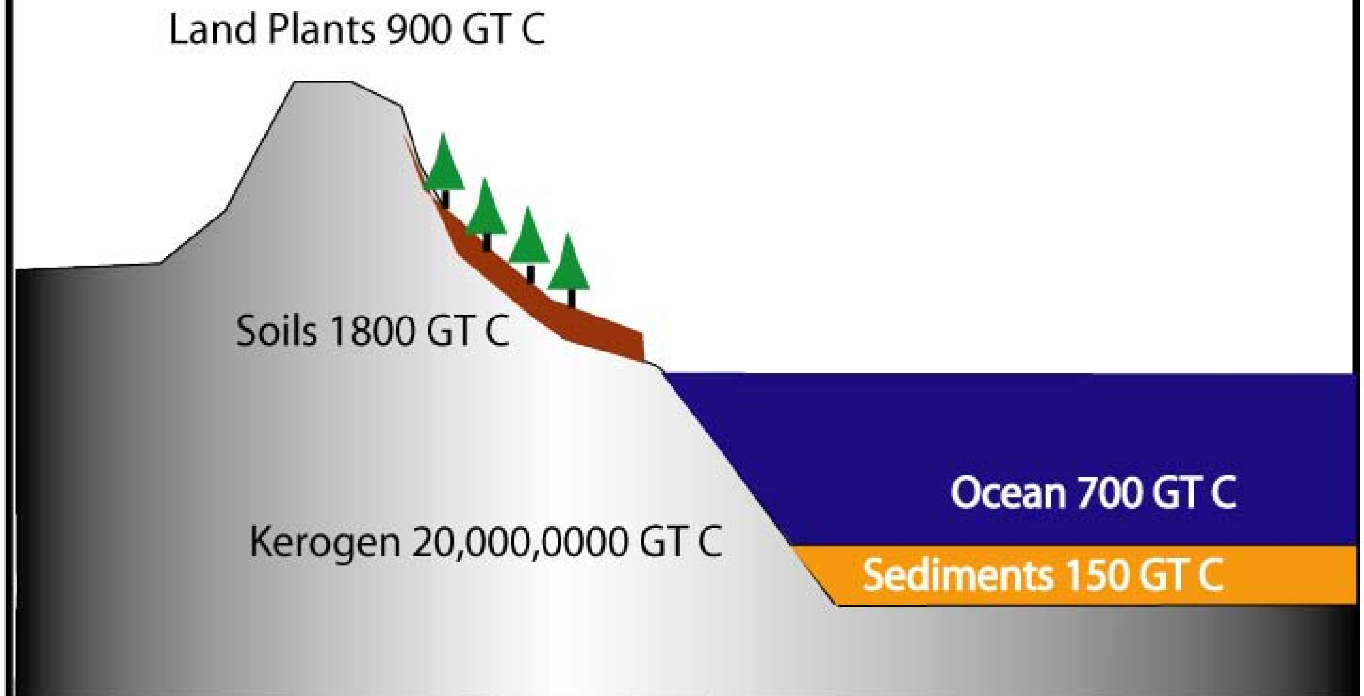
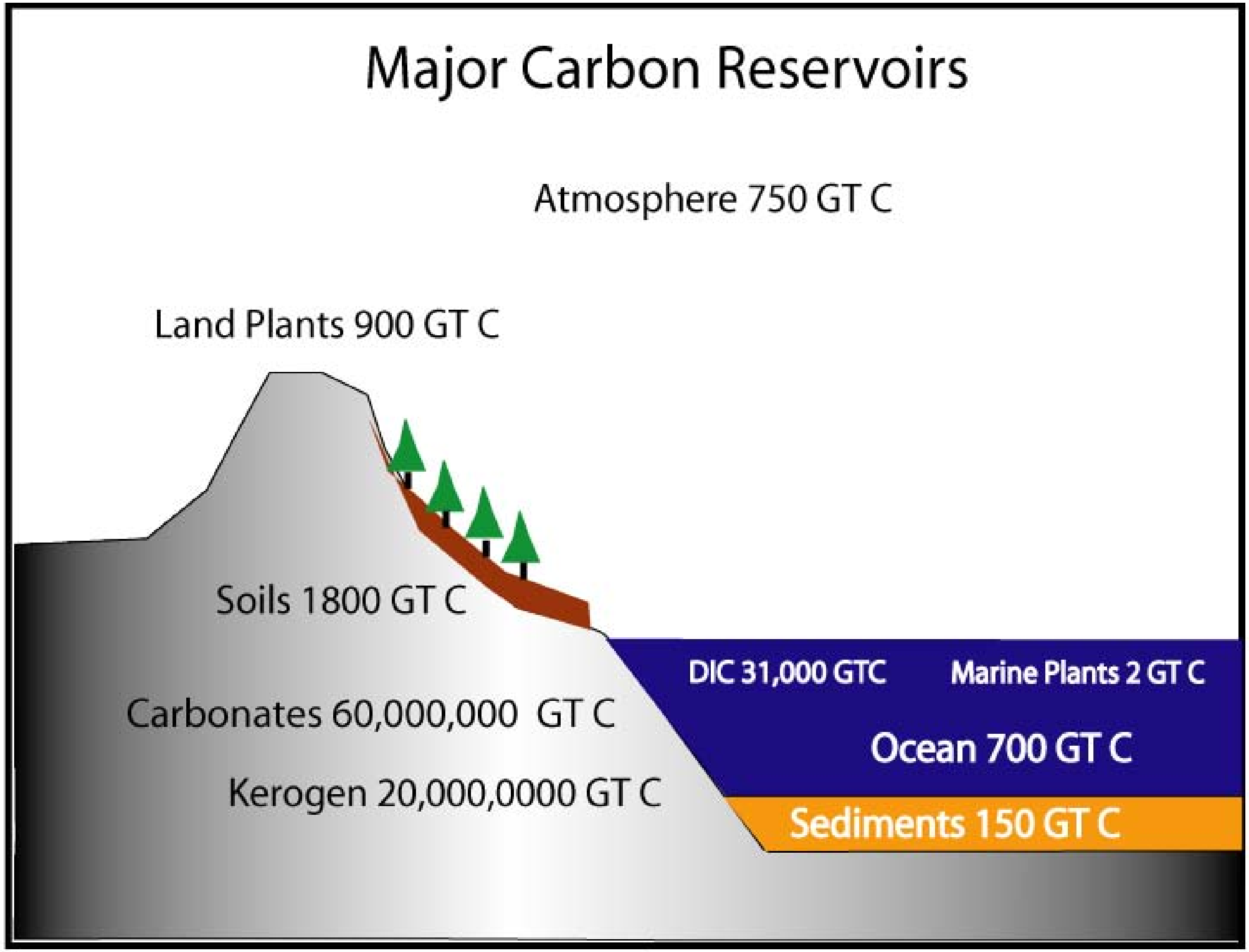
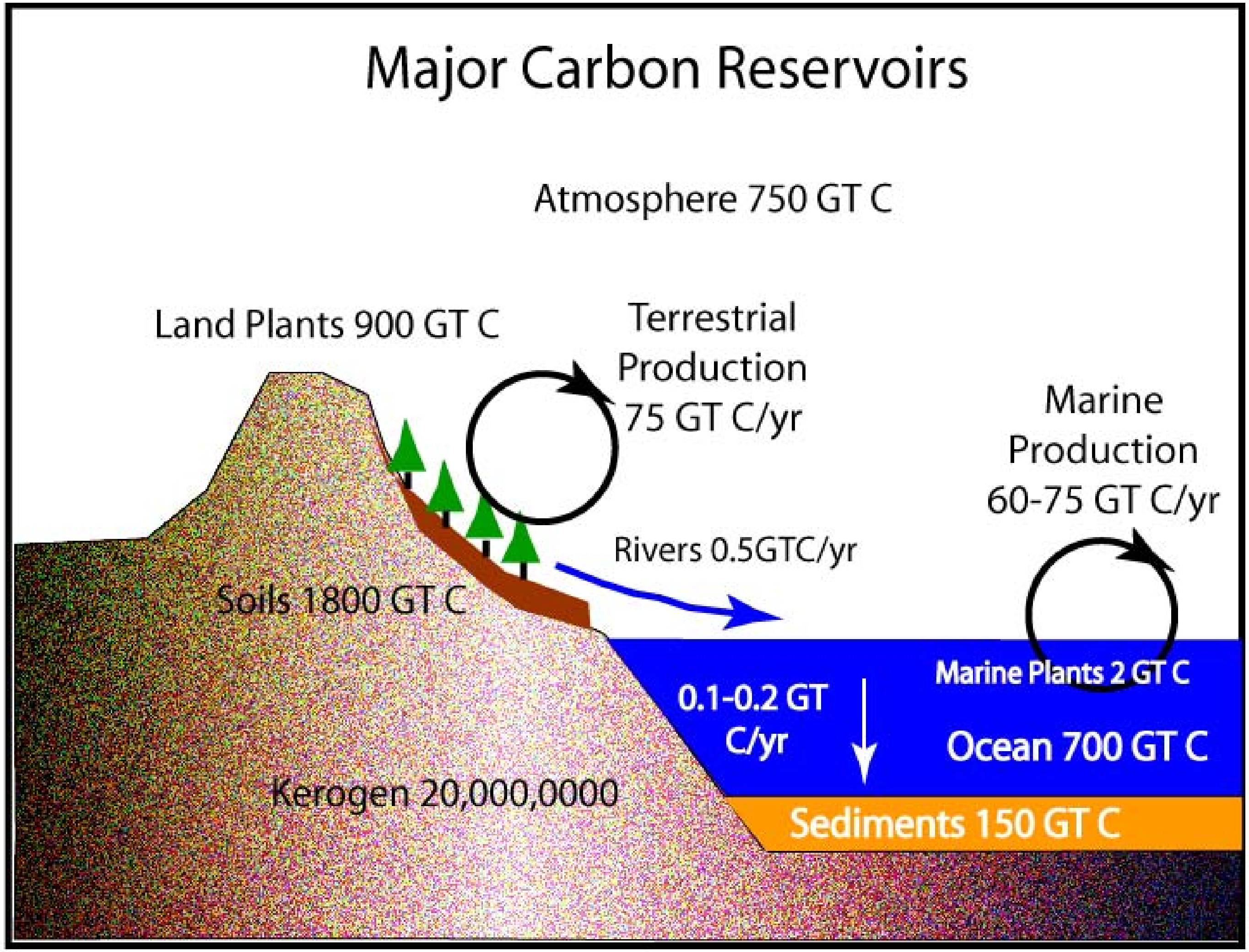
Organic Carbon, Nitrogen, and Phosphorus Cycles and the composition of marine phytoplankton

1. C, N, P cycles
2. Major biochemicals in marine phytoplankton
3. Introduction to dissolved organic carbon

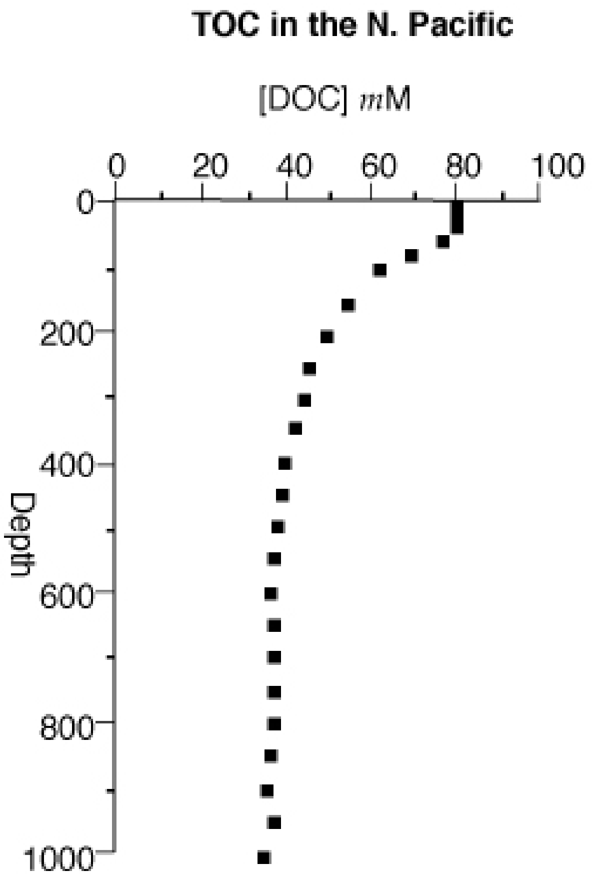
Major Carbon Reservoirs



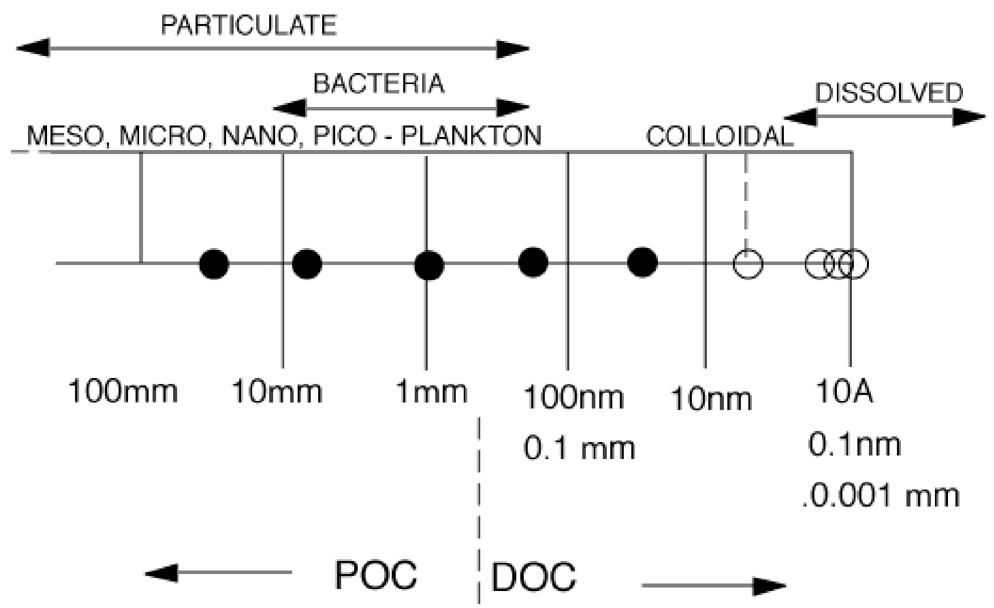

Major Carbon Reservoirs
Atmosphere 750 GT C
Land Plants 900 GT C
Soils 1800 GT C
DIC 31,000 GTC
Marine Plants 2 GT C
Carbonates 60,000,000 GT C
Ocean 700 GT C
Kerogen 20,000,0000 GT C
Sediments 150 GT C


Major Carbon Reservoirs
Atmosphere 750 GT C
Land Plants 900 GT C
Terrestrial Production 75 GT C/yr
Marine Production 60-75 GT C/yr
Rivers 0.5GTC/yr
Soils 1800 GT C
Marine Plants 2 GT C
0.1-0.2 GT C/yr
Ocean 700 GT C
Kerogen 20,000,0000
Sediments 150 GT C

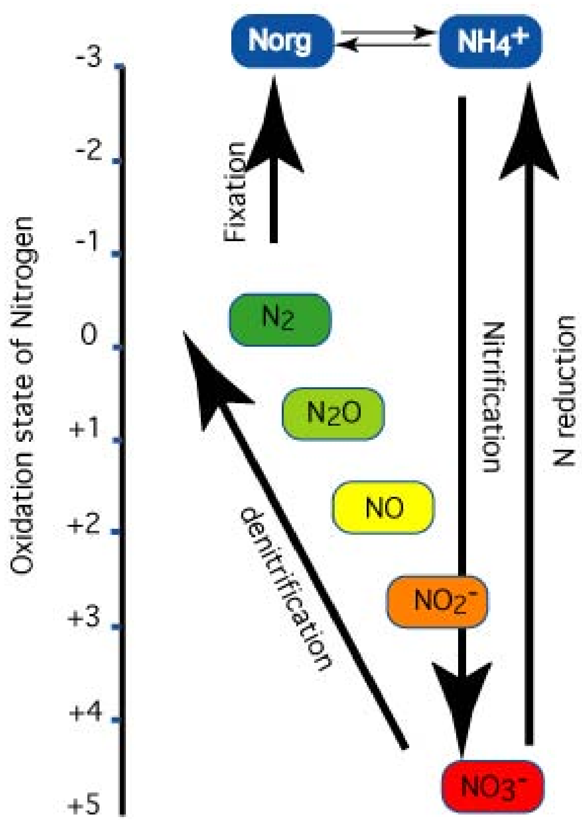
Particulate organic carbon (POC) and Dissolved organic carbon (DOC)

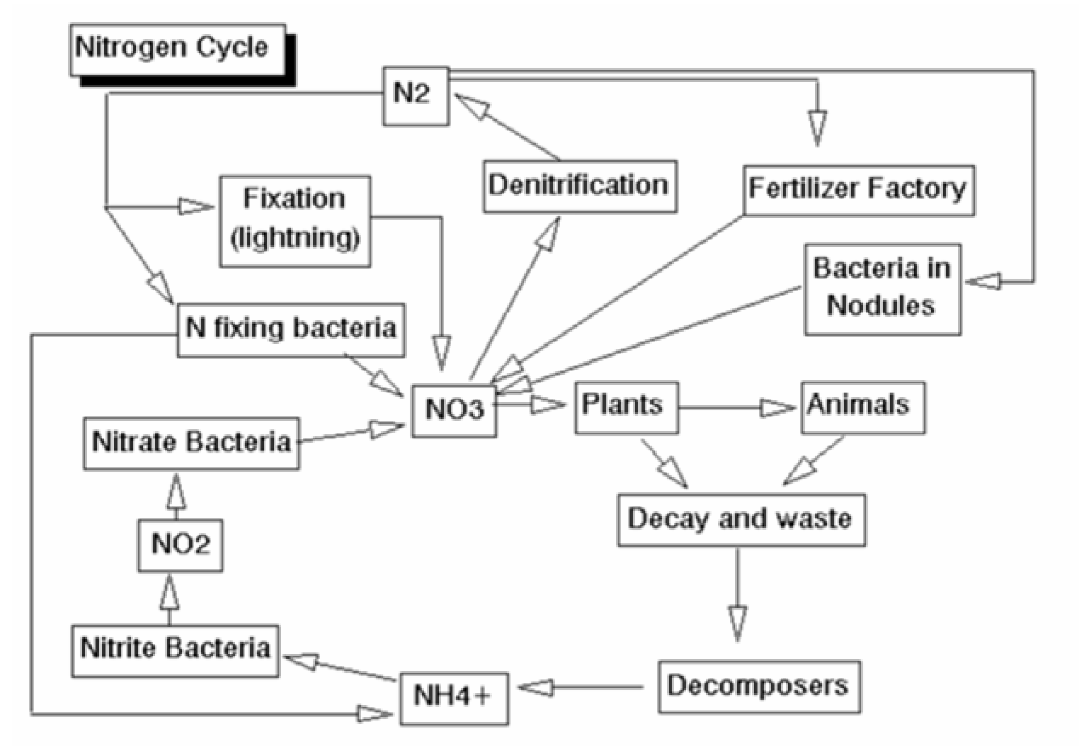


From Peltzer and Hayward, 1996



The Nitrogen Cycle

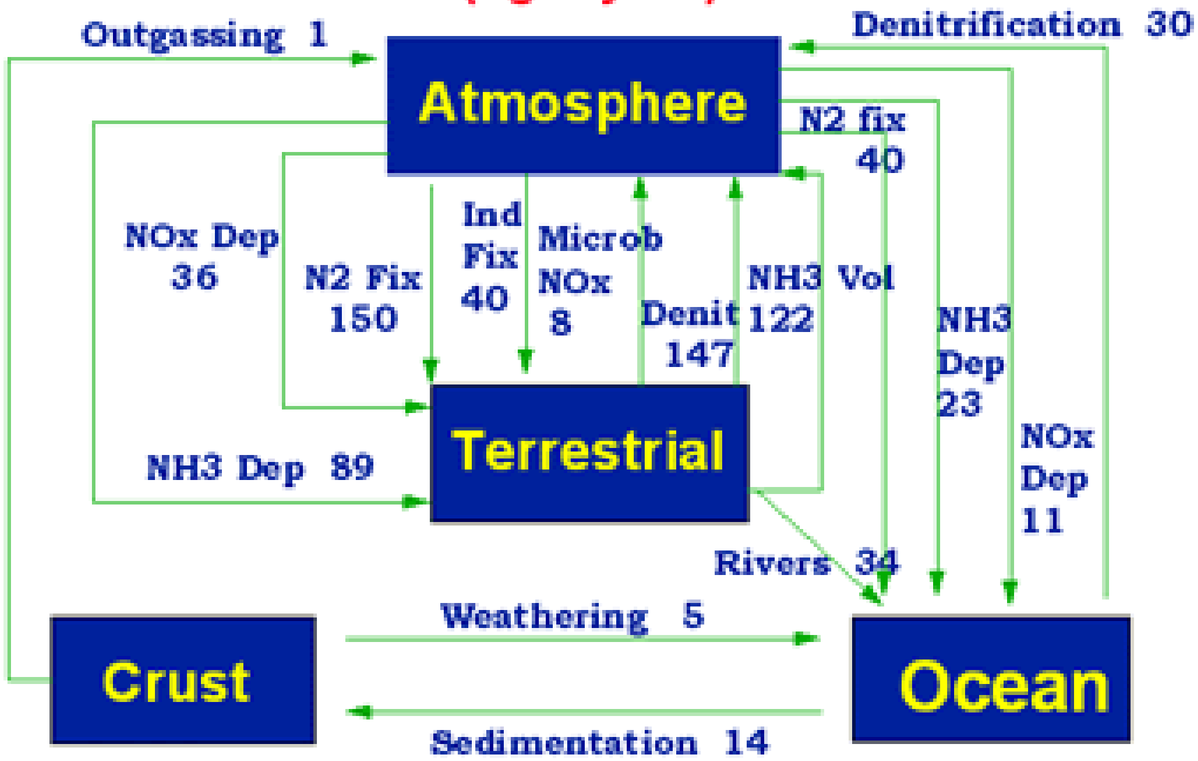




Global Nitrogen Fixation
(GT N/yr)

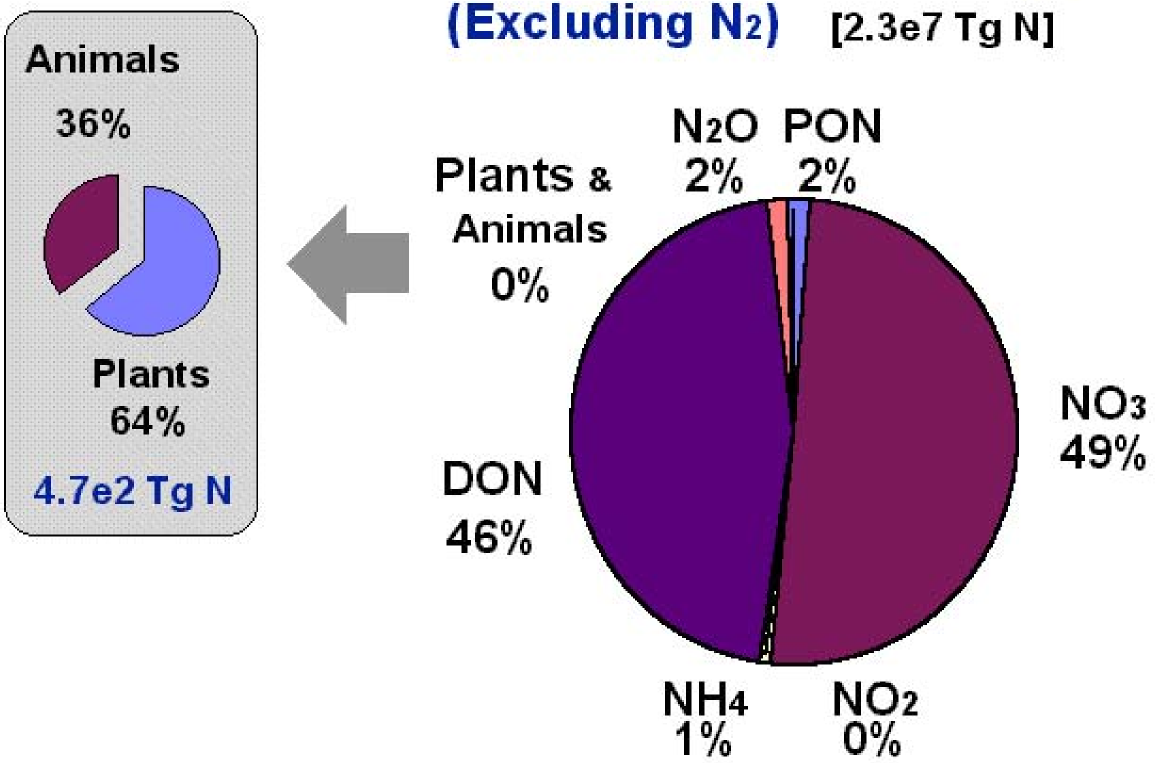
Industrial	0.05
Fossil Fuel Combustion	0.02
Lightning	0.01
Agriculture	0.09
Forests, etc.	0.05
Ocean	0.04

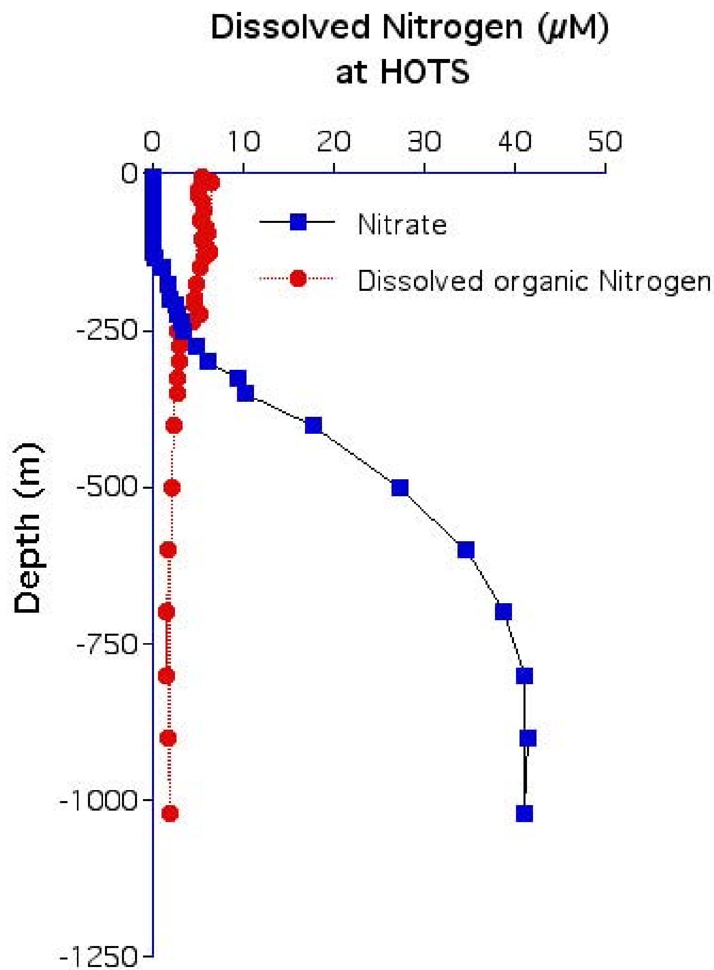
The Nitrogen Cycle
(Tg N/year)



Marine Nitrogen Inventory

(Excluding N_2) [2.3e7 Tg N]





Dissolved Nitrogen (μM)
at HOTS
0
10
20
30
40
50
0
-250
-500
-750
-1000
-1250
Depth (m)
Nitrate
Dissolved organic Nitrogen

P reservoirs and cycling in the ocean

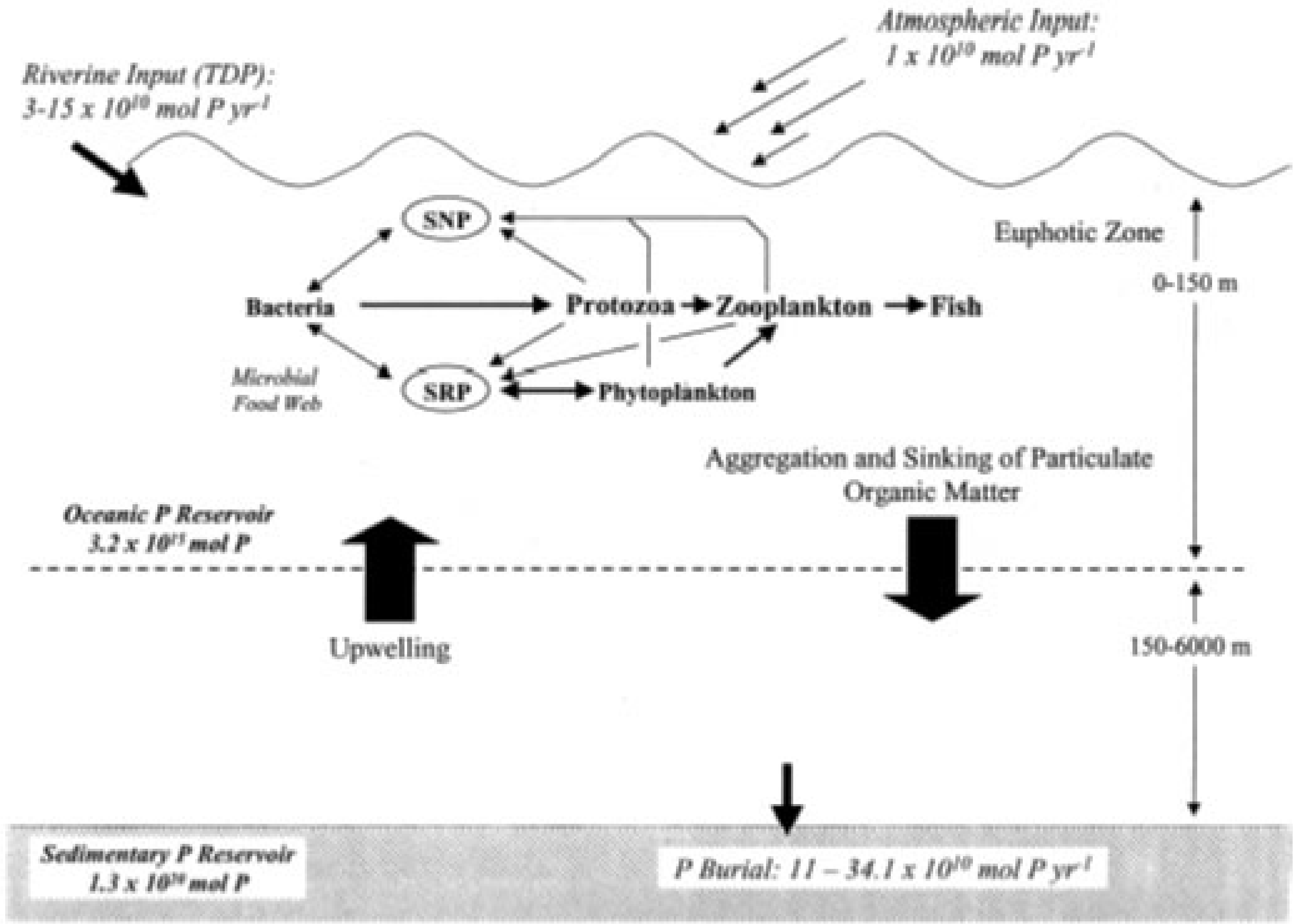


Fig. 3. The pre-anthropogenic marine P cycle. See text for details on fluxes.

Elemental composition and major biochemicals of marine and terrestrial organisms and the Redfield Ratio

Redfield Ratio

C:N:P = 106:16:1

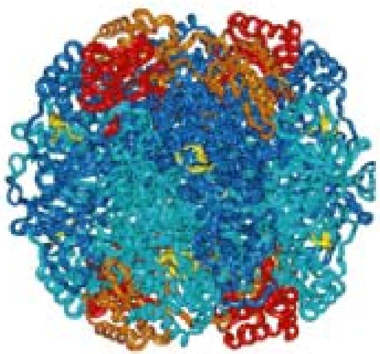
Proteins	4:1;0
Carbohydrates	C only ?
Nucleic Acids	10:4:1
Lipids	C only

Proximate analysis of algal cells

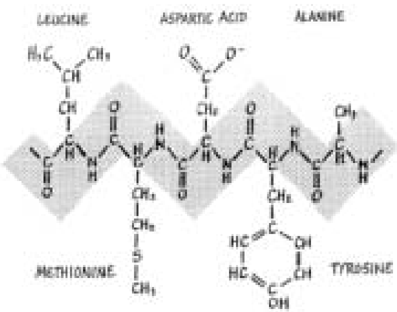
	Protein	Carbohydrate	Lipid	Ash
Chlorophyceae (green algae)				
Tetraselmis maculata	72	21	7	(24)
Dunaliela salina	58	33	10	(8)
Chrysophyceae (golden brown algae)				
Monochrysis lutheri	53	34	13	(6)
Syracosphaera carterae	70	23	7	(37)
Bacillariophyceae (brown algae, diatoms)				
Chaetoceros sp.	68	13	16	(28)
Skeletonema costatum	58	33	10	(39)
Coscinodiscus sp.	74	16	10	(57)
Phaeodactylum tricornutum	49	36	14	(8)
Dynophyceae (dinoflagellates)				
Amphidinium carteri	35	38	23	(14)
Exuriella sp.	37	44	20	(8)
Average	**57**	**29**	**13**	

Proteins

proteins serve as enzmyes
and structural components of cells



RUBISCO
fixes CO_2 in photsynthesis



peptide

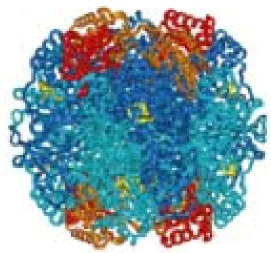
amino acid

R-C-COOH
|
NH_2

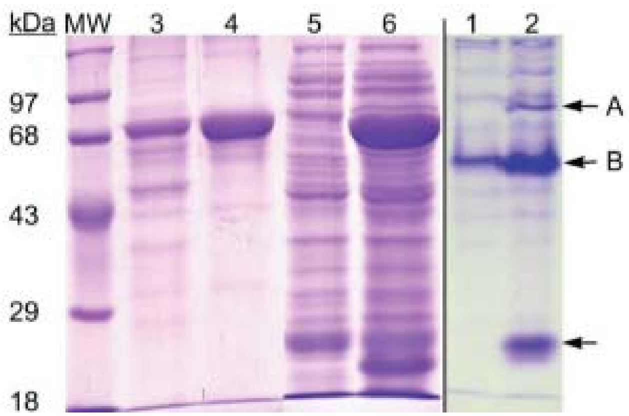
polymers of amino acids
C/N = 4, 80% of all nitrogen in marine algae
>50% of the carbon

Protein Analyses

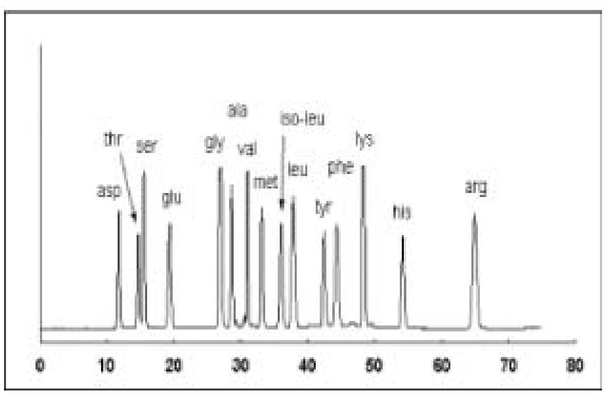
proteins can either be analyzed whole or after hydrolysis



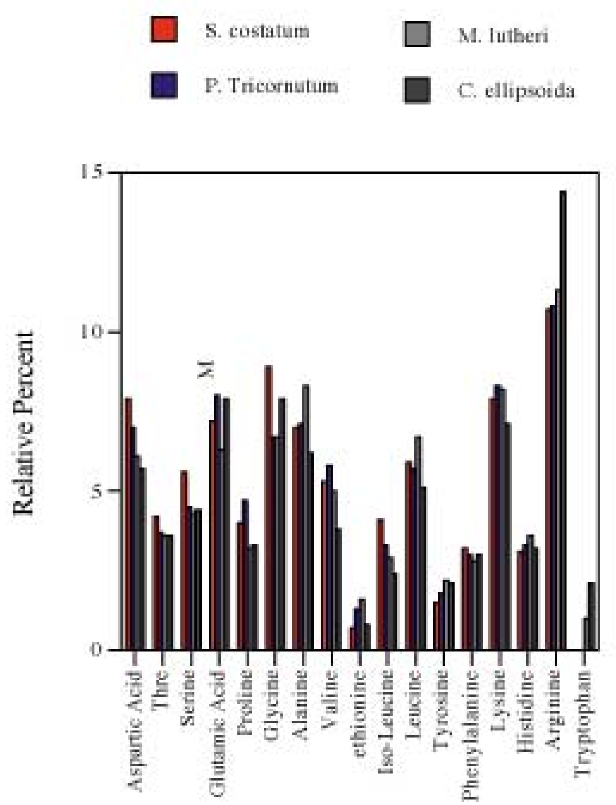
Gel Electrophoresis
of whole proteins



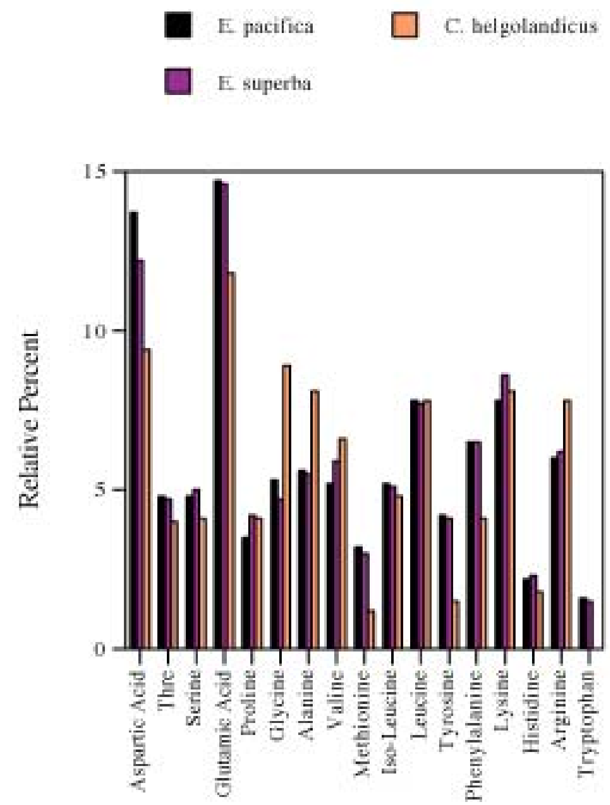
Protein analyses
by amino acid composition



Amino Acid Composition of Marine Algae from Cowey and Corner (1966)

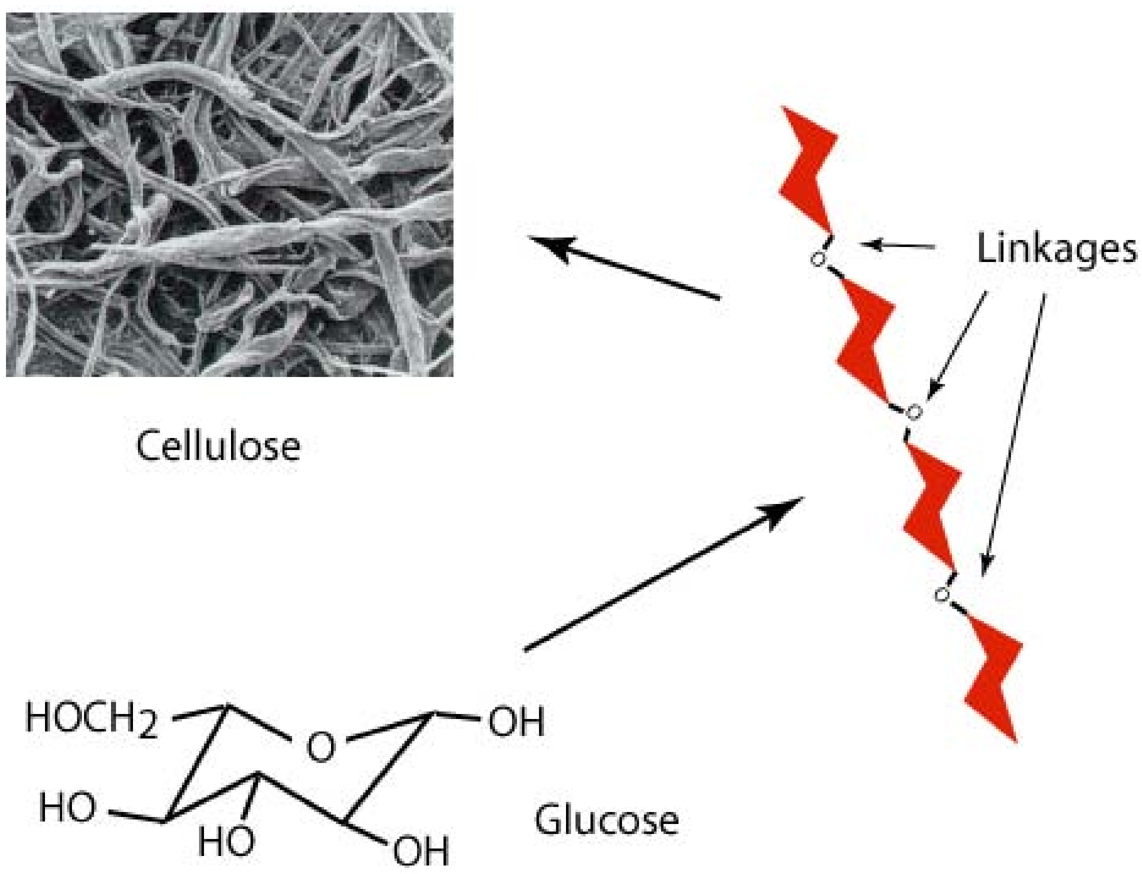


Amino Acid Composition of Zooplankton

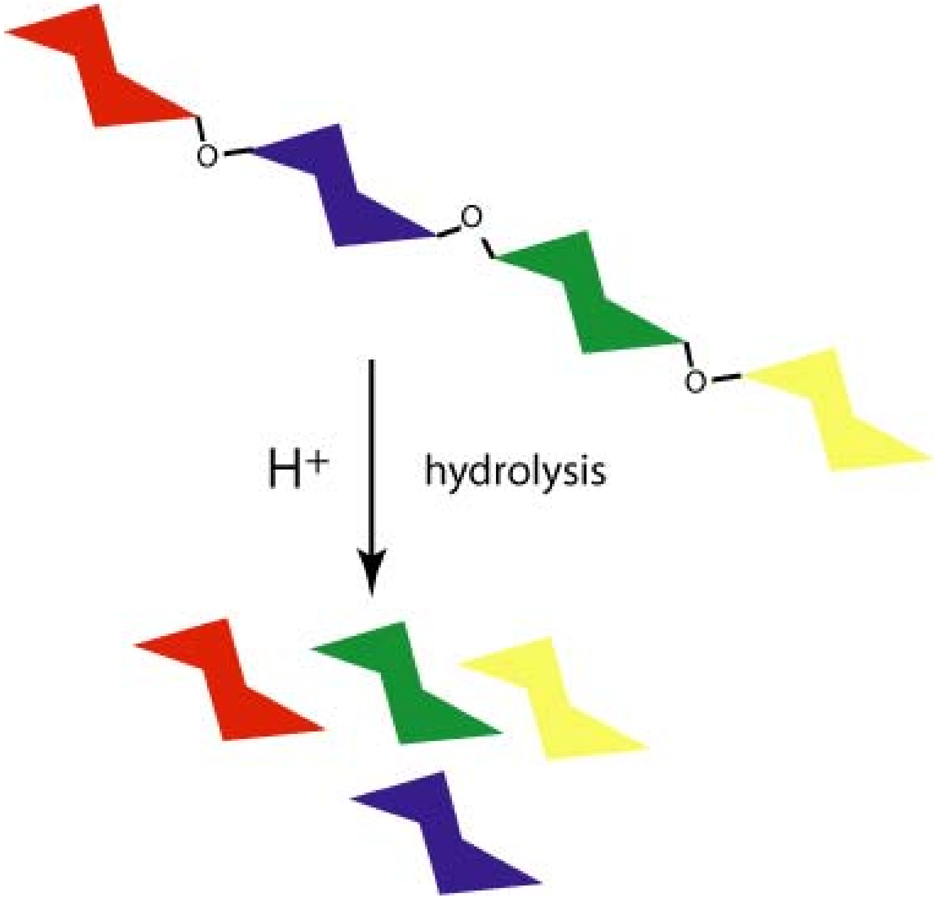


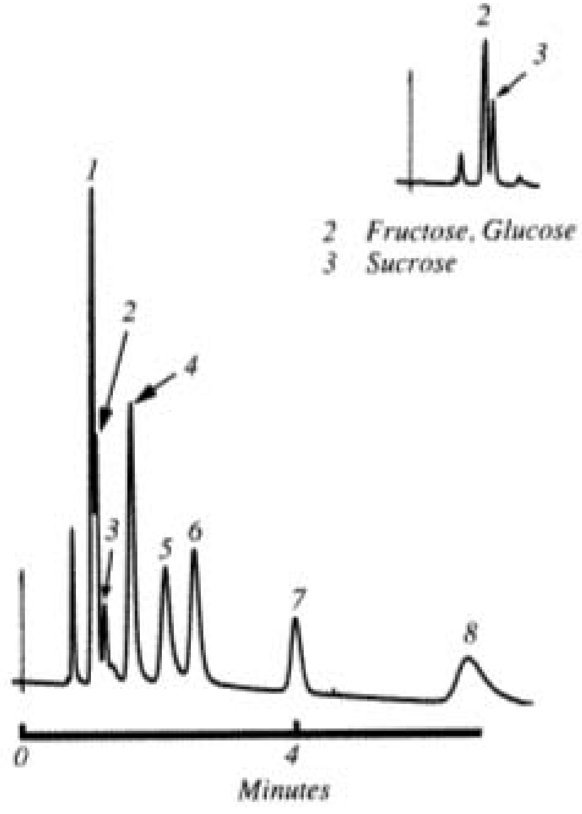
Carbohydrates

CH_2O, no N or P. simple sugars = monosaccharides
2D and 3D polymers = polysaccharides
function as energy storgae and cell structural components



Polysaccharide analysis





Lipids

Distribution

ubiquitious. Many organisms have unique or characteristic suites of lipids, making them excellent tracers for sources of organic matter. Some lipids are also stable over 10^6-10^9 yr, and are therefore useful for paleoenvironmental reconstruction. Lipid mixtures in sediments and rocks are often extremely complex.

Function

Membrane components, energy storage, pigments, cell regulation

Chemical Structure

Polymers with C-C bonds, which are therefore very stable.
Lipids have the general formula C_nH_{2n}, normally with N,O,S,P
Lipids can be linear chains or cyclyze to form rings, making them structurally diverse.

RH

ROH

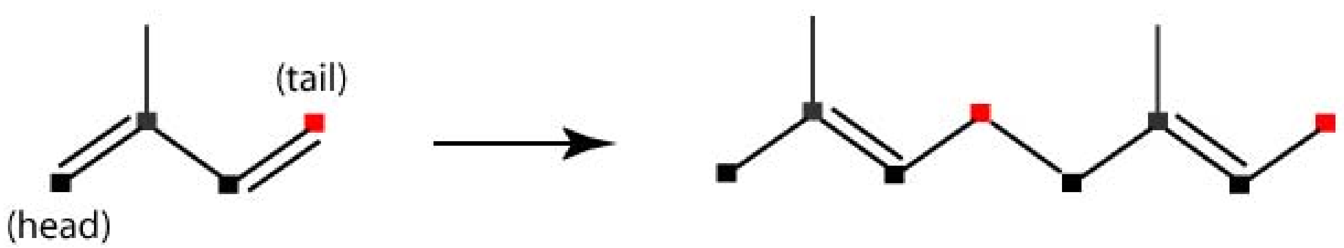
RCOOH

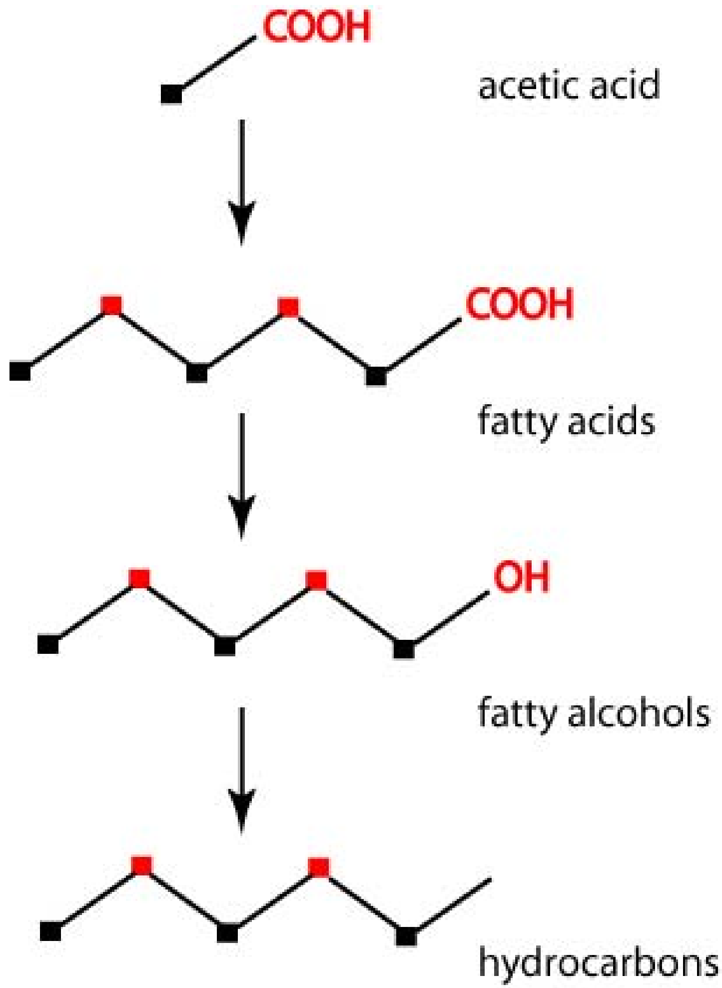
RHNH_2

Lipid biosynthesis occurs via two pathways

1) polyketide
polymerization of acetate (**CH_3COOH**). products usually have an even number of carbons

2) isoprenoid
polymerization of isoprene a five carbon HC. Products have 10, 15, 20....carbons





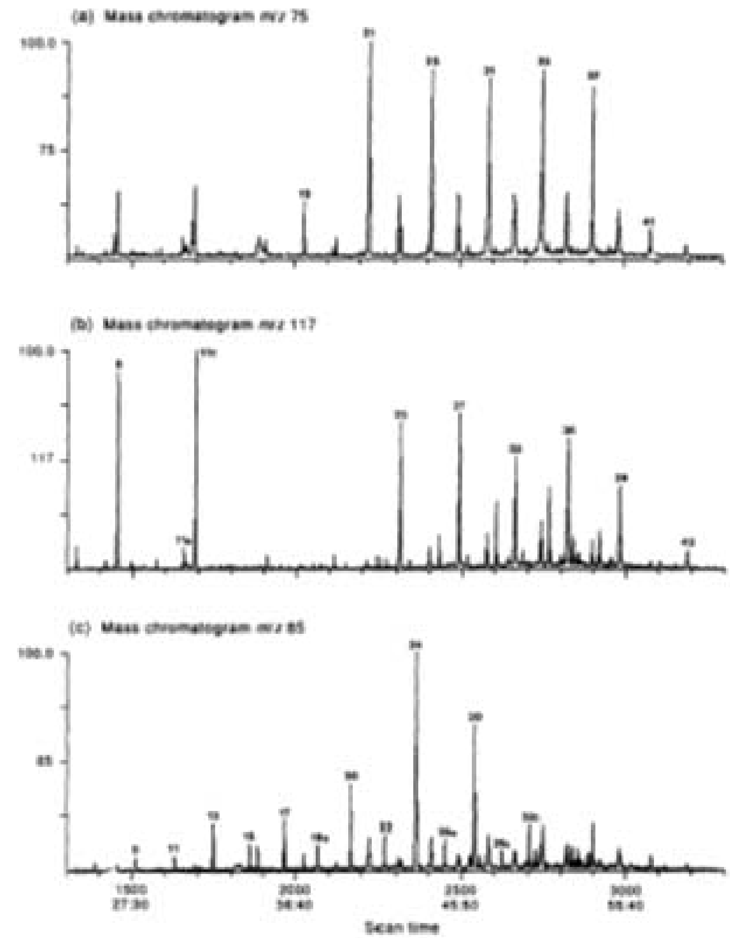
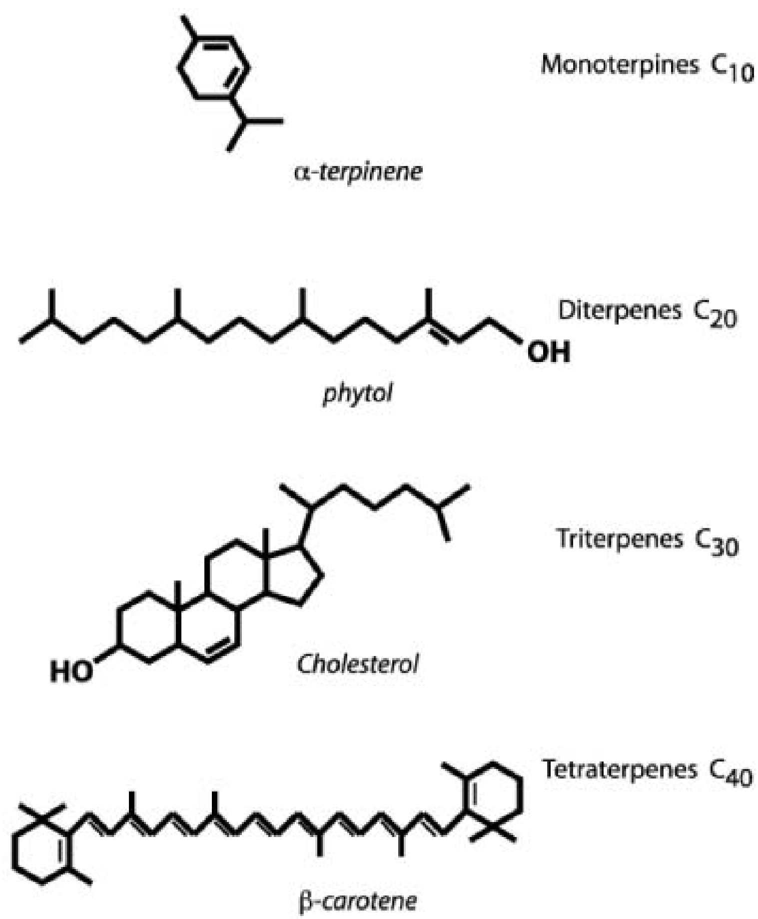
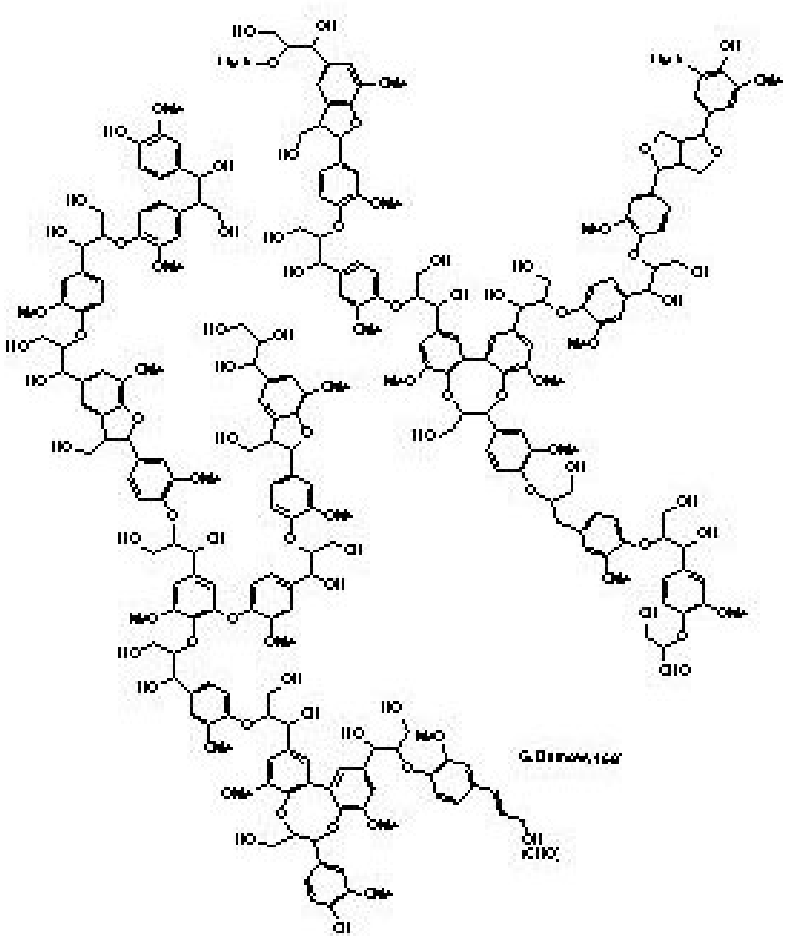


Fig. 3. Mass chromatograms showing n-alkanols (a), n-carboxylic acids (b) and n-alkanes (c) in sample No. 1/2 (101 cm) Thierbach strata, Weisselster Basin, Germany. Assignment of numbered peaks is given in Table 1.

Isoprenoid Biomarkers



Terrestrial Plant organic components



Lignin is a complex structural polymer of hydroxycinnamyl alcohols that are linked together in a number of different linkages and patterns Lignin and cellulose make up a large percentage of the carbonin woody and nonwoody tissues of higher plants.

DIN vs DIP,and TDN vs TDP at station ALOHA

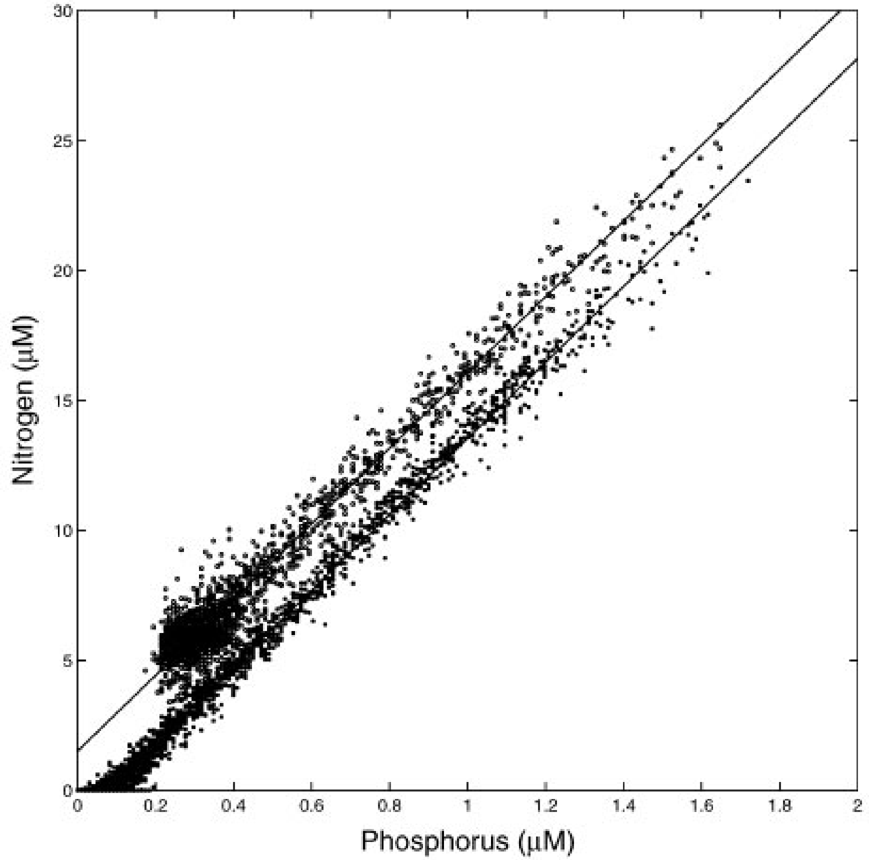
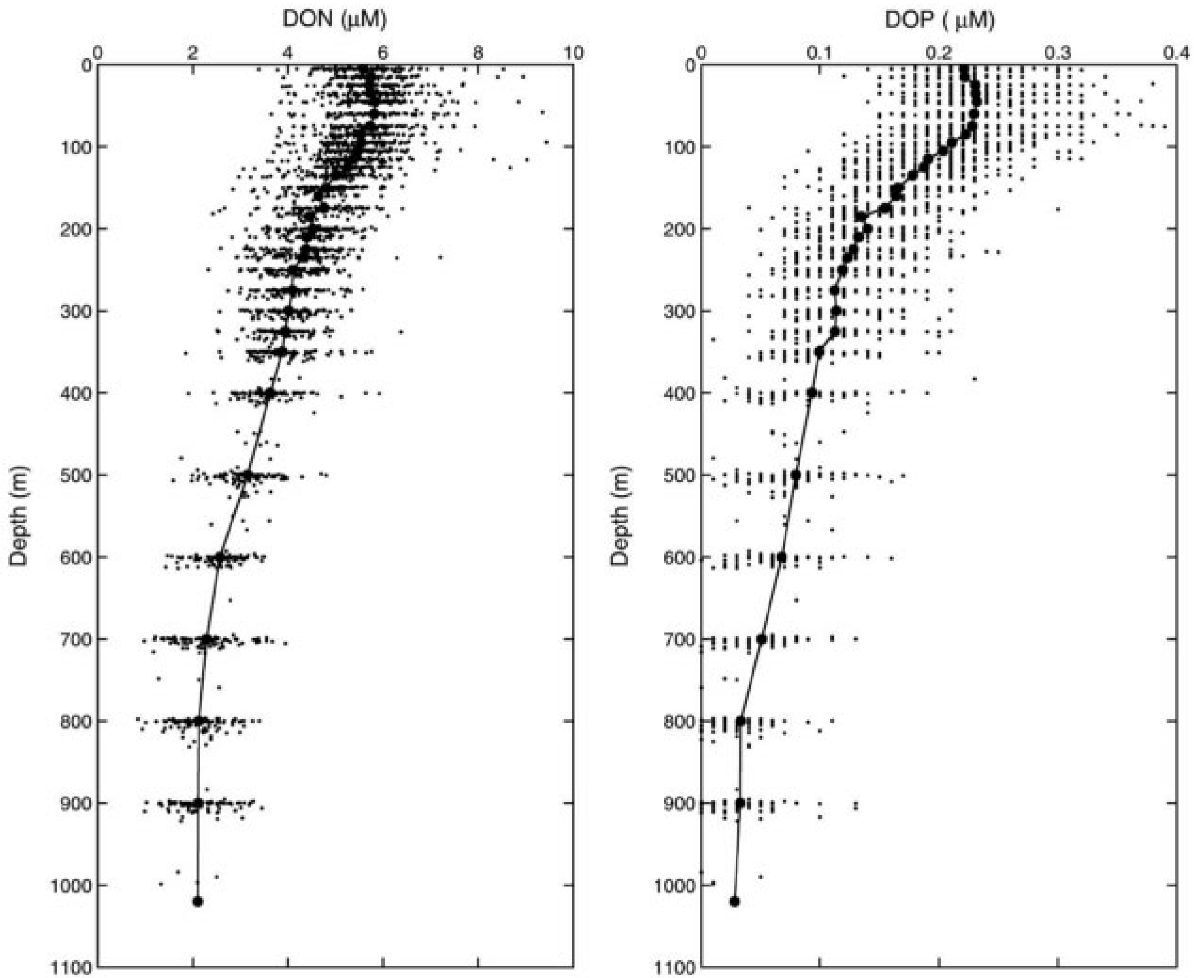


Fig. 10. Nitrogen versus phosphorus correlations for samples collected in the upper 0–400 m of the water column at Sta. ALOHA during the period Oct. 1988 to Dec. 1997. The bottom line is for nitrate plus nitrite (N + N) versus soluble reactive phosphorus (SRP) concentrations and the top line is for total dissolved nitrogen (TDN) versus total dissolved phosphorus (TDP). Model II linear regression analyses: N + N (μM) = 14.62 [14.58 to 14.66] SRP (μM) − 1.08 [− 1.10 to − 1.06], $r = 0.996$, $n = 3299$ and TDN (μM) = 14.57 [14.45 to 14.69] TDP (μM) + 1.50 [1.44 to 1.56], $r = 0.981$, $n = 2060$. Values in brackets indicate the 95% confidence intervals of the respective slope and intercept values.

DON and DOP at station ALOHA,HOTS



N/P ratios at station ALOHA, HOTS

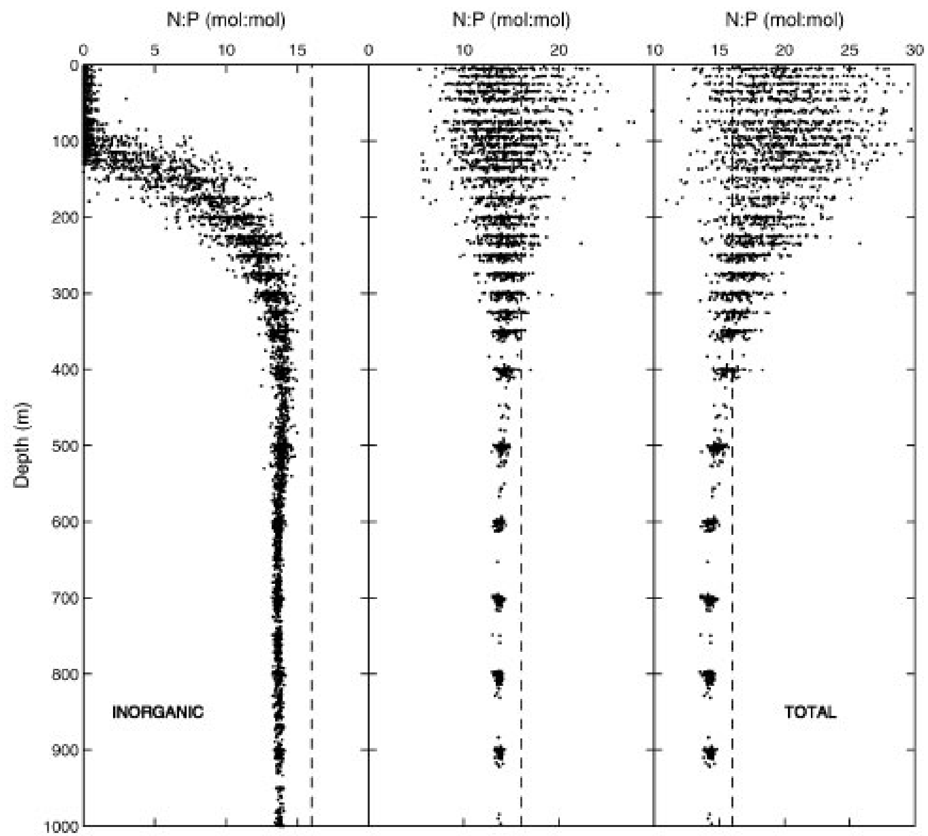
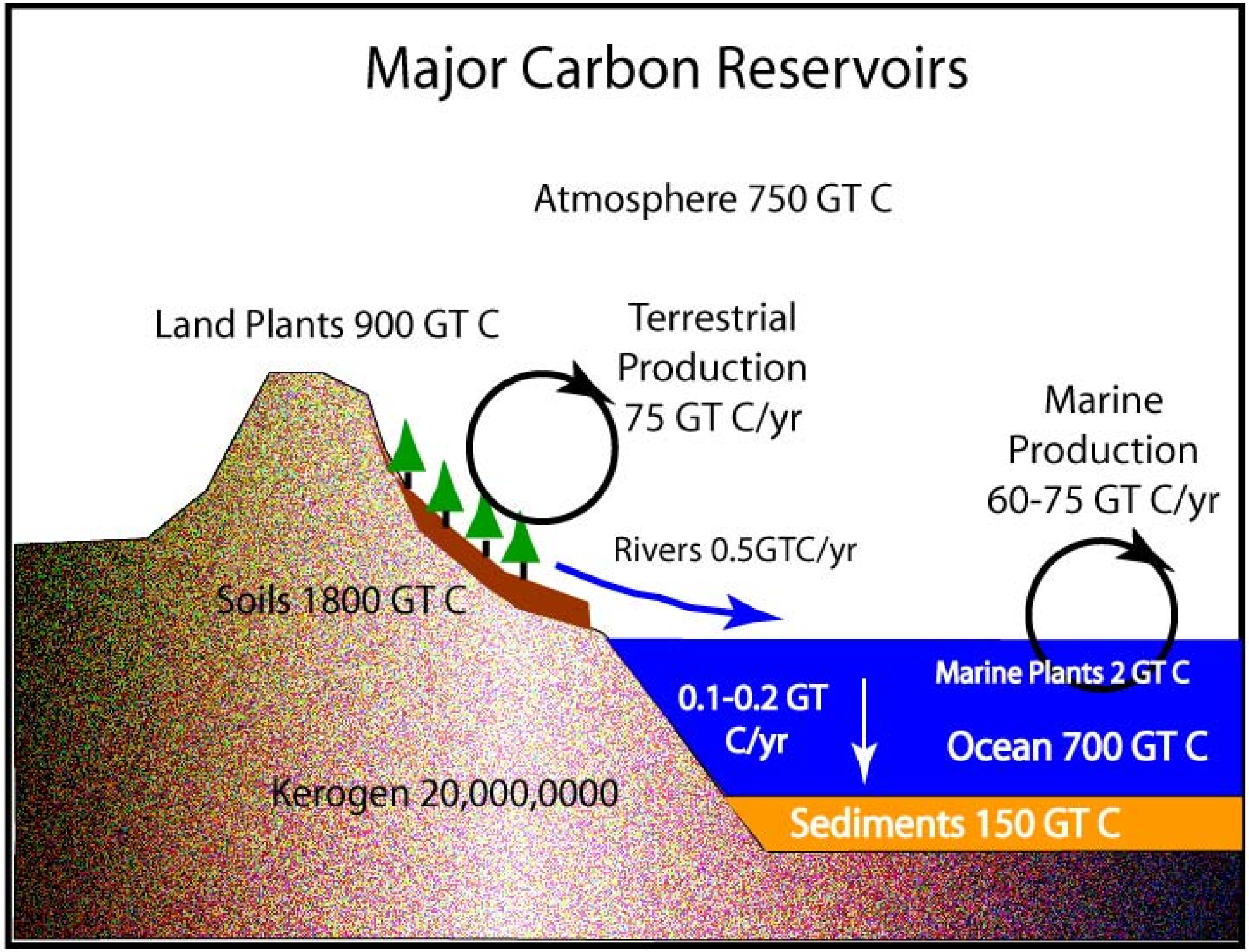
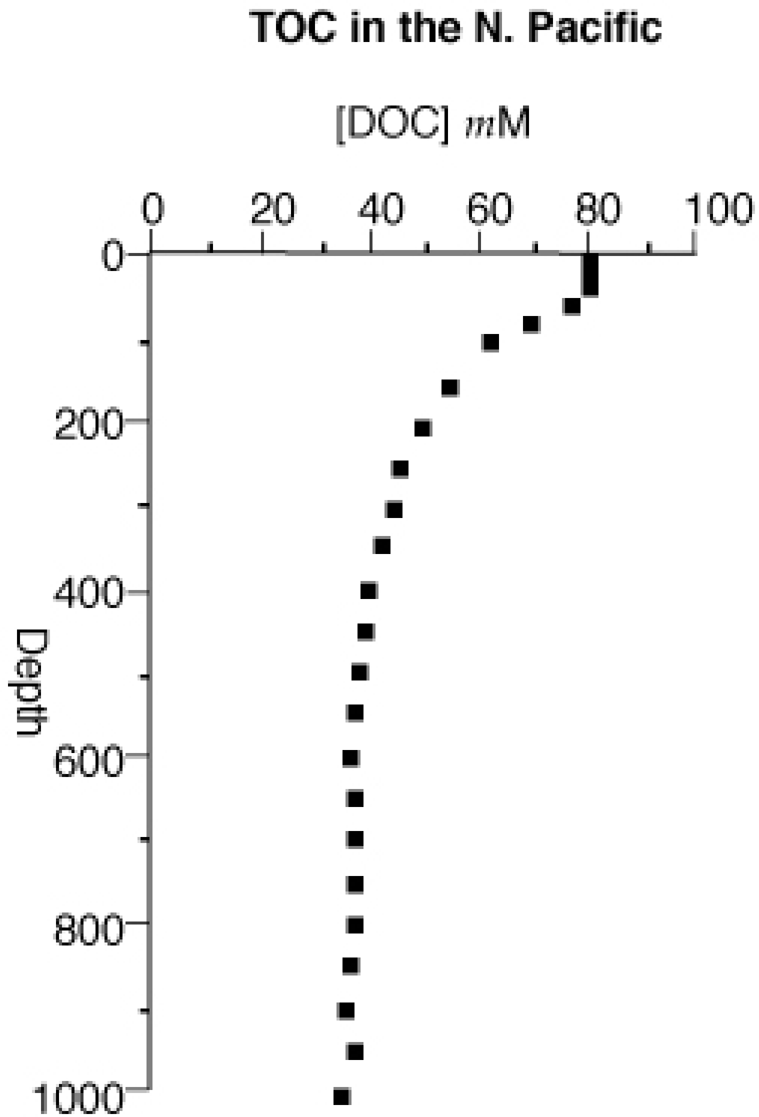


Fig. 8. Nitrogen-to-phosphorus (N : P) ratios versus water depth for samples collected at Sta. ALOHA during the period Oct. 1988 to Dec. 1997. (Left) Molar N : P ratios for dissolved inorganic pools calculated as nitrate plus nitrite (N + N) : soluble reactive phosphorus (SRP). (Center) Molar N : P ratios for the "corrected" total dissolved matter pools (see text for details). (Right) Molar N : P ratios for total dissolved matter pools, including both inorganic and organic compounds, calculated as total dissolved nitrogen (TDN) : total dissolved phosphorus (TDP). As a point for reference, the vertical dashed line in each graph is the Redfield–Ketchum–Richards molar ratio of 16N : 1P.



Major Carbon Reservoirs
Atmosphere 750 GT C
Land Plants 900 GT C
Terrestrial
Production
75 GT C/yr
Marine
Production
60-75 GT C/yr
Rivers 0.5GTC/yr
Soils 1800 GT C
Marine Plants 2 GT C
0.1-0.2 GT
C/yr
Ocean 700 GT C
Kerogen 20,000,0000
Sediments 150 GT C



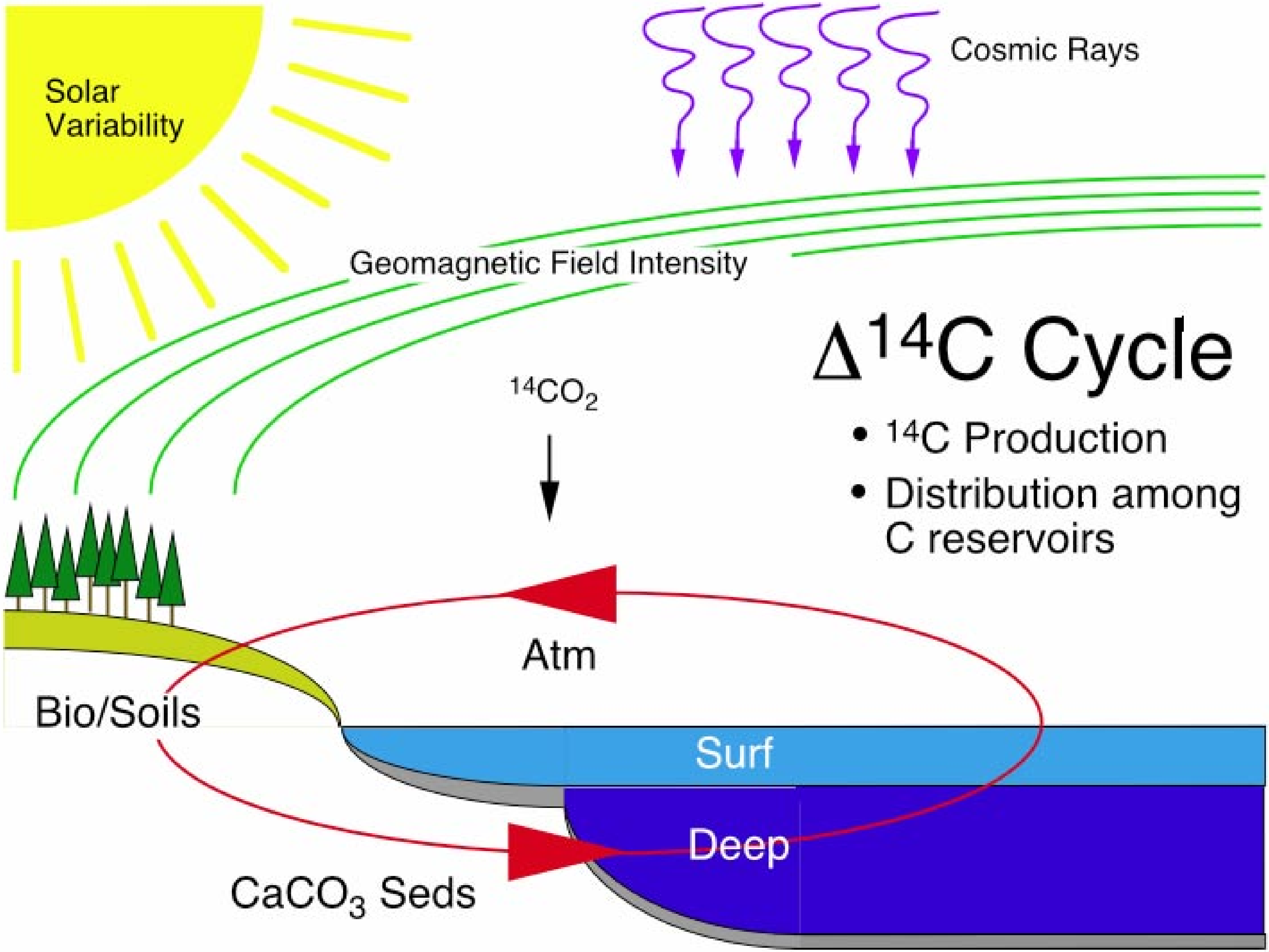
From Peltzer and Hayward, 1996

Global inventory of DOC

DOC measured by high temperature catalytic oxidation (HTCO) method.

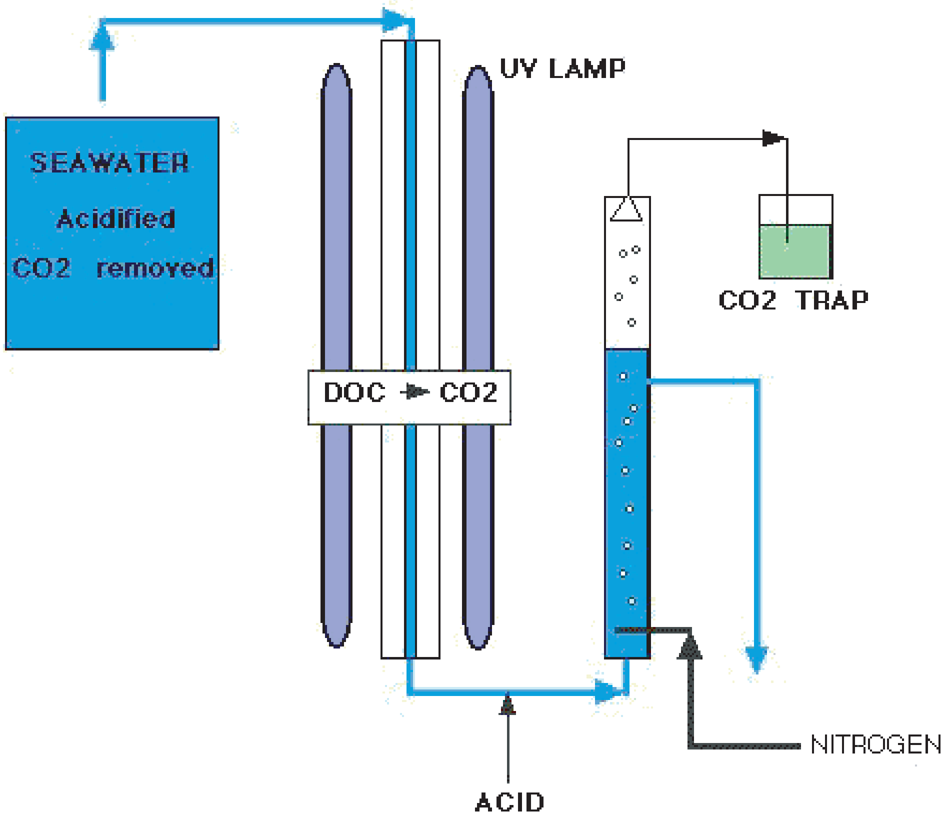
Global inventory was measured by International JGOFS program (680 GT C).

Depth pretty much the same everywhere, with high surface water values (40-80 uM C) and low deep water values (40 uM C). Deep sea concentrations are nearly constant.

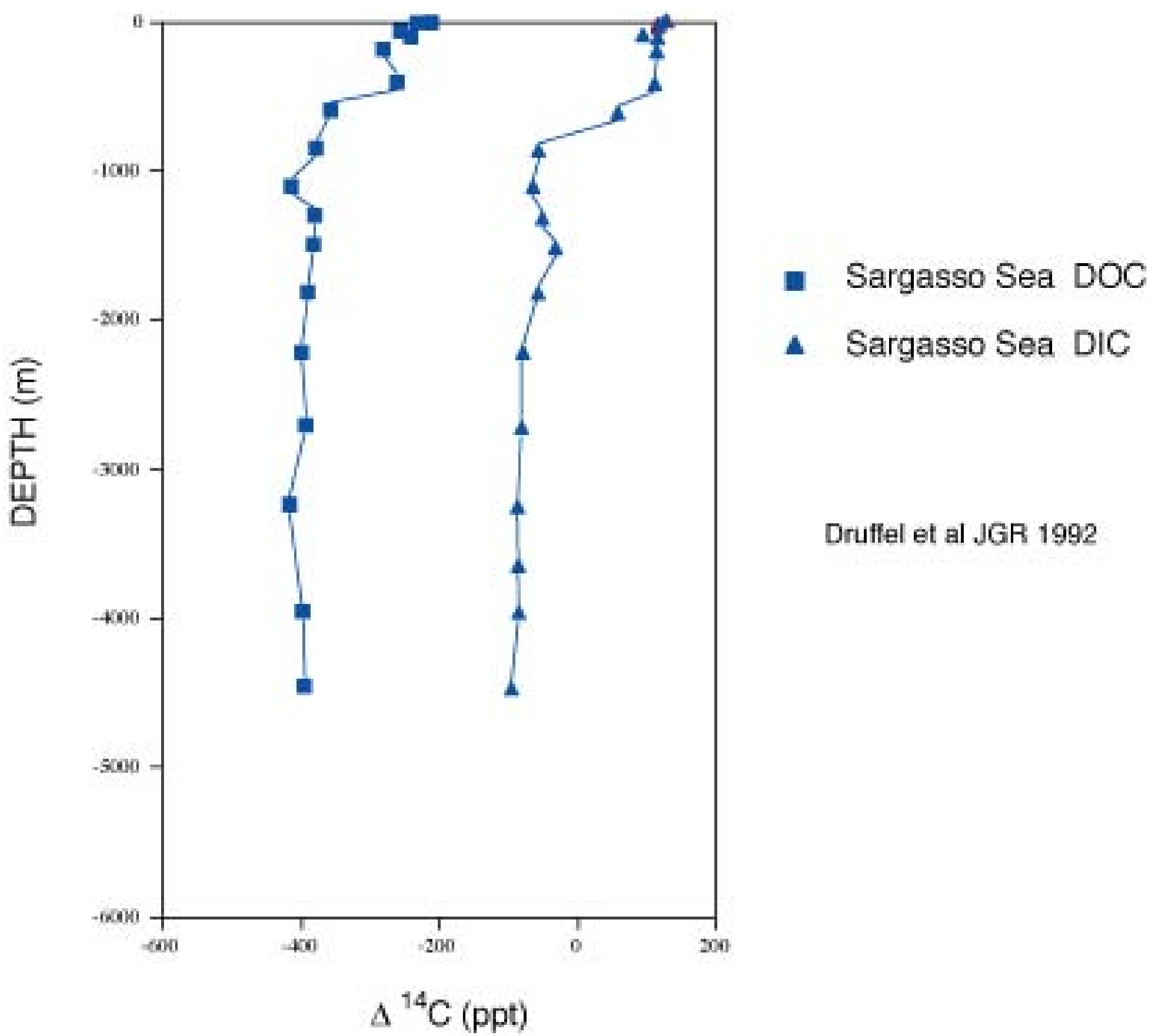


Solar Variability
Cosmic Rays
Geomagnetic Field Intensity
Δ14C Cycle
• 14C Production
• Distribution among C reservoirs
14CO2
Atm
Bio/Soils
Surf
Deep
CaCO3 Seds

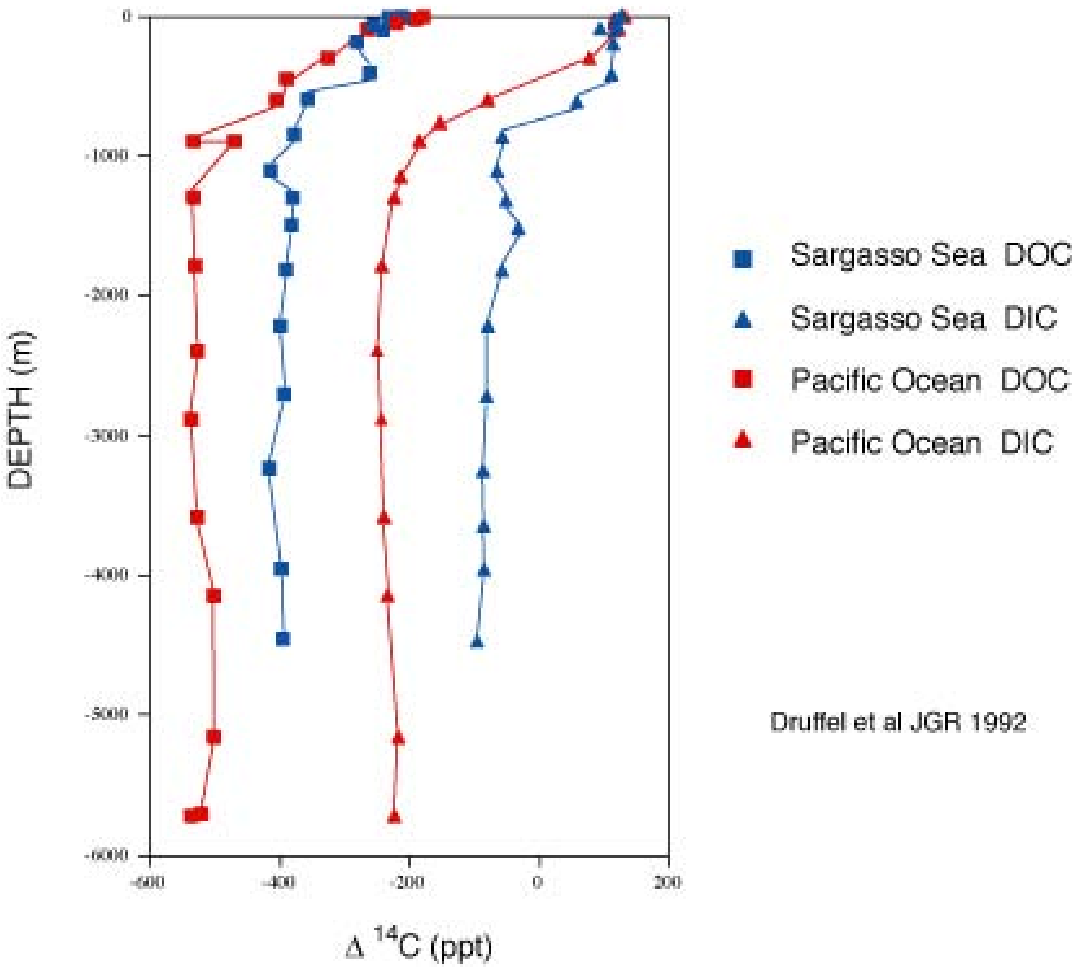
Radiocarbon Age of Dissolved Organic Carbon



DO^{14}C and DI^{14}C in the Atlantic Ocean



DO^{14}C and DI^{14}C in the Atlantic and Pacific Ocean



Druffel et al JGR 1992

Radiocarbon measurements show that the average age of deep sea DOC is > 5000 yr. If the global inventory is 700 GT C, then the annual flux of C to maintain the system at steady state can be calculated as:

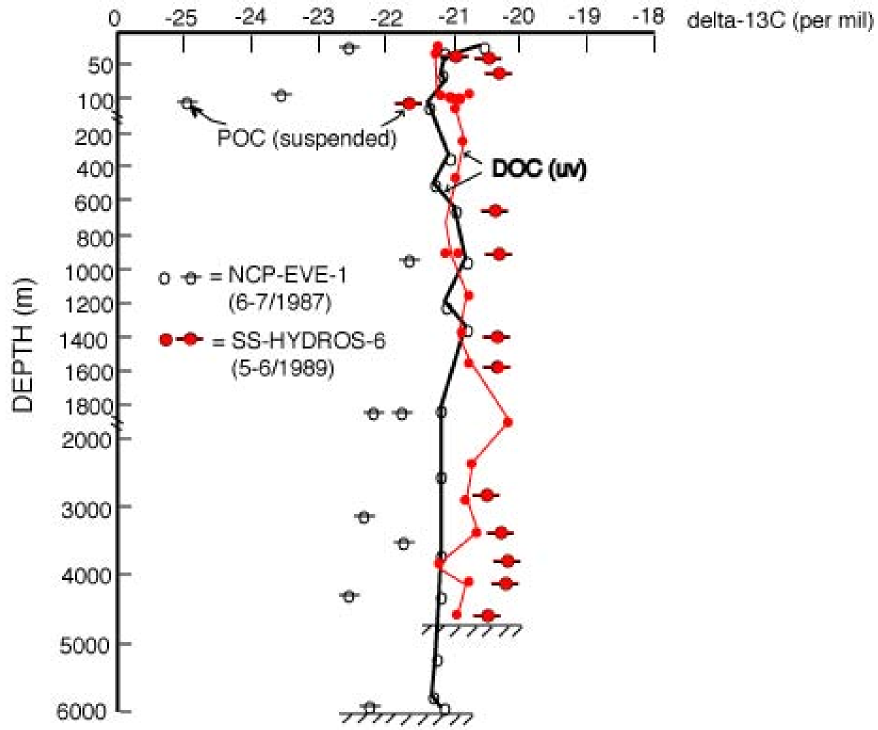
$$700 \text{ GT}/ 5000 \text{ yr} = 0.14 \text{ GT C yr}^{-1}$$

The annual input of DOC from rivers is 0.2-0.4 GT C yr^{-1}, While annual marine primary production is 60-75 GT Cyr-1

Either source adds enough C per year to maintain the system.

So what is the source of oceanic DOC?

Origin of DOC from stable carbon isotopes



A comparison of the stable isotope ratio measurements for DOC uv and suspended POC for the North Atlantic (Hydros-6) and the NCP (Eve-1) site.

Wrap up

The elemental composition (C, N, P, S) of marine and terrestrial organisms is a reflection of their biochemical composition at the molecular level.

Marine organisms (in terms of their carbon) are made of proteins > carbohydrates > lipids > nucleic acids. In terms of N, 70-80% is in proteins. The remaining is distributed between nucleic acids, carbohydrates, pigments, etc. The proportions of biochemicals are variable and reflect both environmental factors And physiological status.

N and P are limiting nutrients in the euphotic zone. Most of the N and P in the euphotic zone occur as DON and DOP. It is not known why these reservoirs of organic nutrients exist. Is the ocean N or P limited???

DOC is the largest reservoir of organic carbon in seawater. >98% of organic carbon in the ocean is DOC. It has high concentrations In the euphotic zone indicating net production or at least input. Values at depth are low (about half surface water values) and nearly Constant.

Radiocarbon values of DOC are highly depleted, consistent with An average residence time of 5000-6000 years. Several ocean Mixing cycles!!! No one knows why, but surely this impacts Organic nutrients.