OCEAN CHEMISTRY:

Enhanced: Black Carbon and the Carbon Cycle

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Black carbon [HN1] is a product of incomplete combustion of vegetation and fossil fuels. It is ubiquitous and can be found in soils, ice, sediments, and the atmosphere. The interest in black carbon is manifold and includes its aerosol form as the main light-absorbing constituent [HN2], in sediments and ice cores that reveal fire history [HN3], as a sink of atmospheric CO_2 in the short-term atmospheric-biospheric carbon cycle, and as a possibly substantial source of oxygen over geological time [HN4] scales. Now on page 1911 of this issue, Masiello and Druffel (1) report the age of sedimentary organic and black carbon; they found black carbon to be 2400 to 13,900 years older than the concurrently deposited sedimentary organic carbon [HN5]. They (1) conclude from this age difference that sedimentary black carbon must have been stored in an intermediate pool, most likely oceanic dissolved organic carbon [HN6].

The figure summarizes current knowledge concerning the life cycle of black carbon. The first measurements of black carbon in ocean sediments were published by Smith *et al.* in 1973 (2). They proposed sedimentary black carbon as a unique tool for studying the history of vegetation fires. In 1980, Seiler and Crutzen (3) reported a substantial sink of atmospheric CO_2 by the formation of black carbon in vegetation fires. They argued that a relatively unknown (at that time) fraction of the vegetation exposed to fire is converted to a refractory form of carbon. Because this black carbon will not be degraded, it is believed to represent a sink for

the fast atmospheric-biospheric carbon cycle and a source for the long-term geological carbon cycle. In 1990, Crutzen and Andreae (4) estimated annual global black carbon formation to be 200 to 600 Tg (10^{12} g) and noticed that this carbon sink may have been an important source of oxygen over geological time scales. Kuhlbusch and Crutzen (5) updated the annual global black carbon formation estimate on the basis of measurements in residues of vegetation fires [HN7]. They calculated annual formation rates for black carbon of 50 to 200 Tg, with the major fraction (>80%) produced in the residues of fires. This rate of black carbon formation reduces net CO_2 release by permanent deforestation [HN8] by 2 to 18% and may constitute a substantial fraction of the "missing carbon" in the anthropogenically disturbed global carbon balance (5). An estimate of oxygen release assuming 10% of today's formation rate of black carbon over the last 340 million years [from the oldest documented record of charcoal (6)] gives 8 times more O_2 than the current atmospheric O_2 content (5). An estimate of oxygen released by the amount of sedimentary organic carbon gives a value of 25 times the present atmospheric oxygen content (7). Some measurements of black carbon in open-ocean sedimentary organic carbon showed that black carbon can constitute a substantial fraction of sedimentary organic carbon [on average 20 to 50% (1, 8, 9)]. These results indicate that estimates of past terrestrial carbon storage [HN9] should include the fraction of black carbon stored in soils and sediments and that black carbon formation by vegetation fires may be important for our past and current atmospheric oxygen concentrations as well.

QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

In the black. Masiello and Druffel (1) determined age differences of 2400 to 13,900 years between sedimentary organic carbon (SOC) and black carbon (BC). Thus, they conclude that sedimentary black carbon must have spent considerable time in an intermediate pool. Candidates are terrestrial soils and the oceanic dissolved organic carbon (DOC) pool [data from (5, 7, 10)]. All values are in petagrams (1 Pg = 10$_{15}$ g) per year.

Masiello and Druffel (1) have concluded from mass and Δ_{14}C measurements [HN10] that black carbon may represent a substantial fraction (4 to 22%) of the oceanic carbon pool. They also argue that the main source of black carbon in the open ocean is the deposition of carbonaceous aerosols. Thus, aerosol black carbon, which is also the main aerosol constituent absorbing solar radiation, may also be an important route by which terrestrial organic carbon is transported to the oceanic carbon pool.

Suman *et al.* (10) estimated atmospheric deposition of aerosol black carbon to coastal and open ocean to be 7 ± 3 Tg of C per year, with about 50% of the carbon deposited onto the coastal ocean. Comparing these deposition rates with sedimentation rates for coastal and open-ocean areas, they found, in agreement with Masiello and Druffel (1), that eolian transport [HN11] is the most important source of open-ocean black carbon. On the other hand, riverine and surface runoff [HN12] may be the most important source of oceanic black carbon closer to the coast, because atmospheric deposition could only explain about 30 to 40% of the sedimentary deposition rate.

Another important conclusion by Masiello and Druffel (1) is the long residence time of black carbon (2400 to 13,900 years) in an intermediate pool, either in soils or in the ocean. This has

important implications for the marine carbon cycle and the interpretation of sediment records of black carbon to reconstruct fire history. Assuming the ocean to be the most important intermediate pool, oceanic transport will dominate the location of sedimentation. In this case, no link of the studied sediment site and source region can be easily made. On the other hand, Verardo and Ruddiman (9) found a correlation of sedimentary black carbon and eolian siliciclastic fluxes [HN13] in an Atlantic deep-sea core. On the basis of their results, they hypothesize that black carbon fluxes to deep-sea sediments are linked to wind speed and direction. In this case, soils would be the main intermediate pool for sedimentary black carbon. Certainly, further measurements of black carbon in sediments as well as in river and ocean water are necessary to address the above question. Additionally, the source strength of aged black carbon from soils becoming airborne by wind erosion should be investigated as well.

But, most importantly, we need to develop an experimentally acceptable definition of black carbon and intercalibrate the various analytical techniques if we wish to build a meaningful data set. Certainly, to understand the role of black carbon and thus of any combustion process in the environment, a complete understanding of the life cycle of black carbon is necessary.

References

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