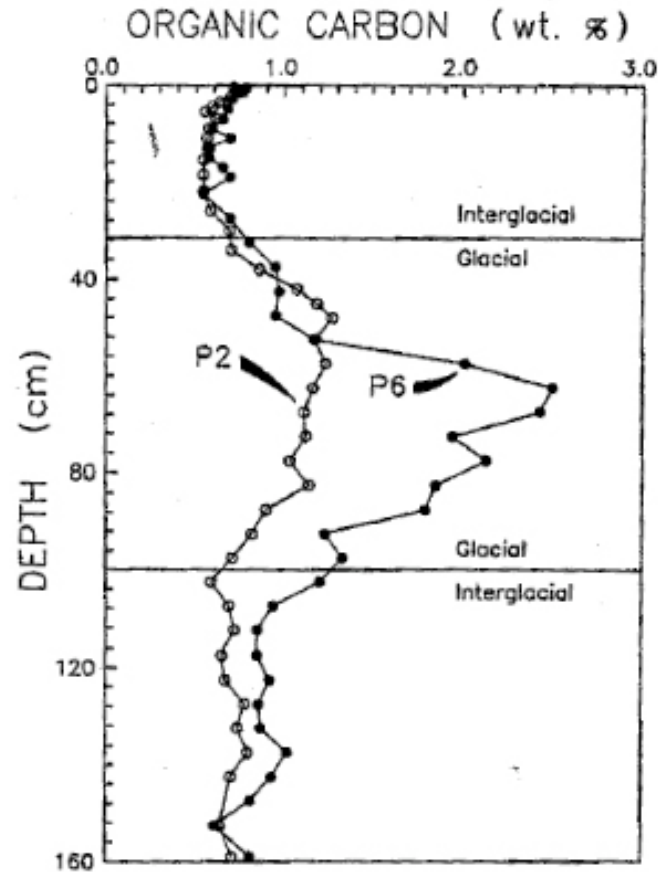
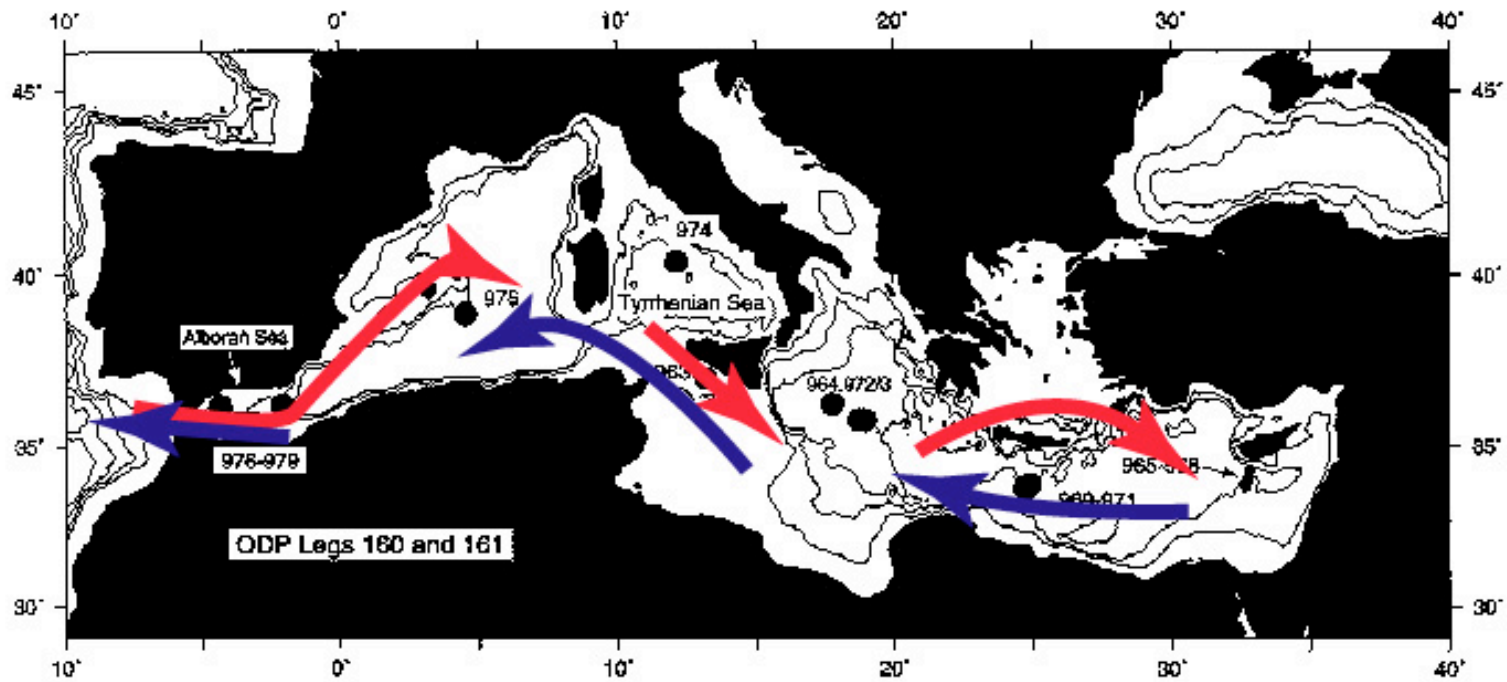


If the ocean is so efficient in remineralizing C and nutrients, why is C preserved at all in sediments?



Organic carbon with depth in late Pleistocene sediments from the eastern Equatorial Pacific Ocean. (Pederson and Calvert, AAPG Bull.(1990) v74, 454-466).

Carbon preservation and the mystery of Mediterranean Sea Sapropels



Sapropels

organic rich
(2-14% TOC)

Periodic deposition

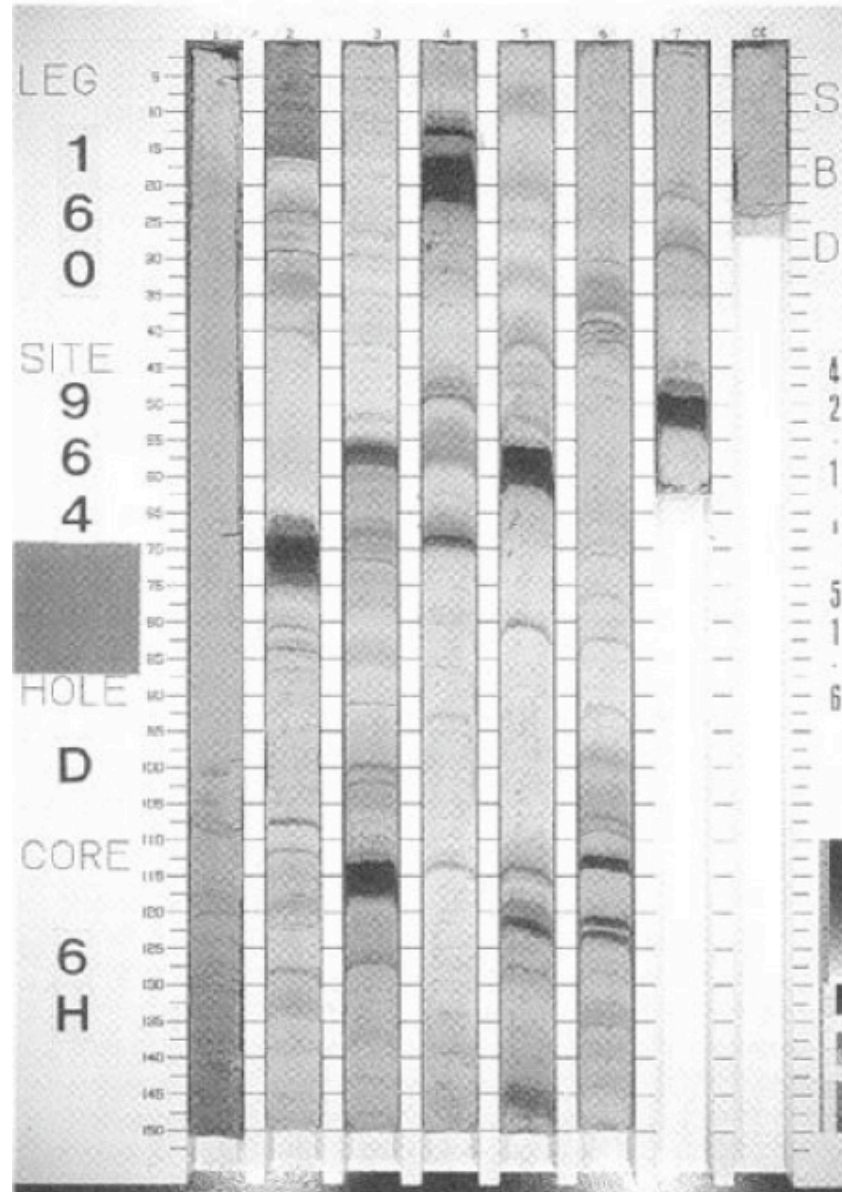
<1 cm to > 10 cm thick

Nonsapropels

Very organic lean
(0.1% TOC)

Most of the deposition

Mediterranean Sea Sediment Core



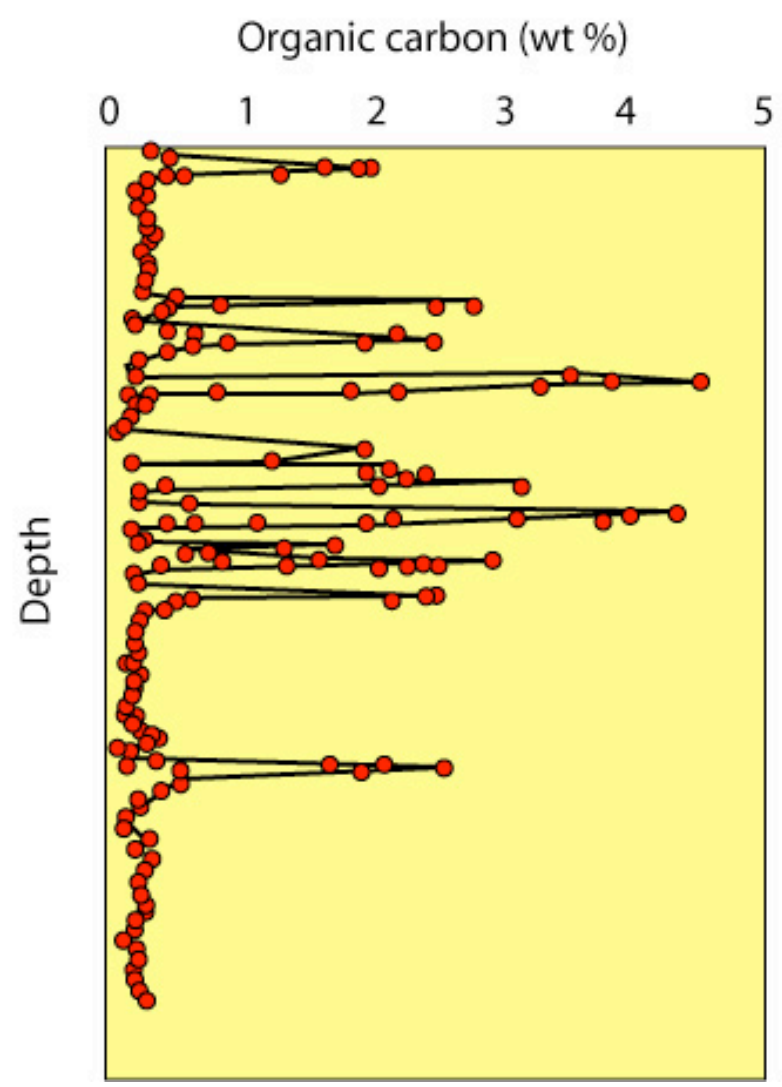
Sapropels

Any organic rich layer of sediment is called a sapropel, Sapropels in the Mediterranean Sea are very interesting however because the Med is one of the least productive bodies of water today, and sediments there are extremely depleted in organic carbon. A very long historical record of sapropel deposition was collected by the Ocean Drilling Program Legs 160 and 161 (see Initial reports...). Sapropels were first discovered in the Eastern Mediterranean Sea, but ODP found them to be synchronous in both basins. The shallowest sapropel is < 1m deep and can be sampled with a gravity core.

close-up of sapropel layer

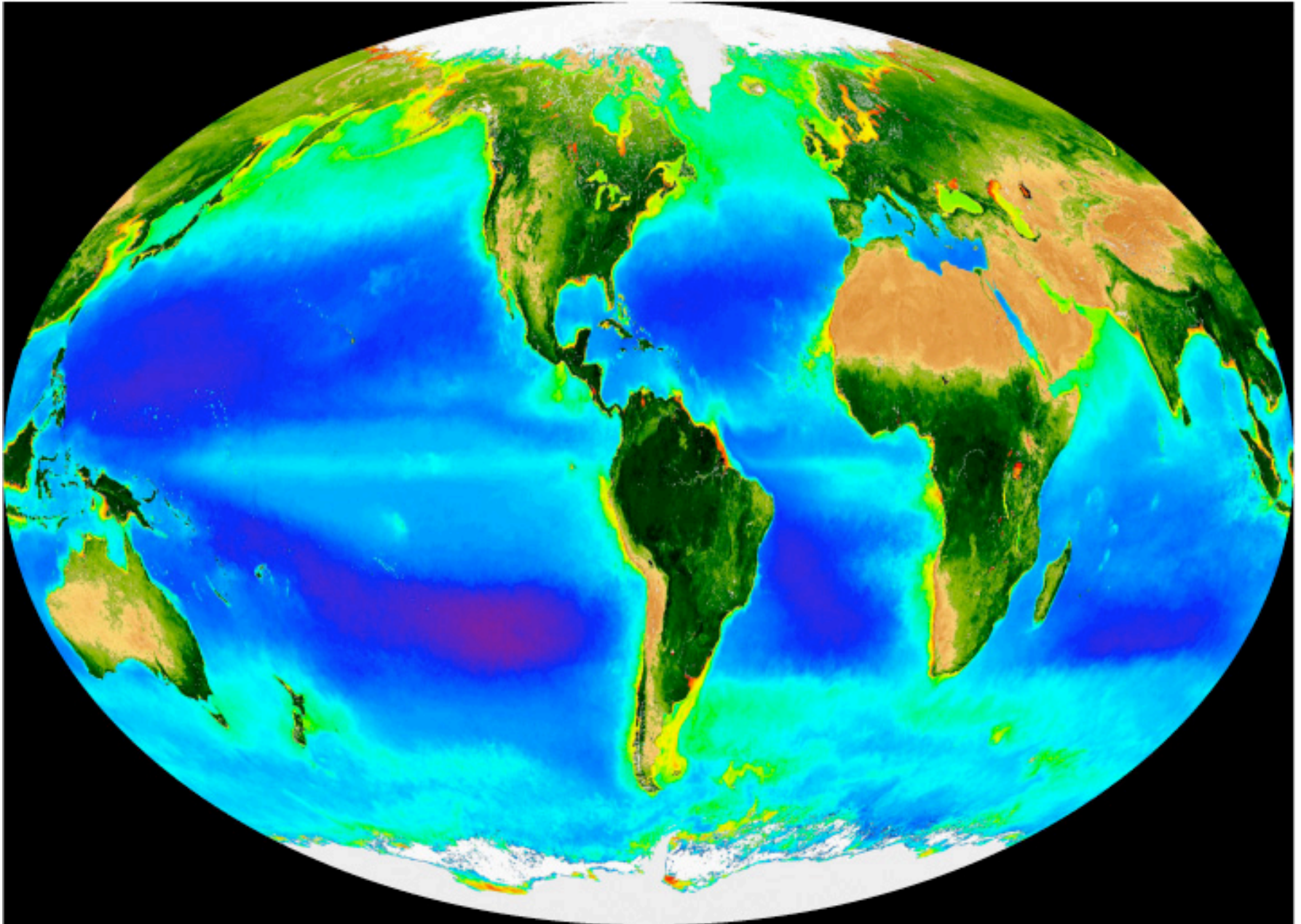


Organic carbon in Mediterranean Sea sediments

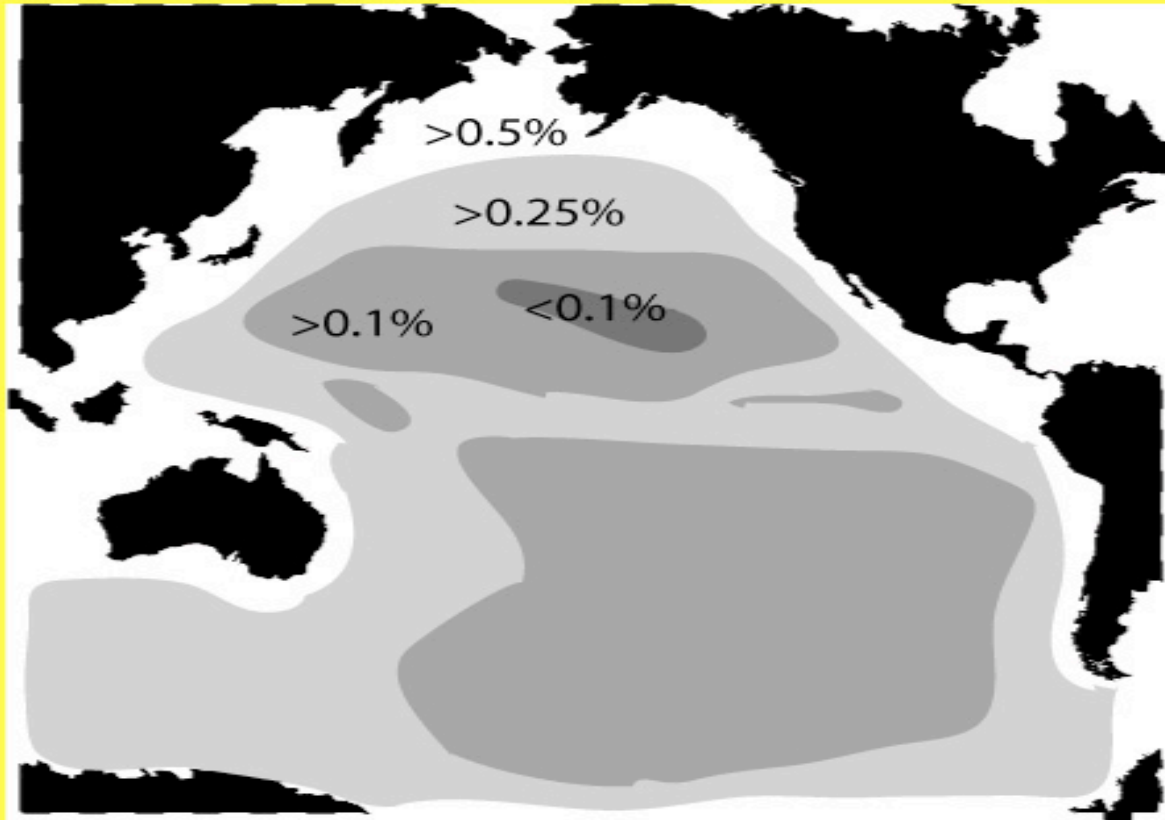


Calvert et al.

Global distribution of chlorophyll-a in September



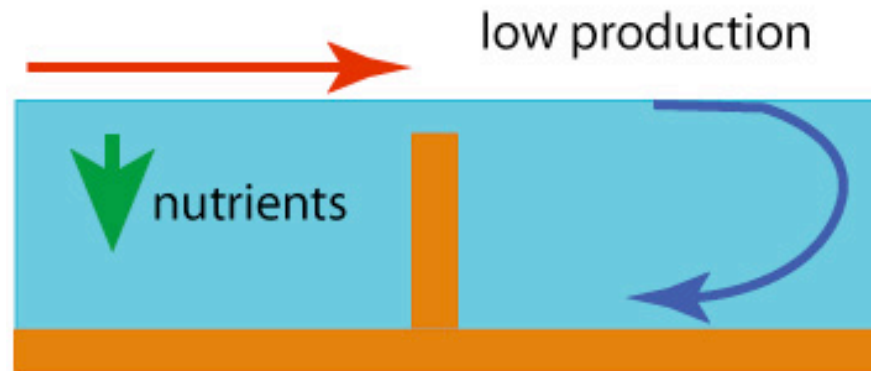
Organic carbon in surface sediments of the Pacific Ocean



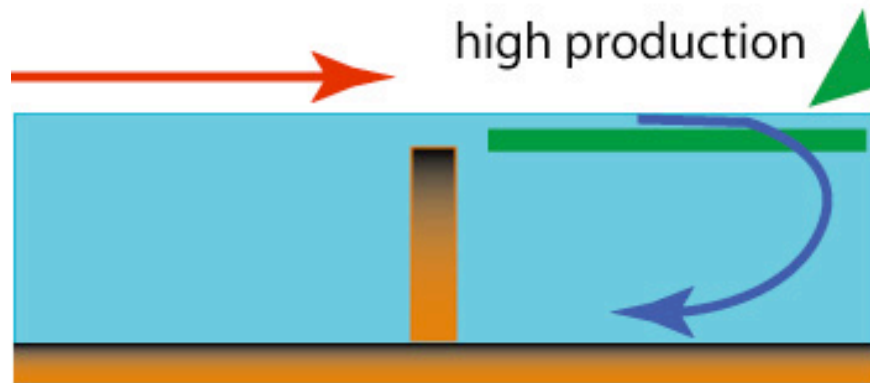
Calvert and Peterson 1998

Formation of Mediterranean Sea Sapropels

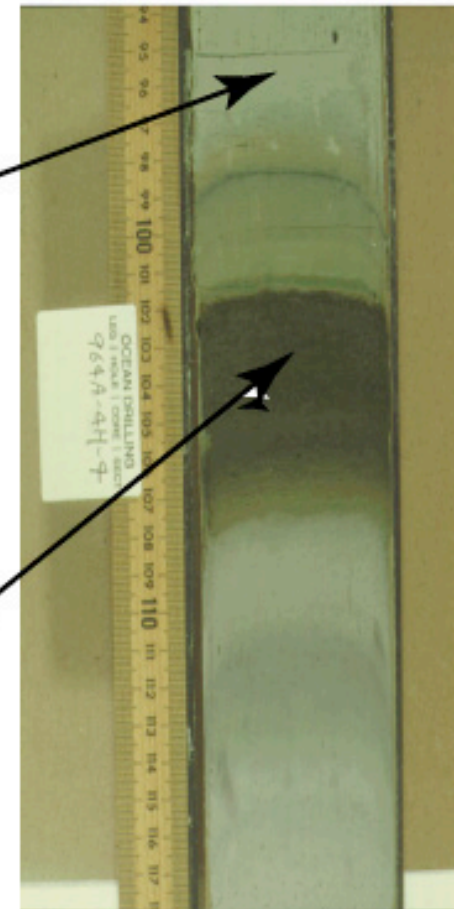
Enhanced productivity hypothesis



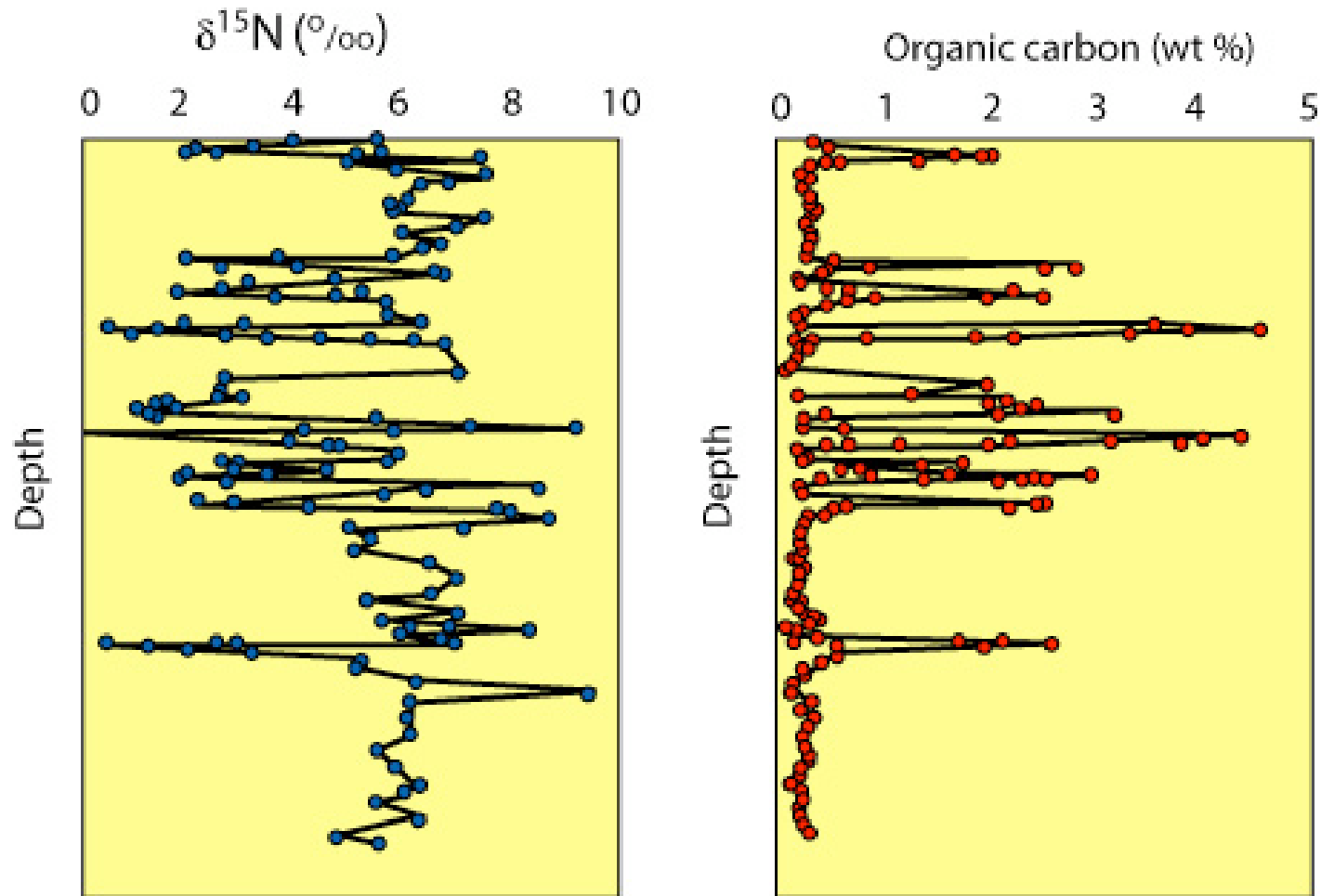
low carbon sediments



sapropel deposition



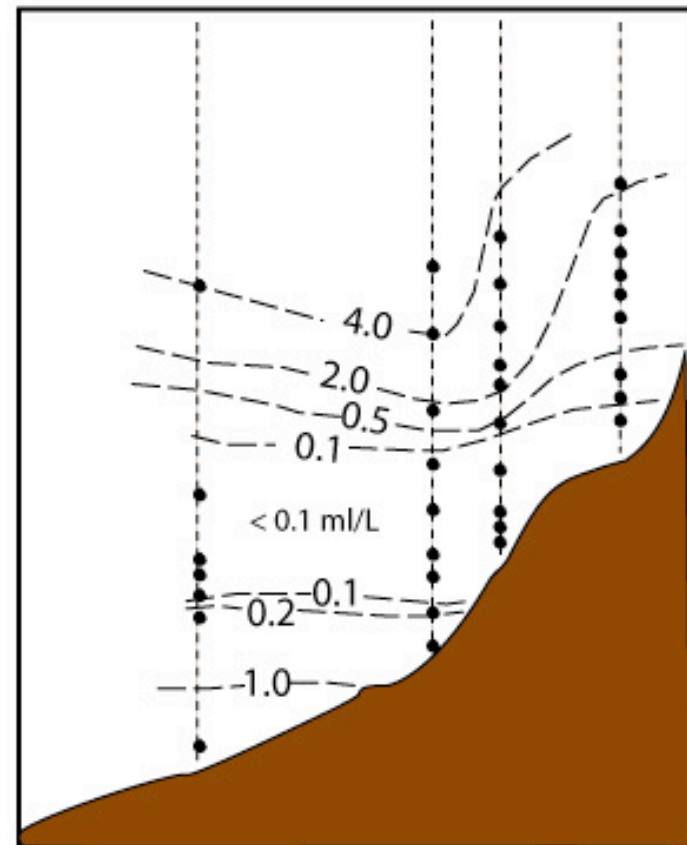
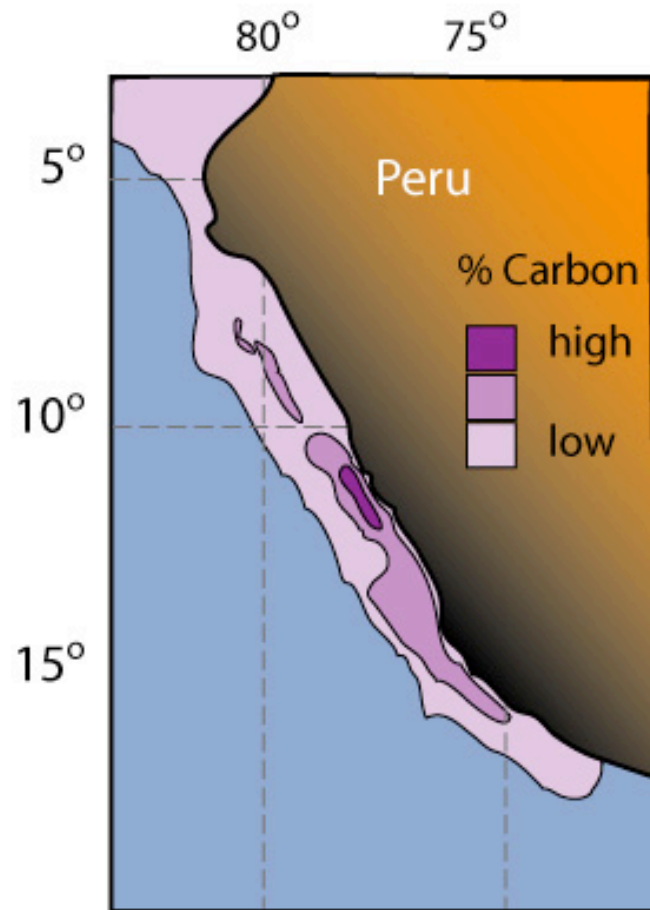
Correlation between %OC and nitrogen isotopes in Mediterranean Sea sediments



Nitrogen isotopes in paleoproductivity and denitrification studies

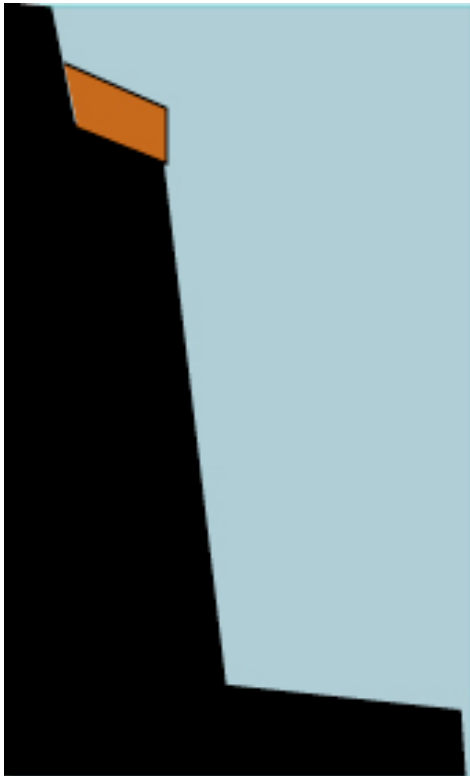
Central Gyres	Upwelling Zones and Polar Seas	Oxygen Minimum Zones
<p>Low Nutrients</p> <p>phytoplankton $\delta^{15}\text{N} = 5.9$ per mil</p> <p>$\text{NO}_3^- \rightarrow \text{N}(\text{organic})$ $\epsilon = 0$ per mil</p>	<p>High Nutrients</p> <p>phytoplankton $\delta^{15}\text{N} < 5.9$ per mil</p> <p>$\text{NO}_3^- \rightarrow \text{N}(\text{organic})$ $\epsilon = 6$ per mil</p>	<p>Low Oxygen</p> <p>phytoplankton $\delta^{15}\text{N} > 5.9$ per mil</p> <p>$\text{NO}_3^- \rightarrow \text{N}_2$ $\epsilon = 20$ per mil</p>
	<p>Deep Sea Nitrate $\delta^{15}\text{N} = 5.9$ per mil</p>	

Carbon accumulation and the oxygen minimum zone of the Peru upwelling system

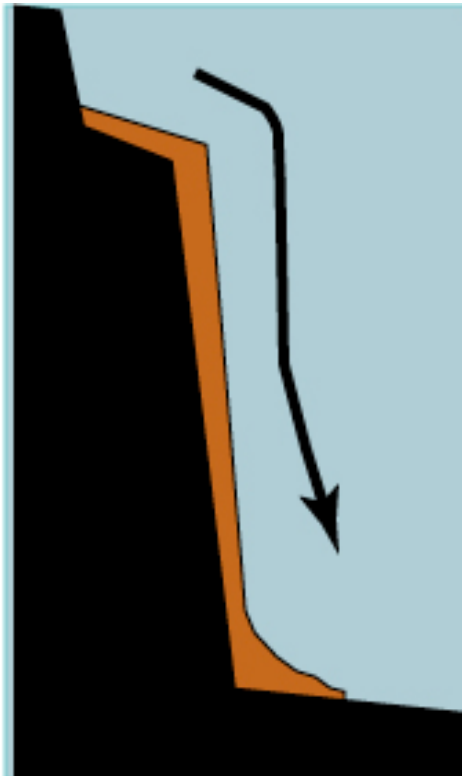


The effect of oxygen on carbon preservation in Maderia Abyssal Plain Turbidites

Before...



During...



and Voila!



The effect of oxygen on carbon preservation in Maderia Abyssal Plain Turbidites

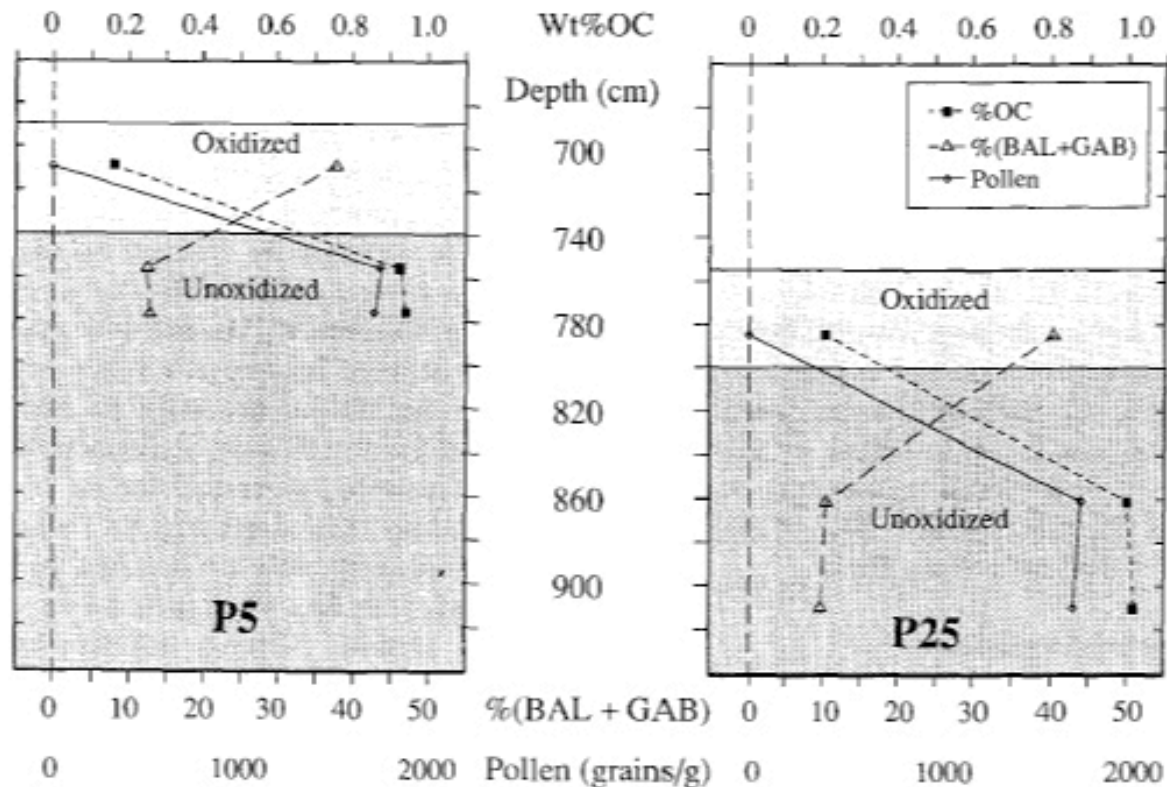
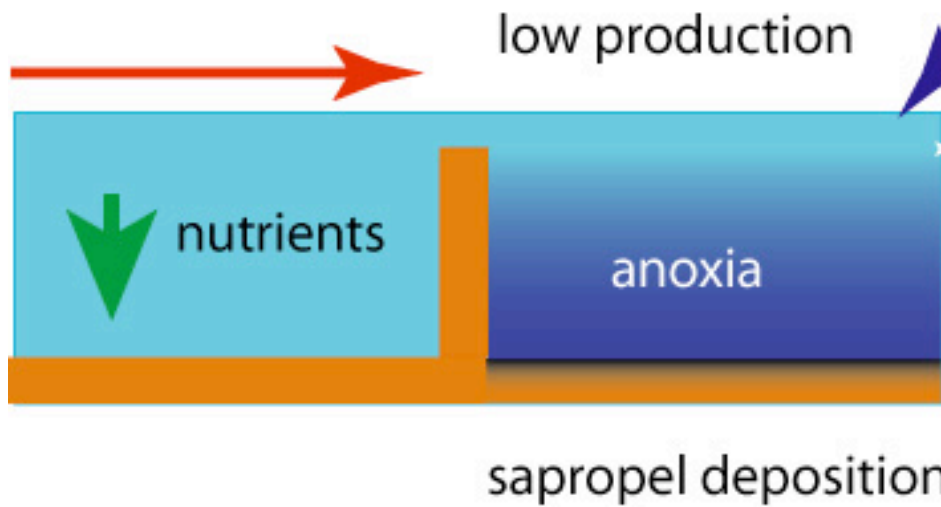
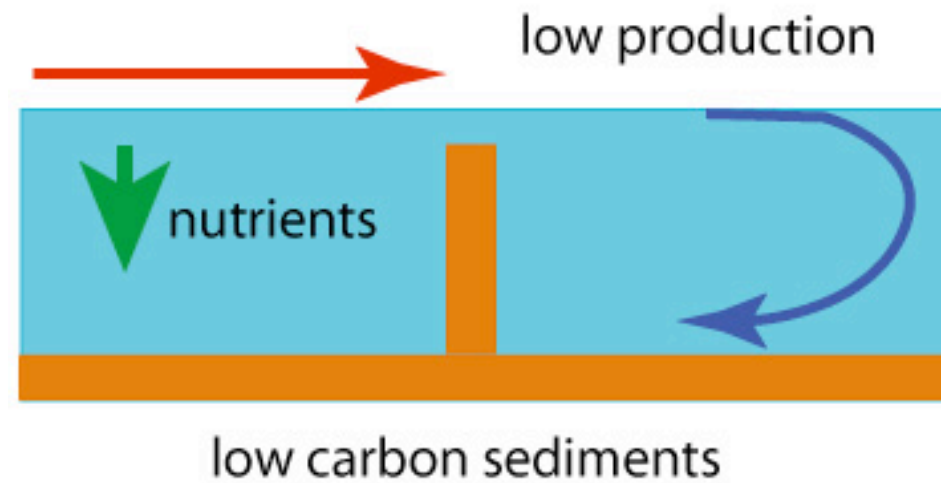
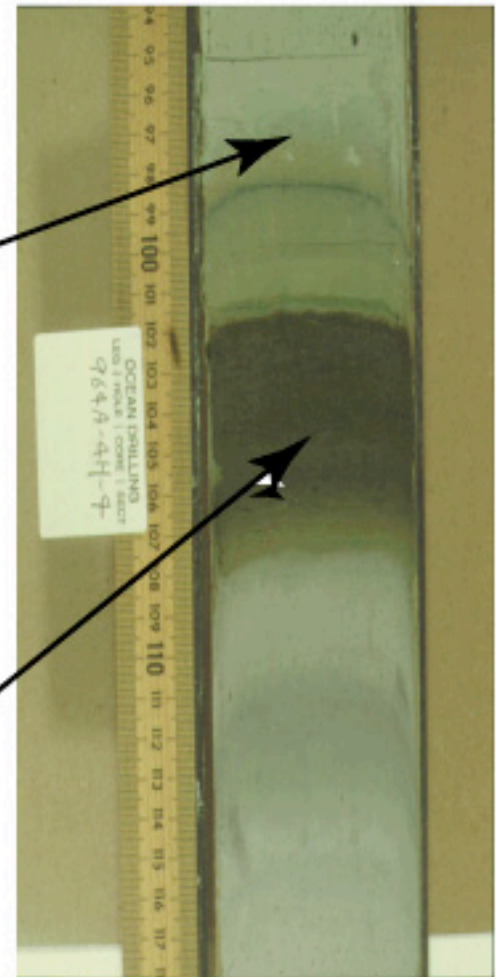


Fig. 10. Depth distributions of (a) weight percent organic carbon, (b) combined mole percent of two nonprotein amino acids (β -alanine plus γ -aminobutyric acid), and (c) total pollen abundances (grains g^{-1}) in oxidized and unoxidized sediments from two cores of the f-turbidite collected at separate sites in the Madeira Abyssal Plain (data from Cowie et al., 1995; Keil et al., 1994b).

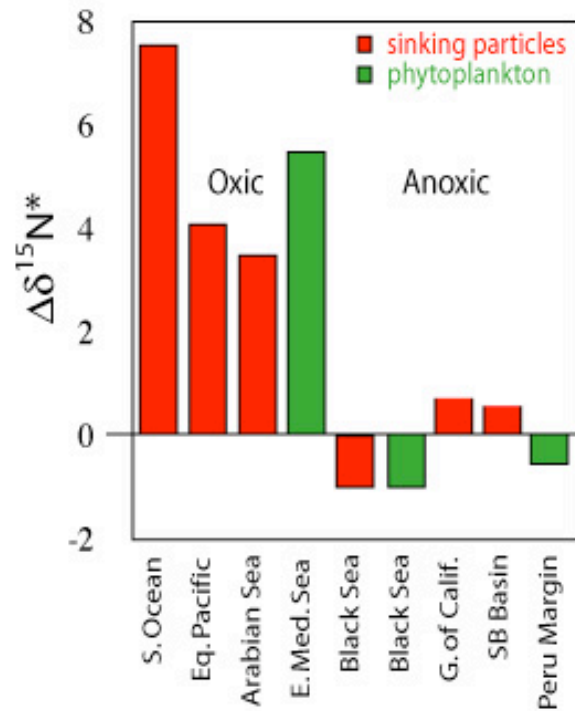
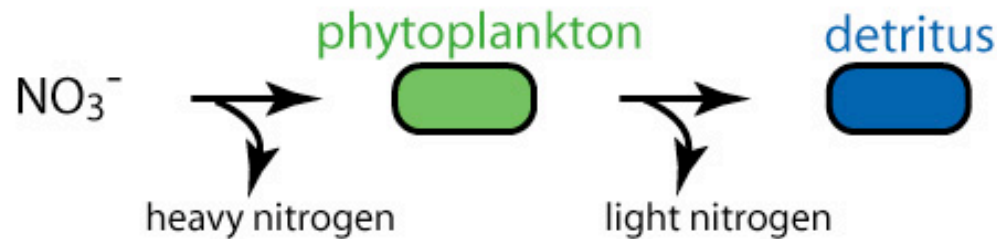
Formation of Mediterranean Sea Sapropels - anoxia hypothesis



Nile River at flood (fresh water)



N isotope fractionation and early diagenesis



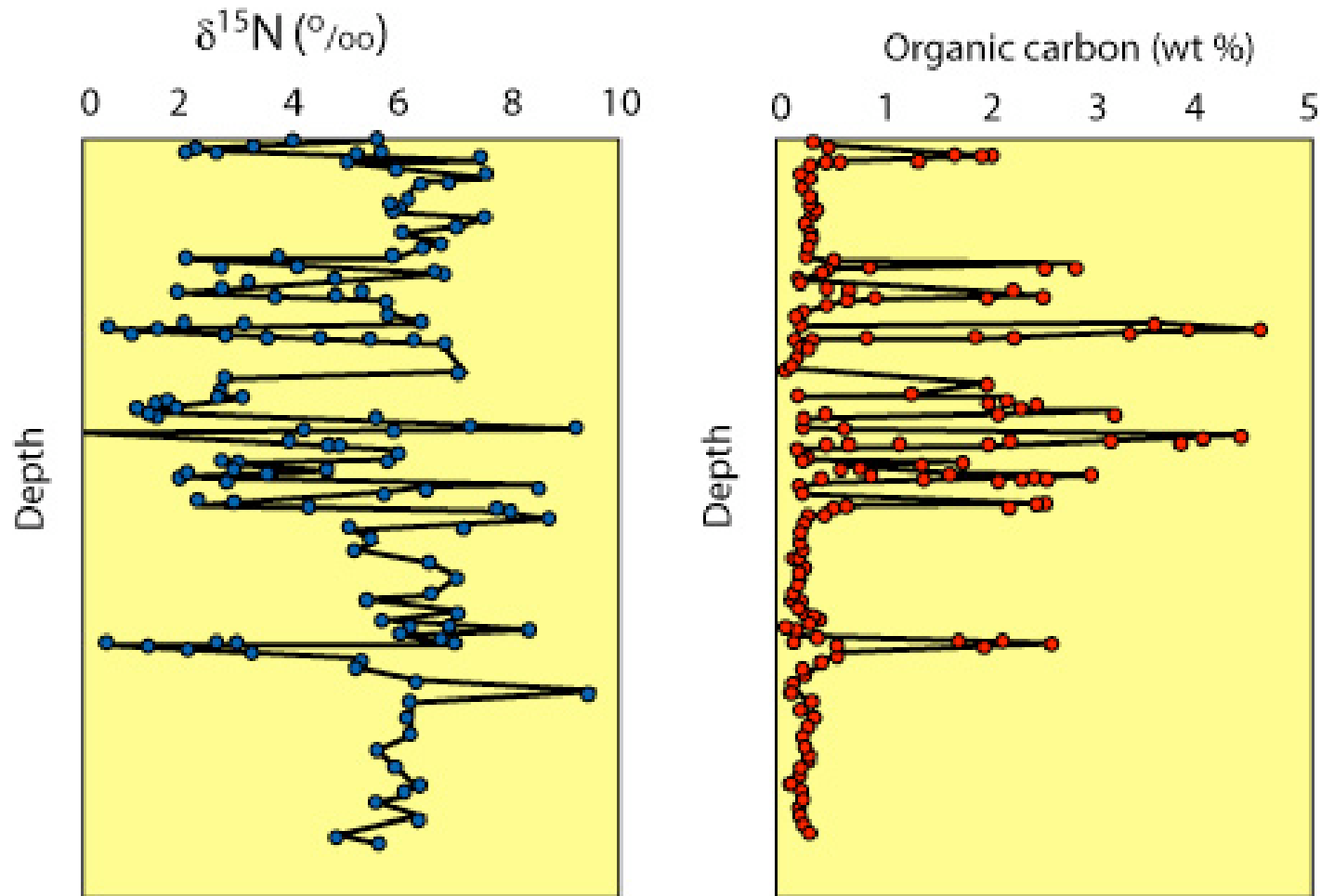
$\Delta\delta^{15}\text{N}$ is ($\delta^{15}\text{N}$ of SPM or phytoplankton - sediment)

Early diagenesis operates like N uptake in biosynthesis. "Light" N is used first, so that sedimentary OM will get heavier (more enriched, or more positive) in N-15 as nitrogen is used during respiration.

However, this is not the case in anoxic systems because degradation proceeds via a different route. In anoxic sediments, there is little N fractionation with diagenesis.

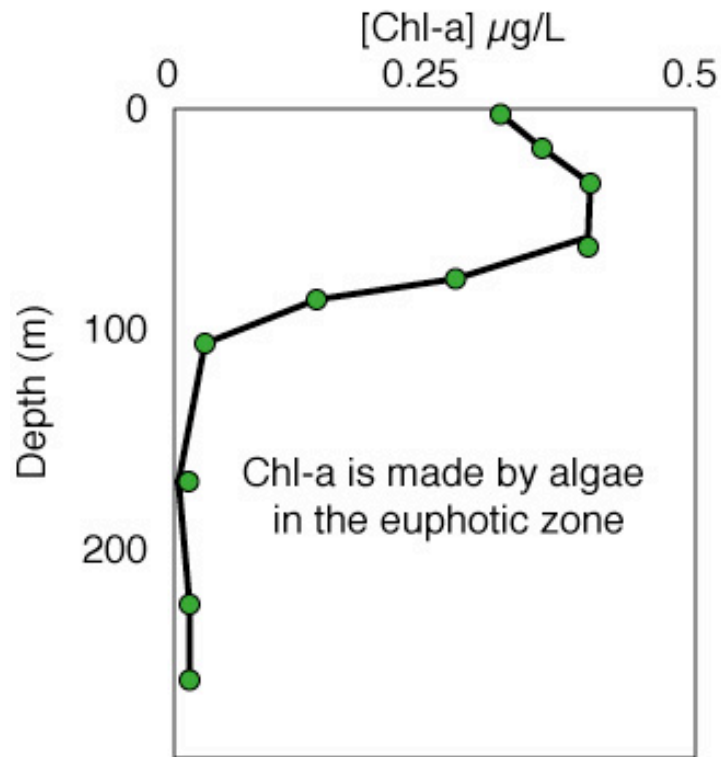
If you measure the isotopic difference between the original N in biomass, and N that is left in sediments, the difference will be large (large fractionation factor in N uptake) in oxic sediments, whereas the difference will be small for anoxic sediments.

Correlation between %OC and nitrogen isotopes in Mediterranean Sea sediments



$\delta^{15}\text{N}$ in chlorophyll and sediment from Mediterranean Sea sapropels

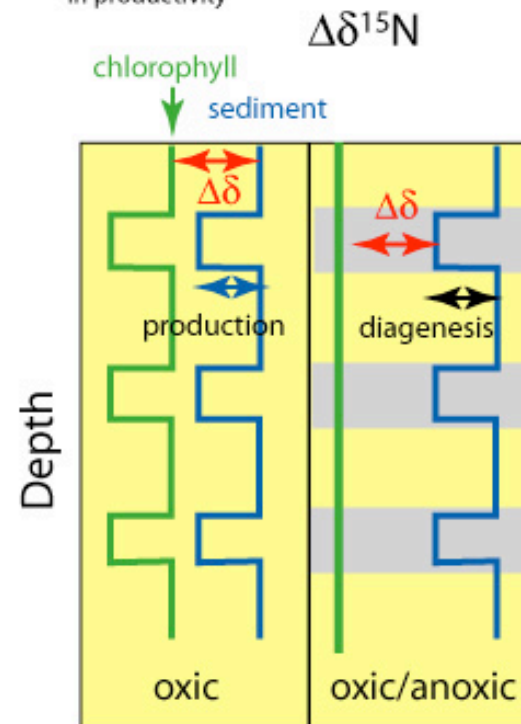
Chlorophyll-a is the light harvesting pigment in nearly all marine algae



1) Chlorophyll (Chl) will record the N isotope value of algal organic matter at the time of synthesis. The isotopic difference between Chl and algal biomass is a constant (5.9 per mil).

2) Diagenesis acts on total N, but will not change the isotopic value of Chl.

4. If the isotopic difference ($\Delta\delta^{15}\text{N}$) decreases during sapropel formation, then N isotopic value is changing due to diagenesis. If it is constant, then the value of N in the water column is changing and $\Delta\delta^{15}\text{N}$ is set by changes in productivity



What causes sapropels to form in the Mediterranean Sea?
And more generally, what processes act to preserve carbon
In marine sediments?

close-up of sapropel layer



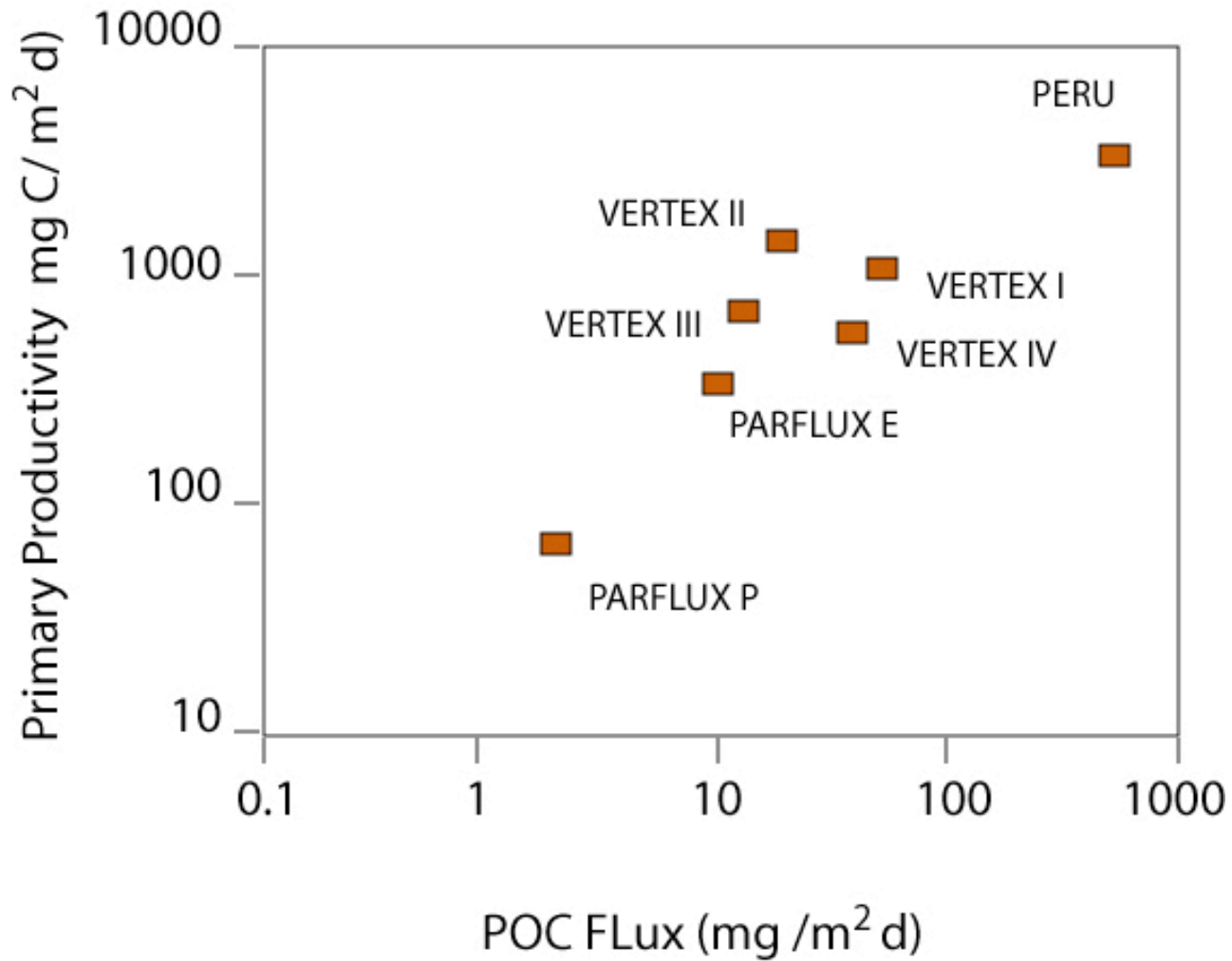
Enhanced productivity due to
Inputs of nutrients?

or

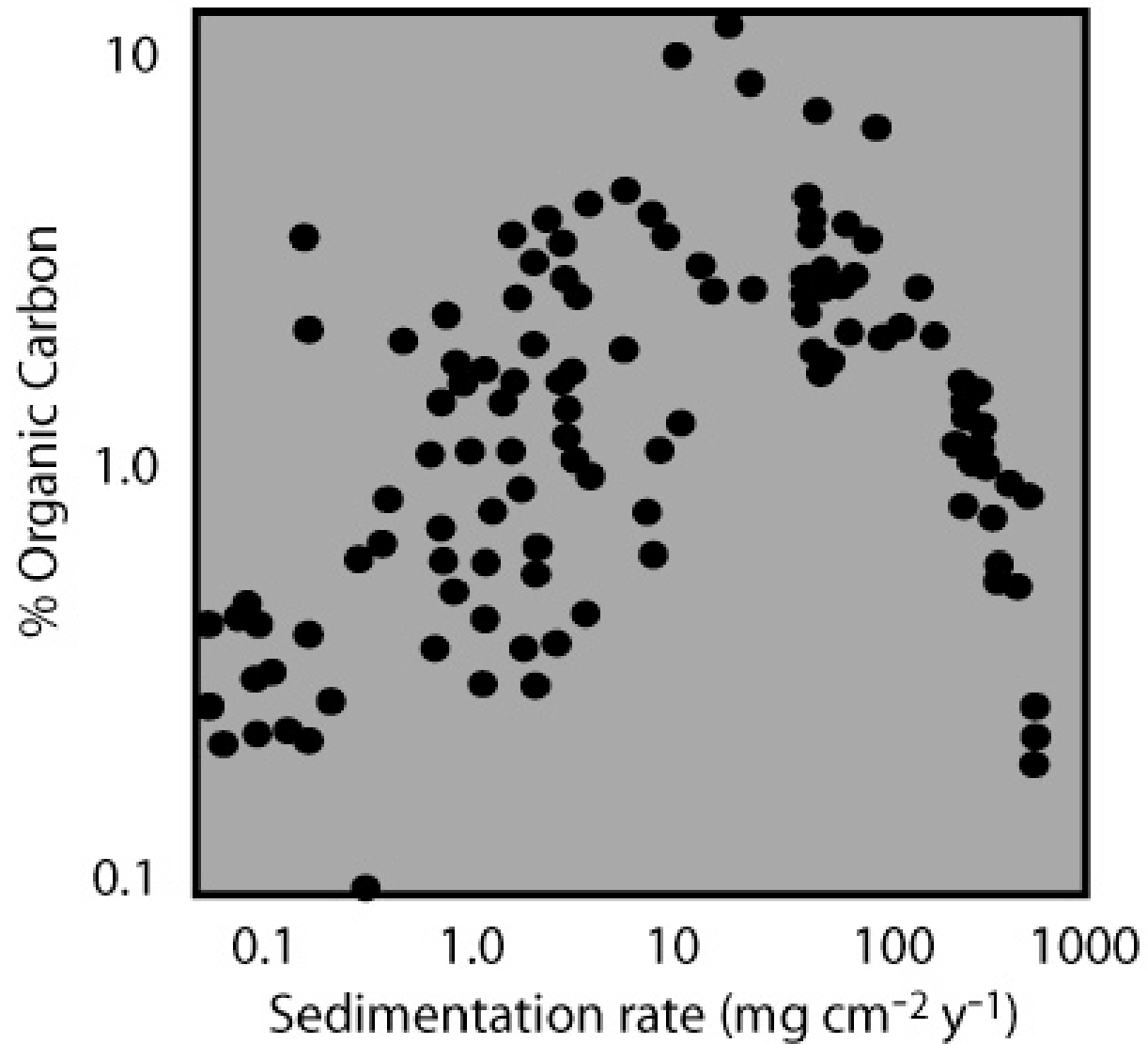
Enhanced preservation due to
Bottom water anoxia?

The productivity vs preservation debate

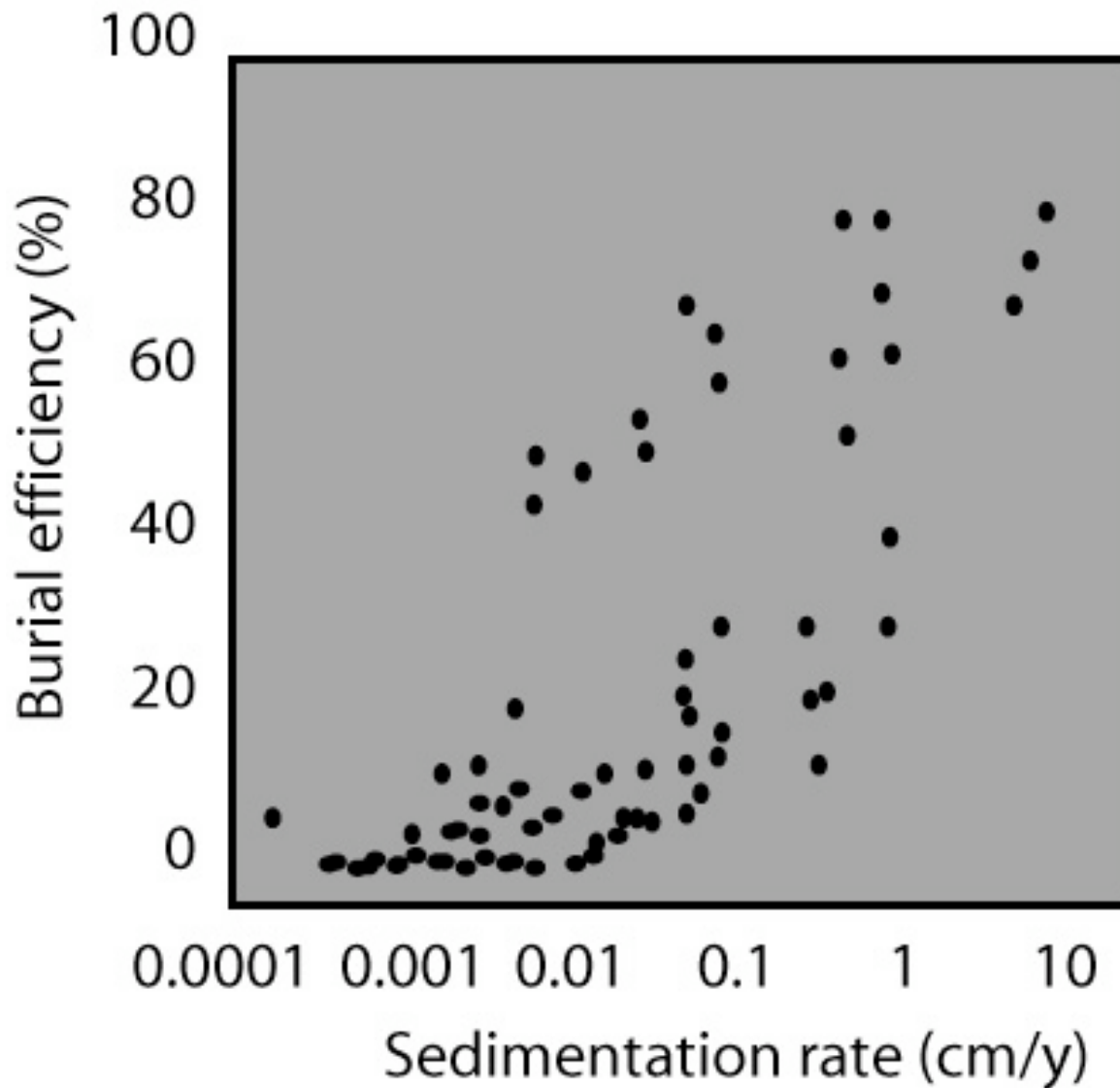
CP factor #1. The argument for productivity.....



Relationship between % OC and sedimentation rate

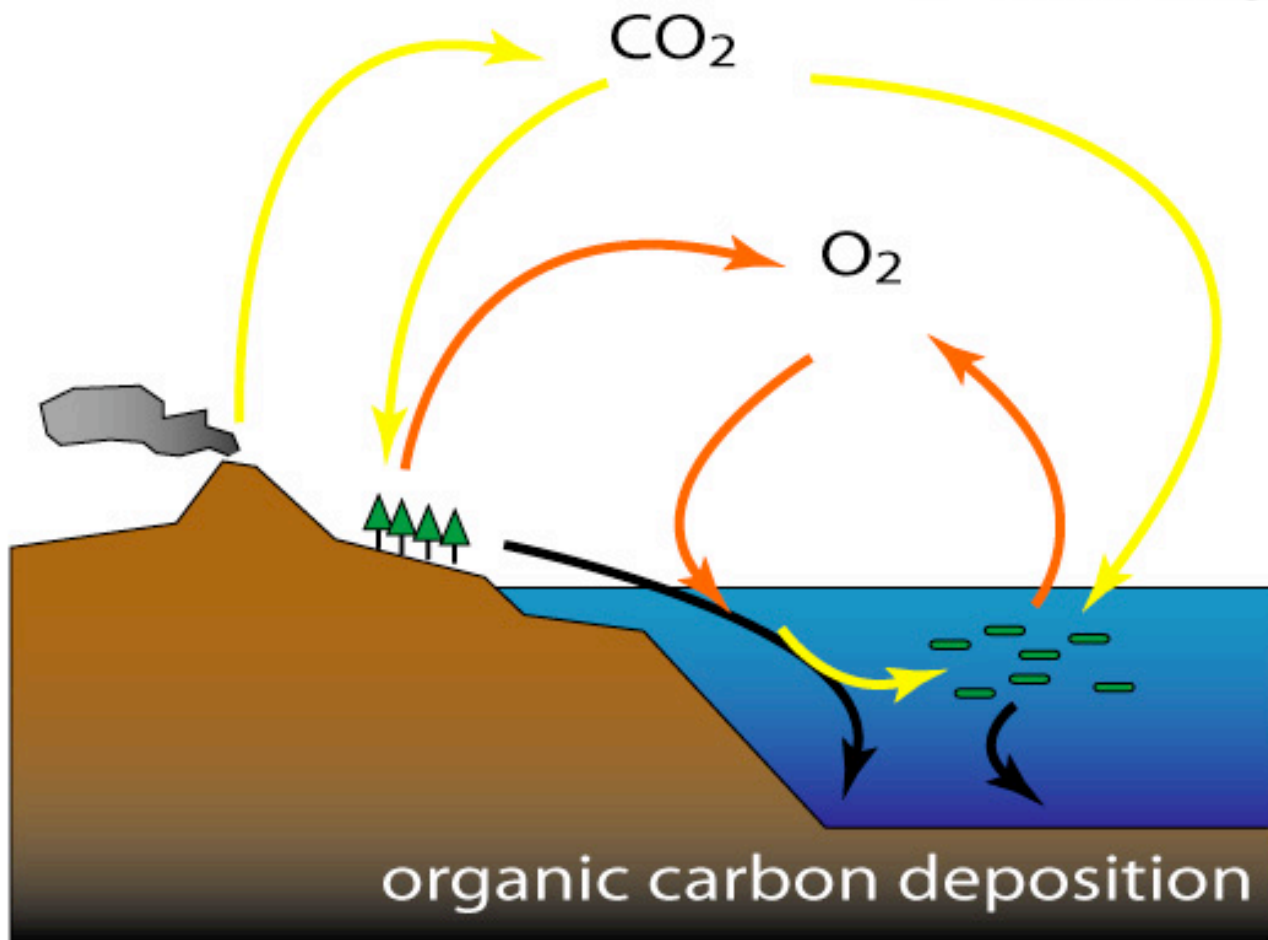


Relationship between burial efficiency and sedimentation rate

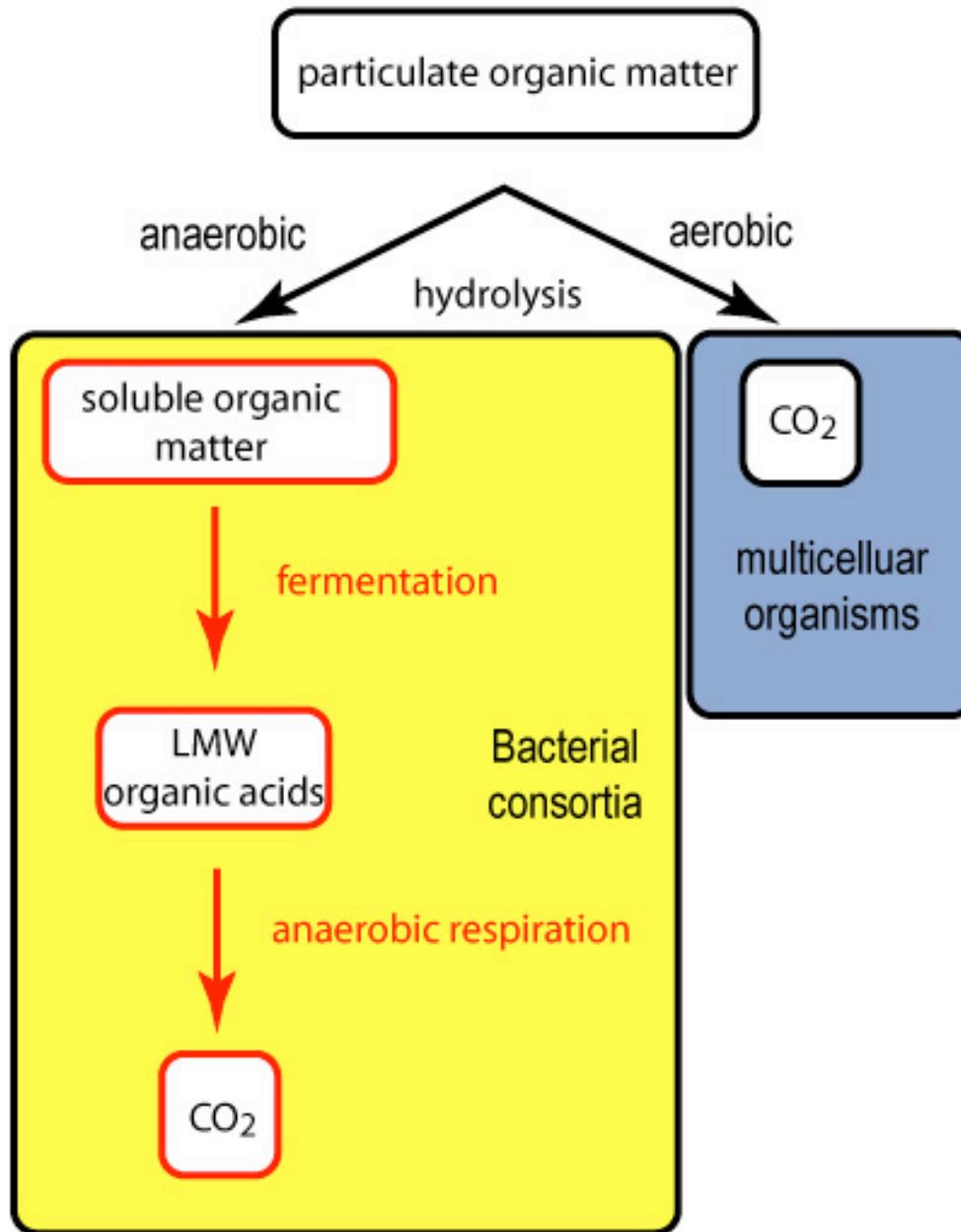


Coupling and feedbacks between carbon and oxygen cycles

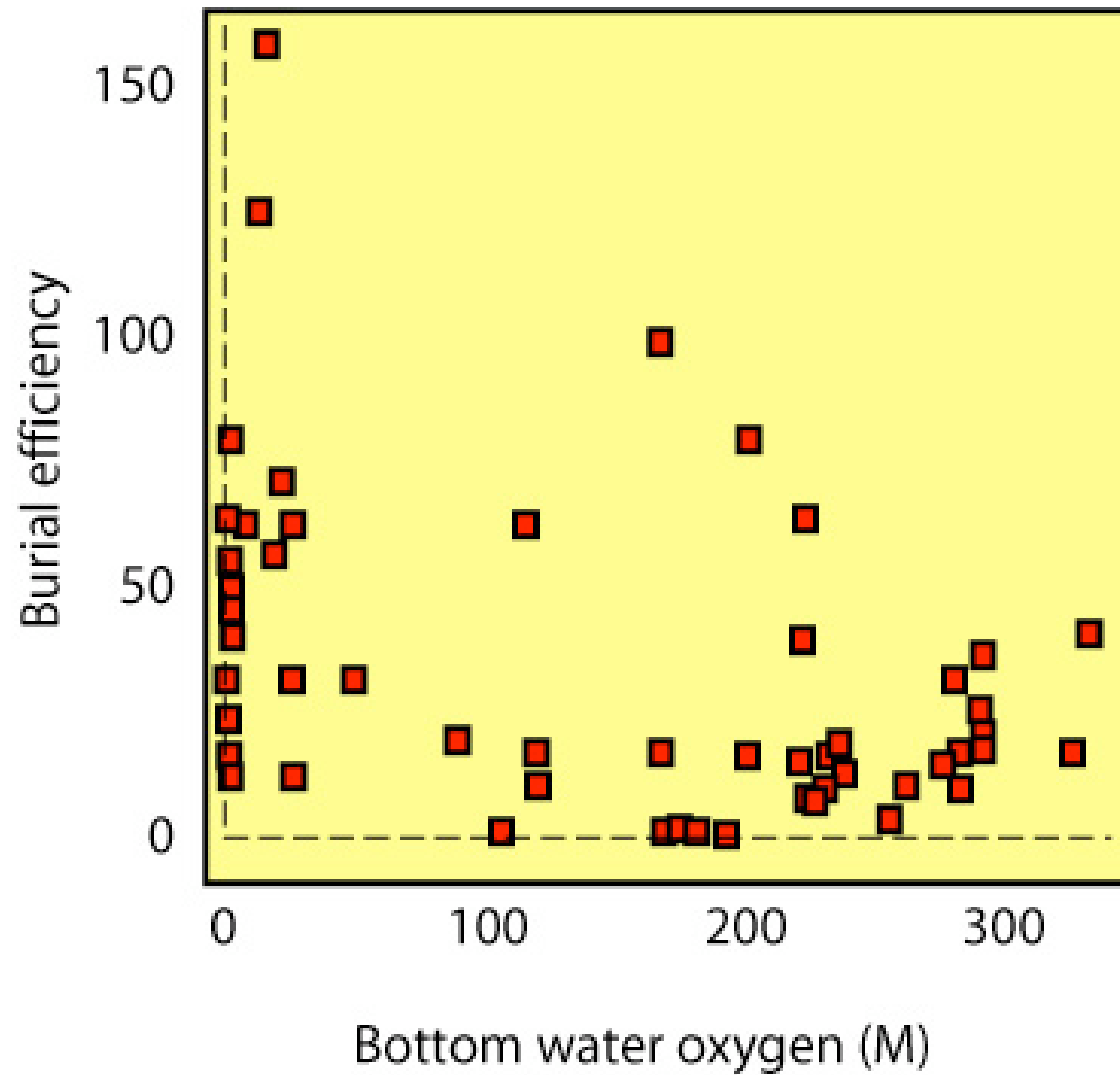
- ★ *tectonic degassing*
- ★ *photosynthesis*
- ★ *burial of organic carbon*



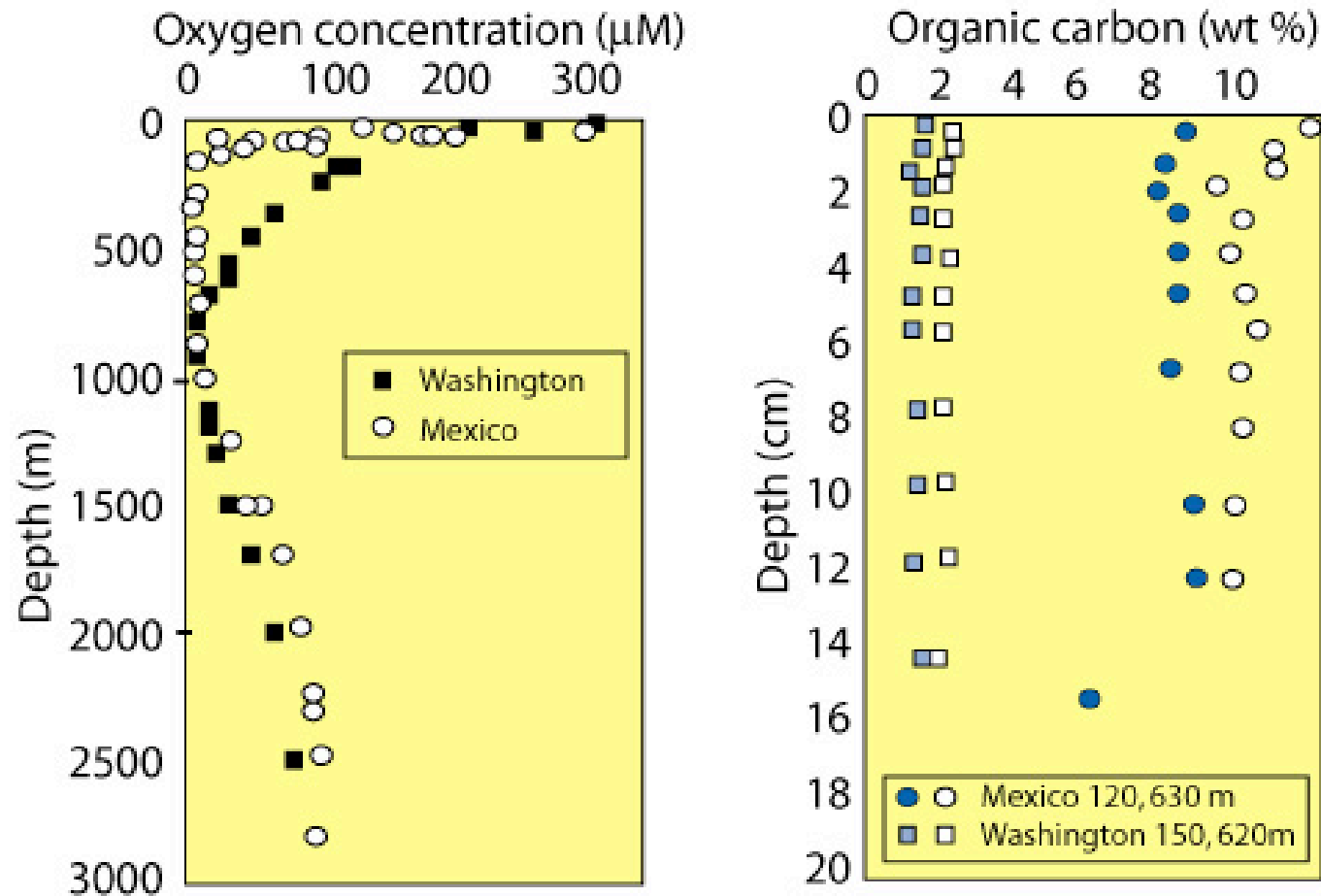
Comparison of aerobic and anaerobic degradation



Effect of bottom water oxygen on burial efficiency



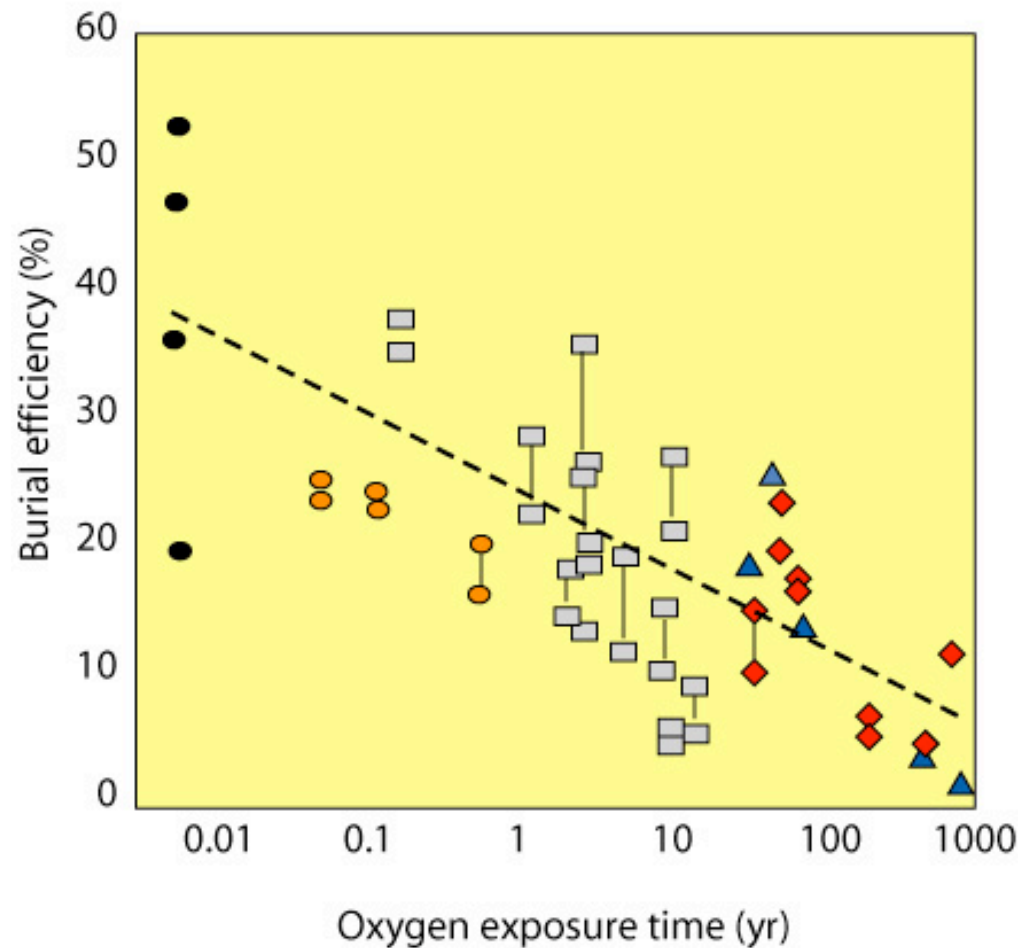
The effect of oxygen on carbon preservation in continental margin sediments



Hartnett et al. (1998) Nature v391, 572-574

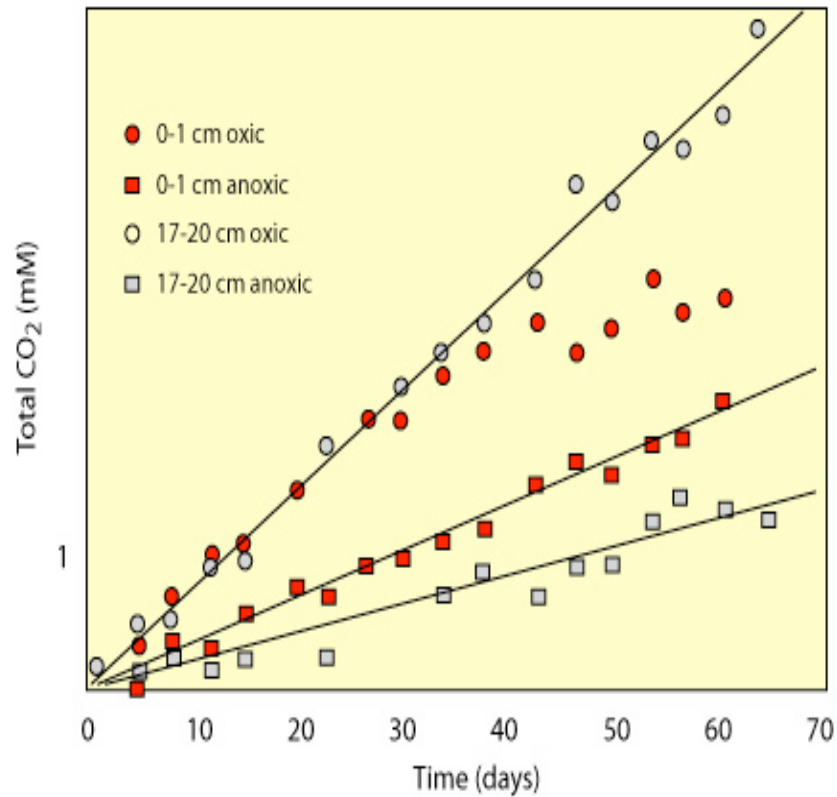
The effect of oxygen has been refined somewhat to adjust for differences in exposure time, which is related to sedimentation rate (depth of O₂ penetration/sedimentation rate) = OET

Effect of oxygen exposure time on burial efficiency

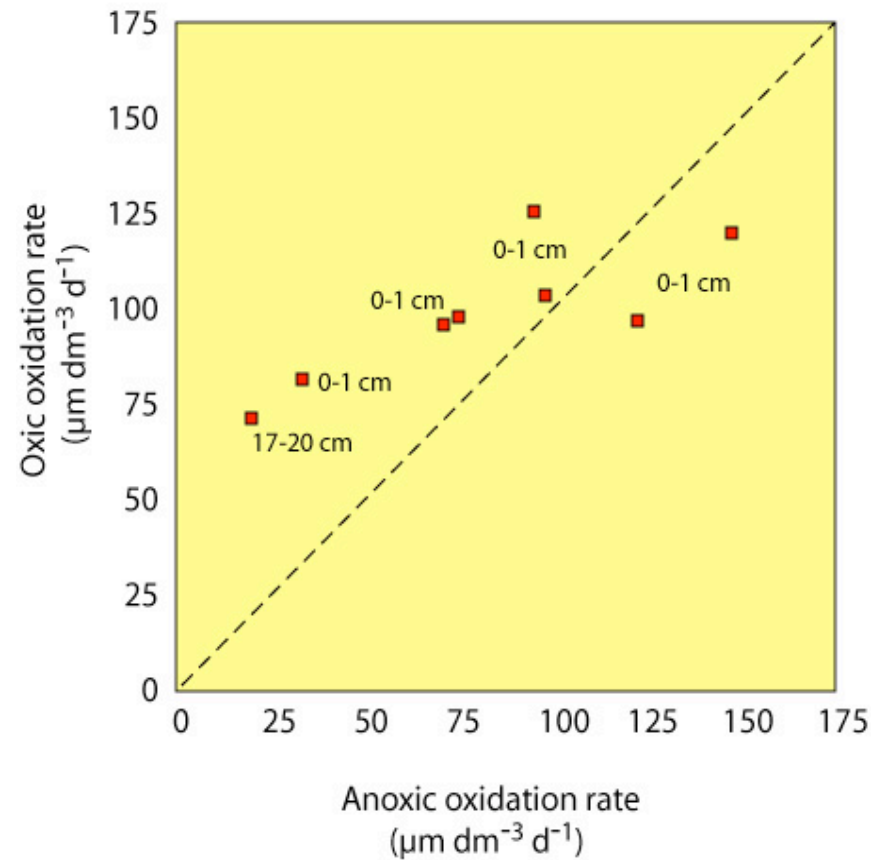


Is carbon more efficiently respired under oxic or anoxic conditions ?

Respiration of carbon in 0-1 cm and 17-20 cm sediment under oxic and anoxic conditions

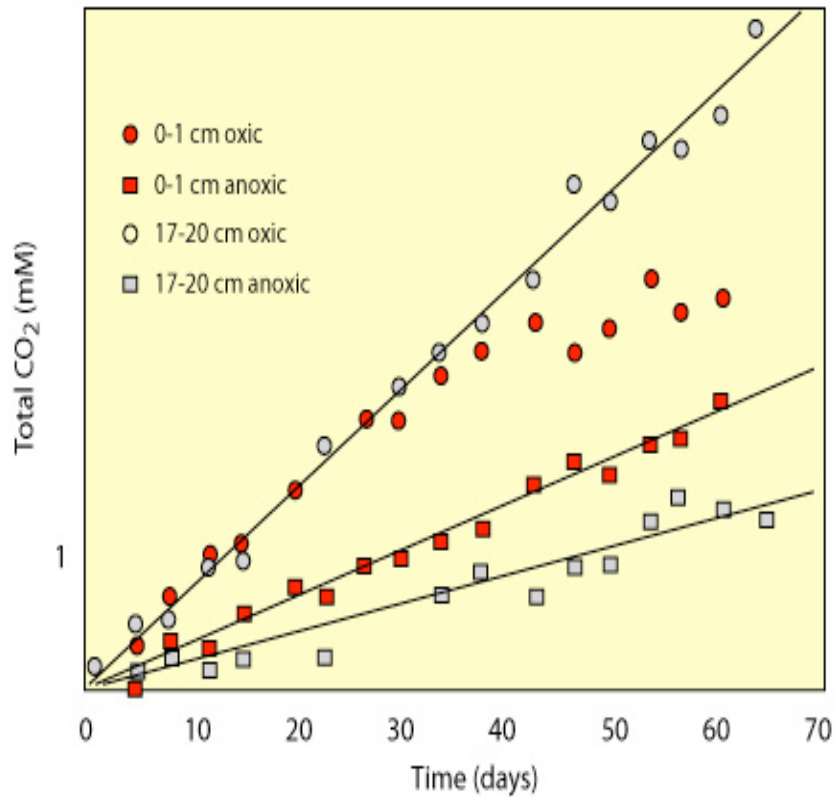


Comparison of oxic and anoxic degradation rates in surface and deep sediments

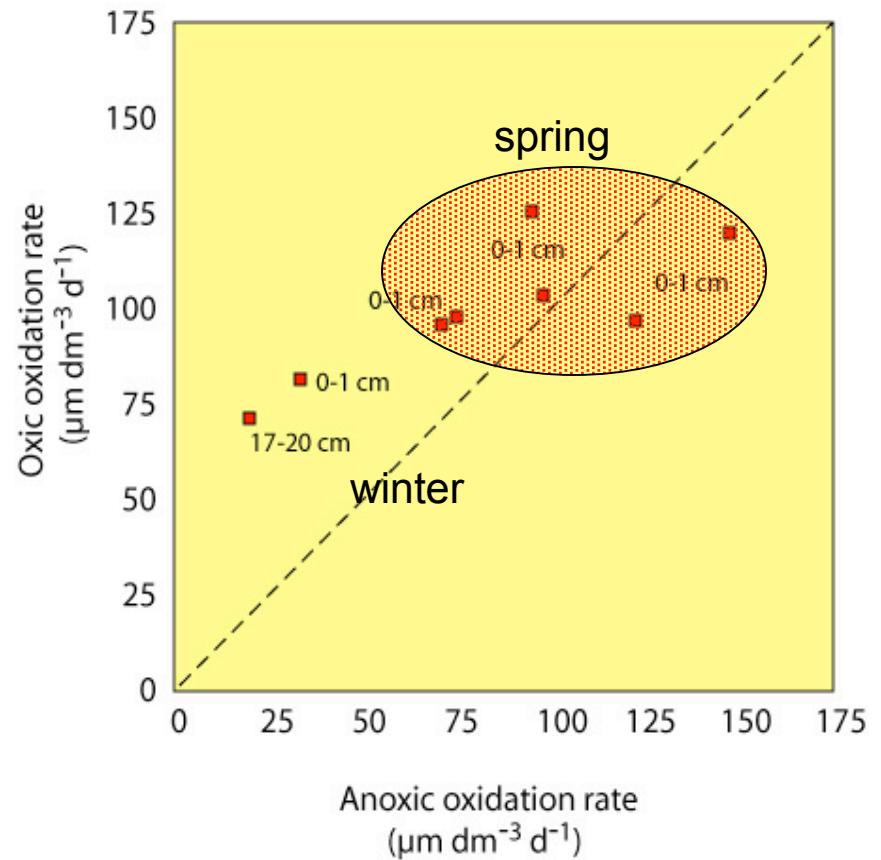


Is carbon more efficiently respired under oxic or anoxic conditions ?

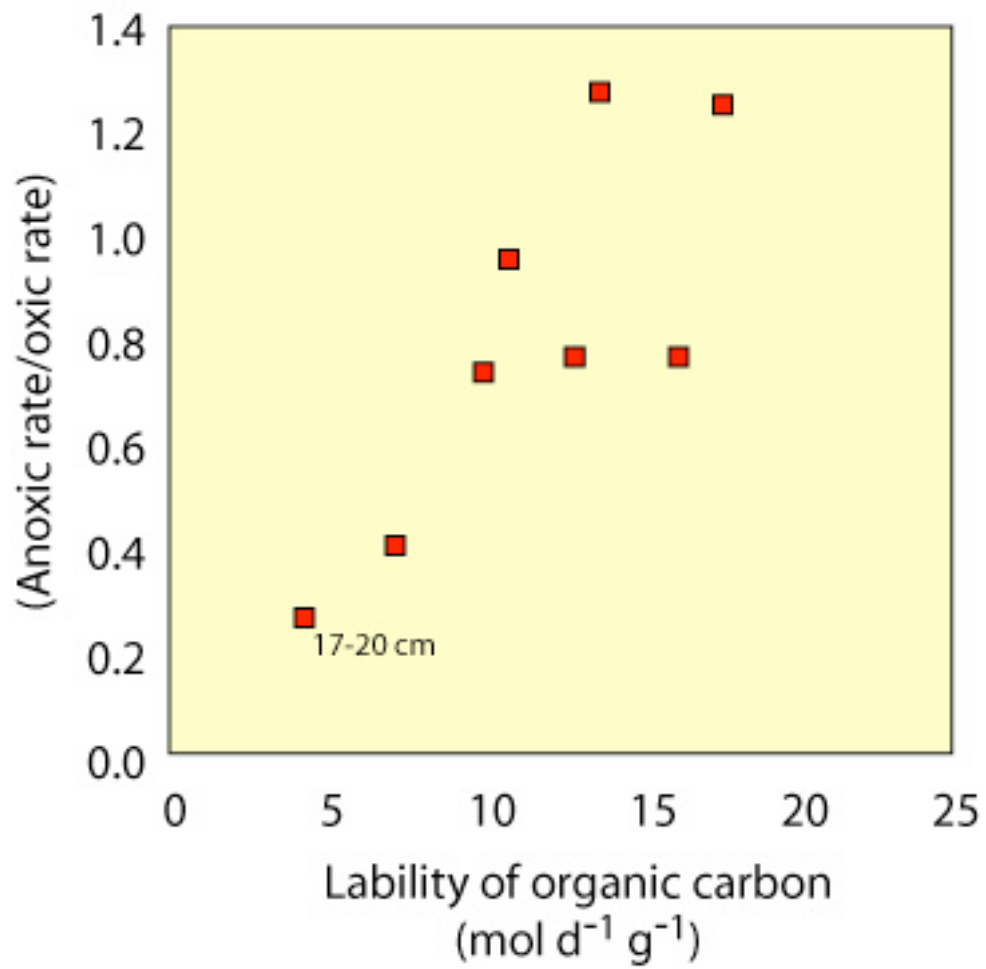
Respiration of carbon in 0-1 cm and 17-20 cm sediment under oxic and anoxic conditions



Comparison of oxic and anoxic degradation rates in surface and deep sediments

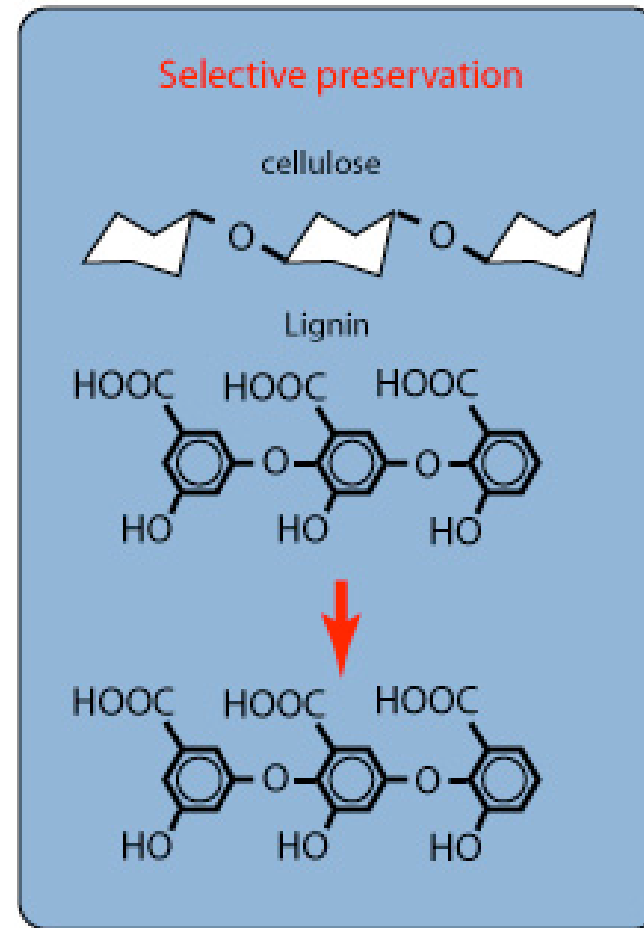
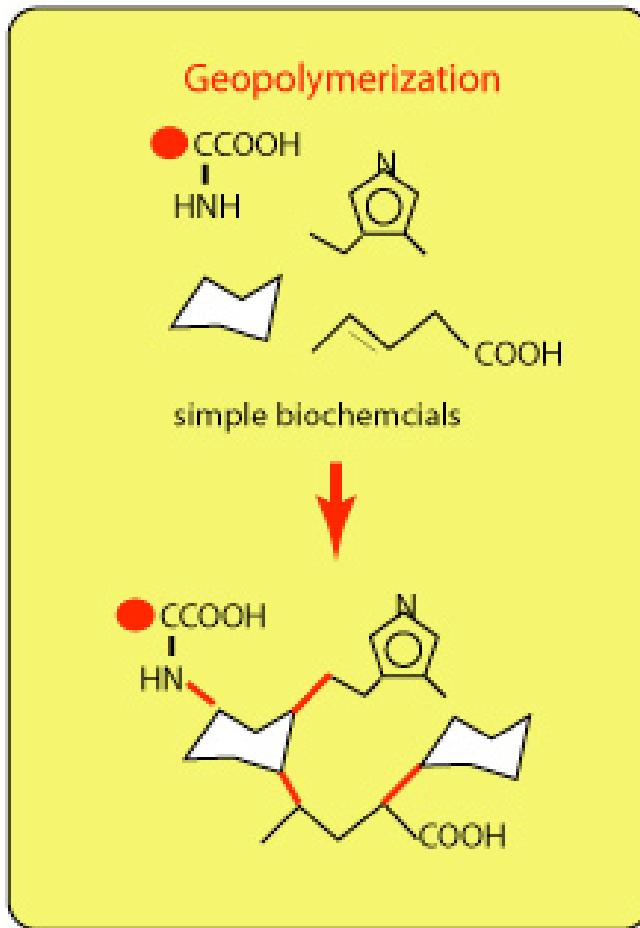


Oxidation rate and the lability of organic carbon

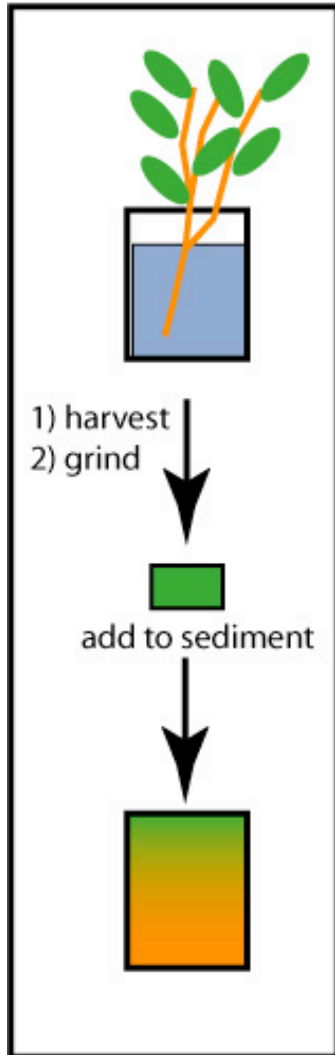


CP Factor #3 The composition of organic matter

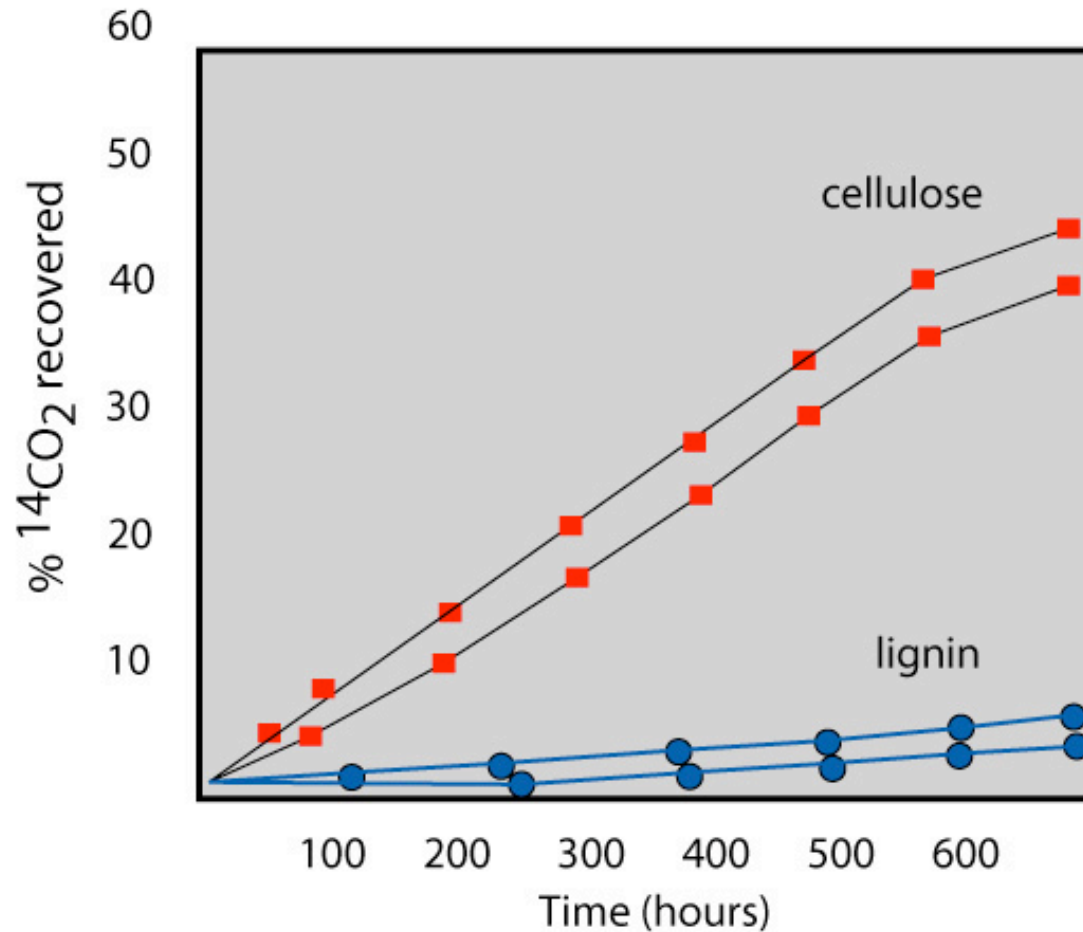
Effect of chemical composition on organic matter degradation in sediments



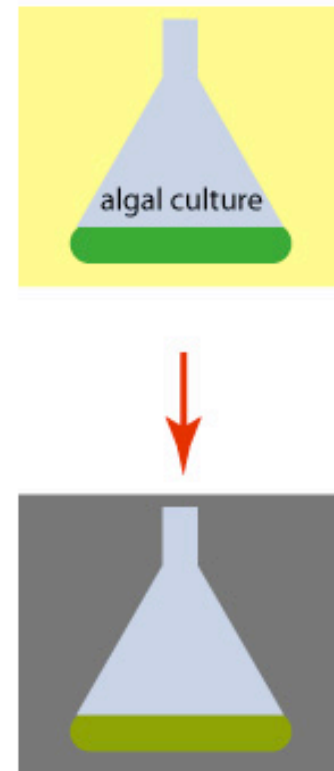
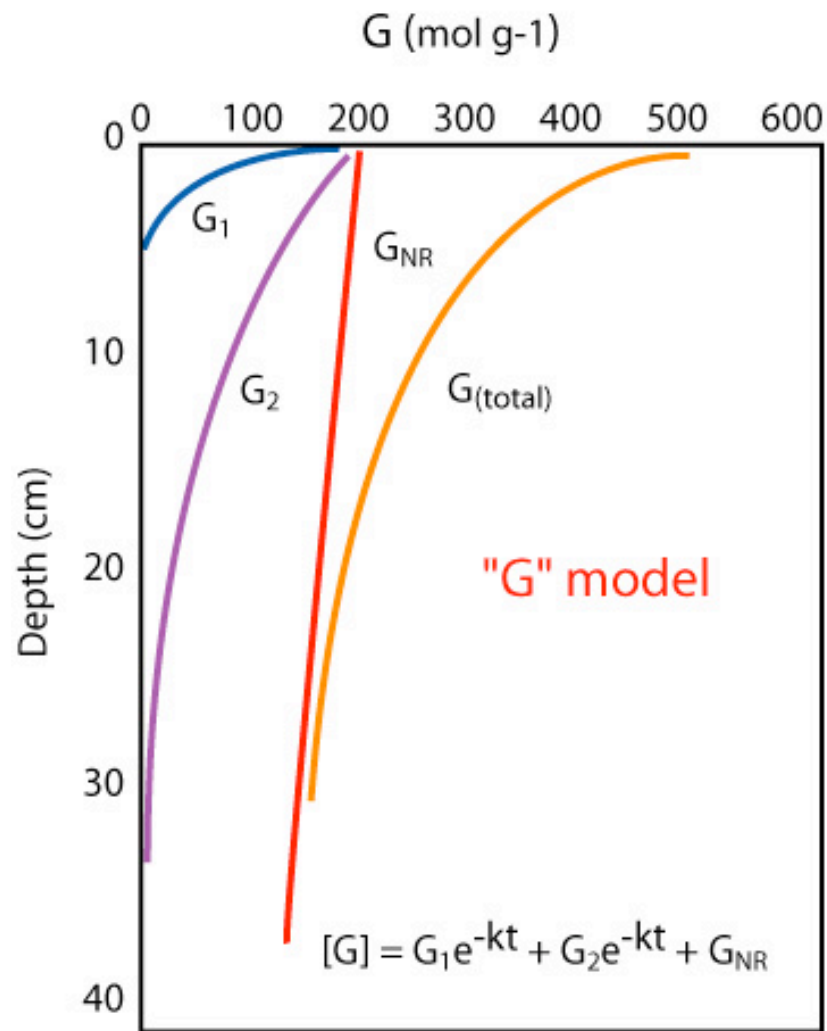
Was the composition of OM in anoxic sediments different than the OM in oxic sediments, thereby producing the Observed difference?



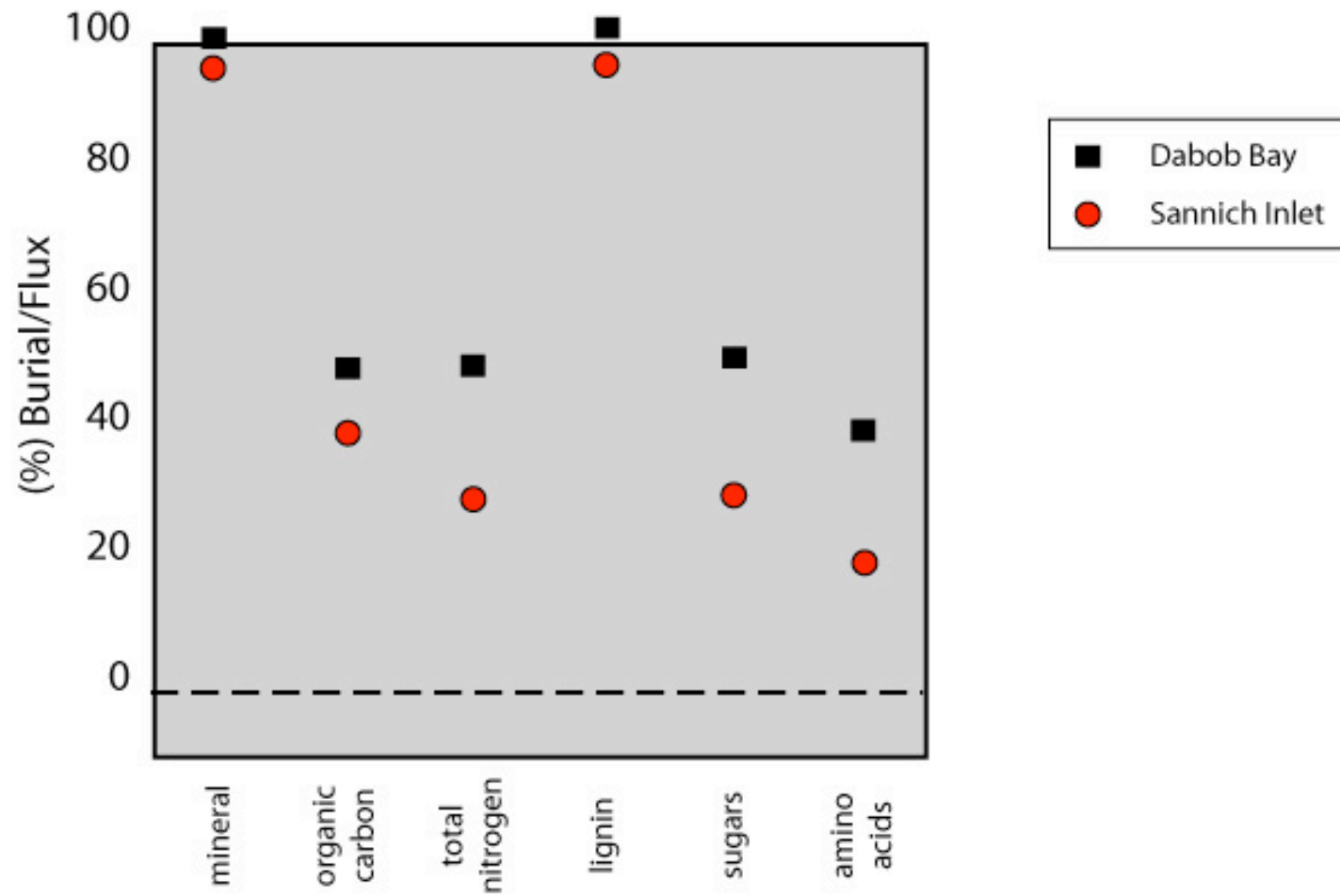
Selective Degradation of polymeric organic matter



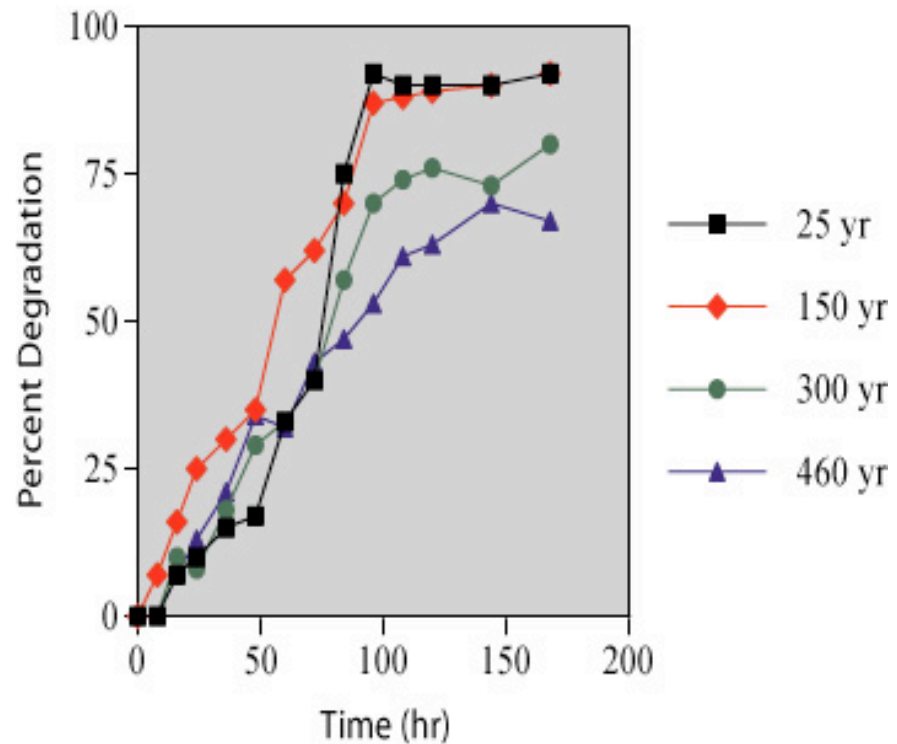
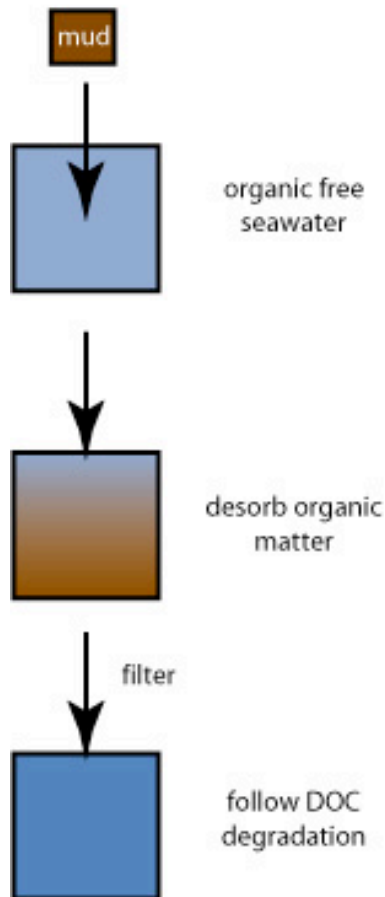
Kinetics of organic matter degradation and the multi "G" model



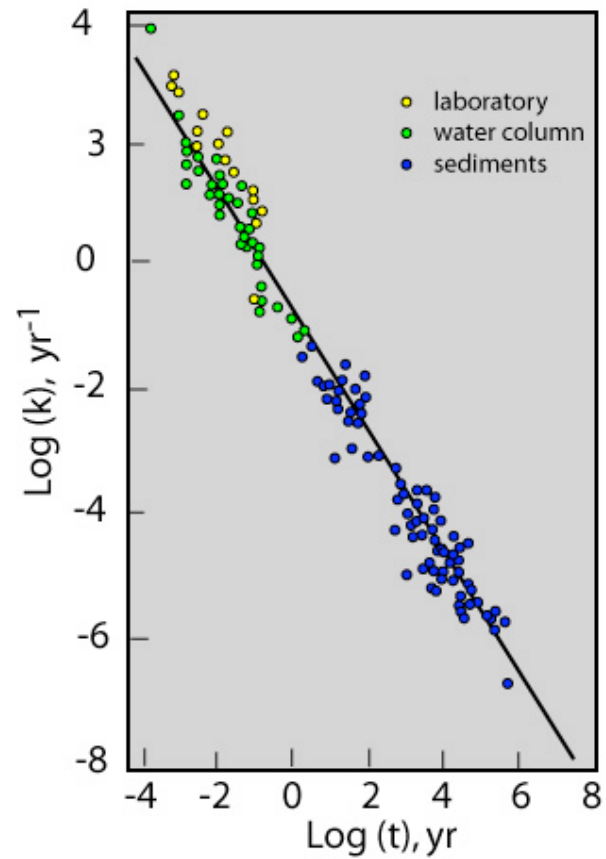
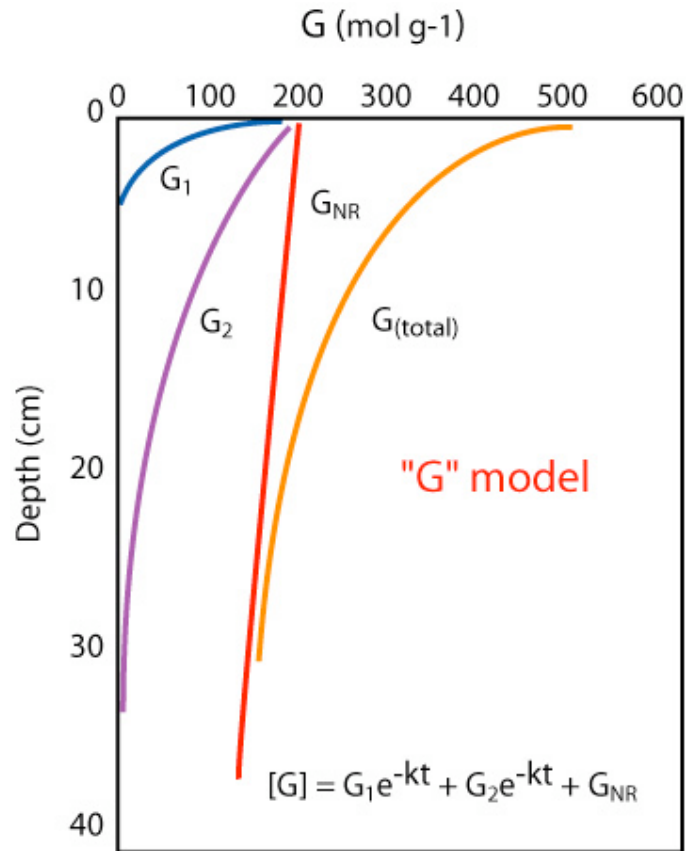
Selective preservation of organic matter in sediments



If selective preservation occurs, then “old”, buried carbon should be recalcitrant. But is it ?



Is the "G" model just an observational artifact?



The carbon preservation quiz!

T

F

productivity affects carbon burial efficiency.

relatively more carbon is buried under anoxic than oxic conditions.

bigger molecules are degraded more slowly than smaller molecules.

The faster you bury carbon, the more likely it is to stay buried.

Carbon preservation summary

Ocean is >99.5% efficient at recycling C.

Annual production is about 50-70GT C yr⁻¹, of which 0.1-0.2% is buried.

Several factors affect C preservation:

organic matter production

oxygen

organic matter composition

*It is difficult to isolate these factors from one another
to elucidate underlying mechanisms*