Nutrient Cycling in Aquatic Ecosystems-II: the Oceans

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- Nitrogen and Phosphorus Budgets for the Sea
- Human Perturbations of Marine Nutrient Cycling

The Sedimentary Record of Biogeochemistry

A detailed breakdown of the water volume in various reservoirs[a]

Environment	Water volume (10^3 km^3)	Percentage of total
Surface water		
Freshwater lakes	125	0.009
Saline lakes and inland seas	104	0.008
Rivers and streams	1.3	0.0001
Total	230	0.017
Subsurface water		
Soil moisture	67	0.005
Ground water	8000	0.62
Total	8067	0.625
Ice caps and glaciers	29,000	2.15
Atmosphere	13	0.001
Oceans	1,330,000	97.2
Totals (approx.)	1,364,000	100

[a] Data from Berner and Berner (1987).

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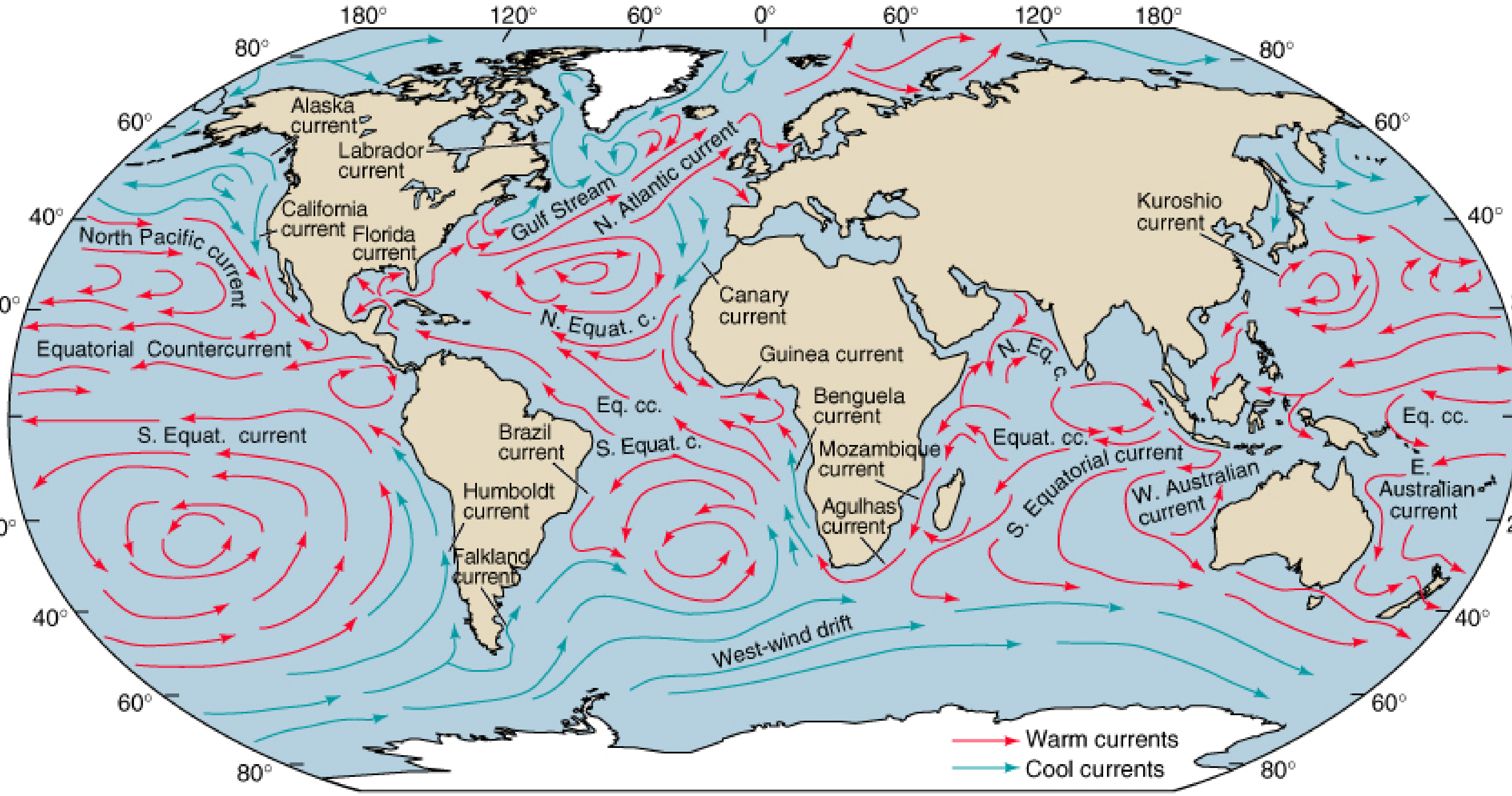
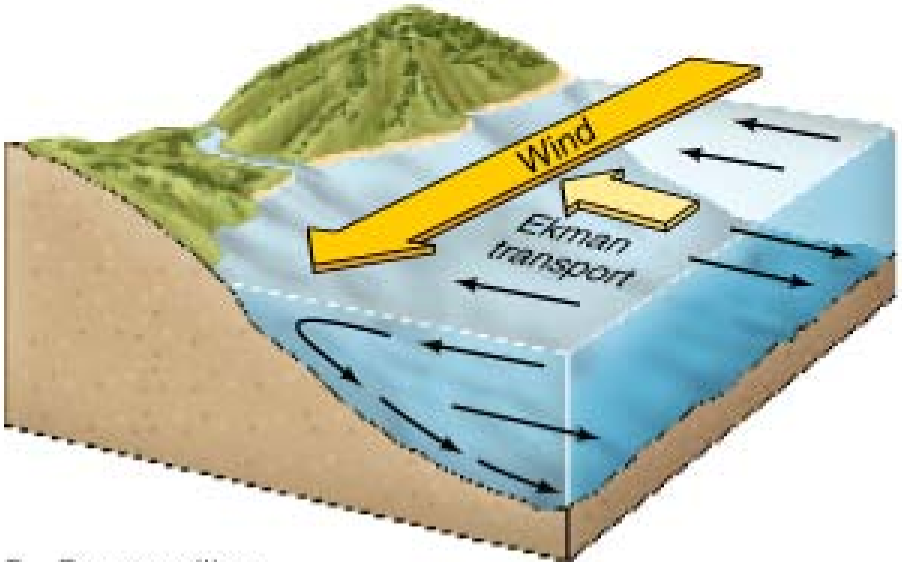
Ocean Circulation

Key points:

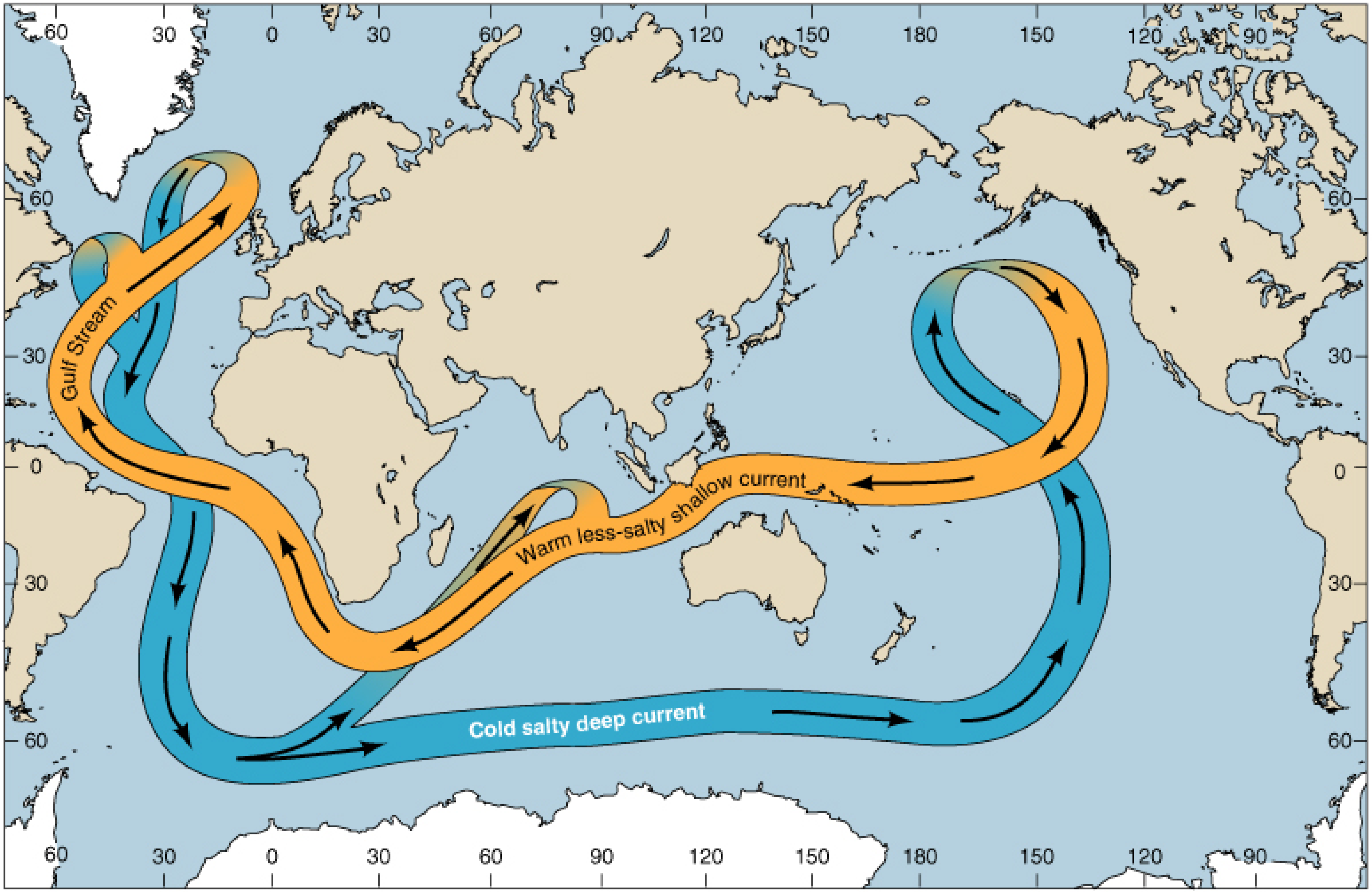
1. Surface water circulations are mainly driven by surface wind patterns plus Coriolis effect
2. Deep ocean circulation is main driven by gradients of temperature and salinity.

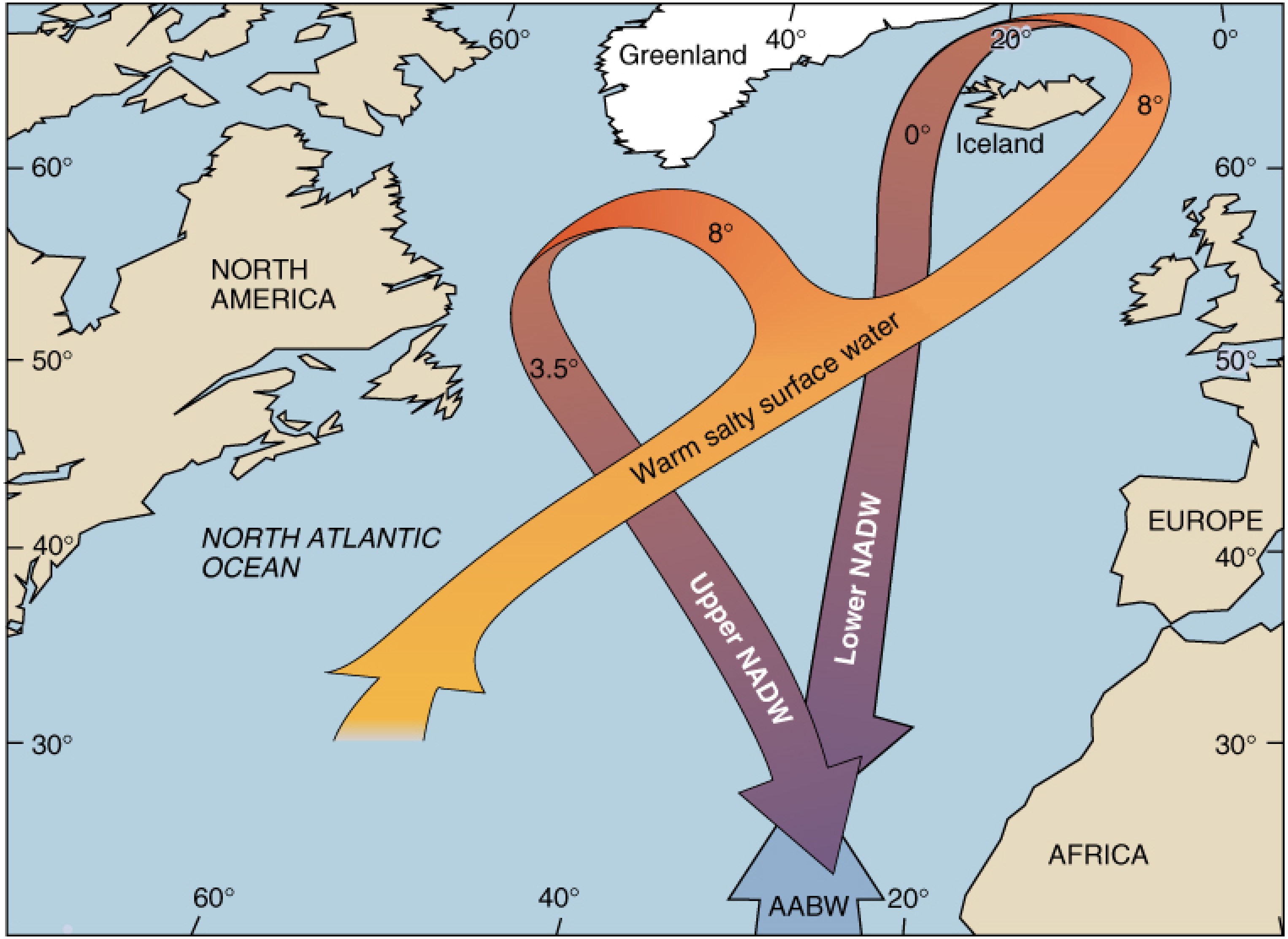

180°
120°
60°
0°
60°
120°
180°
80°
60°
40°
20°
0°
20°
40°
60°
80°
Alaska current
Labrador current
California current
Florida current
Gulf Stream
N. Atlantic current
North Pacific current
Kuroshio current
Canary current
N. Equat. c.
Equatorial Countercurrent
Guinea current
N. Eq. c.
Eq. cc.
Benguela current
Brazil current
S. Equat. c.
Mozambique current
Equat. cc.
S. Equat. current
Humboldt current
Agulhas current
S. Equatorial current
W. Australian current
E. Australian current
Eq. cc.
Falkland current
West-wind drift
Warm currents
Cool currents

A. Upwelling

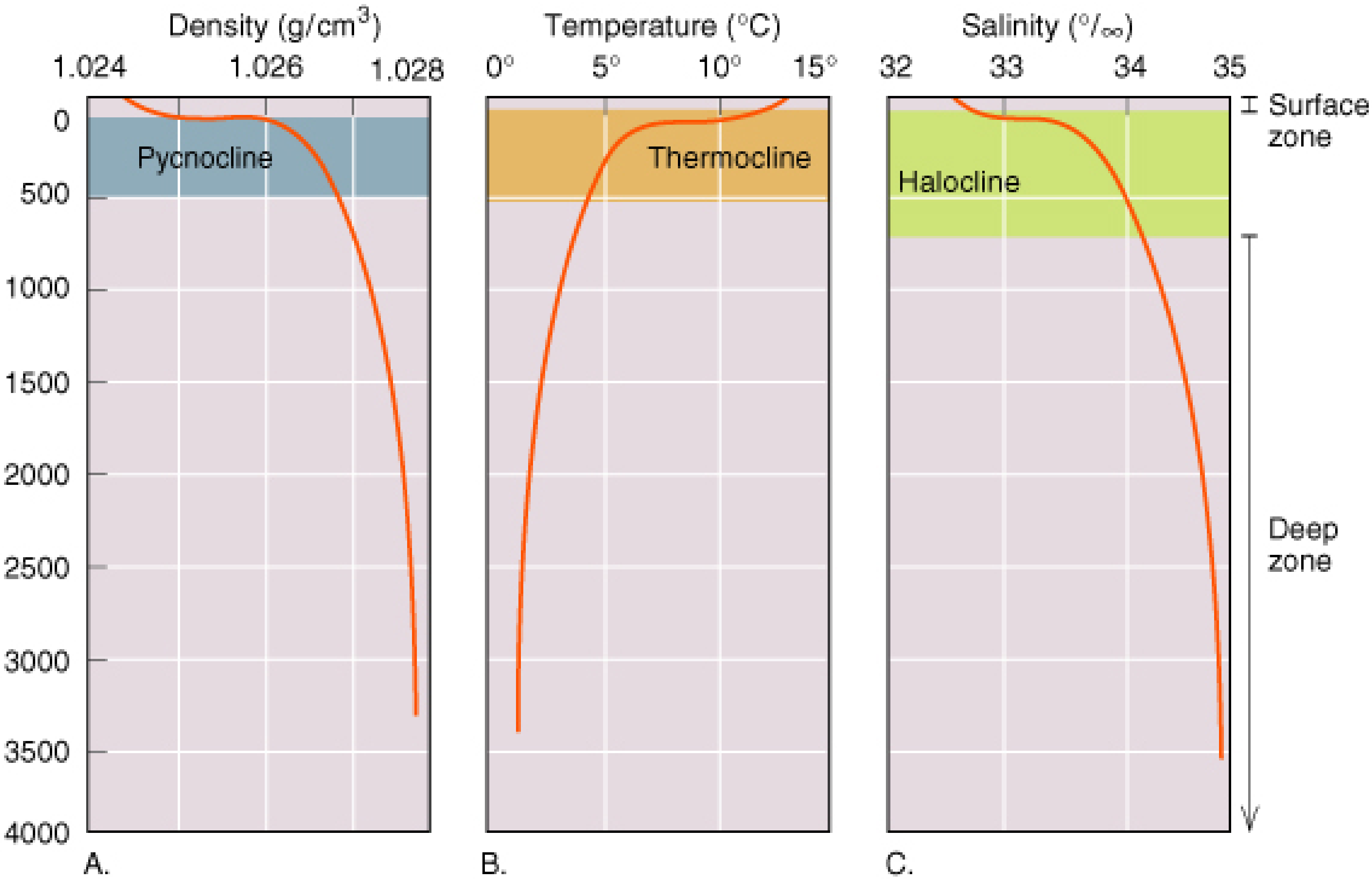


B. Downwelling

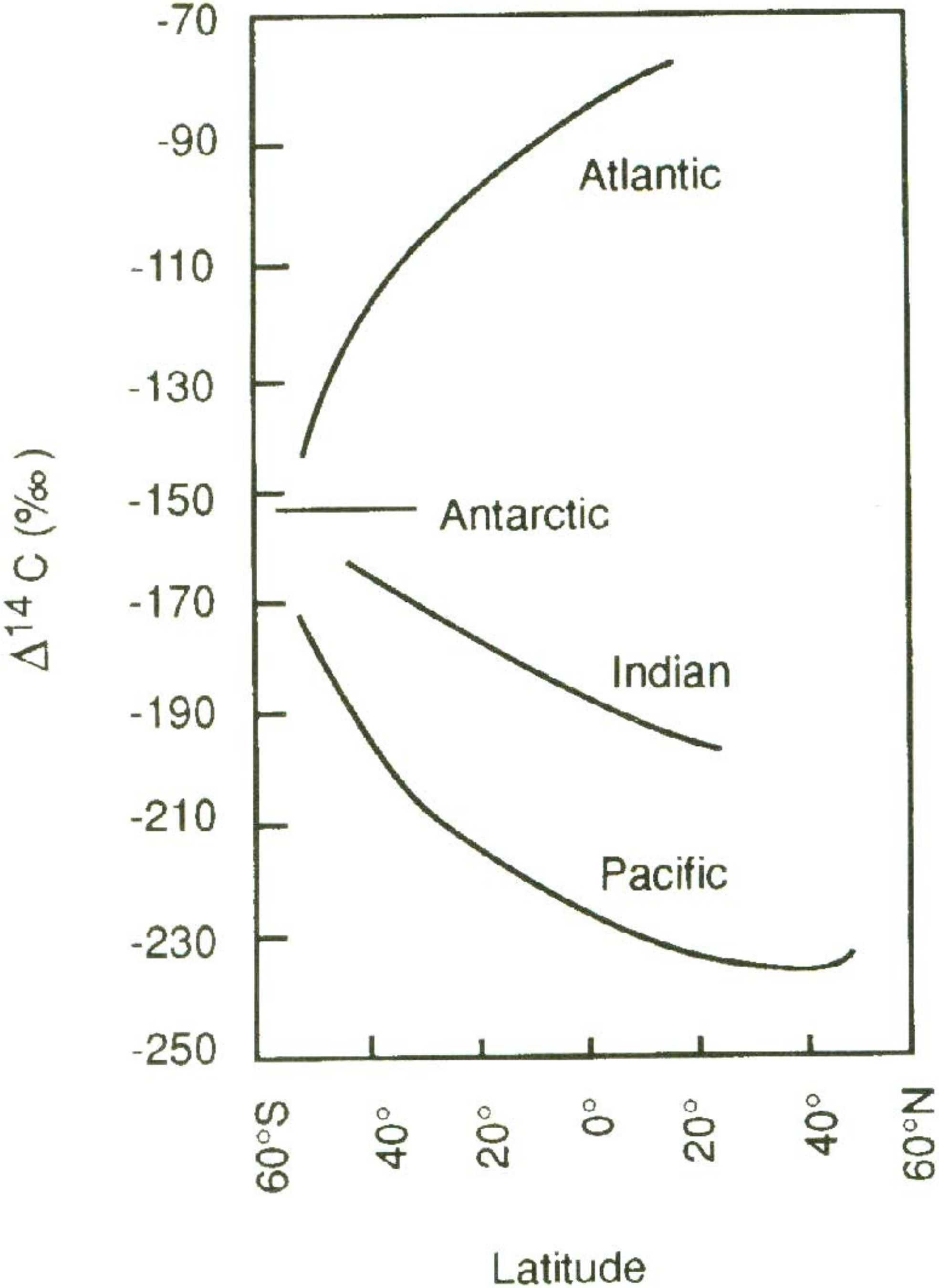

60
30
0
30
60
90
120
150
180
150
120
90
60
30
0
30
60
Gulf Stream
Warm less-salty shallow current
Cold salty deep current



60°
Greenland
40°
20°
0°
8°
0°
Iceland
60°
60°
8°
NORTH
AMERICA
3.5°
Warm salty surface water
50°
50°
EUROPE
40°
NORTH ATLANTIC
OCEAN
40°
Upper NADW
Lower NADW
30°
30°
AFRICA
60°
40°
AABW
20°



Density (g/cm³)
1.024
1.026
1.028
Temperature (°C)
0°
5°
10°
15°
Salinity (°/∞)
32
33
34
35
0
500
1000
1500
2000
2500
3000
3500
4000
Pycnocline
Thermocline
Halocline
Surface zone
Deep zone
A.
B.
C.



Lower delta^{14}C indicates lower relative rate of mixing

Nutrient Cycling in Aquatic Ecosystems-II: the Oceans

The Composition of Seawater

Key points:

1. The bulk of the ions in the oceans is from a few major kinds, but virtually all naturally existing elements are found in the oceans.

2. Although the salinity (total salt content) of ocean waters does vary because of differential heating, evaporation, and sources of input, the relative proportion of ion species tends to remain relatively constant.

3. The mean residence time of each ion tends to negatively correlated to its concentration in river water inputs, and positively correlated to its pool size in the oceans.

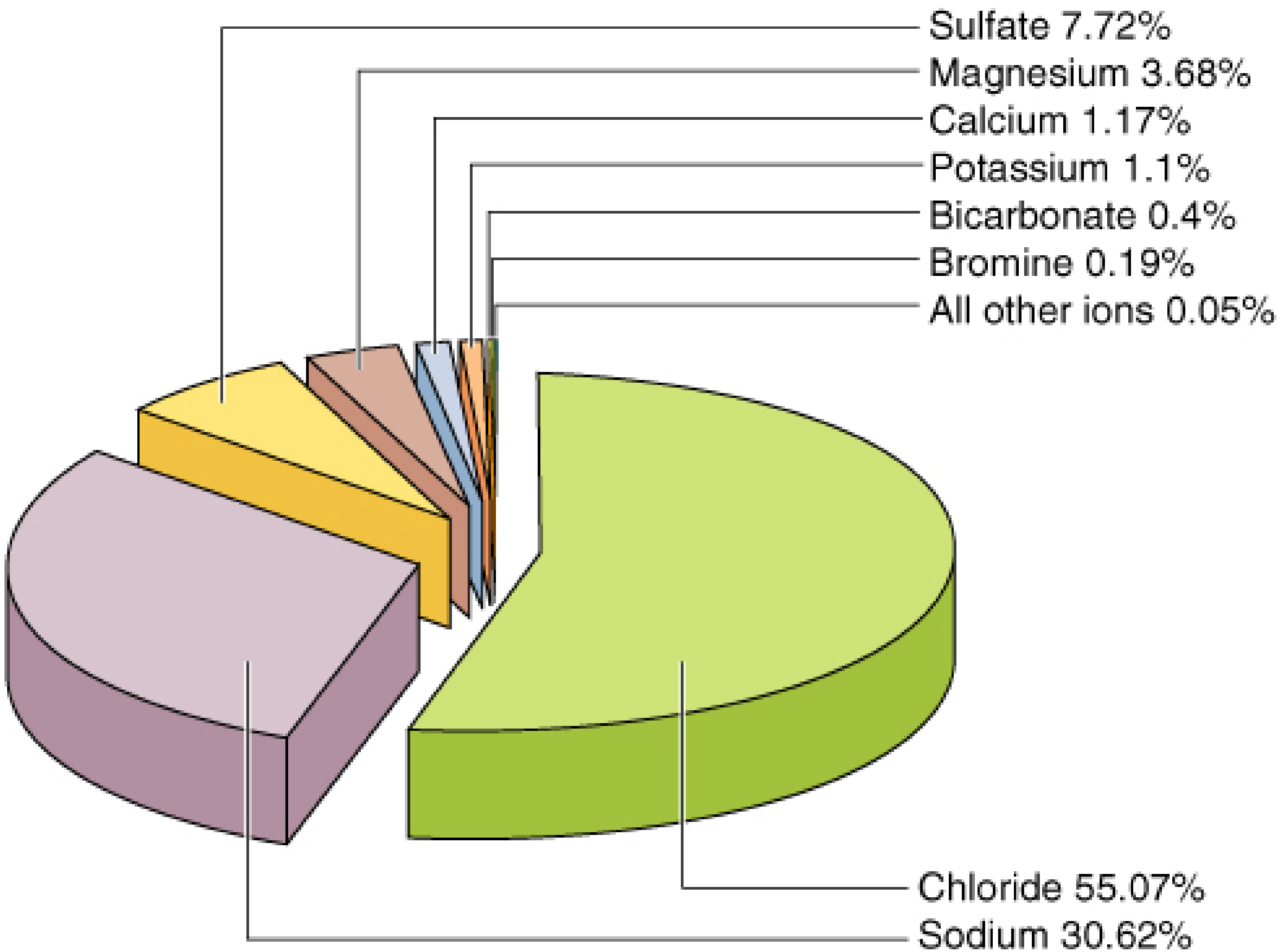

Sulfate 7.72%
Magnesium 3.68%
Calcium 1.17%
Potassium 1.1%
Bicarbonate 0.4%
Bromine 0.19%
All other ions 0.05%
Chloride 55.07%
Sodium 30.62%

TABLE 9.1 Major Ion Composition of Seawater, Showing Relationships to Total Chloride and Mean Residence Times for the Elements with Respect to Riverwater Inputs

Constituent	Concentration in seawater[a] (g kg^{-1})	Chlorinity ratio[a] (g kg^{-1})	Concentration in river water[b] (mg/kg)	Mean residence time[b] (10^6 yr)
Sodium	10.78145	0.556492	5.15	75
Magnesium	1.28372	0.066260	3.35	14
Calcium	0.41208	0.021270	13.4	1.1
Potassium	0.39910	0.020600	1.3	11
Strontium	0.00795	0.000410	0.03	12
Chloride	19.35271	0.998904	5.75	120
Sulfate	2.71235	0.140000	8.25	12
Bicarbonate	0.10481	0.005410	52	0.10
Bromide	0.06728	0.003473	0.02	100
Boron	0.02739	0.001413	0.01	10
Fluoride	0.00130	0.000067	0.10	0.05
Water	964.83496	49.800646		0.034

[a] *Source: Millero et al. (2008).*

[b] *Source: Meybeck (1979) and Holland (1978).*

Nutrient Cycling in Aquatic Ecosystems-II: the Oceans

Net Primary Production

Key Points:

1. All open oceans are oligotrophic, and production is limited by the supply of nutrients either from atmospheric deposition or from deep water.

2. Coastal zone and upwelling areas are more productive because of higher nutrient availability in those areas.

3. Primary production mainly occurs in the surface fixed layer.

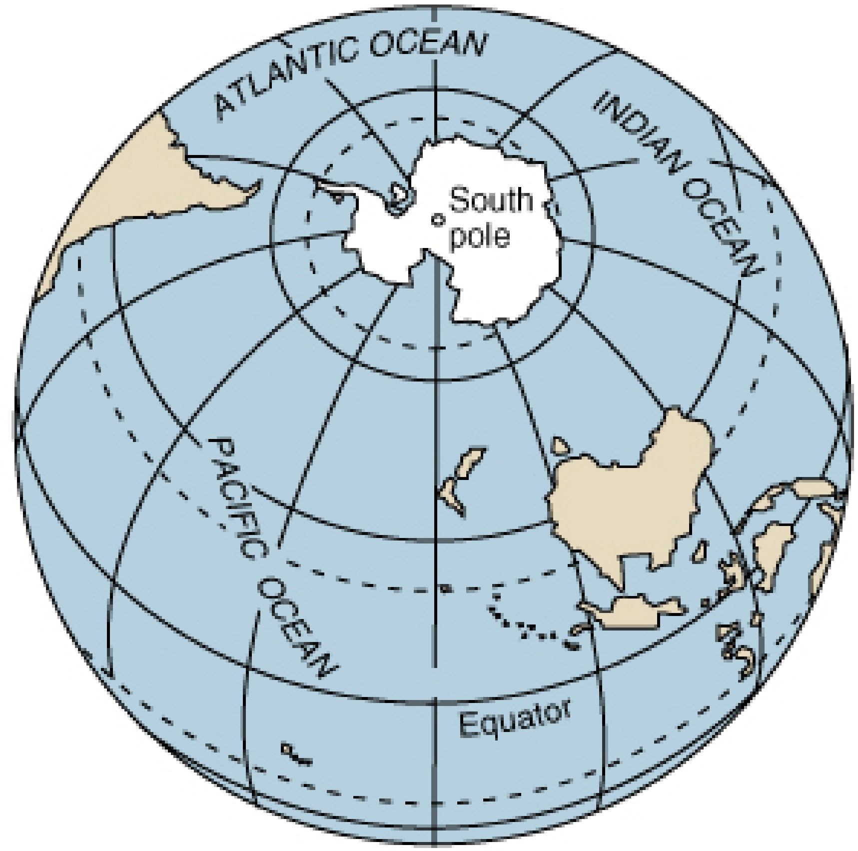
4. The primary producers in oceans are consumed by secondary producers and decomposers in a much faster pace than on land, resulting in higher efficiency of nutrient utilization.

TABLE 9.2 Estimates of Total Marine Primary Productivity and the Proportion That Is New Production

Province	% of ocean	Area ($10^{12}m^2$)	Mean production ($g\ C\ m^{-2}yr^{-1}$)	Total global production ($10^{15}g\ C\ yr^{-1}$)	New production[a] ($g\ C\ m^{-2}yr^{-1}$)	Global new production ($10^{15}g\ C\ yr^{-1}$)
Open ocean	90	326	130	42	18	5.9
Coastal zone	9.9	36	250	9.0	42	1.5
Upwelling area	0.1	0.36	420	0.15	85	0.03
Total		**362**		**51**		**7.4**

[a] *New productivity defined as C flux at 100 m.*
Source: From Knauer (1993). Used with permission of Springer-Verlag.

Land hemisphere
46.4% Land
53.6% Water



Water hemisphere
11.6% Land
88.4% Water

Nutrient Cycling in Aquatic Ecosystems-II: the Oceans

Biogenic Carbonates

Key Points:

1. Marine organisms play a major role in the formation and de-formation of carbonate precipitation.

2. Besides biological activities, bicarbonate concentration and supply of base cations are the two important controlling factors in carbonate precipitation.

3. Marine carbonate dynamics provide the most important control on atmospheric CO_2 concentration.

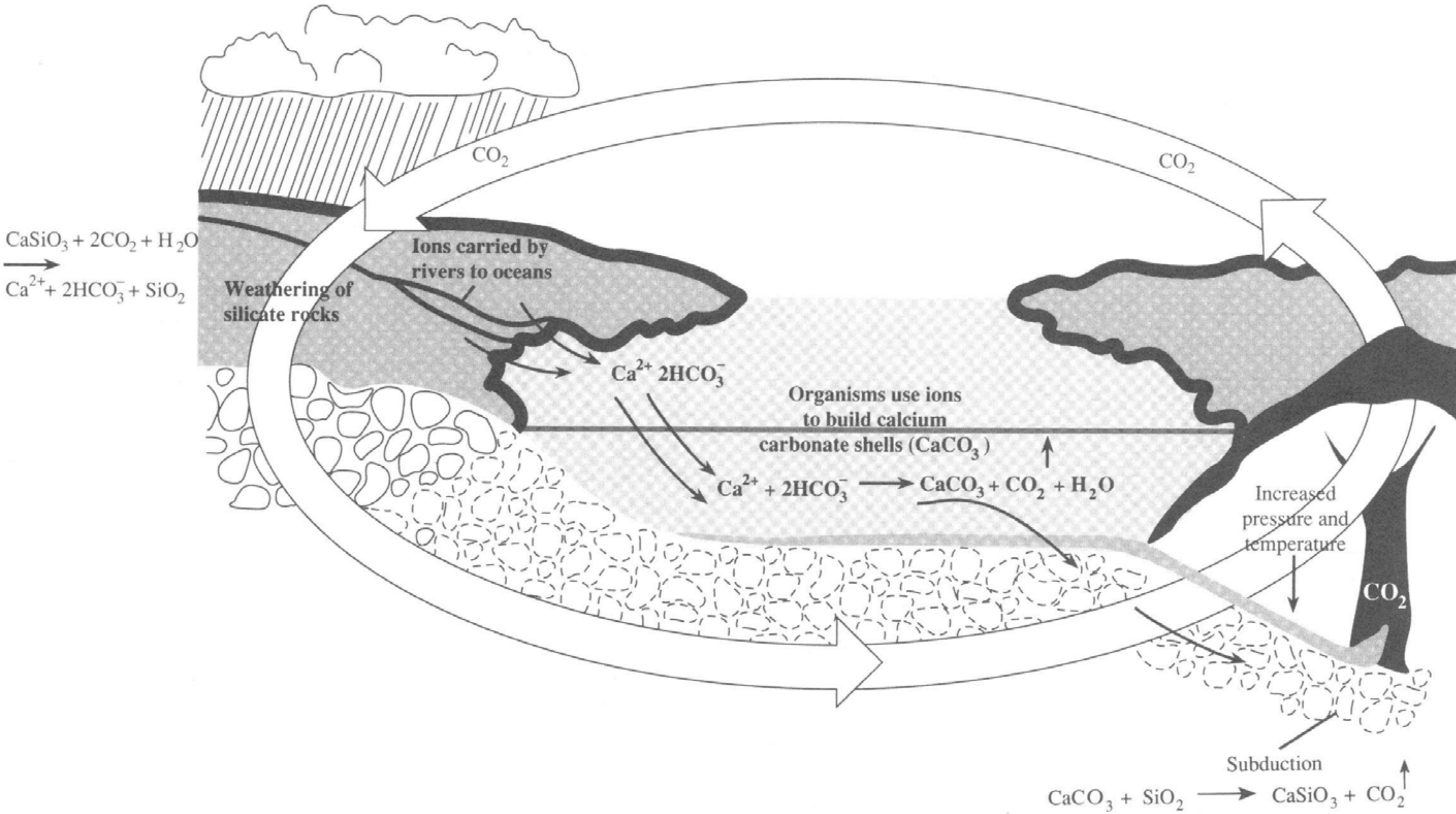


Figure 1.4 The interaction between the carbonate and the silicate cycles at the surface of the Earth. Long-term control of atmospheric CO_2 is achieved by dissolution of CO_2 in surface waters and its participation in the weathering of rocks. This carbon is carried to the sea as bicarbonate (HCO_3^-), and it is eventually buried as part of carbonate sediments in the oceanic crust. CO_2 is released back to the atmosphere when these rocks undergo metamorphism at high temperature and pressures deep in the Earth. Modified from Kasting et al. (1988).

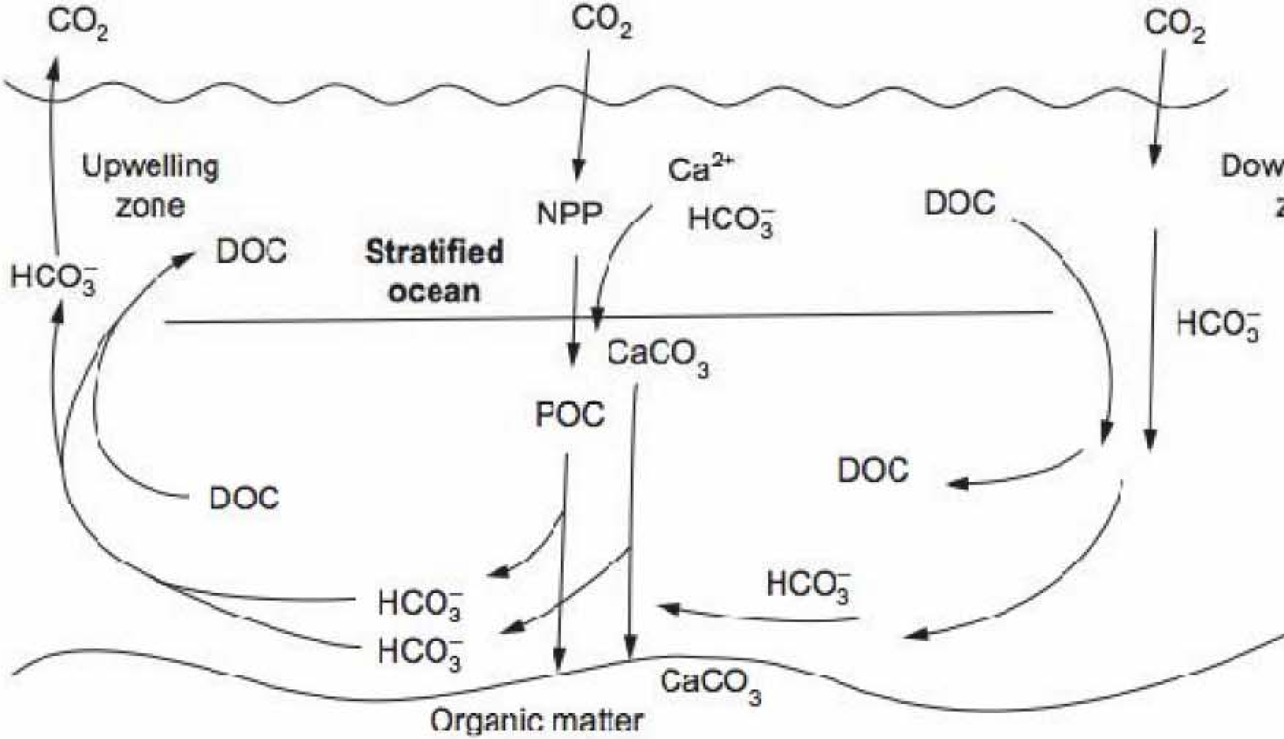


FIGURE 9.16 The marine biotic pump, showing the formation of organic matter (POC) and carbonate keletons in the surface ocean and their downward transport and the downwelling of DOC and bicarbonate to the deep ocean.

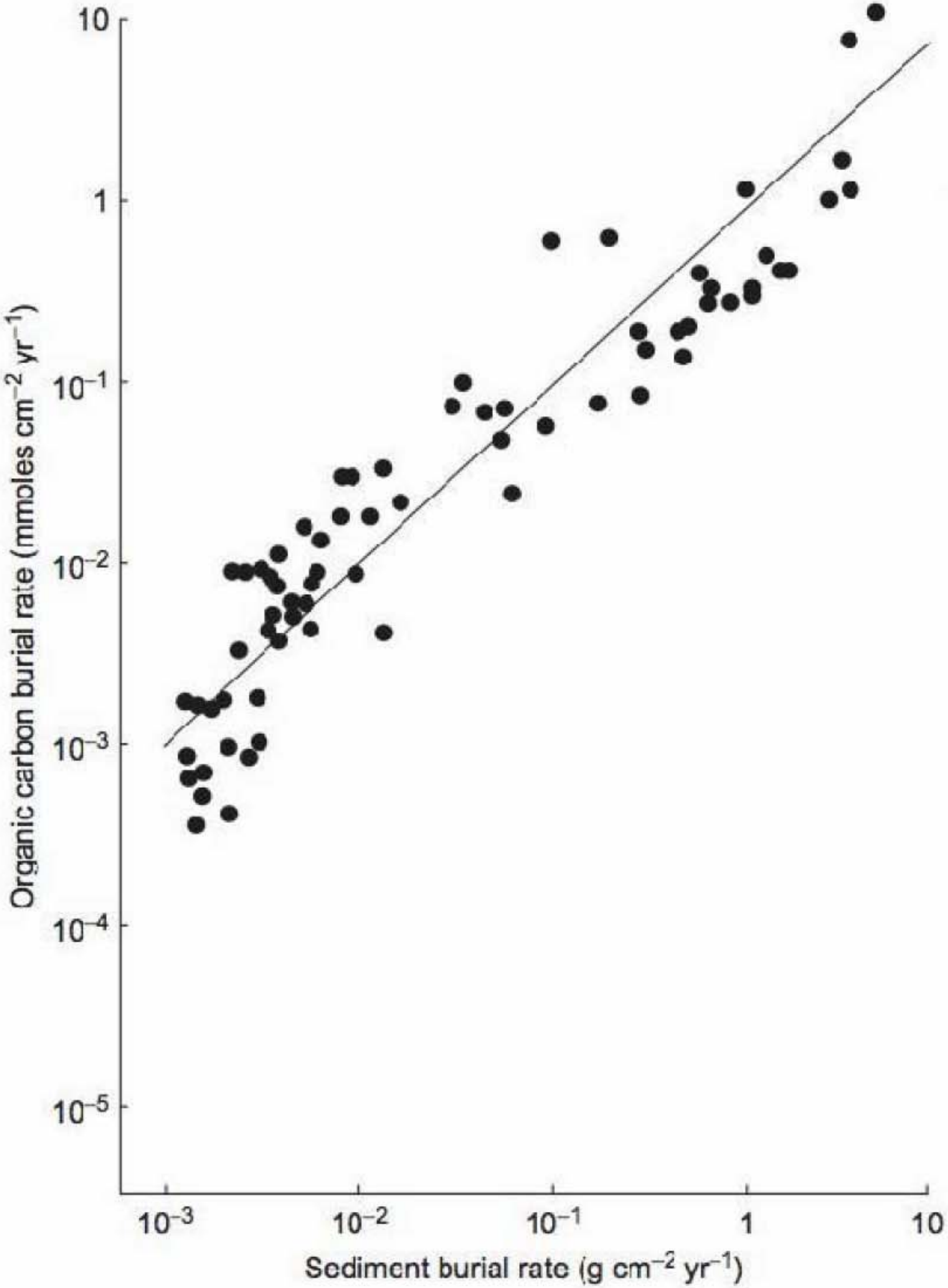


FIGURE 9.11 Burial of organic carbon in marine sediments as a function of the overall rate of sedimentation. *Source: From Berner and Canfield (1989). Reprinted by permission of* American Journal of Science.

Nutrient Cycling in Aquatic Ecosystems-II: the Oceans

Nutrient Cycling in the Ocean

Some Key Points:

1. Although majority of the nutrients for primary production is supplied by internal cycling, outside nutrient inputs may alter marine biogeochemistry.

2. Oceans exert crucial controls on the global climate by, for example, El Nino, DMS, etc.

3. A question: shall we fertilize the oceans more?

Table 9.3 Calculation of the Sources of Nutrients to Sustain a Global Net Primary Production of 50×10^{15} g C/yr in the Surface Waters of the Oceans[a]

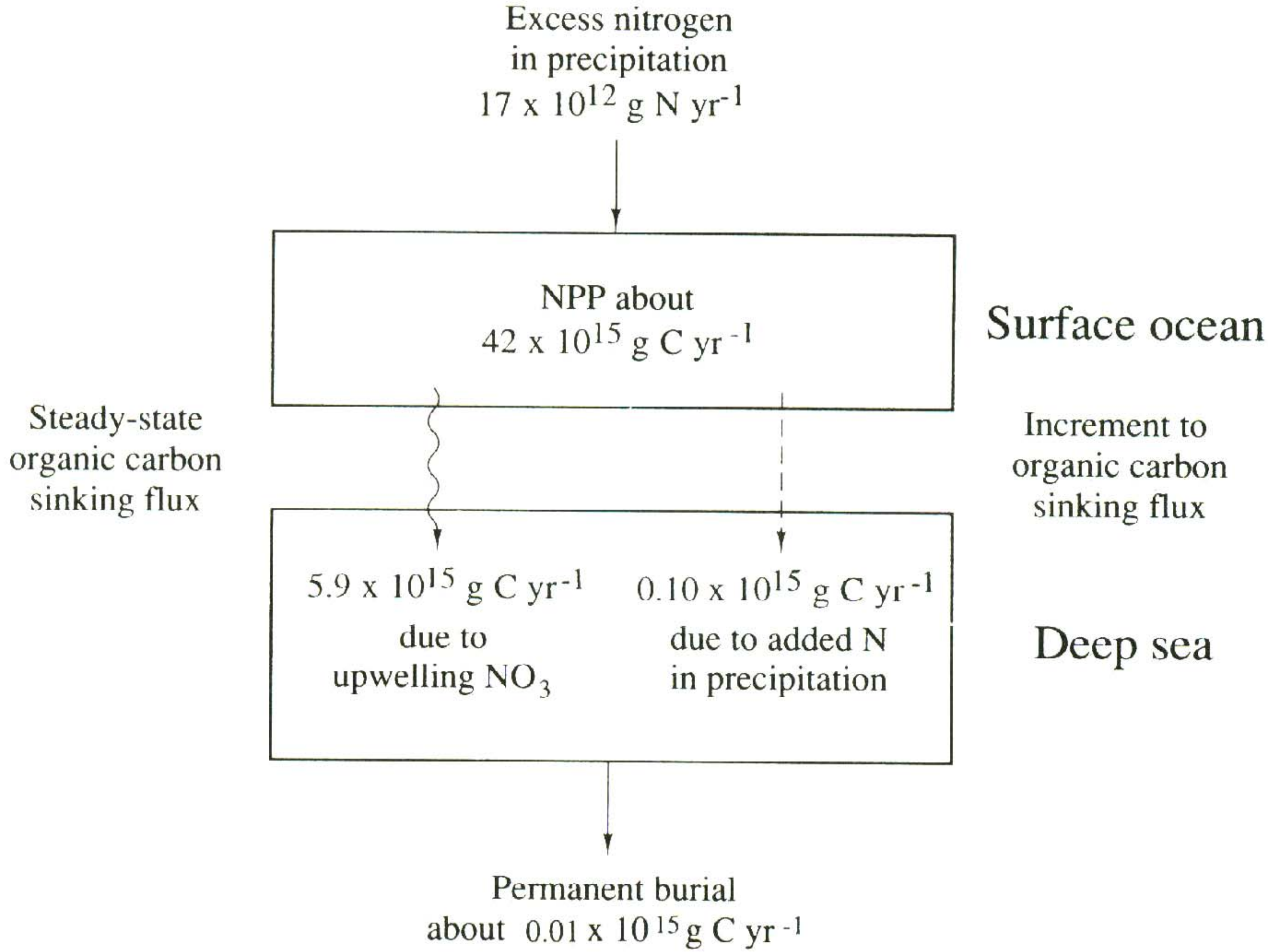
Flux	Carbon (10^{12} g)	Nitrogen (10^{12} g)	Phosphorus (10^{12} g)
Net primary production[b]	50,000	8838	1219
Amounts supplied			
By rivers[c]		36	2
By atmosphere[d]		45	1
By upwelling		1189	106
Recycling (by difference)		7568	1110

[a] Based on an approach developed by Peterson (1981).

[b] Assuming a Redfield atom ratio of 106:16:1.

[c] Meybeck (1982).

[d] Figure 9.16.



Estimated increase in the sedimentation of organic carbon that might be caused by human additions of nitrogen to the world's oceans by precipitation. Updated from an original conception by Peterson and Melillo (1985).

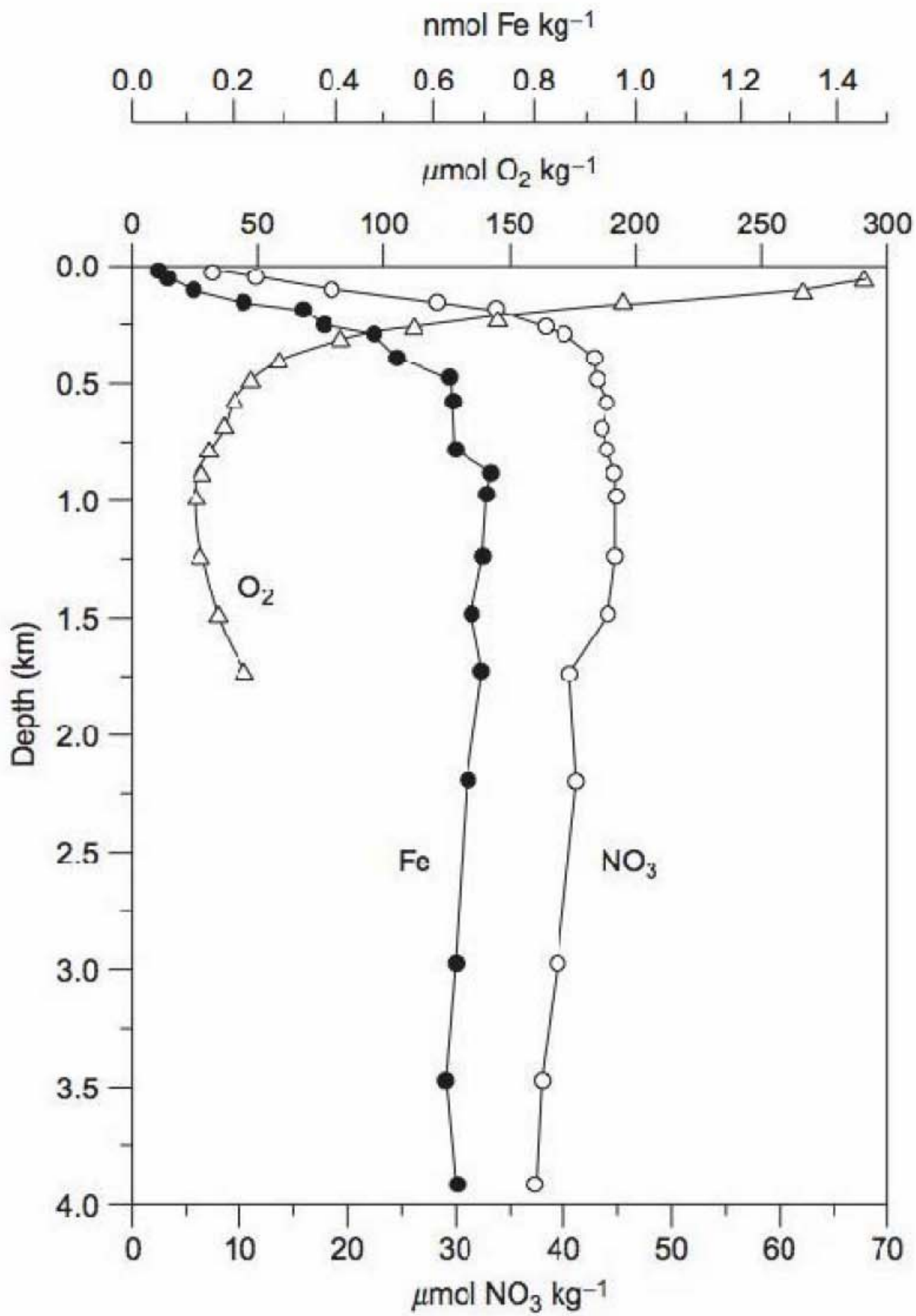
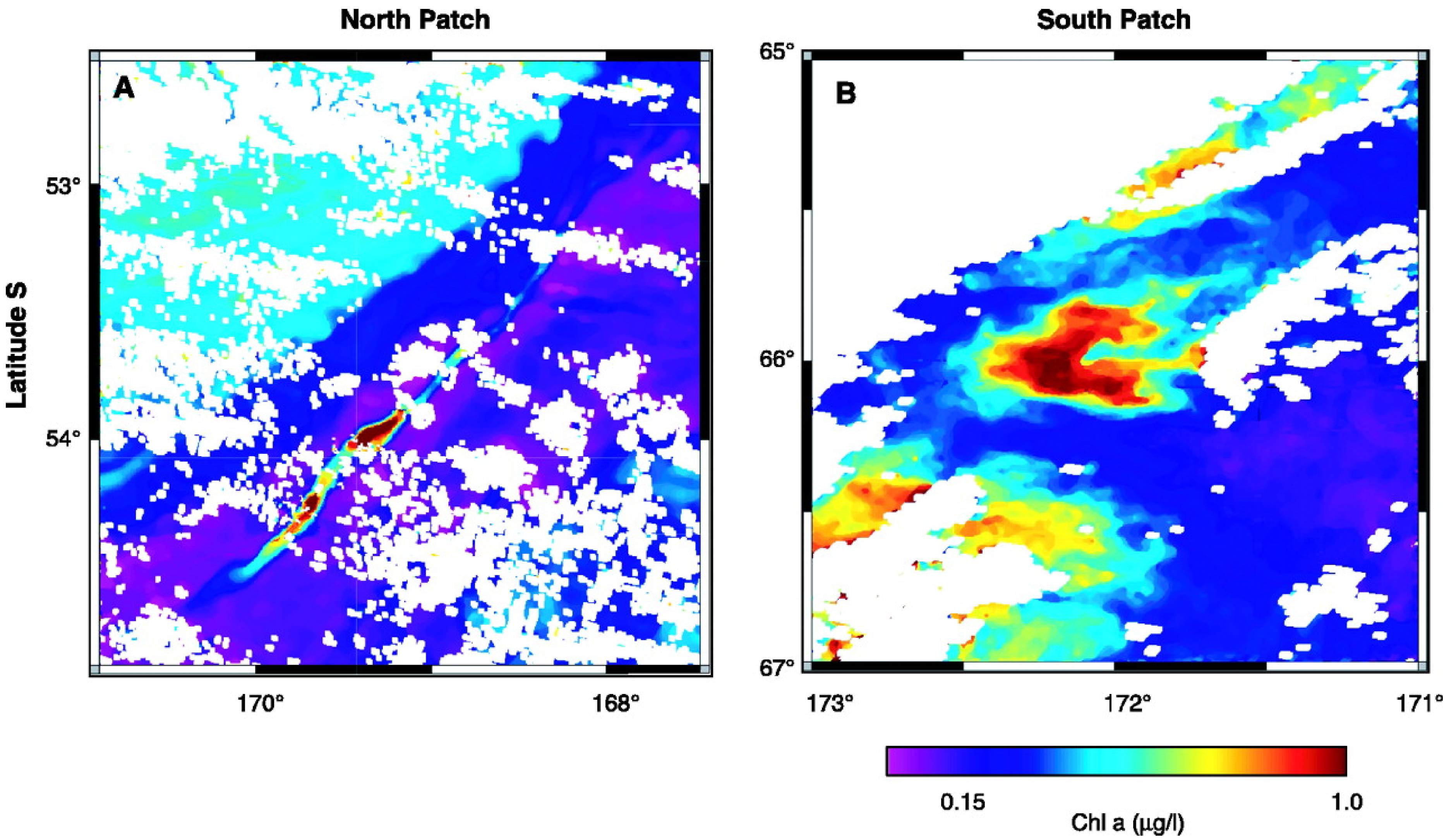


FIGURE 9.26 Vertical distribution of Fe, NO_3, and O_2 in the central North Pacific Ocean. *Source: From Martin et al. (1989).*



A question: shall we fertilize the oceans more?

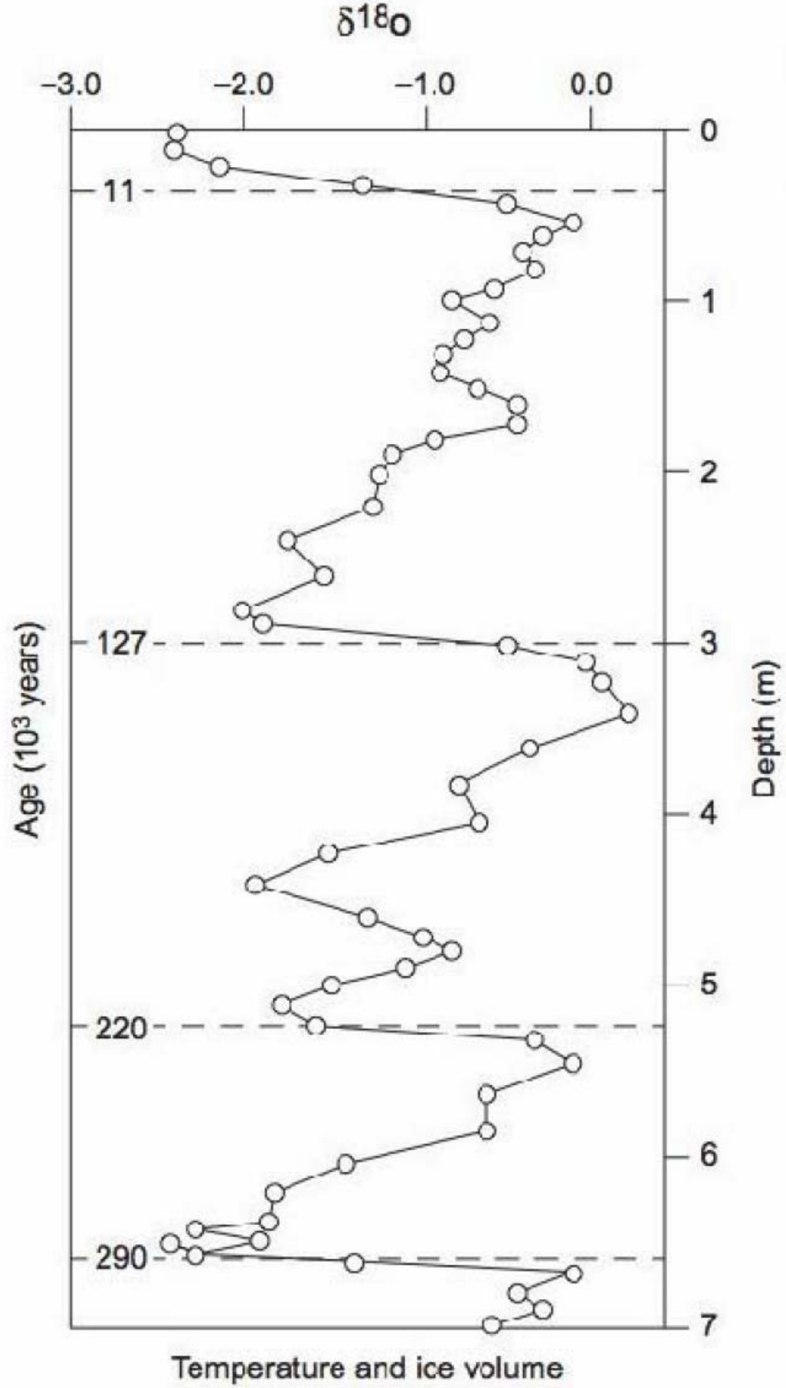


FIGURE 9.31 Changes in the $\delta^{18}O$ in sedimentary carbonates of the Caribbean Sea during 300,000 years. Enrichment of $\delta^{18}O$ during the last glacial epoch (20,000 years ago) is associated with lower sea levels and a greater proportion of $H_2{}^{18}O$ in seawater. *Source: From Broecker (1973).*