Developing a global perspective on the dynamics of fluvial transfer of terrestrial biospheric carbon to the ocean

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Introduction

The burial of terrestrial biospheric organic carbon (OC) in continental margin sediments represents an important component of the global carbon cycle. Organic signatures preserved in continental margin and deep-sea sediments can also provide continuous records of past continental and oceanic dynamics. Recent studies have greatly advanced our understanding of the flux and composition of particulate organic matter that is exported by different river systems to the oceans and is sequestered in marine sediments. However, several key aspects of the transfer of carbon from biological source to geological sink remain much more poorly constrained. In particular, we still have a limited understanding of the provenance of these signals, the timescales associated with their transfer from biological source to sedimentary sink, and the potential links between climate and signal transmission times.

Fundamental questions that remain unresolved include:

1. From where within drainage basin does the organic matter that is ultimately discharged originate (i.e., what is its provenance)?
2. How and where does organic matter become associated with mineral phases, how does the "partnership" between organic matter and the mineral load evolve during transit through the drainage basin, and how does it influence its ultimate fate ?
3. What are the timescales involved in the transfer of carbon from the terrestrial biosphere to the marine environment (i.e., what is the "residence time" of biospheric carbon on the continents)?

Additional questions related to Question #3 are:

i. How do residence times vary with climate?
ii. Does residence time on land influence the fate of terrestrial OC discharged to the marine environment?
iii. How are human activities modifying the storage time, flux and composition of organic materials exported by rivers to the ocean?

Answers to these questions of organic matter provenance, disposition and dynamics are crucial for examining:

a. The role of fluvial systems in the global carbon cycle and the sensitivity of these systems to climate and anthropogenic perturbation.
b. Interpretation of sedimentary records of past terrestrial vegetation change through studies of tracer organic signatures (e.g., vascular plant biomarkers, pollen) preserved within the marine sedimentary record.

General Approach

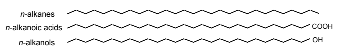
We are exploring the variability in the composition and radiocarbon age of terrestrial organic matter - both at the bulk and molecular level - in a wide range of river drainage basins. A primary goal of this work is to build a global perspective on the controls on terrestrial biospheric carbon residence times. The overall approach involves:

- Exploration of global variations in terrestrial organic carbon "residence times" via studies of sediments near the terminus of different river drainage basins.
- Examination of within-drainage basin isotopic signatures via sampling of river tributaries and mainstem.
- Assessment of different biospheric carbon components Tracing the "bomb spike" in vascular plant biomarkers from source to sink.
- Down-core studies to examine links between residence times and climate

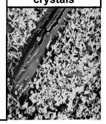
Analytical Approach

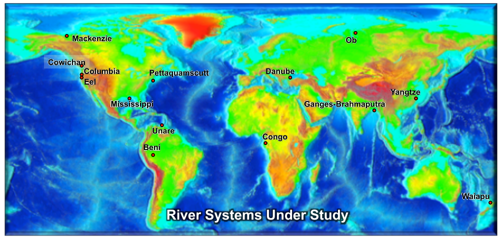
- Radiocarbon and stable isotopic measurements on organic compounds specific to vascular land plants.
  - Epicuticular leaf wax lipids
  - Lignin-derived phenols

Epicuticular wax lipids



Epicuticular wax crystals





Observation – 1

- There are no obvious systematic relationships between the age of terrestrial plant wax lipids and river drainage basin area (Fig. 1a), water discharge (Fig. 1b), sediment load (Fig. 1c), or sediment yield (Fig. 1d).

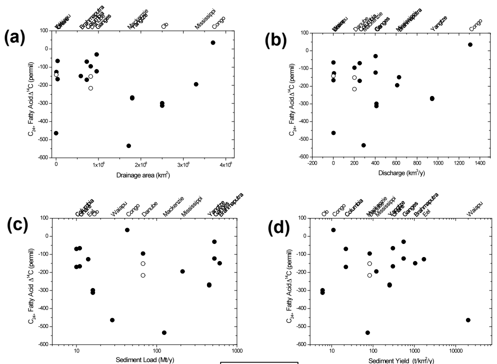


Figure 1

Observation – 2

- There ***is*** an apparent relationship between the stable hydrogen isotopic composition of the plant waxes and their radiocarbon content/age (Fig. 2a).
- The deuterium content of plant waxes is strongly related to latitude (Fig. 2b) due to the well-known latitudinal gradient in the hydrogen isotopic composition of meteoric water, which plant waxes have been demonstrated to track (e.g., Sachse et al., 2004). This suggests that temperature and/or aridity/humidity, may be the primary factors in controlling the age of plant waxes discharged from river drainage basins.

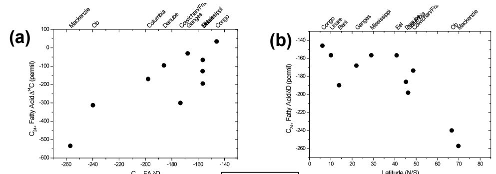


Figure 2

Observation – 3

- The above observations reveal a general relationship between the latitude of a drainage basin and the age of terrestrial plant wax biomarkers that are discharged by the rivers (Fig. 3a). Low latitude systems export young vascular plant-derived OC while high latitude systems exports older compounds.
- Although the measurements have mostly been made on only one class of compounds (higher plant wax fatty acids), the limited number of data we have obtained on other higher plant markers (other plant wax lipids and lignin-derived phenols) suggests this general relationship is robust, although there may be differences in the slope of the relationship.
- There is, of course, considerable scatter within the overall trend in higher plant marker ^{14}C content versus latitude. This scatter must reflect the influence other facets of the drainage basin on vascular plant residence time (e.g. Kusch et al., 2010).
- Total Organic Carbon (TOC) does not display a similar relationship (Fig. 3b), presumably due to the influences of other organic matter sources (within-river productivity, sedimentary rock kerogen) on TOC ^{14}C content.

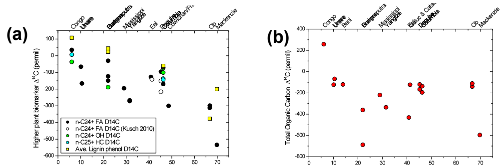


Figure 3

Potential Explanations

- Transit time through each drainage basin varies with latitude due to temperature-related soil cycling/mobilization rates.
- Low latitude rivers are dominated by OC supplied from regions draining the lower reaches the river, whereas at higher latitudes the OC derives from a greater fraction of the overall drainage basin.
- At high latitudes, young vascular plant carbon is preferentially remineralized with the residual POC exported from the rivers being derived from more refractory [older] pools (soil, permafrost?), whereas remineralization is less selective at low latitudes.

Implications

- Apparent residence times may reflect the extent to which a river acts as a "conveyor" of organic matter (pipeline) versus as a "bioreactor" (incinerator).
- Different explanations for ^{14}C relationship with latitude have different implications concerning the provenance of terrestrial biomarker signals discharged to the oceans.
- Records of past terrestrial vegetation change constructed from biomarkers preserved in continental margin sediment records may be subject to considerable lags (esp. for high latitude systems).

References

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- Kusch S., Rethemeyer J., Schefuss E., Mollenhauer G. (2010) Controls on the age of vascular plant biomarkers in Black Sea sediments. Geochim. Cosmochim. Acta 74, 7031-7047.

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