

UC Irvine

Faculty Publications

Title

Organic and black carbon

13

C and

14

C through the Santa Monica Basin sediment oxic-anoxic transition

Permalink

<https://escholarship.org/uc/item/54h9s5xz>

Journal

Geophysical Research Letters, 30(4)

ISSN

0094-8276

Authors

Masiello, C. A

Druffel, Ellen R

Publication Date

2003

DOI

10.1029/2002GL015050

Copyright Information

This work is made available under the terms of a Creative Commons Attribution License, available at <https://creativecommons.org/licenses/by/4.0/>

Peer reviewed

Organic and black carbon ^{13}C and ^{14}C through the Santa Monica Basin sediment oxic-anoxic transition

C. A. Masiello^{1,2} and E. R. M. Druffel¹

Received 5 March 2002; revised 1 May 2002; accepted 31 May 2002; published 26 February 2003.

[1] Black carbon (BC) is a significant percentage of sedimentary organic carbon (SOC) at abyssal ocean sites, but its presence in shelf sediments is not well studied. Approximately 1600AD, Santa Monica Basin bottom waters shifted from oxic to very low oxygen (dysoxic) deposition conditions. Under oxic deposition conditions BC was $11 \pm 4\%$ of SOC, whereas after the overlying water became dysoxic (and sediments became anoxic), BC was $5.2 \pm 1.2\%$ of SOC. This shift may reflect the preferential remineralization of non-black SOC under oxic conditions. There is an offset between BC and SOC ^{14}C ages which changes with oxidation conditions, suggesting that BC storage is related to oxygen exposure and confirming a previously published report of the vulnerability of BC to sedimentary oxidation [Middelburg, 1999]. Terrestrial carbon is $17 \pm 5\%$ of total SOC in this core's anoxic region, and $31 \pm 11\%$ of this terrestrial carbon is BC. **INDEX TERMS:** 1030 Geochemistry: Geochemical cycles (0330); 4219 Oceanography: General: Continental shelf processes; 1615 Global Change: Biogeochemical processes (4805); 1050 Geochemistry: Marine geochemistry (4835, 4850); 1040 Geochemistry: Isotopic composition/chemistry. **Citation:** Masiello, C. A., and E. R. M. Druffel, Organic and black carbon ^{13}C and ^{14}C through the Santa Monica Basin sediment oxic-anoxic transition, *Geophys. Res. Lett.*, 30(4), 1185, doi:10.1029/2002GL015050, 2003.

1. Introduction

[2] 'BC' is the suite of refractory carbonaceous compounds remaining after biomass burning and fossil fuel combustion and is best understood as a geochemical continuum, ranging from partially charred biomass to submicron soot spheres. While char retains some plant chemistry and morphology, soot is created by the secondary condensation of hot combustion gases, and its geochemistry is reflective of combustion conditions.

[3] We focus on BC in coastal ocean sediments to understand the role of BC as a component of stored SOC. BC is on the order of 10% of the carbon buried in the deep ocean [Herring, 1985; Masiello and Druffel, 1998; Smith *et al.*, 1973; Suman *et al.*, 1997], suggesting feedbacks between biomass burning and ocean SOC storage, including the possibility that biomass burning is a long term carbon cycle sink as well as a short term carbon cycle source.

¹Department of Earth System Science, University of California at Irvine, Irvine, California, USA.

²Now at Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory, 7000 East Ave, P.O. Box 808, Livermore, CA, USA and Division of Geology and Planetary Sciences, California Institute of Technology, Pasadena, CA, USA.

[4] However, abyssal sediments account for only $\sim 5\%$ of Holocene SOC burial, while continental slope and shelf sediments, along with river deltas, account for the remaining 95% [Hedges and Keil, 1995]. Because shelves are closer to continental sources of combustion, they receive a much higher BC flux than the open ocean [Suman *et al.*, 1997]; however, data on coastal BC storage are sparse. Measurements of BC in coastal sediments and river deltas are essential in determining the role of BC in the ocean carbon cycle.

[5] Data is also lacking on BC loss processes. Mass balance calculations show that a large BC sink exists in the terrestrial biosphere: if BC has been produced since the last glacial maximum at the current biomass burning rate of 0.050–0.270 Gt/year [Kuhlbusch, 1998] and soils have been developing for at least 7,000 years, then there should be a soil BC pool of 350–1900 Gt, or 25–125% of the total soil OC pool. Even the lower end of this range requires substantial changes in our understanding of soil carbon cycling. Similarly, the BC production rate is currently greater than the removal rate of carbon to deep-sediments [Hedges and Keil, 1995]. Imbalances of this magnitude would eventually ($\sim 10,000$ years) lead to geologically implausible perturbations in atmospheric O_2 . It had been suggested that there were no loss processes for BC once it reached open ocean sediments [Herring, 1985]; however, recent evidence shows that there is a significant oxygen exposure effect on BC concentration [Middelburg *et al.*, 1999].

[6] Santa Monica Basin (SMB) sediments are a coastal system more representative of global SOC storage conditions. Also, the geochemistry of one of the major terrestrial sources of carbon to this coastal region (Santa Clara River) is now available [Masiello and Druffel, 2001]; making possible a more complete estimate of basinwide SOC and BC sources and sinks. Finally, SMB bottom waters underwent a transition from oxic to dysoxic deposition conditions recently (\sim A.D. 1600) [Hagadorn *et al.*, 1995], creating an opportunity to study BC and SOC storage at one site under varying oxidation states.

[7] BC had two 20th century sources: biomass burning and fossil fuel combustion, which can be separated based on their ^{14}C : BC from fossil fuel combustion is ^{14}C -free ($>45,000$ years BP or $\Delta^{14}\text{C} = -1000\%$), while BC from biomass burning is modern (<100 y BP or $\Delta^{14}\text{C} > -50\%$). Accelerator mass spectrometry (AMS), routinely measures $\Delta^{14}\text{C}$ to $\pm 5\%$, making BC source identification possible.

2. Study Site and Methods

[8] The SMB is one of the California Borderland Basins, a series of sills and basins bordered by San Diego, Santa Barbara, and the Channel Islands. Until recently the sediments have been anoxic and laminated, but not varved.

Although there is apparently no single process controlling the formation of laminae, surface fluxes of OC and fluxes of terrestrial OC are correlated to varve thickness [Hagadorn *et al.*, 1995]. The sedimentation rate is 16.0 ± 0.4 mg/cm²/yr.

[9] We collected cores from the centermost, oldest region of anoxia (902 m at 33°44.00'N, 118°49.99'W). Sediments from this region have been studied as part of the Department of Energy California Basins Study, and both ²¹⁰Pb and X-rays are available from a neighboring core collected in 1988 (DOE 26) [Christensen *et al.*, 1994]. The 8 year difference between the collection of DOE core 26 and our core results in <1 cm offset between our depths and those previously published [Christensen *et al.*, 1994]. All data is archived at the national geophysical data center.

3. Results and Discussion

[10] Signatures of non-black SOC (SOC_{nBC}) can be calculated by mass balance (e.g. $SOC_{total} = SOC_{nBC} + BC$; $\Delta^{14}C_{SOC_{total}} = \Delta^{14}C_{SOC_{nBC}} \cdot SOC_{nBC} + \Delta^{14}C_{BC} \cdot BC$). This allows meaningful calculation of $\Delta^{14}C_{SOC_{nBC}}$ (Fig. 2b). However, error from BC/SOC_{total} measurements is large enough to render indistinguishable SOC_{nBC} and SOC_{total} $\delta^{13}C$ values (not shown).

3.1. Bomb Carbon, Fossil Carbon, and the Potential Effects of Increased Erosion On SOC_{total} and BC

[11] The atmospheric tests of nuclear weapons in the late 1950s and early 1960s nearly doubled the ¹⁴C concentration in the atmosphere, creating an isotopic marker for modern biological, chemical, and physical processes. The ¹⁴C ages of SOC_{total} and SOC_{nBC} at the sediment's surface are negative, reflecting the presence of 'bomb carbon,' that is, carbon fixed since humans began detonating thermonuclear weapons.

[12] Another human-influenced trend appears in the BC ¹⁴C age profile, which is linear from 10 to 20 cm, reflecting a slow aging of BC downcore. However, at 5 cm (~1880 A.D.) the BC ¹⁴C age profile folds, reflecting the increasing contribution of an older pool of BC in the surface sediments. One explanation for this trend is the Suess effect: the lowering of ¹⁴C in the atmosphere and environment due mostly to the combustion of fossil fuels. Fossil fuels became a source of BC in the late 19th century, and as humans burned more coal and oil, they 'aged' the Earth's BC pool through injection of ¹⁴C-free BC. Another possible explanation for this trend is the increase in California soil erosion rates in the 19th century due to land use change. Increasing inputs of SOC and BC from eroding deep soils may have aged coastal California sediments.

3.2. Effects of Deposition Conditions on Bulk and Isotopic Properties

[13] The transition from oxic to anoxic conditions occurs between 20 and 25 cm, simultaneously with changes in the downcore profiles of %SOC_{total}, OC/N, (not shown) $\delta^{13}C_{SOC_{total}}$ and the ¹⁴C age of SOC pools and BC. The cause of the ~1600 A.D. shift in oxygen concentrations is not known, although increases in marine productivity and carbon rain rate are related to bottom water O₂ concentration in this basin [Stott *et al.*, 2000]. This shift occurred concurrent with a drop in atmospheric CO₂ recorded in Antarctic ice cores [Etheridge *et al.*, 1996; Trudinger *et al.*, 1999], and a series of global climate events, including a

massive California flood and a drought in eastern N. America [Schimmelmann *et al.*, 1998]. Analysis of varve thickness in the nearby Santa Barbara Basin show the abrupt onset of interdecadal-frequency oscillations [Biondi and Lange, 1997]. It appears that some combination of a very strong El Niño, a solar irradiance maximum, and a series of volcanic events [Schimmelmann *et al.*, 1998] either changed upwelling, circulation, and/or productivity patterns in California's coastal basins and caused the onset of anoxia in the SMB.

[14] Although massive flooding associated with the 1600 AD climate event could have caused a shift in local rivers, increasing delivery of OC to sediments and causing the onset of dysoxia, $\delta^{13}C$ data show that this did not happen. SOC $\delta^{13}C$ became ~1.5‰ heavier after 1600 AD (Fig. 2a). However, we cannot rule out the possibility that changes in circulation may have caused changes in productivity, increasing or decreasing the delivery of OM to sediments. Therefore in discussion below we state only that our results are consistent with the effects of an oxic-anoxic shift, not that this shift is the exclusive cause of our observations.

[15] Under oxic conditions, SOC decomposition was much more efficient. The average SOC concentration increased by >3x following the onset of anoxia, from $1.4 \pm 0.1\%$ below 21.0 cm to $4.5 \pm 0.5\%$ above 21.0 cm (Fig. 1a). The SOC/N ratio (not shown) changed from an oxic average of 10.3 ± 0.2 to an anoxic average of 8.9 ± 0.5 , suggesting a more efficient preservation of N under anoxic conditions. While there was less SOC_{total} stored in sediments under oxic conditions, the percent of SOC_{total} composed of BC was higher, $5.2 \pm 1.2\%$ vs. $11 \pm 4\%$ at the bottom of the core, suggesting preferential storage of the more refractory BC component of SOC_{total}.

[16] Finally, both SOC and BC ¹⁴C age profiles are discontinuous at the oxic-anoxic transition. When oxygen is present the top 5–20 cm of sediments are bioturbated, effectively averaging the ¹⁴C age of the bioturbated region and giving the surface an older ¹⁴C age. However, under dysoxic bottom water conditions there are no bioturbating organisms, creating an age discontinuity when sediments undergo a drop in O₂ concentration (Fig. 2b).

3.3. Controls on the BC-SOC_{nBC} Age Offset: Oxygen Exposure and Continental Proximity

[17] The ¹⁴C age trends for SOC_{total}, SOC_{nBC}, and BC at this site show the same general trends as sediments from open ocean sites [Masiello and Druffel, 1998], with BC significantly older than concurrently deposited SOC_{nBC}. In the SMB sediments the age offset between BC and SOC_{nBC} is 1700 ± 800 ¹⁴C y in the anoxic, top portion of the core (calculated in the sediment regions not affected by either bomb or fossil ¹⁴C), while in the deeper, oxic region of the core the BC-SOC_{nBC} age offset more than doubles to 4400 ± 800 ¹⁴C y. This offset is less than that in the abyssal Northeast Pacific ($5,400 \pm 520$ ¹⁴C y) and the Antarctic ($13,900 \pm 3,900$ ¹⁴C y) [Masiello and Druffel, 1998]. The smaller age offset is a result of the proximity of the SMB to North America, and the difference in offset between the oxic and anoxic portions of the core is consistent with the expected effects of sedimentary oxidation on BC.

[18] The concept of a BC combustion continuum explains site-to-site variation and sediment oxidative effects on age

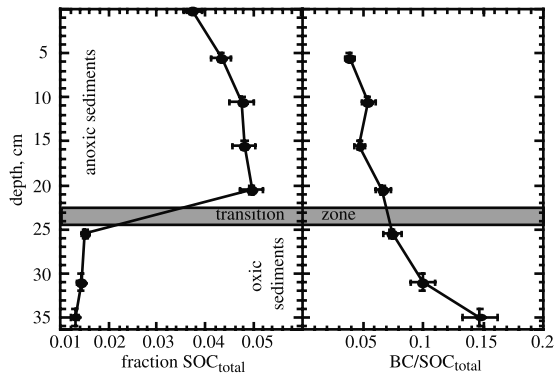


Figure 1. (a) OC per dry sediment. (b) BC/OC ratio. $\text{SOC}_{\text{total}}\%$ measurements were made on a Carlo-Erba NA1500. Reproducibility of $\% \text{SOC}_{\text{total}}$ is better than 5%. BC concentration was calculated using an average Pacific BC half-life with respect to dichromate oxidation of 474 ± 75 (1σ) hours [Masiello *et al.*, 2002]. All data have been salt-corrected.

offset. BC particle size, transport pathways, oxidizability, and retention of plant morphology vary along the combustion continuum. Lightly charred biomass, for example, tends to be composed of identifiable plant fragments >10 μm , and is easily chemically oxidized, while more refractory soot bears no chemical resemblance to biomass and is $0.1\text{--}1\mu\text{m}$. Smaller BC particles (e.g. soot) have long atmospheric residence times and are widely disbursed in sediments. Large BC particles are deposited close to the combustion source, while small particles remain aerosols, causing abyssal sediments to receive predominantly small, refractory, particles while coastal sediments while sediments preserve a broad region of the combustion continuum. Because charcoal is more susceptible to oxidation than soot [Masiello *et al.*, 2002] charcoal soil and sediment residence times should be younger, and should have a relatively younger sedimentary ^{14}C age. The addition of these larger, less refractory charcoal particles to coastal sediments should decrease the BC-SOC age offset.

[19] The abrupt change in the offset between BC and SOC_{NBC} at the oxic-anoxic boundary is also consistent with the effects of oxidation on the combustion continuum model of BC. It has previously been shown that BC can be destroyed in oxic ocean sediments [Middelburg *et al.*, 1999]. As the SMB became anoxic, it became easier for regions of the combustion continuum more prone to oxidation (charcoal and char) to be stored in sediments. The increase in preservation of younger char and charcoal fragments in the anoxic surface sediments may account for the decrease in the age offset between BC and SOC.

3.4. Terrestrial Carbon in the Santa Monica Basin

[20] A major source of terrestrial carbon to the California coastal basins is the Santa Clara River, which drains into the Pacific north of the SMB. It is appropriate to compare Santa Monica sediment isotopic data to weighted average Santa Clara isotopic data, as flood sediment is thoroughly dispersed [Wheatcroft *et al.*, 1997]. The $\Delta^{14}\text{C}$ of high-flow river particulate OC was older than the SMB surface carbon samples on average ($-428 \pm 76\text{‰}$, [Masiello and Druffel, 2001]) and for all river events sampled. The age difference

between the SMB and Santa Clara $\text{SOC}_{\text{total}}$ pools can be explained by the inclusion of bomb carbon in SMB sediments (surface sediment $\Delta^{14}\text{C} = +1\text{‰}$). The SMB marine SOC source is dissolved inorganic carbon in Northeastern Pacific surface waters, which currently contains bomb carbon [Masiello *et al.*, 1998]. There is no observable bomb signal present in Santa Clara carbon pools, likely due to the erosion of soil from deep within the soil profile [Masiello and Druffel, 2001]. The $\Delta^{14}\text{C}$ of BC exported by the Santa Clara river is 295% lighter than the BC observed in SMB surface sediments, likely due to increased erosion as Southern California land use changed, and may have been exacerbated by the heavy rainfall of the 1997–1998 ENSO event.

[21] SMB stable isotope data suggest effective storage of terrestrial sediment carbon: average $\text{SOC}_{\text{total}}$ (-22.5‰) is lighter than pure marine SOC ($\sim -19\text{‰}$ to -21‰), consistent with a mixture of marine and terrestrial sources. Additionally, the lighter $\delta^{13}\text{C}$ signature prior to the onset of anoxia suggests that under more oxidizing conditions, $\delta^{13}\text{C}$ -light terrestrial OC was preferentially preserved, a trend also observed in the Madeira Abyssal Plain turbidite [Prahla *et al.*, 1997]. Average $\delta^{13}\text{C}$ signatures are the same for the Santa Clara River particulate OC and the SMB anoxic SOC (-22‰), precluding the use of $\delta^{13}\text{C}$ to deconvolve the amount of terrestrial vs. marine OC stored at this site.

[22] However, the average $\Delta^{14}\text{C}$ signature of these two pools is significantly different, making it possible to estimate the amount of OC using the equation: $\Delta^{14}\text{C} \text{ SOC}_{\text{tot}} = \Delta^{14}\text{C} \text{ SOC}_{\text{terr}}(\text{FT}) + \Delta^{14}\text{C} \text{ SOC}_{\text{mar}}(1 - \text{FT})$, where FT is the fraction of carbon with a terrestrial source, $\Delta^{14}\text{C} \text{ SOC}_{\text{terr}}$ is the average $\Delta^{14}\text{C}$ of organic carbon exported by the Santa Clara River, $\Delta^{14}\text{C} \text{ SOC}_{\text{mar}}$ is the prebomb reservoir age of surface SMB waters, and $\Delta^{14}\text{C} \text{ SOC}_{\text{tot}}$ represents the $\Delta^{14}\text{C}$ signature of surface SMB sediments. Petroleum hydrocarbons can be omitted as a source of SOC_{tot} because they are present in only the n -alkane fraction of the lipids and made up $\sim 5\%$ of lipids in prebomb horizons [Pearson *et al.*, 2001]. As lipids are $\sim 5\%$ of SOC [Wang *et al.*, 1996], petroleum is not more than 0.2% of SOC.

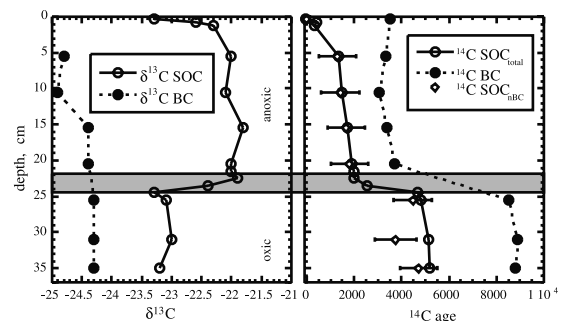


Figure 2. (a) $\delta^{13}\text{C}$ of Santa Monica SOC and BC. Error is $\pm 0.1\text{‰}$. (b) ^{14}C ages of Santa Monica SOC and BC. Errors for ^{14}C ages are less than the size of the points. We extracted CO_2 for ^{14}C measurement as described by Druffel *et al.* [1992] and prepared graphite as described by Vogel *et al.* [1987]. Radiocarbon measurements were made at LLNL Center for AMS. For discussion of uncertainties associated with BC measurement, see Schmidt and Noack [2000]; Schmidt *et al.* [2001]; and Masiello *et al.* [2002]. For discussion of ^{14}C terminology, see Stuiver and Polach [1977].

[23] The pre-bomb $\Delta^{14}\text{C}$ of S. CA coastal waters has been estimated at an average of $-84 \pm 8\%$ [Ingram and Southon, 1996]. We use this value for an age-corrected $\Delta^{14}\text{C}$ SOC_{mar}. For $\Delta^{14}\text{C}$ SOC_{terr} we use the average $\Delta^{14}\text{C}$ of particulate OC exported by the Santa Clara River in 1997–98, $-428 \pm 76\%$. Because this estimate for the average $\Delta^{14}\text{C}$ of Santa Clara OC may be low, the resulting FT will be a lower bound.

[24] This does not include a term for bomb or fossil ^{14}C , requiring that the $\Delta^{14}\text{C}$ SOC_{total} value be taken from the 5.5 cm horizon, which is deep enough in the sediment core to exclude fossil or bomb carbon influences. Because this sediment has aged since deposition the $\Delta^{14}\text{C}$ value must be age-corrected [Stuiver and Polach, 1977] to its value in 1880 \pm 25 AD (the year of deposition, taken from previously published stratigraphy [Hagadorn et al., 1995]), giving $-142 \pm 2.6\%$ (FM = 0.8505). Using this data, we estimate SOC_{terr} to be $17 \pm 5\%$ of the SOC_{tot} stored in the anoxic portion of Santa Monica sediments. As BC is $5.2 \pm 1.2\%$ of SOC_{tot}, BC is $31 \pm 11\%$ of SOC_{terr}.

4. Conclusions

[25] At this coastal site BC is $5.2 \pm 1.2\%$ of SOC_{tot} under anoxic deposition conditions and $11 \pm 4\%$ of SOC_{tot} under oxic conditions. The difference in BC storage can be explained by preferential remineralization of SOC_{nBC} in the presence of oxygen. Radiocarbon evidence is consistent with the explanation that BC is decomposed more efficiently in oxic environments, and also suggest that the sedimentary BC-SOC_{nBC} age offset is related to at least two variables: the distance from the nearest continent (a variable that has been previously suggested to control overall BC sediment storage [Suman et al., 1997]), and the sediment's oxidative exposure history. Implicit in this second variable is the idea that different regions of the BC continuum suffer environmental oxidation at different rates, with larger, less combusted char and charcoal particles decaying more rapidly than smaller soot particles.

[26] Our estimate of the terrestrial fraction of the Santa Monica sediments is $17 \pm 5\%$, making BC $31 \pm 11\%$ of the terrestrial organic carbon stored at this site. As at least the soot fraction of BC lacks all plant biochemical tracers, this fraction of terrestrial organic matter is 'invisible' to the standard biochemical techniques (such as lignin analysis) used to identify the presence of terrestrial material in ocean sediments.

[27] **Acknowledgments.** We appreciated the laboratory assistance of Sheila Griffin and ^{14}C preparation facilities provided by Susan Trumbore and Shuhui Zheng. All ^{14}C data were measured by CAMS LLNL, and $\delta^{13}\text{C}$ measurements were made by Eben Franks at WHOI and at UC Davis. Samples were collected with the assistance of the crew of the R/V Revelle. Early drafts of this manuscript benefited from the comments of Susan Trumbore and Bill Reeburgh, and the final document was improved by the comments of two anonymous reviewers.

References

Biondi, F., and C. B. Lange, Inter-decadal signals during the last millennium (AD 1117–1992) in the varve record of Santa Barbara basin, California, *Geophys. Res. Lett.*, 24(2), 193–196, 1997.

Christensen, C. J., D. S. Gorsline, D. E. Hammond, and S. P. Lund, Non-annual laminations and expansion of anoxic basin-floor conditions in Santa-Monica Basin, California Borderland, over the past 4 centuries, *Marine Geology*, 116(3–4), 399–418, 1994.

Druffel, E. R. M., P. M. Williams, J. E. Bauer, and J. R. Ertel, Cycling of dissolved and particulate organic matter in the open ocean, *J. Geophys. Res.*, 97(C10), 15,639–15,659, 1992.

Etheridge, D. M., L. P. Steele, R. L. Langenfelds, and R. J. Francey, Natural and anthropogenic changes in atmospheric CO_2 over the last 1000 years from air in Antarctic ice and firn, *J. Geophys. Res., Atmospheres*, 101(D2), 4115–4128, 1996.

Hagadorn, J. W., L. D. Stott, A. Sinha, and M. Rincon, Geochemical and sedimentologic variations in inter-annually laminated sediments from Santa Monica Basin, *Marine Geology*, 125(1–2), 111–131, 1995.

Hedges, J. I., and R. G. Keil, Sedimentary organic matter preservation—an assessment and speculative synthesis, *Marine Chemistry*, 49(2–3), 81–115, 1995.

Herring, J. R., Charcoal fluxes into sediments of the North Pacific Ocean: the Cenozoic record of burning, in *The Carbon Cycle and Atmospheric CO_2 : Natural Variations, Archaeon to Present*, edited by E. T. Sundquist and W. S. Broecker, pp. 419–442, A.G.U., 1985.

Ingram, B. L., and J. R. Southon, Reservoir ages in eastern Pacific coastal and estuarine waters, *Radiocarbon*, 38(3), 573–582, 1996.

Kuhlbusch, T. A. J., Ocean Chemistry—Black carbon and the carbon cycle, *Science*, 280(5371), 1903–1904, 1998.

Masiello, C. A., and E. R. M. Druffel, Black carbon in deep-sea sediments, *Science*, 280(5371), 1911–1913, 1998.

Masiello, C. A., and E. R. M. Druffel, The isotope geochemistry of the Santa Clara River, *Global Biogeochem. Cycles*, 15(2), 407–416, 2001.

Masiello, C. A., E. R. M. Druffel, and J. E. Bauer, Physical controls on dissolved inorganic radiocarbon variability in the California Current, *Deep-Sea Research Part II-Topical Studies in Oceanography*, 45(4–5), 617–642, 1998.

Masiello, C. A., E. R. M. Druffel, and L. A. Currie, Radiocarbon measurements of black carbon in aerosols and ocean sediments, *Geochimica Cosmochimica Acta*, 66(6), 1025–1036, 2002.

Middelburg, J. J., J. Nieuwenhuize, and P. vanBruegel, Black carbon in marine sediments, *Marine Chemistry*, 65(3–4), 245–252, 1999.

Pearson, A., A. P. McNichol, B. C. Benitez-Nelson, J. M. Hayes, and T. I. Eglinton, Origins of lipid biomarkers in Santa Monica Basin surface sediment: A case study using compound-specific $\Delta^{14}\text{C}$, *Geochimica et Cosmochimica Acta*, 65(18), 3123–3137, 2001.

Prahl, F. G., G. J. DeLange, S. Scholten, and G. L. Cowie, A case of post-depositional aerobic degradation of terrestrial organic matter in turbidite deposits from the Madeira Abyssal Plain, *Organic Geochemistry*, 27(3–4), 141–152, 1997.

Schimmelmann, A., M. Zhao, C. C. Harvey, and C. B. Lange, A large California flood and correlative global climatic events 400 years ago, *Quaternary Research*, 49, 51–61, 1998.

Schmidt, M. W. I., and A. G. Noack, Black carbon in soils and sediments: Analysis, distribution, implications, and current challenges, *Global Biogeochem. Cycles*, 14(3), 777–793, 2000.

Schmidt, M. W. I., J. O. Skjemstad, C. I. Czimeczik, B. Glaser, K. M. Prentice, Y. Gelin, and T. A. J. Kuhlbusch, Comparative analysis of black carbon in soils, *Global Biogeochem. Cycles*, 15(1), 163–167, 2001.

Smith, D. M., J. J. Griffin, and E. D. Goldberg, Elemental carbon in marine sediments: A baseline for burning, *Nature*, 241, 268–271, 1973.

Stott, L. D., W. Berelson, R. Douglas, and D. Gorsline, Increased dissolved oxygen in Pacific intermediate waters due to lower rates of carbon oxidation in sediments, *Nature*, 407, 367–370, 2000.

Stuiver, M., and H. A. Polach, Reporting of ^{14}C data, *Radiocarbon*, 19(3), 355–363, 1977.

Suman, D. O., T. A. J. Kuhlbusch, and B. Lim, Marine sediments: A reservoir for black carbon and their use as spatial and temporal records of combustion, in *Sediment Records of Biomass Burning and Global Change*, edited by J. S. Clark, H. Cachier, J. G. Goldammer, and B. J. Stocks, Springer Verlag, Berlin, 1997.

Trudinger, C. M., I. G. Enting, R. J. Francey, and D. M. Etheridge, Long-term variability in the global carbon cycle inferred from a high-precision CO_2 and $\delta^{13}\text{C}$ ice-core record, *Tellus*, 51B, 233–248, 1999.

Vogel, J. S., D. E. Nelson, and J. R. Southon, ^{14}C Background Levels in an Accelerator Mass Spectrometry System, *Radiocarbon*, 29(3), 323–333, 1987.

Wang, X. C., E. R. M. Druffel, and C. Lee, Radiocarbon in organic compound classes in particulate organic matter and sediment in the deep Northeast Pacific Ocean, *Geophys. Res. Lett.*, 23(24), 3583–3586, 1996.

Wheatcroft, R. A., C. K. Sommerfield, D. E. Drake, J. C. Borgeld, and C. A. Nittrouer, Rapid and widespread dispersal of flood sediment on the northern California margin, *Geology*, 25(2), 163–166, 1997.

Wolbach, W. S., and E. Anders, Elemental carbon in sediments: Determination and isotopic analysis in the presence of kerogen, *Geochimica Cosmochimica Acta*, 53, 1637–1647, 1989.

C. A. Masiello and E. R. M. Druffel, Department of Earth System Science, University of California at Irvine, Irvine, CA 92697-3100, USA. (masiello@gps.caltech.edu)