What controls Organic C preservation in sediments?

(Sediment accumulation rate)
(Bottom water oxygen concentration)
(Productivity / carbon flux)

Organic C sorption onto mineral surfaces

Turbidite data (a clear role for O$_2$)

**Oxygen exposure time**

Focus on continental margins – that’s where the carbon is.

Premuzic et al. - % C org in surficial sediments.
90% of burial on deltas, shelves, & upper slope

The role of sedimentation rate.

1:1 slope “built in”; slope > 1 suggests role

Müller & Suess, 1979
% C org. vs. sed rate
not too impressive.

Fig. 4. Plot of weight percent of organic carbon (SDOC) vs. accumulation rate for sediments from a variety of depositional environments. □ = data from Müller and Sprovieri, 1979; ○ = data compiled by Heinrichs and Rennich, 1987; □ = data from Rennich et al. (unpublished paper); ○ = data from the Washington Coast (Carsewell et al., 1981, 1982).

Burial Efficiency = burial / (burial + remineralization)

Fig. 5. Plot of percent burial efficiency of detrital organic carbon vs. sediment accumulation rate at different sites. Burial efficiency is defined as the organic carbon accumulation rate below the diagnostically active surface layer divided by the input rate of the sediment-water interface data compiled from Heinrichs, 1992).
Very low O₂

Weird plot; but no sign of oxygen control

But Hedges and Keil 1995 conclude –

No obvious oxygen control

Henrichs and Reeburgh, 1987

Higher burial efficiency in anoxic settings (not just low O₂, but no O₂)
Rough correspondence between high % C org and primary production. A carbon flux control on carbon preservation, or is the correlation driven by other factors?

What about productivity?

High % C org in upwelling regions – more than a coincidence.
But Peru margin is low O_2 as well as high C flux.

“Carbon flux (productivity) vs. bottom water oxygen”
Calvert, 1987
Oxygen not the primary control; observed O₂:Corg relationships often due to particle properties (e.g., grain size) that are correlated with O₂.
No convincing $C_{org}:O_2$ relationship

But all of these sites have relatively low bottom water $O_2$, and many of the $\%C$ values are very high.

Are these good sites to generalize from?

Canfield (1989) Sulfate reduction and oxic respiration in marine sediments: implications for organic carbon preservation in euxinic environments

~ 10 cm / ky

Compare rates of sulfate reduction and oxic respiration, to see whether oxygen is "special".

Sulfate reduction rate vs. sed rate.

How “normal” are these “normal marine sediments?”
Convert sulfate reduction and oxic respiration rates to organic C oxidation rates.

Offset at low sed rate due to near-total C org oxidation by O_2 (the good stuff is gone)

No obvious offset between SR and O_2 resp at high sed rate / oxidation rate

Just compare integrated organic C oxidation rates between “normal marine” sediments, and euxinic and semi-euxinic sites (anoxic & near-anoxic).

Again, no obvious offset – anaerobic decomposition not inherently slower
Organic C protection by adsorption onto mineral grains:

Surface area control - C org concentrations consistent with a “monolayer equivalent” OM coating of mineral surfaces

C org concentrations decrease downcore, evolving toward the “monolayer equivalent” OM coating predicted based on previous figure
The shelf sediment C\textsubscript{org}/SA relationship seems global.

But different environments seem to yield different slopes:
Lower in deltas and abyssal sediments, higher in high-productivity/low-oxygen regions.
Fig. 14. Weight percent of organic carbon plotted vs. minimal surface area for surficial sediments from productive regions with low bottom water oxygen concentrations such as the Black Sea (bulk material), Mexico shelf (bulk material), and Peru margin (split size fractions). The typical data range for continental margin sediments exhibiting monolayer-equivalent organic loadings is given for comparison (e.g. Keil et al., 1994a).

Washington margin –
OC/SA constant (so change in %C at this site doesn’t reflect evolution toward monolayer equivalent.
(paleoceanography)
Desorbed organic matter is quite reactive (implying protection by mineral surfaces)
25-50% could be desorbed
70–95% of this, decomposed

Can oxygen exposure time explain the observed range of preservation behaviors?

**Figure 1** Water column O₂ and sediment carbon contents for study sites from the Washington and Mexican margins. **a.** Dissolved O₂ concentration as a function of water depth for the continental margins of Washington State (squares) and northwestern Mexico (circles). Note that the Mexican O₂ concentrations between 150 and 600m depth are indistinguishable from zero. **b.** Weight per cent organic carbon as a function of depth in sediments for representative stations from the Washington (empty squares, 630m; filled squares, 120m) and Mexican continental margins (empty circles, 620m; filled circles, 150m).
Wilson et al. 1985 – turbidite evidence for the importance of oxygen

"Burn-down" into a turbidite

Organic C that had been buried (and preserved) is readily decomposed in the presence of porewater oxygen – O\(_2\) matters.
Fig. 7. Schematic of model profiles for organic-carbon, oxygen and nitrate. The model is valid for the interval 0 < Z < Z_0. Below Z_0, the organic layer breakdown rates for the processes of oxidation and denitrification are estimated from the oxygen and nitrate fluxes through Z_0 (see text).

Fig. 8. Lithology and element vs. depth profiles for \( \text{CaCO}_3 \), \( \text{C}_{\text{org}} \) and \( \text{S} \) in the core samples studied.

Thomson et al. 1998
Decreases in percent C org and # pollen grains, and selective preservation of resistant amino acids.

Hedges and Keil, 1995

\[ x_E = \text{O}_2 \text{ penetration depth (cm)} \]
\[ w = \text{sediment burial rate (cm/yr)} \]
\[ \text{O}_2 \text{ exposure time (yr)} = \frac{x_E}{w} \]

Note – particle mixing doesn’t alter average OET
Empirical – no particular mechanism proposed.

Figure 2. Organic carbon burial efficiency as a function of oxygen exposure times. Symbols are as follows: the Mexican shelf, 100–190 cm (empty circles); Mexican slope, oxygen-deficient zone, 0–100 cm (filled circles); the Washington shelf, 125 cm (filled diamonds); the California margin, 3.0–4.2 cm (shaded triangles). 

Harnett et al., 1998


Fig. 3. Log/Log plot of the measured density (kg) of organic carbon in the tongue area of the experimental measurements: • = data from laboratory studies; O = data from microcosm experiments; D = data from sediment cores. The apparent data point (O) is calculated for 789 micrometer of the samples over an average age range of 1242 kyr (Craw and Hedges, in press) after Metaxidigio, 1999.)
Comparison of low O$_2$ and high(er) O$_2$ sites.

At 100 m, $RC(WA) > RC(Mex)$

At 1000 m, $RC(WA) \approx RC(Mex)$

Devol and Hartnett, 2001

Fig. 1. Locations of the Washington State and Mexican continental margin transects along with the dissolved oxygen profiles from the two areas.

Fig. 2. Carbon rain derived from the sedimentary data for the two Washington and Mexican transects. Rain rates are shown as histograms of the two components with the solid portion representing benthic carbon oxidation rate and the white portion showing the carbon burial component.

At 100 m, $R_c(WA) > R_c(Mex)$

At 1000 m, $R_c(WA) - R_c(Mex)$

Devol and Hartnett, 2001
Different attenuation of organic C sinking flux
(in response to deep-water oxygen?)

Devol and Hartnett, 2001

Fig. 3. Power-curve regressions of the sediment-derived carbon rain rates (C_rain) for the Washington margin ($C_rain = 16.2 \cdot [C/\text{m}^3]^{0.65}$) and the Mexican margin ($C_rain = 7.4 \cdot [C/\text{m}^3]^{0.65}$). Note that the scale on the x-axis is different between the two panels.

Fig. 4. Sediment-trap-derived rain rates (solid symbols) from three deployments of trap strings and rain rates derived from carbon oxidation and burial (open circles) on the Mexican margin. Also shown are a 650 m rain rate of 1.5 mmol C m$^{-2}$ d$^{-1}$ attenuated as the Martin et al. (1997) power function with the attenuation coefficient derived from the Mexican data, $\alpha = 0.35$ and the attenuation coefficient derived from the Washington data, $\alpha = 0.35$. Error bars on the trap data show the range of replicate sediment-trap measurements, while error bars on oxidation plus burial derived rain rates are standard deviations.
Deeper oxygen penetration farther offshore (in deeper water)

Hedges et al., 1999
So OET increases offshore

And lower sedimentation rates farther offshore (in deeper water)

Percent organic C and the Organic C/Surface Area ratio decrease moving offshore (OC/SA not constant)

Hedges et al., 1999
Amino-acid based "degradation indicators" increase moving offshore.

Hedges et al., 1999.