29%), Niger Delta (11%), Senegal Delta (1%), and Northwest Argentina Basin (3%). Carbonates were removed to determine the total organic carbon and black carbon concentrations.

S.1.3 Organochlorine Pesticides (OCP)

Select OCPs were measured using an Agilent 6890N gas chromatograph connected to a 60m by 0.25µm DB5-MS column coupled to a Waters-Micromass Quattro MicroGC mass spectrometer.

S.1.4 Polycyclic Aromatic Hydrocarbons

Polycyclic aromatic hydrocarbons can have multiple sources including raw petroleum and from the combustion of both fossil fuels and biomass burning events (Yunker et al., 2002). PAHs are sometimes apportioned into the general class of persistent organic pollutants and have known toxic, carcinogenic, and mutagenic effects on organism (Patel et al., 2020). Polycyclic aromatic hydrocarbons are hydrophobic, with hydrophobicity increasing with molecular weight; thus, PAHs will often sorb to particles in the marine systems (Nam et al., 2008; Bakhtiari et al., 2009). Thus, accumulation of total organic carbon into marine sediment can also be associated with a net export of PAHs to the deep ocean.

S.1.4 Definitions

Total Organic Carbon – the total concentration of organic carbon in the sediments, including black carbon. Carbonates (inorganic carbon) are removed.

Soot-like Black Carbon – incompletely combusted organic carbon as defined by the carbon remaining after a chemothermal oxidation at 375°C.

Organic Carbon – the difference between the total organic carbon and black carbon concentration in a sediment sample.

Text S2. Results and Discussion

S.2.1 Petrographic Black Carbon Concentrations

Petrographic results varied depending on the soot effective density used to convert the volume concentration into a mass percentage. The mass concentration of microscopic soot in the Amazon Delta, using a soot effective density of 1 g cm^{-3}, decreased with sediment depth from 0.8% (0-4 cm) to 0.6% (5.5-9 cm) to 0.2% (8.5-12 cm). No char (natural or from coal combustion) was detected.

Microscopic soot percentages (0.4-1.7%) mostly agreed with the BC_{CTO} derived measurement (0.5%) in the Sierra Leone Rise surface sediments. Char produced from coal combustion was detected at this site with a mass concentration of 0.1%, suggesting that soot was the primary from of BC, but that char-like material was present. The Sierra Leone Rise top sediments also had volume concentration 0.4% of fusinite, a rare char associated with wildfires, demonstrating that this region received fire-derived carbon inputs.

S.2.2 Organic carbon extrapolation

Although few particulate BC inventories and bulk carbon content values are available for the abyssal ocean floor, particularly for subtropical Atlantic sediments, there have been basin-wide attempts aimed at extrapolating organic carbon concentrations and accumulation rates. For example, Mollenhauer et al. (2004) quantified over 1000 surface sediment samples in the South Atlantic Ocean to extrapolate the regional variation in organic carbon content. Our bulk sediment total organic carbon values are in-line with the values derived by Mollenhauer et al. (2004). For example, their extrapolation estimated an organic carbon (OC) content of ~5 g_{OC} kg_{sed}^{-1} for the Amazon, ~7.5 g_{OC} kg_{sed}^{-1} for the Sierra Leone Rise, ~15 g_{OC} kg_{sed}^{-1} for the Niger Delta, and ~2.5 g_{OC} kg_{sed}^{-1} for the NW Argentina Basin, all of which are within a factor of 2-3 of this study's TOC values. This demonstrates that removing the carbonate fraction in our TOC concentration did not have substantial effects on our value ranges.

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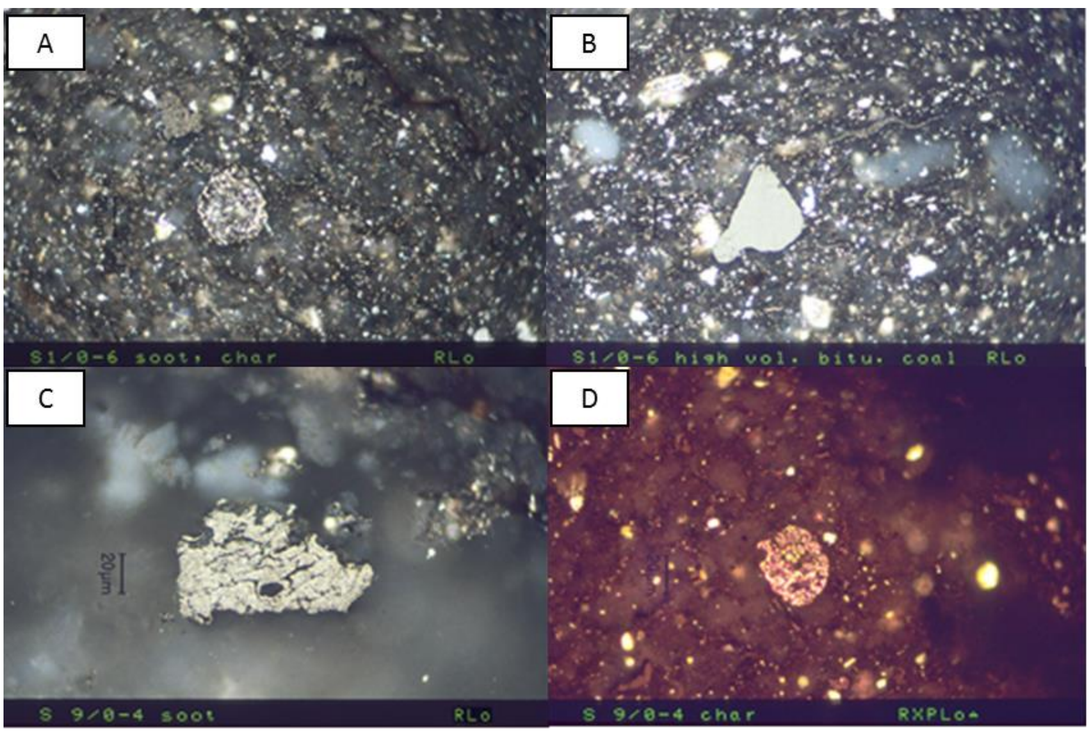

Figure S1. Microscopic images of anthropogenic particles from the Amazon Delta (A,B) and Sierra Leone Rise (C,D). A) soot and char particle, B) high volatile bituminous coal, C) soot, and D) char.

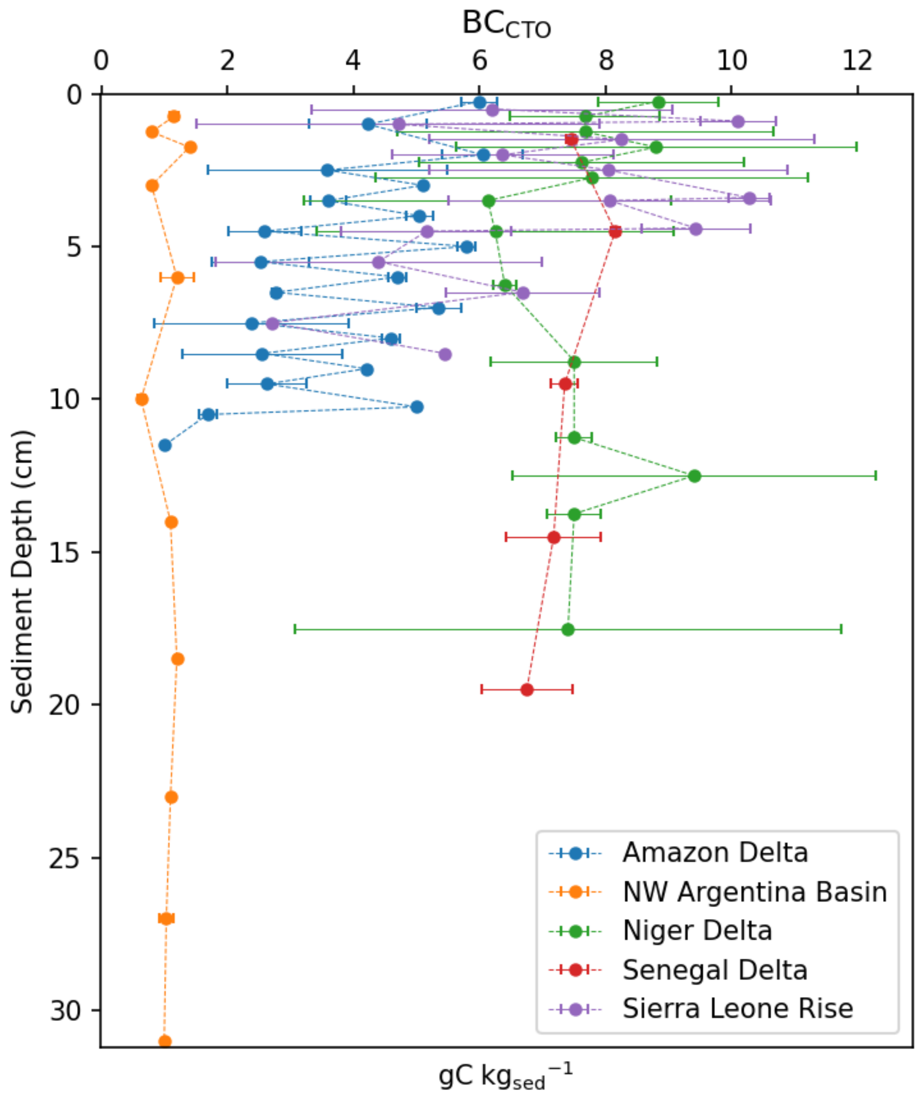

Figure S2. Upcore concentrations of black carbon via the chemothermal oxidation method (BC_{CTO}) for all regions.

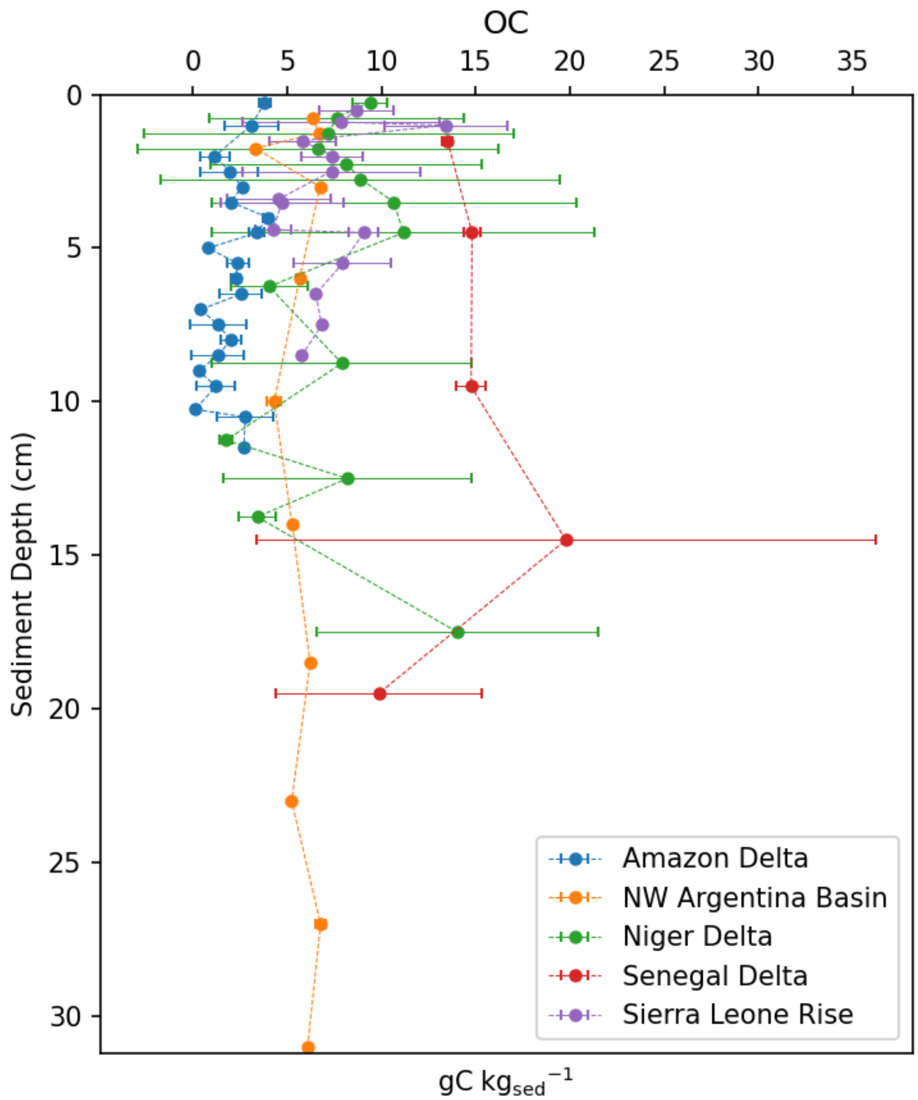

Figure S3. Upcore concentrations of the derived, thermally labile organic carbon (OC) fraction for all regions.

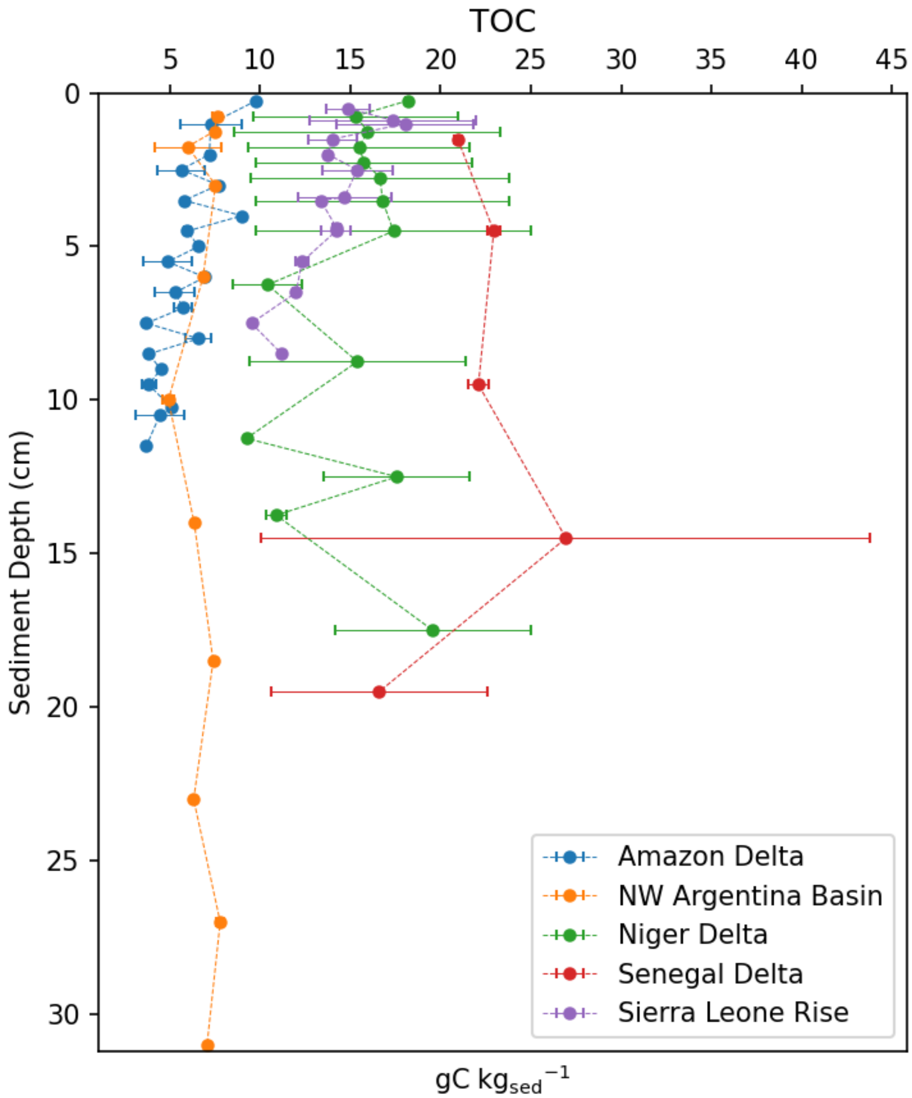

Figure S3. Upcore concentrations of total organic carbon (TOC) for all regions.

Region	***%BC***	***%BC/TOC***	***BC flux ($mgcm^{-2}ka^{-1}$)***	***Reference***	***Methodological Approach***
Mississippi River	0.38-0.78	1.9-28	NA	Mitra et al., 2002	chemothermal oxidation at 375°C
Swedish continental shelf	0.10 - 0.34	2.3 - 6.6	n/a	Sanchez-Garcia et al. 2012	chemothermal oxidation at 375°C
South American Coast	0.04 - 0.10	8-34	0.6 - 2.6	Lohmann et al. 2009	chemothermal oxidation at 375°C
African Coast	0.08 - 0.11	3-12	0.5 - 7.8	Lohmann et al. 2009	chemothermal oxidation at 375°C
Iberian Margin (Atlantic Ocean)	0.22-0.63	16 - 29	n/a	Middelburg et al. 1999	chemothermal oxidation at 375°C
Iberian Margin (Atlantic Ocean)	0.047 - 0.16	16 - 29	n/a	Middelburg et al. 1999	chemical treatment via HNO_3
North Sea	0.028 - 0.457	16 - 61	n/a	Middelburg et al. 1999	chemothermal oxidation at 375°C; chemical treatment via HNO_3
Gulf of Maine, USA	0.011 - 0.173	3.1 - 14.6	86 - 190	Gustafsson and Gschwend 1998	chemothermal oxidation at 375°C
Brazil (SE coast)	0.03 - 0.31	2.32 - 12.75	n/a	Ribeiro et al. 2008	chemothermal oxidation at 375°C
Washington Coast, USA	0.014-0.065	1.01-5.6	1.5 - 3.1	Dickens et al. 2004	chemical treatment (HCl + HF + CF_3CO_2H) and chemothermal oxidation at 375°C
Pacific Abyssal Plain	n/a	15 ± 2	n/a	Masiello and Druffel 1998	chemical treatment ($H_2Cr_2O_7$ + H_2SO_4)
Deep Pacific Ocean	0.044	na	0.057	Griffin and Goldberg, 1975	chemical treatment (HCl + HF + H_2O_2)
Saanich Inlet (British Columbia)	0.55	na	74	Griffin and Goldberg, 1975	chemical treatment (HCl + HF + H_2O_2)
Gulf of Cadiz (Iberian Margin)	0.034-0.102%	4.1-14.4%	NA	de la Rosa et al, 2011	chemical treatment (HCl + HF + CF3CO2H) and chemothermal oxidation at 375°C; chemical treatment (benzenepolycarboxilic acids)
Open Ocean Pacific	n/a	n/a	0.002 - 3.6	Suman et al. 1997	Mixed (synthesis)
Coastal	n/a	n/a	26 - 354	Suman et al. 1997	Mixed (synthesis)

Table S1. Global comparison of black carbon (BC) percentages and fluxes to marine sediments from selected studies. Note that all chemothermal oxidations includes an HCl treatment unless otherwise noted; please reference the cited study for more details on the specific methodological approach.

Sediment ID	Sampling Month/Year	Latitude	Longitude	Location	Water Depth (m)
EN-480-1	July 2010	4.282778	-47.484444	Amazon Delta	2365
EN-480-2	July 2010	5.915833	-45.001111	Amazon Delta	3545
EN-481-6	August 2010	7.003889	-20.795278	Sierra Leone Rise	3853
EN-481-7	August 2010	5.018056	-21.243611	Sierra Leone Rise	2811
EN-481-7	August 2010	4.968889	-21.201667	Sierra Leone Rise	2787
EN-481-7	August 2010	5.005833	-21.250556	Sierra Leone Rise	2794
EN-481-8	August 2010	4.560833	-24.509167	Sierra Leone Rise	4030
EN-481-9	August 2010	7.435278	-24.010556	Sierra Leone Rise	4065
GeoB 4901	February/March 1998	2.668889	6.717222	Niger Delta	2180
GeoB 4903	February/March 1998	1.916667	8.166944	Niger Delta	2834
GeoB 4904	February/March 1998	0.95	8.8	Niger Delta	1208
GeoB 4905	February/March 1998	2.5	9.384444	Niger Delta	2184
GeoB 4907	February/March 1998	-0.584722	8.018333	Niger Delta	2060
GeoB 4908	February/March 1998	-0.701667	6.834167	Niger Delta	3028
GeoB 9501	April/May 2003	16.834444	-16.719167	Senegal Delta	330
GeoB 2814	July/August 1994	-37.618056	-39.116667	South Atlantic (NW Argentina Basin)	4949

Table S2. Dates, coordinates, and water depth of sediment sampling.

A. Amazon Delta		(0-6 cm)	(5.5-9 cm)	(8.5-9 cm)
Maceral Group	**Maceral subgroup**	**(vol. %)**	**(vol. %)**	**(vol. %)**
Huminite	Telohuminite			
	Detrohuminite			
	Gelohuminite			
Vitrinite	Telovitrinite	0.6	x	x
	Detrovitrinite	2.4	3	2.2
	Gelovitrinite			
Liptinite	Sporinite	x	x	x
	Cutinite	x	x	
	Fluorinite			
	Suberinite			
	Resinite	x	x	x
	Chlorophyllinite			
	Telalginite	1.4	0.8	1.8
	Lamalginite			
	Liptodetrinite	1.4	0.6	x
	Bituminite (AOM) grey	60.4	26.6	40
	Bituminite (AOM) gray-brown	30.9	67.6	55.2
	Migrabitumen			
	Oil inclusions			
	Oil expulsions			
Inertinite	Fusinite	x	x	
	Semifusinite	0.2	x	x
	Secretinite	0.4	x	0.2
	Macrinite			
	Micrinite			
	Inertodetrinite	0.7	0.2	0.2
Natural Coke				
Natural Char				
Hard Coal	Sub-bituminous	x	0.2	x
	High volatile bit. Coal	x	0.2	
	Medium-volatile bit. Coal			
	Low-volatile bit. Coal			
	Anthracite			x
Coke (coal carbonization)		x	x	
Char (coal combustion)		x	x	x
Soot (traffic combustion)		1.4	1	0.4
Coal/petroleum-derived		x	x	x
Plastic		0.2	x	x

B. Sierra Leone Rise		(0-4 cm)	(4-9 cm)
Maceral Group	**Maceral subgroup**	**(vol. %)**	**(vol. %)**
Huminite	Telohuminite		
	Detrohuminite		
	Gelohuminite		
Vitrinite	Telovitrinite	0.2	0.6
	Detrovitrinite	7.4	8.4
	Gelovitrinite		
Liptinite	Sporinite	x	x
	Cutinite	0.2	x
	Fluorinite		
	Suberinite		
	Resinite		
	Chlorophyllinite		
	Telalginite	x	x
	Lamalginite		
	Liptodetrinite	x	x
	Bituminite (AOM) grey	46.2	76
	Bituminite (AOM) gray-brown	41.2	10.6
	Migrabitumen		
	Oil inclusions		
	Oil expulsions		
Inertinite	Fusinite	0.4	0.2
	Semifusinite	0.2	1.4
	Secretinite	1	0.2
	Macrinite		
	Micrinite		
	Inertodetrinite	1	0.8
Natural Coke			
Natural Char			
Hard Coal	Sub-bituminous		
	High volatile bit. Coal		
	Medium-volatile bit. Coal		
	Low-volatile bit. Coal		x
	Anthracite		
Coke (coal carbonization)		x	x
Char (coal combustion)		0.4	x
Soot (traffic combustion)		1.4	x
Coal/petroleum-derived		x	x
Plastic		0.4	0.2

Table S3. Summary chart of petrographic analysis for sediments from the (A) Amazon Delta and (B) Sierra Leone Rise (SLR). Note that concentrations are in %volume. The x indicates that the Maceral group was present, but a volume concentration was not expressed due to scarcity.

Region	Average Sedimentation Rate (cm kyr^{-1})	Citation(s)
Amazon Delta	1.26	Curry et al. (1988), Curry and Crowley (1987), Ruhlmann et al. (1996)
Niger Delta	10	Lohmann et al. (2009)
Senegal Delta	6.925	Seibold (1972)
Sierra Leone Rise	2.67	Sarnthein et al. (1994), Broecker et al. (1991)
NW Argentina Basin	2.5	Lohmann et al. (2009)

Table S4. Estimates sedimentation rates used to derive the fluxes in this study. Sedimentation rates were accessed from **www.pangaea.de**.

Analyte Name	EN-480-1 ($ng\ g^{-1}_{sediment}$)						EN-481-9 ($ng\ g^{-1}_{sediment}$)					$ng\ g^{-1}_{sediment}$	
	0-2 cm	2-3 cm	3-4 cm	5-6 cm	6-7 cm	1 -11 :m	0-1 cm	2-3 cm	3-4 cm	4-5 cm	8 -9 :m	Blank	
a-HCH	0	0	0	0	0	0	0	0	0	0	0	0	0
C13-HCBz	0	0	0	0	0	0	0	0	0	0	0	0	0
HCBz	12.226	12.052	23.737	0	23.265	0	30.727	38.734	46.886	48.495	0	29.097	20.518
b-HCH	0	0	0	0	0	0	0	0	0	0	0	0	0
g-HCH	0	0	0	0	0	0	0	0	0	0	0	0	0
d-HCH	0	0	0	0	0	0	0	0	0	0	0	0	0
Dibromodiphenyl PRC	0	0	0	60.053	0	0	0	125.571	0	68.487	0	147.575	110.62
Heptachlor	0	0	0	0	0	0	0	0	0	0	0	0	0
Aldrin	0	0	0	0	0	0	0	0	0	0	0	0	0
TriBB Inj Std	0	0	0	33.41	15.148	0	0	31.622	0	0	0	15.246	19.922
Oxychlordane	0	0	0	0	0	0	0	0	0	0	0	0	0
Heptachlor epoxide	0	0	0	0	0	0	0	0	0	0	0	13.9	0
d-Chlordane	0	0	0	13.429	0	0	0	0	29.748	49.345	0	0	0
a-Chlordane	0	0	0	0	0	0	0	0	0	37.363	0	0	0
t-Nanachlor	0	0	0	0	0	0	0	0	0	17.645	0	0	0
p,p'-DDE	0	0	0	0	0	0	103.869	133.184	0	652.275	0	100.878	73.382
Endosulfan I	0	0	0	0	0	0	0	0	0	0	0	0	0
Dieldrin	0	0	0	0	0	0	0	0	0	0	0	0	0
o,p'-DDD	0	0	0	0	0	0	0	0	0	732.677	0	0	80.129
Endrin	0	0	0	0	0	0	0	0	0	0	0	0	0
Endosulfan II	0	0	0	0	0	0	0	0	0	0	0	0	0
p,p'-DDD & o,p'-DDT	0	0	0	252.516	0	0	0	0	0	0	0	130.634	0
Endrin aldehyde	0	0	0	0	0	0	0	0	0	0	0	0	0
Tetrabromodiphenyl PRC	0	0	0	0	0	0	30.843	376.299	0	235.398	0	136.782	97.637
Endosulfin sulfate	0	0	0	0	0	0	0	0	0	0	0	0	0
C13-p,p'-DDT	0	0	0	0	0	0	0	0	0	0	0	0	0
p,p'-DDT	0	0	0	0	0	0	0	0	0	1575.635	0	0	0
Endrin ketone	0	0	0	0	0	0	0	0	0	0	0	0	0
Methoxychlor	0	0	0	0	0	0	0	0	0	0	0	0	0
Pentabromodiphenyl PRC	0	0	0	0	0	0	0	310.456	0	197.758	0	82.04	82.382
Octachloronaphthaline	0	0	48.976	0	0	0	0	0	0	37.089	0	0	0

Table S5. Analysis of organochlorine pesticides in Amazon Delta and Sierra Leone Rise sediments to generalize the bioturbation depth.

Region	Core	Depth	∑PAHs (ng g_{sed}^{-1})	IP/(IP+Bghi)	Fl/(Fl+Py)	An/178
Amazon Delta	1b	0.25	2503	0.00	1.00	0.98
Amazon Delta	1a	1	1287	0.55	0.59	0.50
Amazon Delta	1b	1	346	na	1.00	0.97

Amazon Delta	2b	1	1603	0.79	0.62	0.21
Amazon Delta	1b	2	1381	1.00	0.98	0.99
Amazon Delta	1a	2.5	2580	0.54	0.58	0.67
Amazon Delta	1b	3	1283	1.00	1.00	0.00
Amazon Delta	1a	3.5	1467	0.55	0.66	0.55
Amazon Delta	1b	4	2743	0.34	0.22	0.12
Amazon Delta	1a	4.5	2701	0.55	0.66	0.49
Amazon Delta	1b	5	2133	0.39	1.00	1.00
Amazon Delta	1a	5.5	1660	0.56	0.62	0.52
Amazon Delta	1b	6	4726	0.51	1.00	0.89
Amazon Delta	1a	6.5	1421	0.56	0.63	0.46
Amazon Delta	1b	7	1282	0.52	0.69	0.26
Amazon Delta	1a	7.5	1464	0.63	0.45	0.12
Amazon Delta	1a	8.5	2442	0.56	0.65	0.53
Amazon Delta	1b	9	2468	0.36	0.59	0.98
Amazon Delta	1a	9.5	1188	0.57	0.63	0.40
Amazon Delta	1b	10.25	2571	0.37	0.38	0.96
Amazon Delta	1a	10.5	1527	0.57	0.62	0.35
Amazon Delta	1a	11.5	954	0.61	0.63	0.49
Sierra Leone Rise	9a	0.5	1167	0.48	0.74	0.36
Sierra Leone Rise	9a	0.5	1368	0.47	0.71	0.25
Sierra Leone Rise	9a	0.5	922	0.62	0.81	0.38
Sierra Leone Rise	9a	0.5	2361	0.23	0.74	0.24
Sierra Leone Rise	7a IV	1	386	0.57	0.69	0.63
Sierra Leone Rise	7a 1	1	621	0.54	0.70	0.30
Sierra Leone Rise	8a 0-1	1	381	0.61	0.49	0.56
Sierra Leone Rise	8a 0-1.5	1	1107	0.55	0.74	0.52
Sierra Leone Rise	9a	2	754	0.40	0.70	0.36
Sierra Leone Rise	9a	2.3	1111	0.29	0.64	0.29
Sierra Leone Rise	9a	2.5	1740	0.41	0.69	0.25
Sierra Leone Rise	9a	3.3	4099	0.13	0.72	0.43
Sierra Leone Rise	9a	3.5	830	0.34	0.69	0.21
Sierra Leone Rise	9a	4.5	930	0.49	0.67	0.14
Sierra Leone Rise	9a	5.5	689	0.34	0.76	0.38
Sierra Leone Rise	9a	6.5	532	0.39	0.64	0.30
Sierra Leone Rise	9a	7.5	606	0.34	0.77	0.43
Sierra Leone Rise	9a	8.5	654	0.34	0.81	0.32
NW Argentina Basin	2814	0.75	3818	1.00	0.10	0.84
NW Argentina Basin	2814	1.25	10094	0.63	0.11	0.85
NW Argentina Basin	2814	1.75	258	na	0.08	0.74
NW Argentina Basin	2814	6	4785	1.00	0.13	0.87

NW Argentina Basin	2814	10	256	na	0.07	0.91
NW Argentina Basin	2814	14	9670	1.00	0.12	0.85
NW Argentina Basin	2814	18.5	2049	1.00	0.14	0.71
NW Argentina Basin	2814	23	9020	1.00	0.22	0.72
NW Argentina Basin	2814	27	17246	0.80	0.16	0.63
NW Argentina Basin	2814	31	6638	1.00	0.12	0.41
Niger Delta	4907	0.25	7543	0.41	0.65	0.67
Niger Delta	1701	0.5	1753	0.00	0.09	0.62
Niger Delta	4901	0.75	32886	0.14	0.70	0.12
Niger Delta	4903	0.75	1216	na	0.66	0.90
Niger Delta	4907	0.75	1914	0.46	0.69	0.34
Niger Delta	4908	0.75	193	na	0.69	0.21
Niger Delta	4901	1.25	40357	0.05	0.68	0.14
Niger Delta	4903	1.25	28176	0.72	0.41	0.88
Niger Delta	4905	1.25	24492	0.56	0.54	0.54
Niger Delta	4908	1.25	135	na	0.60	0.54
Niger Delta	1701	1.5	1102	na	0.15	0.31
Niger Delta	4901	1.75	19727	0.00	0.73	0.27
Niger Delta	4903	1.75	14135	0.59	0.50	0.56
Niger Delta	4905	1.75	144171	0.00	0.34	0.32
Niger Delta	4908	1.75	217	0.00	0.67	0.22
Niger Delta	4901	2.25	15695	0.11	0.68	0.17
Niger Delta	4903	2.25	17136	0.59	0.41	0.65
Niger Delta	4908	2.25	5320	0.00	0.69	0.16
Niger Delta	4901	2.75	8521	1.00	0.71	0.50
Niger Delta	4903	2.75	19980	0.50	0.58	0.56
Niger Delta	4908	2.75	261	na	0.65	0.32
Niger Delta	4901	3.5	34105	0.00	0.75	0.13
Niger Delta	4903	3.5	1569	0.00	0.58	0.58
Niger Delta	4904	3.5	5873	0.39	0.54	0.81
Niger Delta	4908	3.5	10199	0.10	0.64	0.01
Niger Delta	4901	4.5	12295	0.12	0.62	0.04
Niger Delta	4903	4.5	3812	0.36	0.53	0.81
Niger Delta	4904	4.5	7486	1.00	0.46	0.23
Niger Delta	4905	4.50	15768	0.59	0.49	0.89
Niger Delta	4908	4.5	150	na	0.61	0.56
Niger Delta	4901	6.25	1996	0.00	0.66	0.83
Niger Delta	4905	6.25	21323	0.51	0.51	0.60
Niger Delta	4908	6.25	180	na	0.58	0.71

Niger Delta	4901	8.75	17739	0.05	0.44	0.23
Niger Delta	4903	8.75	6500	0.55	0.41	0.23
Niger Delta	4904	8.75	3662	0.43	0.41	0.70
Niger Delta	4905	8.75	8731	0.42	0.42	0.67
Niger Delta	4908	8.75	136	na	0.56	0.25
Niger Delta	4908	11.25	217	na	0.51	0.55
Niger Delta	4901	12.5	48963	0.00	0.34	0.32
Niger Delta	4903	12.5	4599	0.38	0.52	0.88
Niger Delta	4904	12.5	10022	0.46	0.45	0.68
Niger Delta	4905	12.50	4891	0.00	0.38	0.47
Niger Delta	4908	13.75	96	na	0.47	0.33
Niger Delta	4901	17.5	26212	0.19	0.38	0.47
Niger Delta	4903	17.5	2147	0.41	0.59	0.93
Niger Delta	4904	17.5	6968	0.47	0.44	0.70
Niger Delta	4905	17.50	10553	0.40	0.45	0.64
Senegal Delta	9501	1.5	5413	0.63	0.57	0.24
Senegal Delta	9501	4.5	4970	0.79	0.64	0.28
Senegal Delta	9501	9.5	1214	na	0.54	0.28
Senegal Delta	9501	14.5	13598	0.16	0.45	0.93
Senegal Delta	9501	19.5	2881	1.00	0.52	0.91

Table S6. Compilation of ΣPAH data (sum of 24 analytes) and four fingerprinting ratios as defined by Yunker et al., 2002 where IP is indeno(1,2,3-c,d)pyrene, Bghi is benzo(g,h,i)perylene, Fl is fluoranthene, Py is pyrene, An is anthracene and 178 is the sum of phenanthrene and An.