Factors influencing the Chemical- biological pump in the oceans

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The Hebrew University of Jerusalem

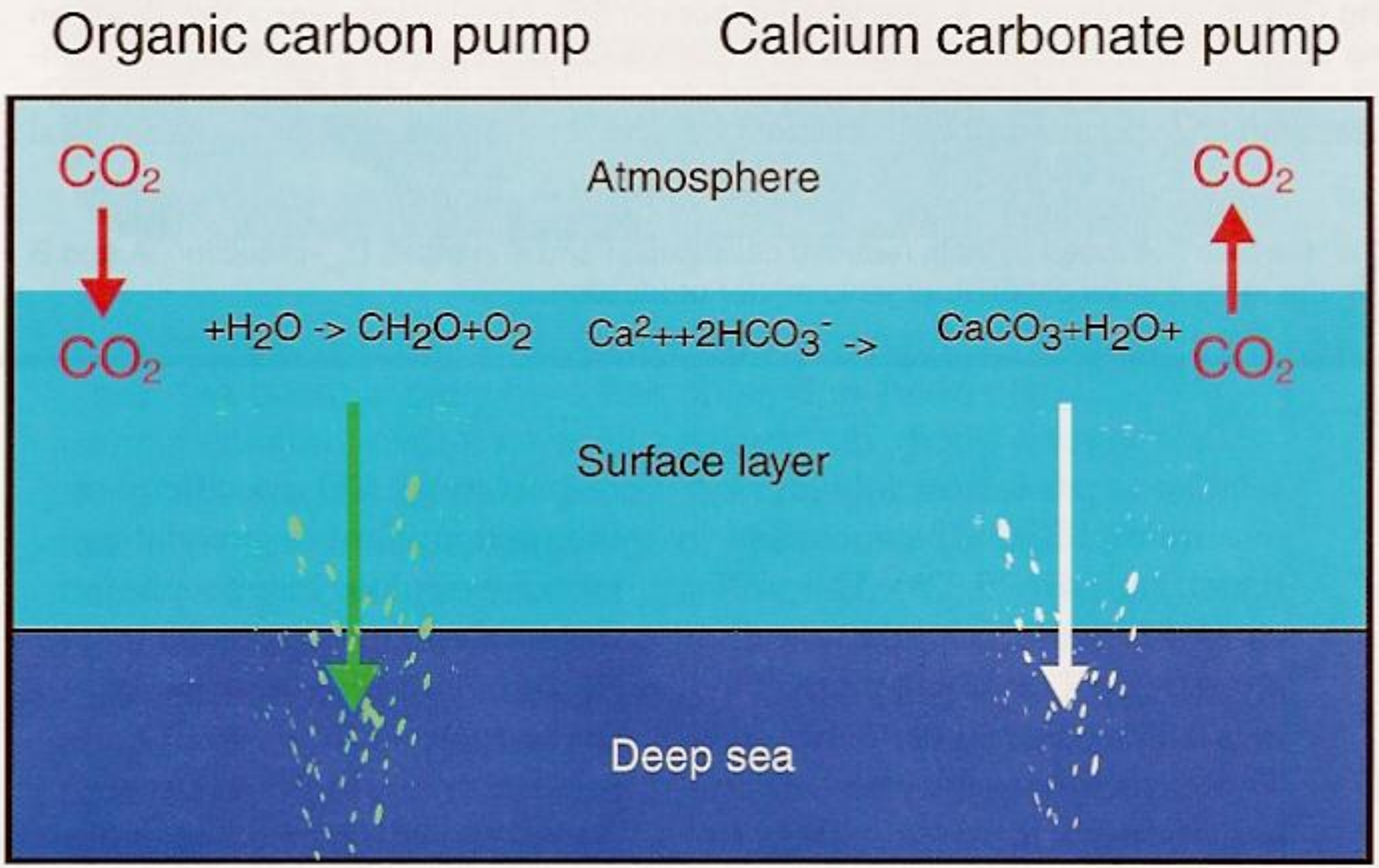


Figure 2. The biological carbon pumps: Photosynthetic carbon fixation in the surface layer of the flux of organic matter to depth, termed organic carbon pump, generates a CO_2 sink in the ocean. In contrast, calcium carbonate production and its transport to depth, referred to as the calcium carbonate pump, releases CO_2 in the surface layer. The relative strengths of these two processes largely determine the biologically-mediated ocean atmosphere CO_2 exchange.

Definitions

- Productivity of an ecological unit is its rate of biomass accumulation. Many units (individuals or communities) are heterotrophic hence they are secondary (or tertiary) producers.
-
- Primary production: the rate of production of organic matter by autotrophic organisms. i.e. organisms that using external energy can **produce organic matter from inorganic compounds**. Most primary producers are photosynthetic.

- Primary production in the ocean is abundant in the photic zone: rate of photosynthesis of planktonic or benthic primary producers (algae, microbes and plants).

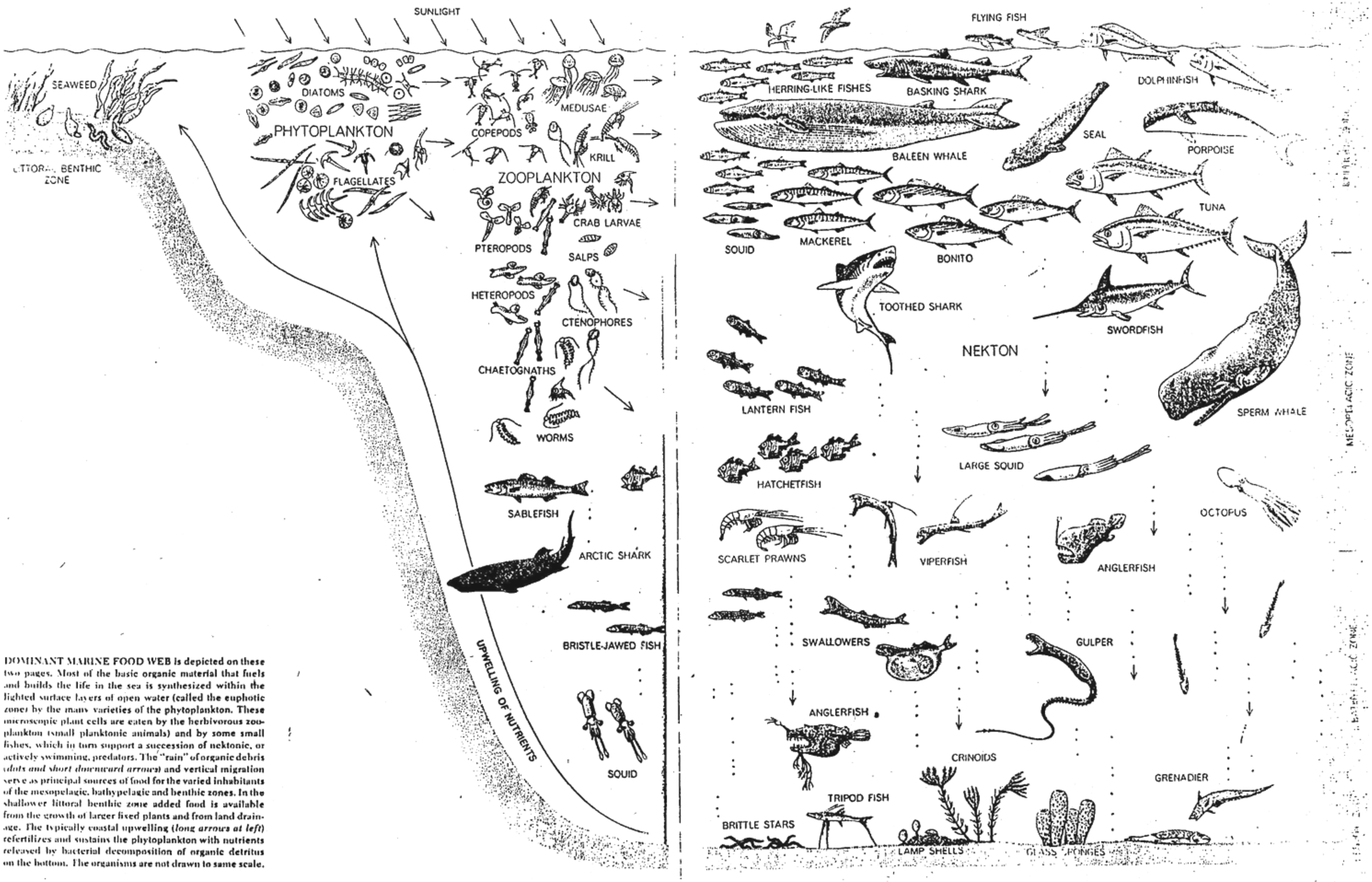
- Primary production in chemosynthetic systems occurs usually on the ocean floor at the boundary of oxic and anoxic conditions

PHOTOSYNTHESIS

$$6CO_2 + 6H_2O \xrightarrow{} C_6H_{12}O_6 + 6O_2$$

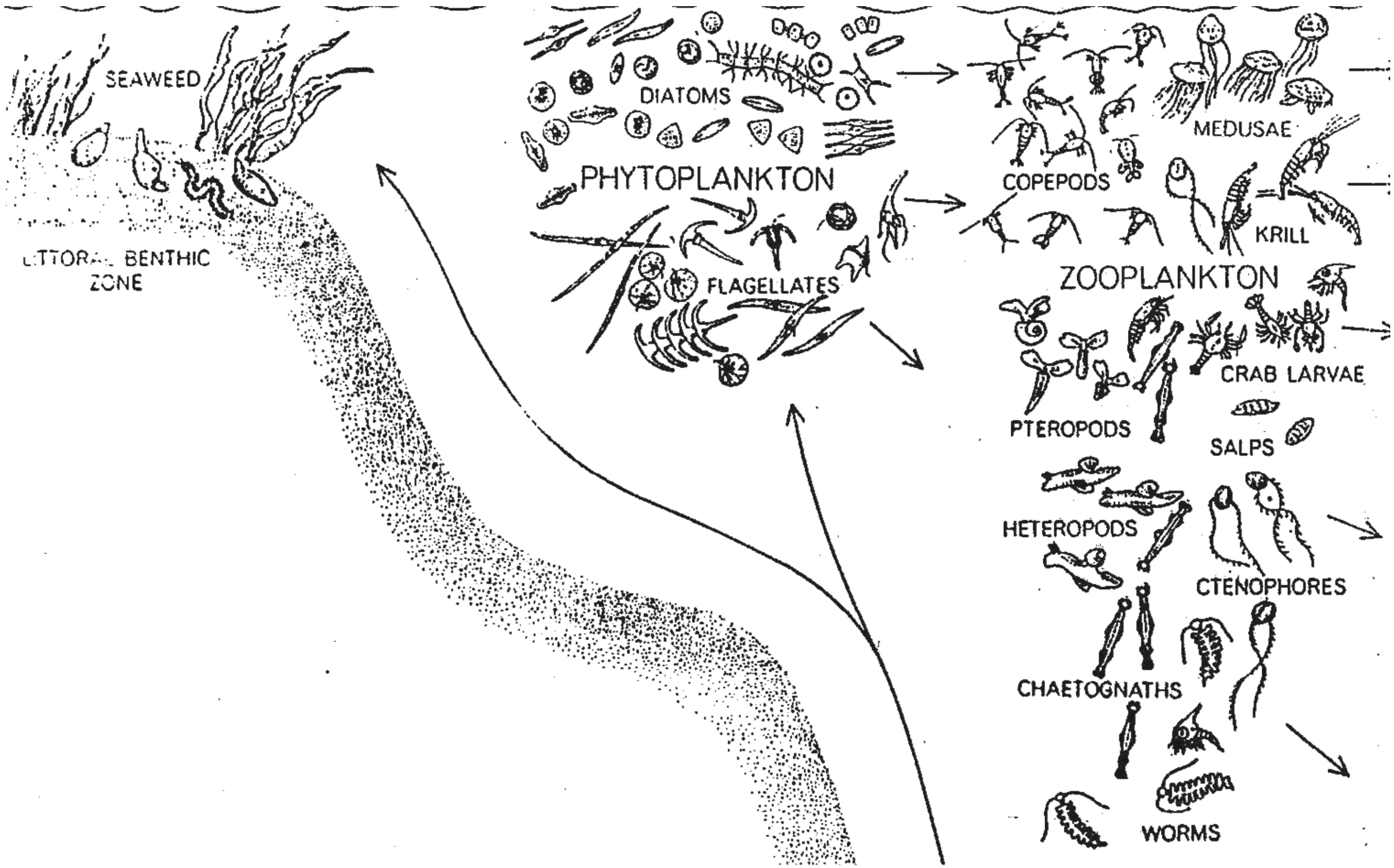
RESPIRATION

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{} 6CO_2 + 6H_2O$$



DOMINANT MARINE FOOD WEB is depicted on these two pages. Most of the basic organic material that fuels and builds the life in the sea is synthesized within the lighted surface layers of open water (called the euphotic zone) by the many varieties of the phytoplankton. These microscopic plant cells are eaten by the herbivorous zooplankton (small planktonic animals) and by some small fishes, which in turn support a succession of nektonic, or actively swimming, predators. The "rain" of organic debris (*dots and short downward arrows*) and vertical migration serve as principal sources of food for the varied inhabitants of the mesopelagic, bathypelagic and benthic zones. In the shallower littoral benthic zone added food is available from the growth of larger fixed plants and from land drainage. The typically coastal upwelling (*long arrows at left*) refertilizes and sustains the phytoplankton with nutrients released by bacterial decomposition of organic detritus on the bottom. The organisms are not drawn to same scale.

Primary and secondary producers (Phytoplankton, Zooplankton and microbes)



MARINE MODES OF LIFE

NEKTON

PLANKTON

BENTHOS

FISH

WHALE

TURTLE

SQUID

ZOOPLANKTON

PHYTOPLANKTON

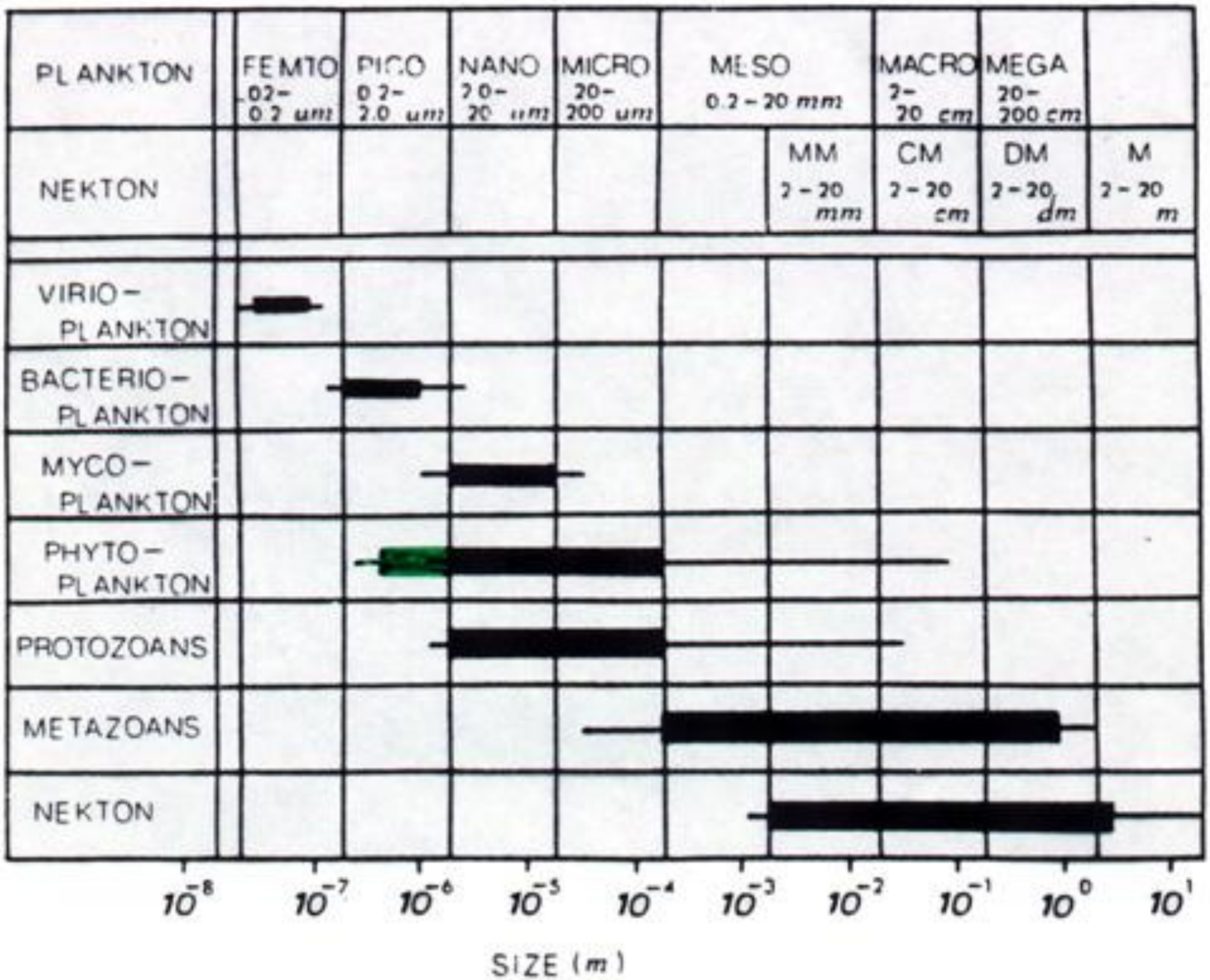
MACRO	MICRO	NANO	PICO
>2000 μM	2000-64 μM	64-2 μM	< 2 μM

PSEUDOPLANKTON

MEROPLANKTON

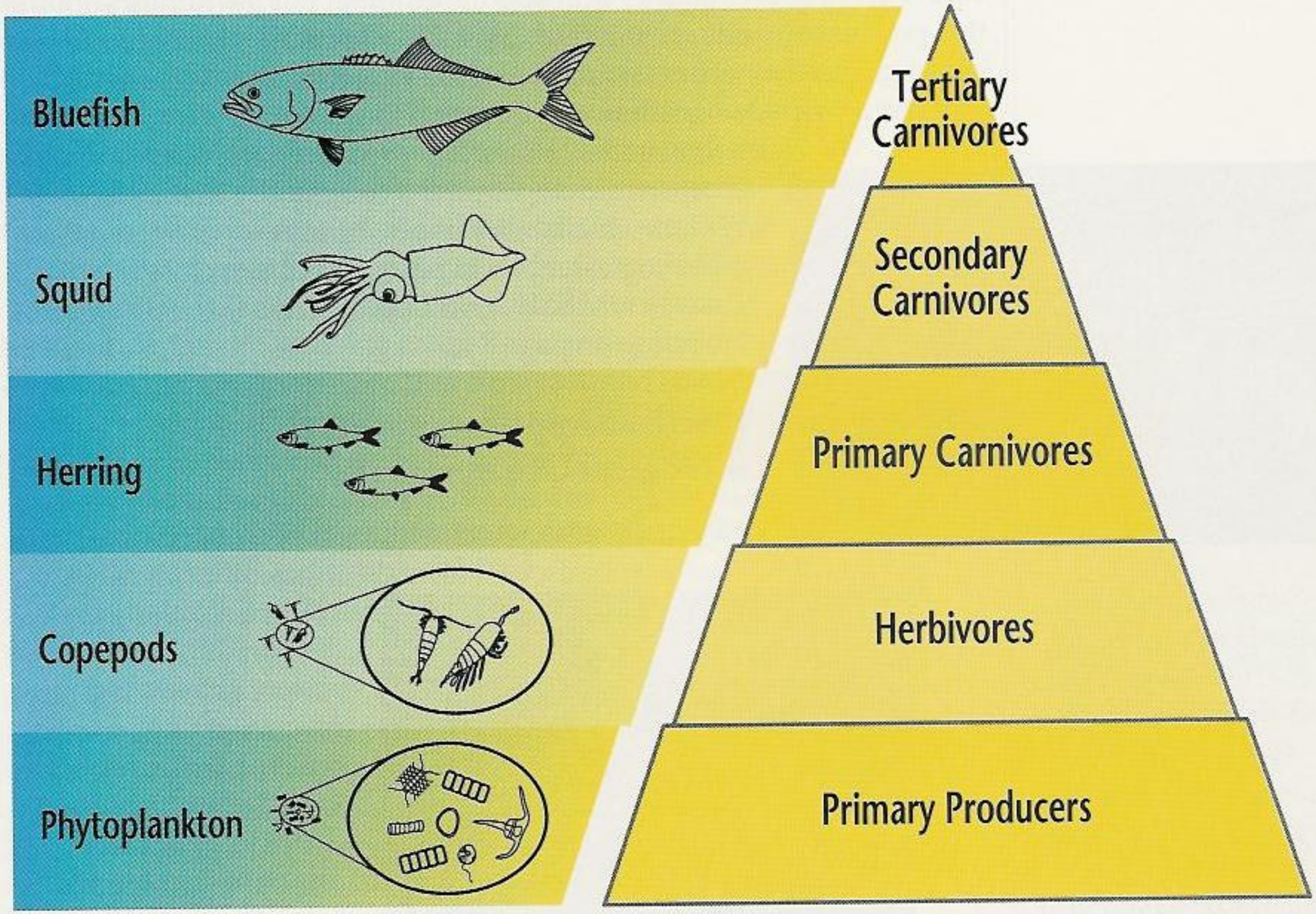
ICHTIOPLANKTON

DEMERSAL PLANKTON



PLANKTON
FEMTO .02– 0.2 um
PICO 0.2– 2.0 um
NANO 2.0– 20 um
MICRO 20– 200 um
MESO 0.2 – 20 mm
MACRO 2– 20 cm
MEGA 20– 200 cm
NEKTON
MM 2 – 20 mm
CM 2 – 20 cm
DM 2 – 20 dm
M 2 – 20 m
VIRIO-PLANKTON
BACTERIO-PLANKTON
MYCO-PLANKTON
PHYTO-PLANKTON
PROTOZOANS
METAZOANS
NEKTON
10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1}
SIZE (m)

Trophic Relationships in a Simple Food Web

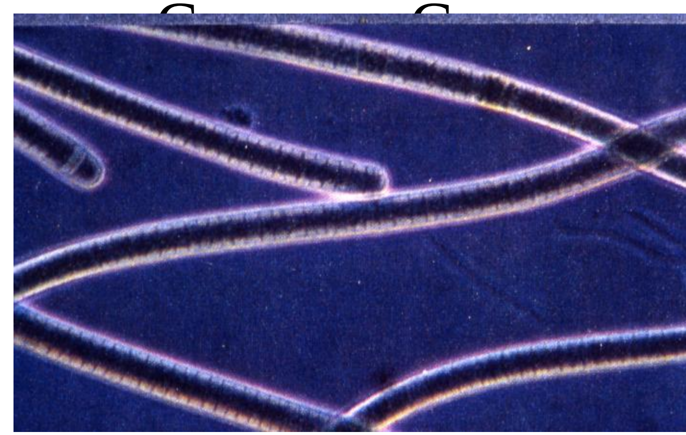


Jayne Doucette/WHOI Graphics

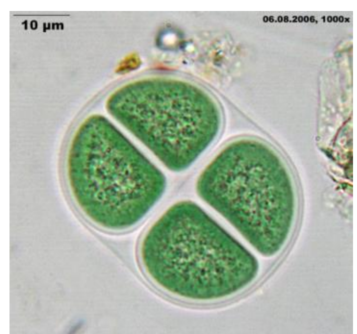
Blue-green Algae (Cyanobacteria)

www.micrographia.com

Aphanizomenon



Oscillatoria

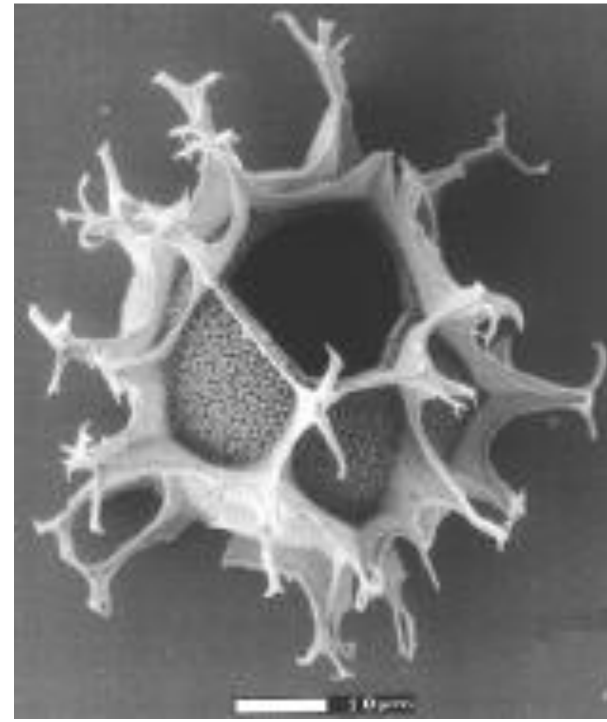


Chroococus

Microcystis

Dinoflagellates - Pyrrhophyta

living



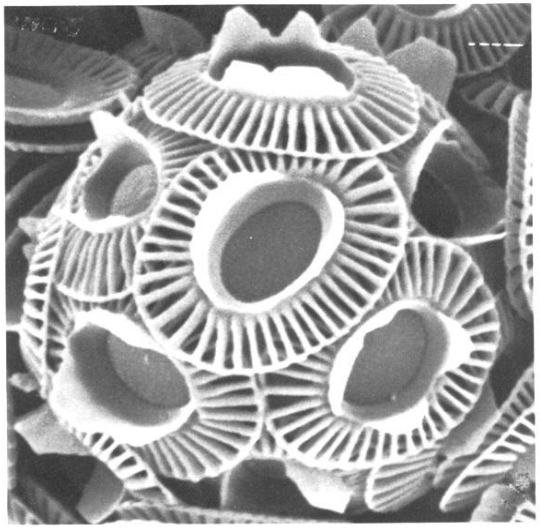
fossil

Diatoms

Diatoms

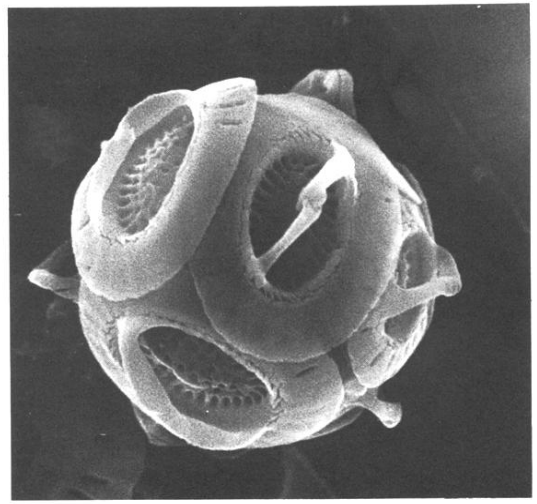
Coccolithophores

S. Nishida



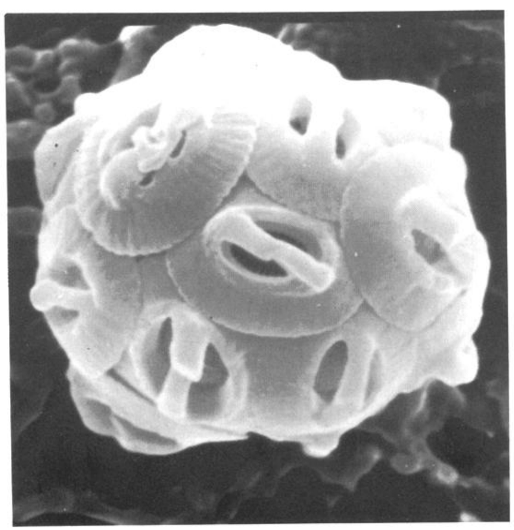
33 *Emiliania huxleyi* var. *corona*
known range: Late Pleistocene - Recent
known distribution: Pac (NE,C); Atl (N)

A. Kleijne



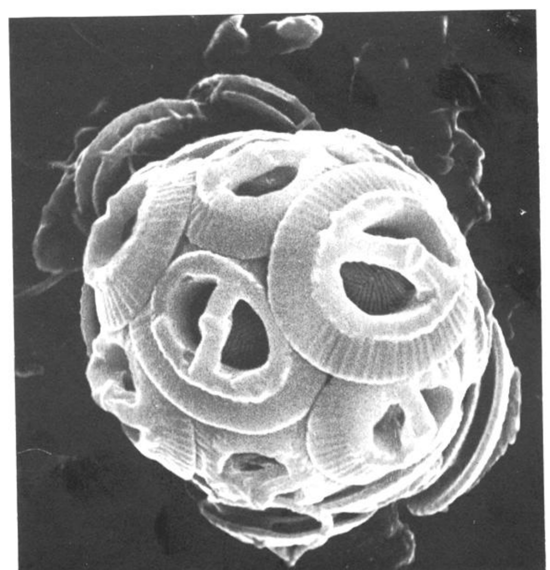
35 *Gephyrocapsa ericsonii*
known range: Pleistocene - Recent
known distribution: Pac (NE,C); Atl (N); Ind; Med; Red

J. Alcober



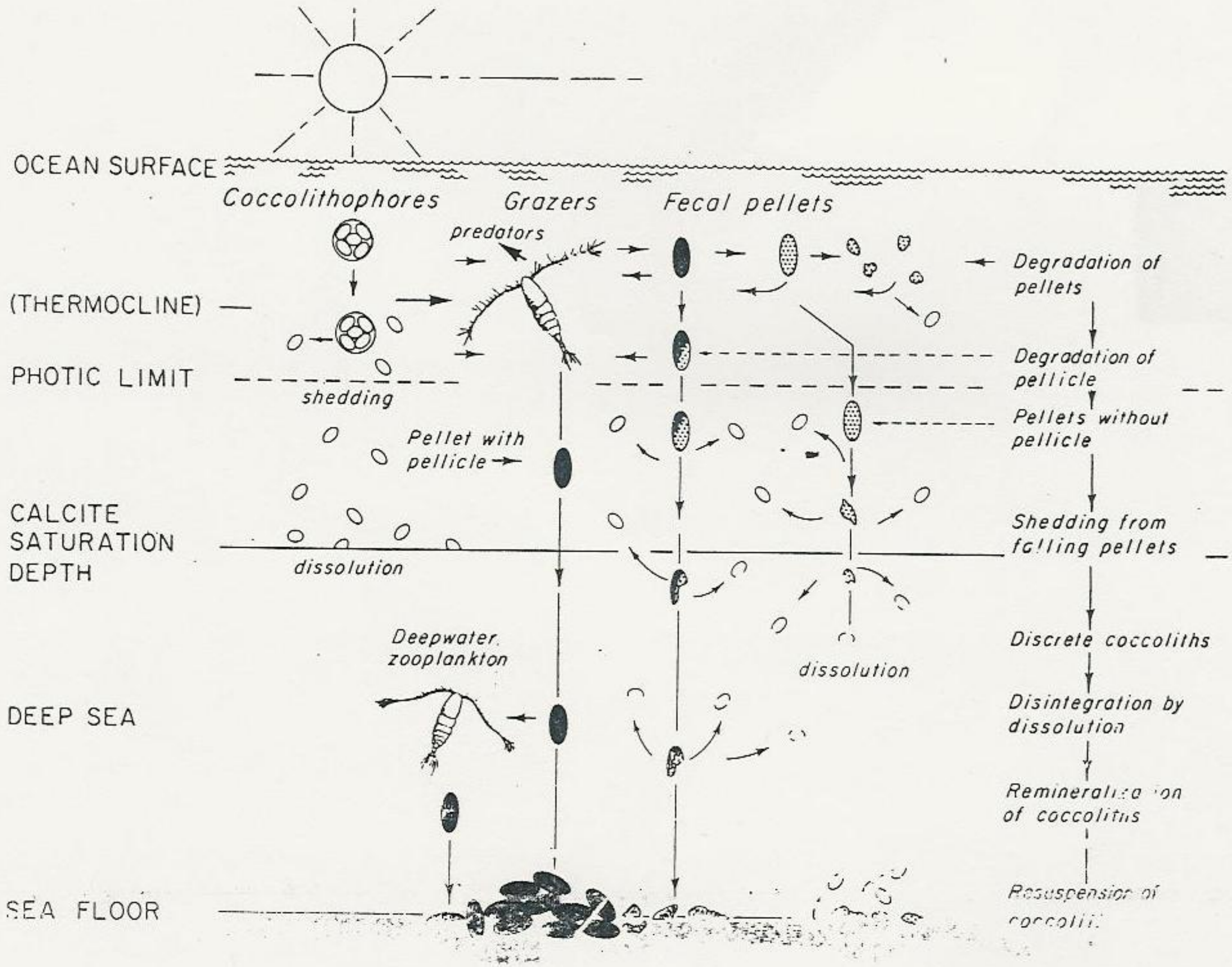
36 *Gephyrocapsa muellerae*
known range: Late Pleistocene - Recent
known distribution: Atl (N); Med

S. Kling



37 *Gephyrocapsa oceanica*
known range: Early Pleistocene - Recent
known distribution: Pac (NW,NE,C,S); Atl (N,C,S); Ind; Med; Car; Red, Wed

Zooplankton Copepods



Sinking rates of coccoliths; in a pellet - 150m day; a discrete coccolith - 0.15 m day

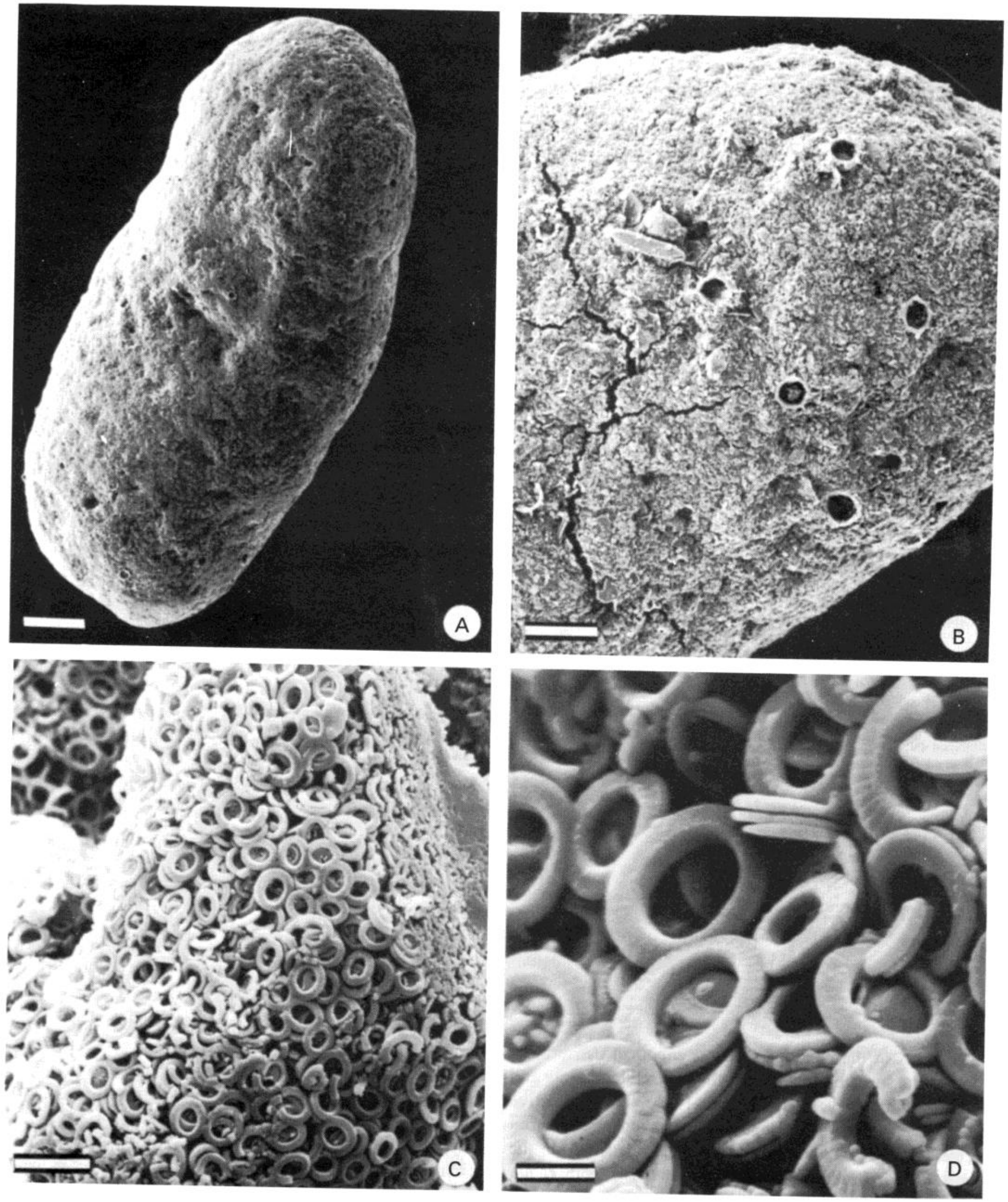
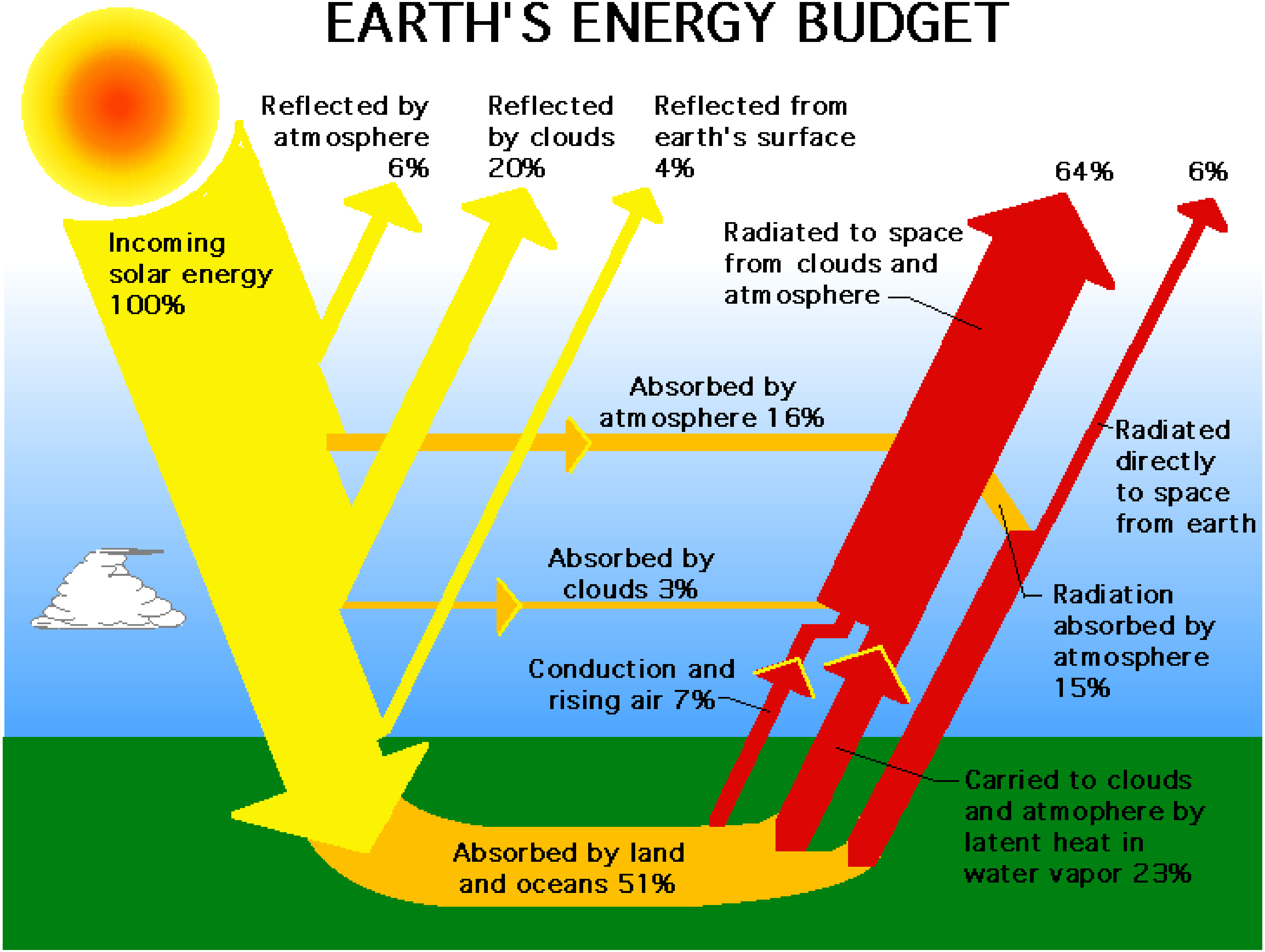


Fig. 2. Fecal Pellets. A. Typical fecal pellet. Scale bar is 100 μm. B. Close-up of the surface of a fecal pellet. Circular objects on the surface are silicoflagellates. Scale bar is 50 μm. C. and D. Close-up of the surface of a fecal pellet composed entirely of the coccolithophore *Umbilicosphaera sibogae* . Scale bars are 10 μm and 2 μm, respectively. SEM photos compliments of C. Pilskaln; C. and D. from Pilskaln (1985).

EARTH'S ENERGY BUDGET



The photic zone:
rate of PS = respiration

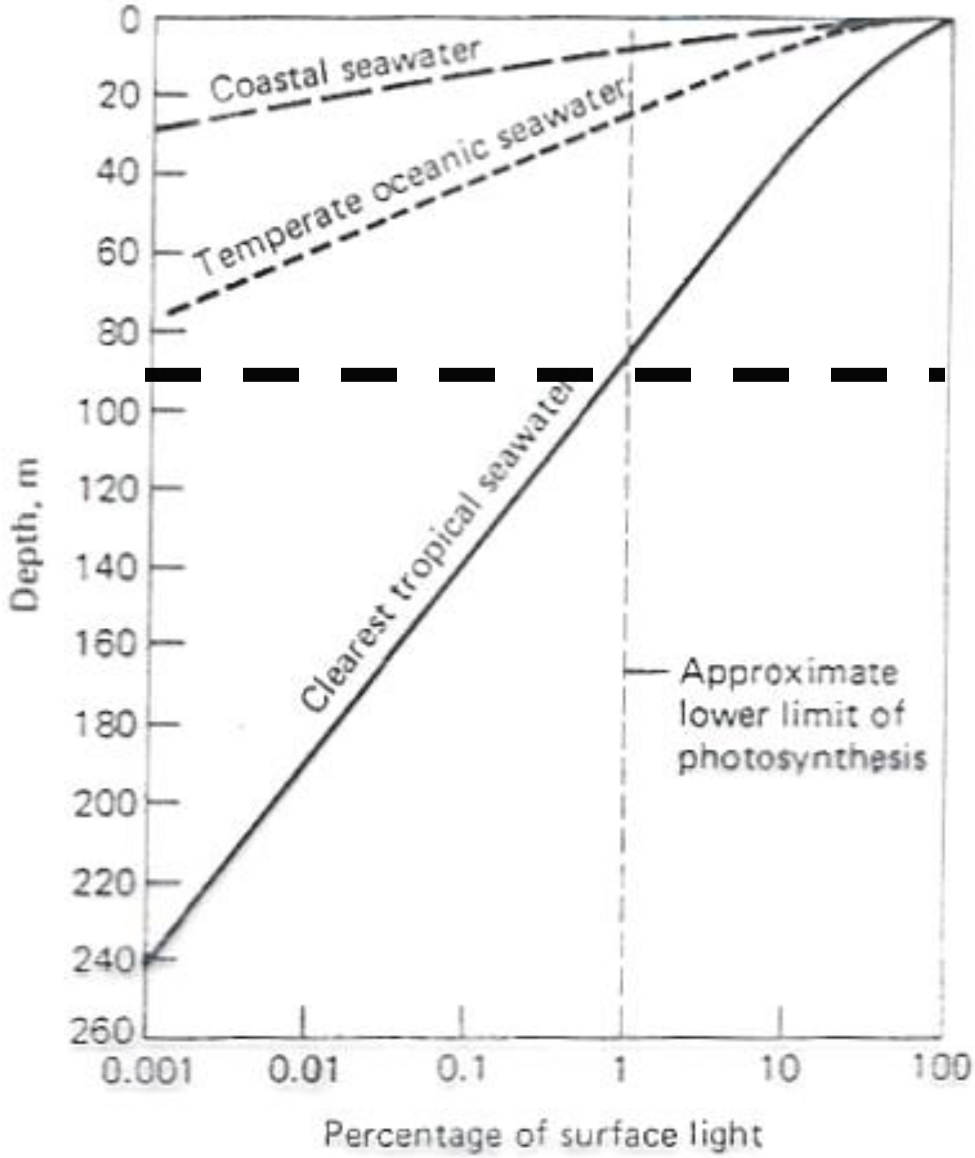


FIGURE 11.9 Penetration of sunlight in various types of seawater. (From Sumich, 1976, adapted from Jerlov, 1956.)

$$P_g = \frac{P_{\max}[I]}{K_I + [I]} \tag{3.2}$$

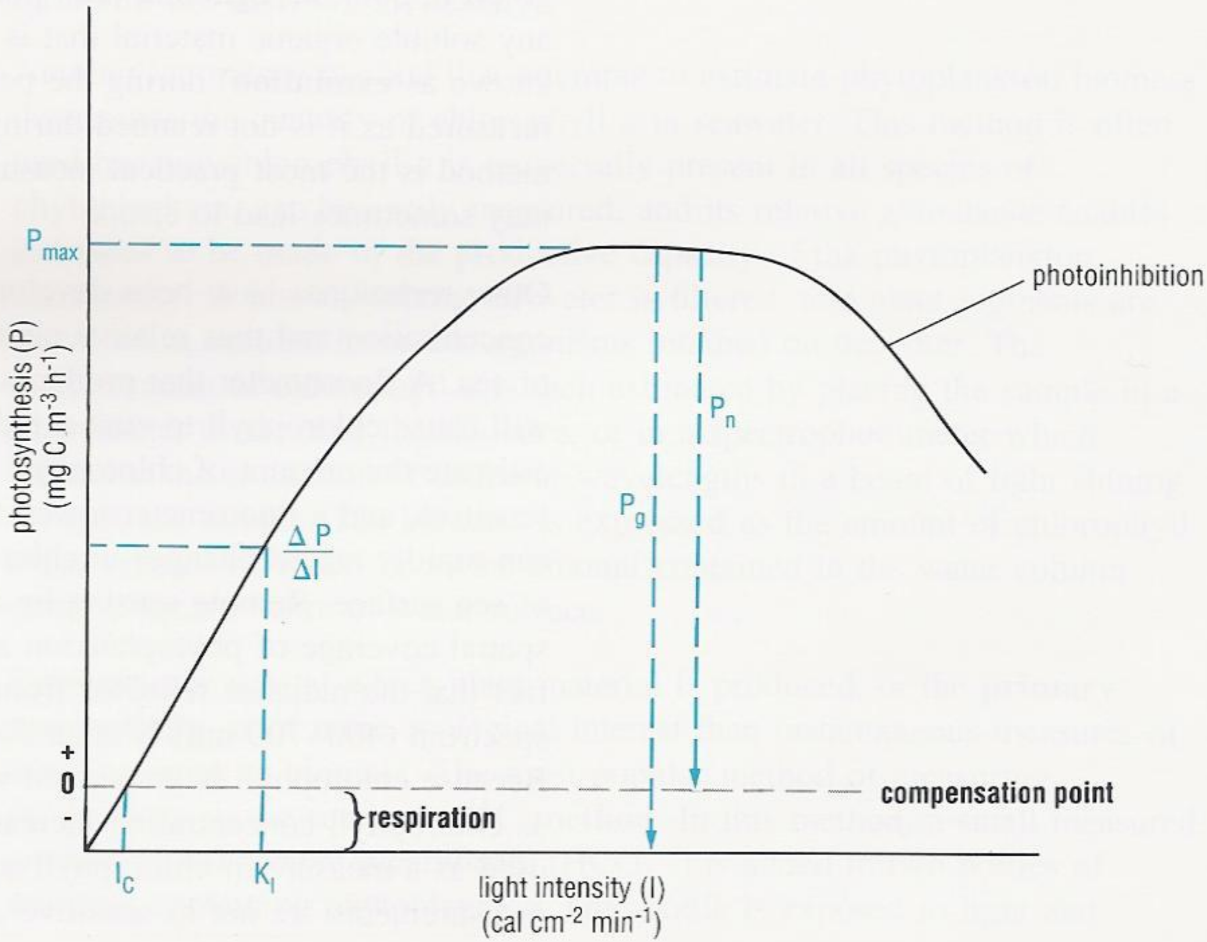


Figure 3.5 The response of photosynthesis (P) to changes in light intensity (I). I_C, compensation light intensity; K_I, the half-saturation constant, or the light intensity when photosynthesis equals 1/2 of maximal photosynthesis (P_{max}); P_g, gross photosynthesis; and P_n, net photosynthesis. Absolute units not shown because all units are species specific.

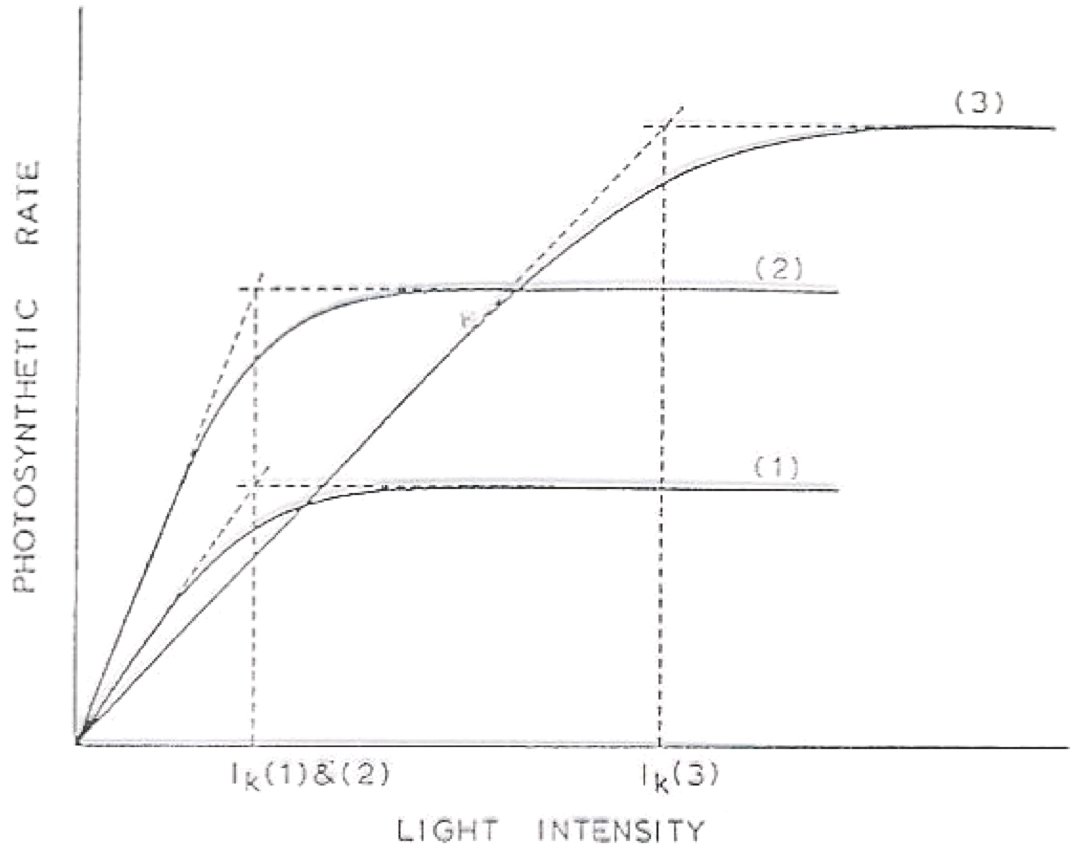


FIG. 27. Three types of P vs I curves. (1) and (2) shade type algae showing similar I_k values but with higher photosynthetic efficiency in (2) than (1). Sun-type community (3) showing lower photosynthetic efficiency than (1) or (2) at lower light intensity.

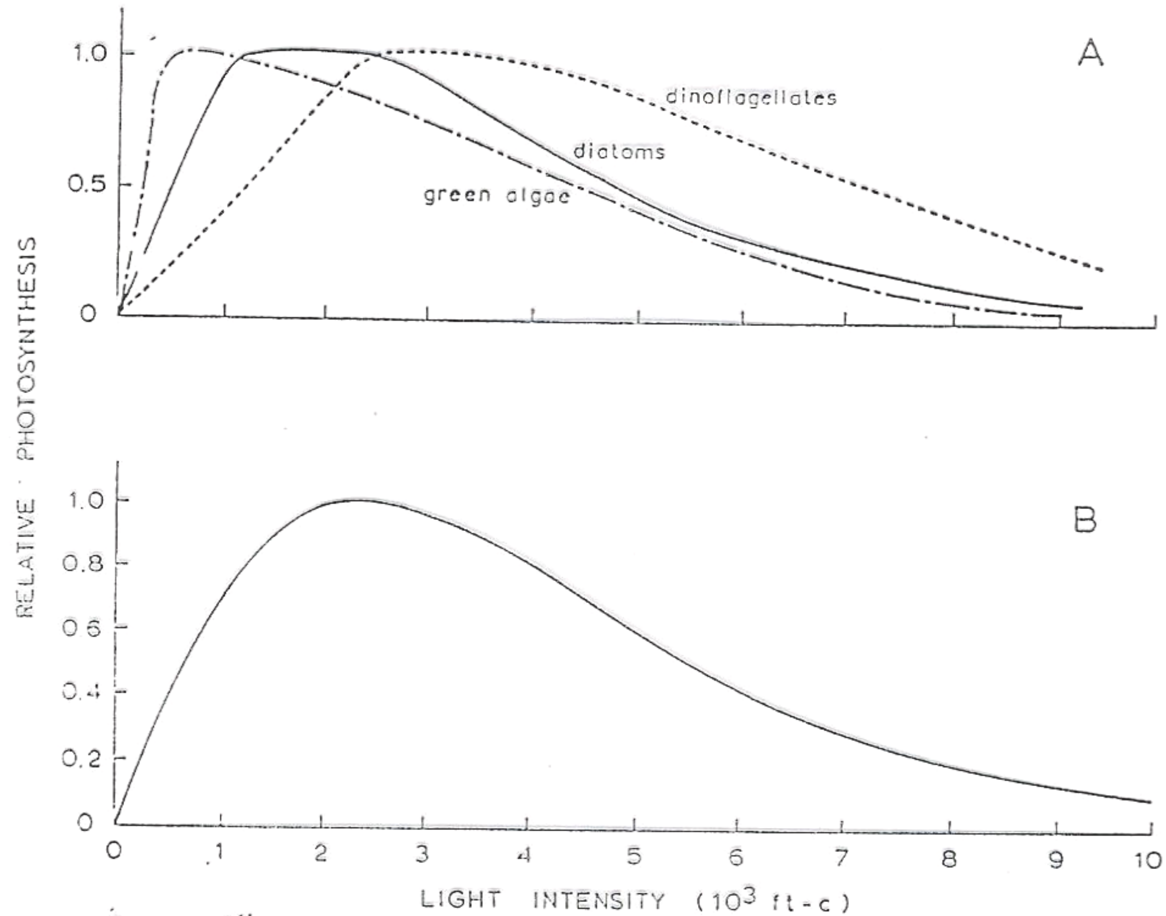
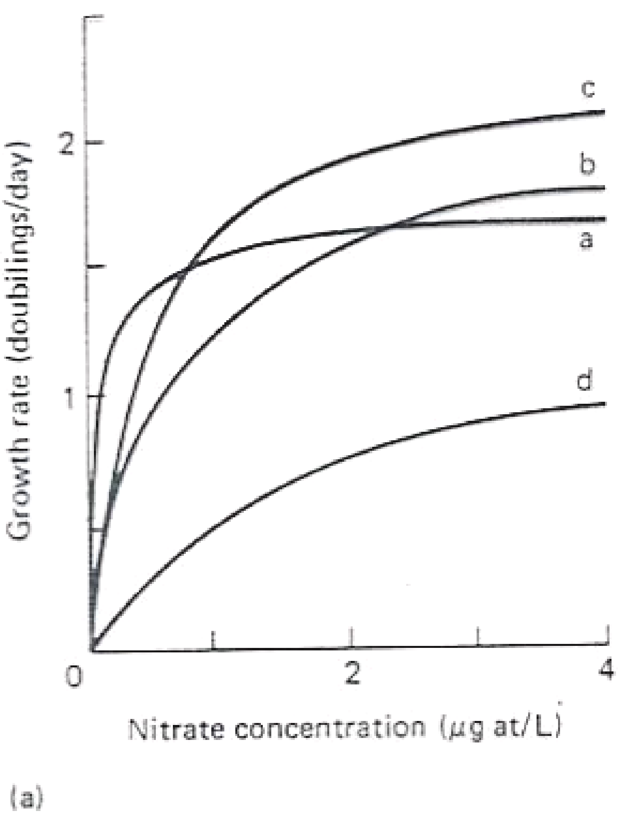


FIG. 26A. Relative photosynthesis–light curves in some marine phytoplankton. Green algae: *Dunaliella euchlora*, *Chlamydomonas sp.*, *Platymonas sp.*, *Carteria sp.*, *Mischococcus sp.*, *Stichococcus sp.*, and *Nannochloris sp.* Diatoms: *Skeletonema costatum*, *Nitzschia closterium*, *Navicula sp.* and *Coscinodiscus excentricus*. Dinoflagellates; *Gymnodinium splendens*, *Gyrodinium sp.*, *Exuviaella sp.*, and *Amphidinium klebsi*. (Redrawn from Ryther, 1956).

FIG. 26B. Mean curve from Fig. 26A.



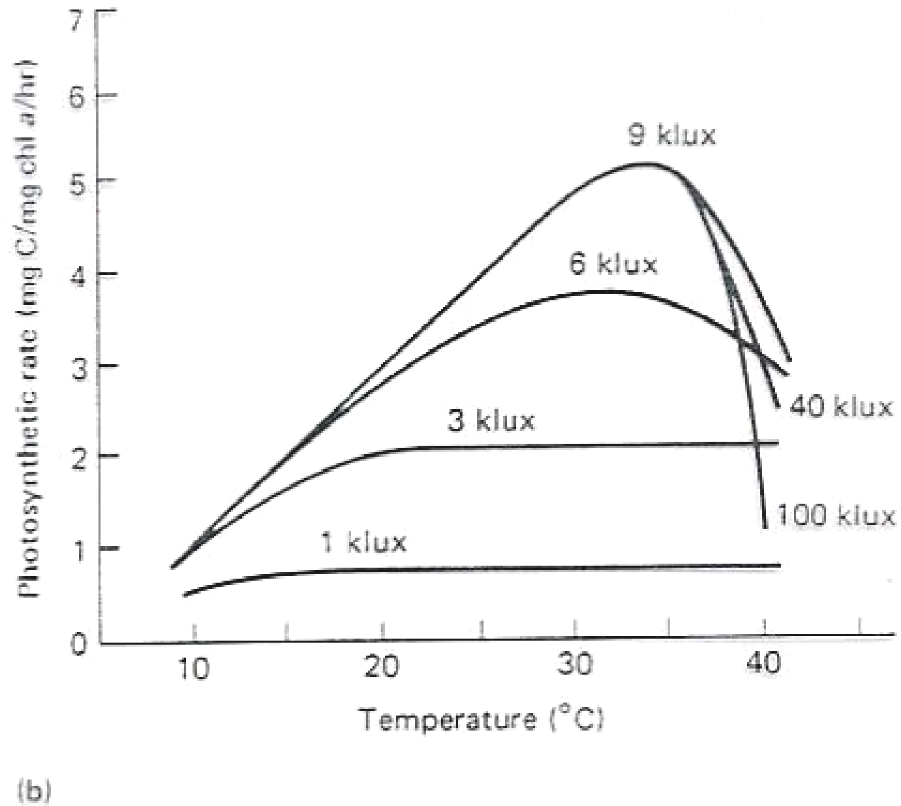


FIGURE 11.10 Laboratory evidence of the control of photosynthesis by light intensity, temperature, and nitrate concentration. (a) Growth rates of four algal species (a–d) over a range of different external nitrate concentrations. Internal concentrations of nitrogen also need to be considered. (b) Photosynthesis as a function of temperature (°C) and light intensity (klux) in cultured specimens of the alga *Scenedesmus*. Photosynthetic rate is expressed as mg of carbon fixed per mg of chlorophyll *a* per hour. (From Parsons and Takahashi, 1973, redrawn from Eppley et al., 1969 (a) and Aruga, 1965 (b).)

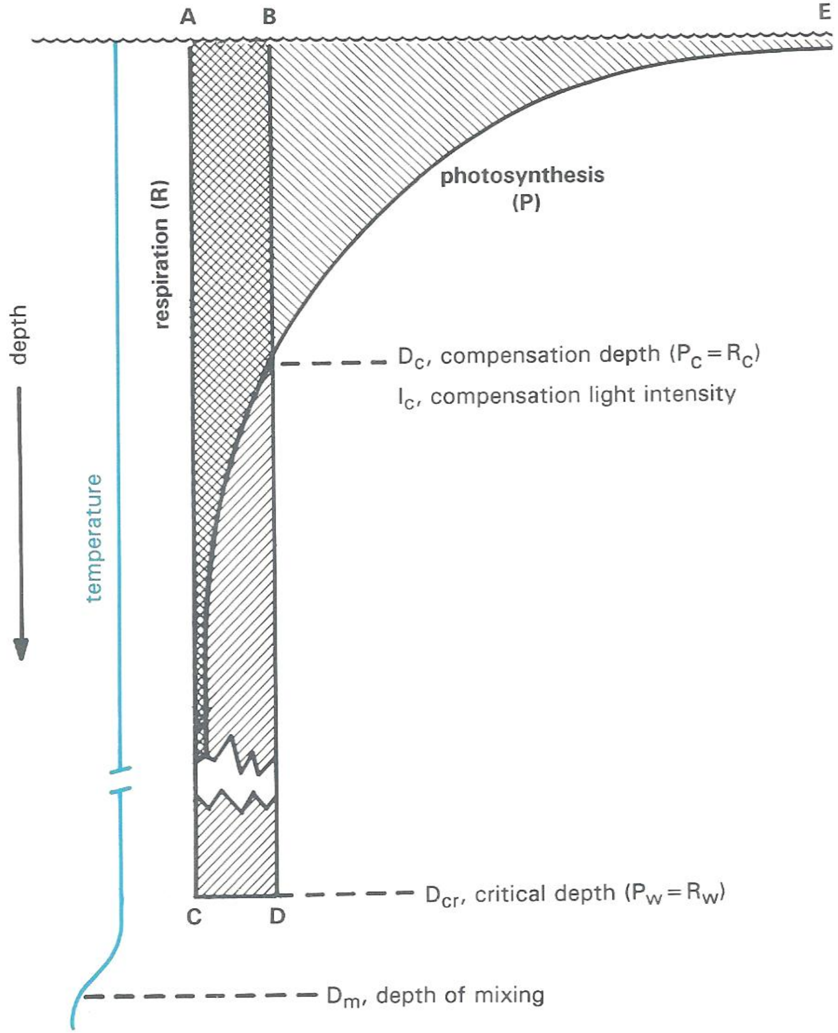
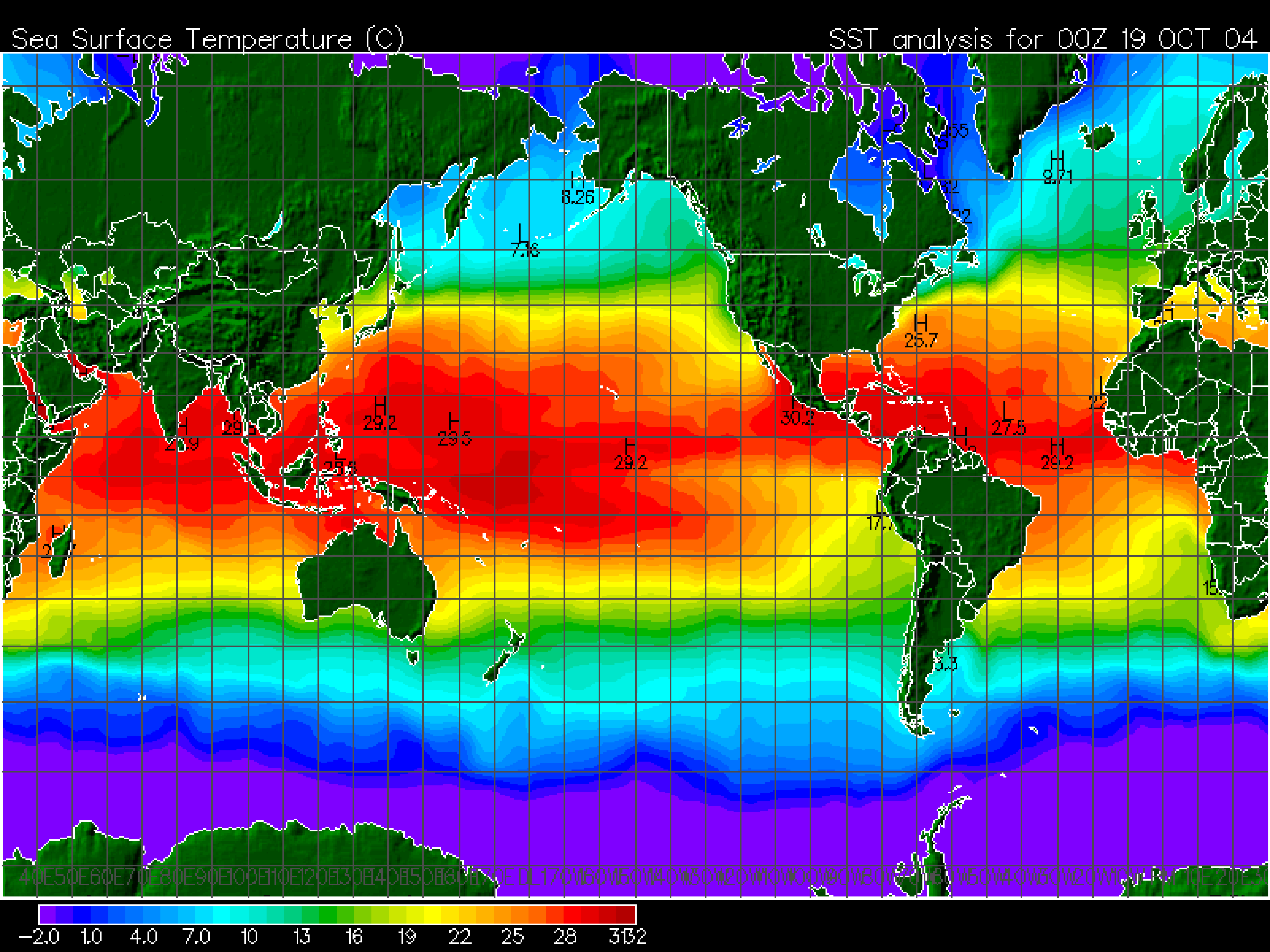
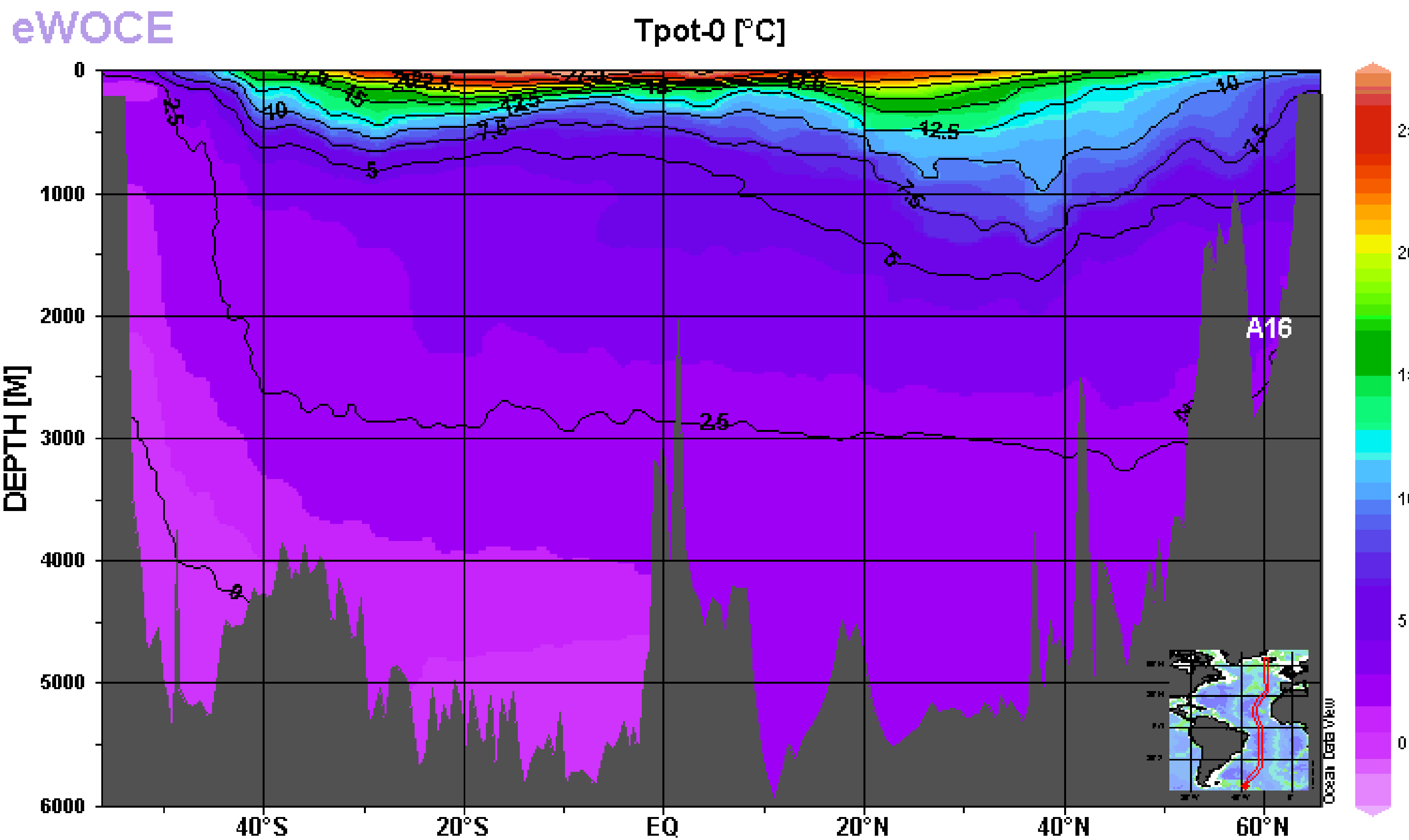


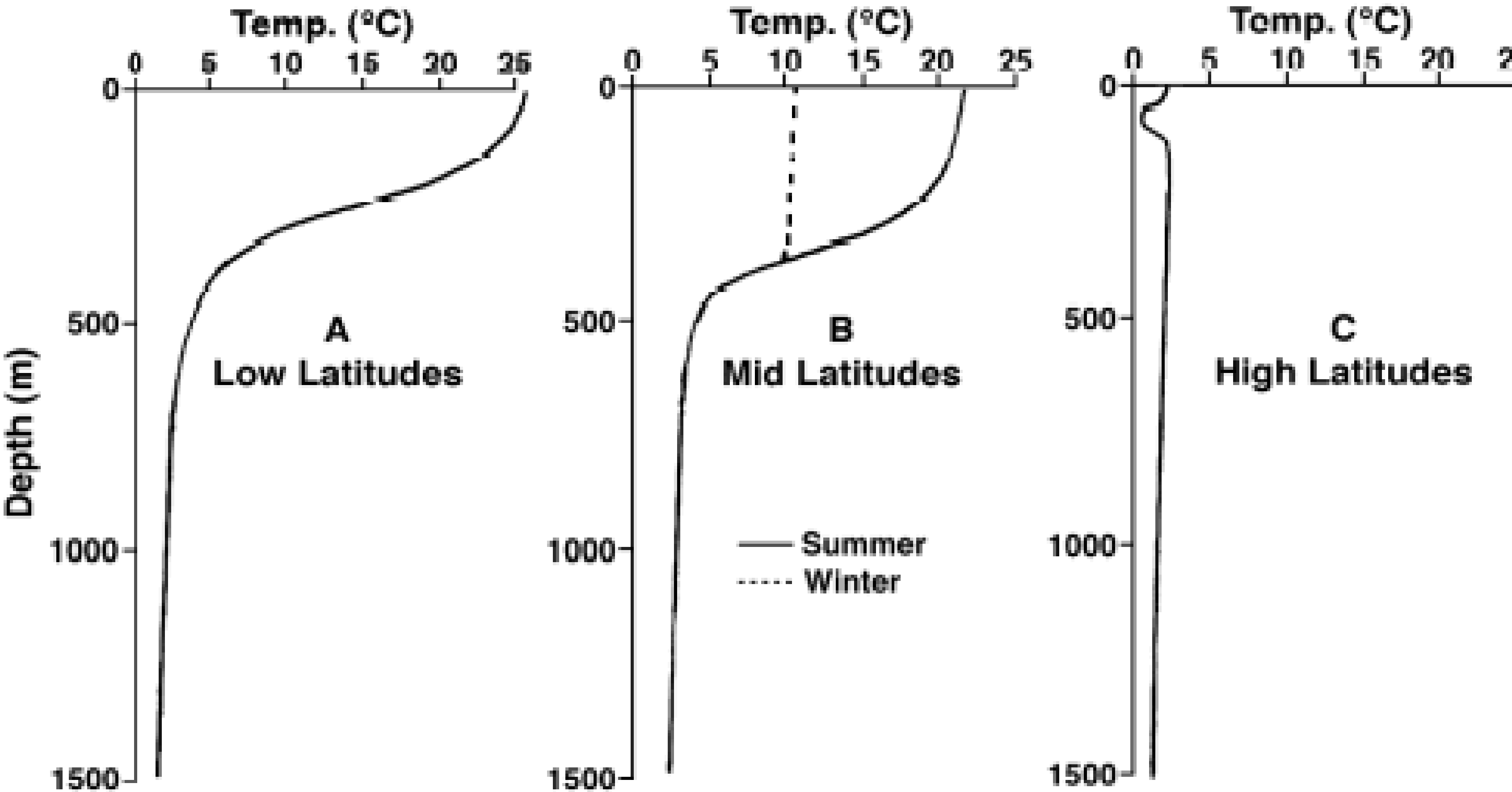
Figure 3.6 An illustration of the relationships among the compensation light depth, the critical depth, and the depth of mixing. At the compensation depth (D_C), the light intensity (I_C) is such that the photosynthesis of a single cell (P_C) is equal to its respiration (R_C); above this depth there is a net gain from photosynthesis ($P_C > R_C$) and below it there is a net loss ($P_C < R_C$). As phytoplankton cells are mixed above and below the compensation depth, they experience an average light intensity (I_D) in the water column. The depth at which I_D equals I_C is the critical depth (D_{cr}) where photosynthesis throughout the water column (P_w) equals phytoplankton respiration throughout the water column (R_w). The area bounded by points A, B, C and D represents phytoplankton respiration, and the area bounded by points A, C and E represents photosynthesis; these two areas are equal at the critical depth. When the critical depth is less than the depth of mixing (D_M) (as illustrated in this figure), no net production takes place because $P_w < R_w$. Net production of the phytoplankton ($P_w > R_w$) only occurs when the critical depth lies below the depth of mixing.

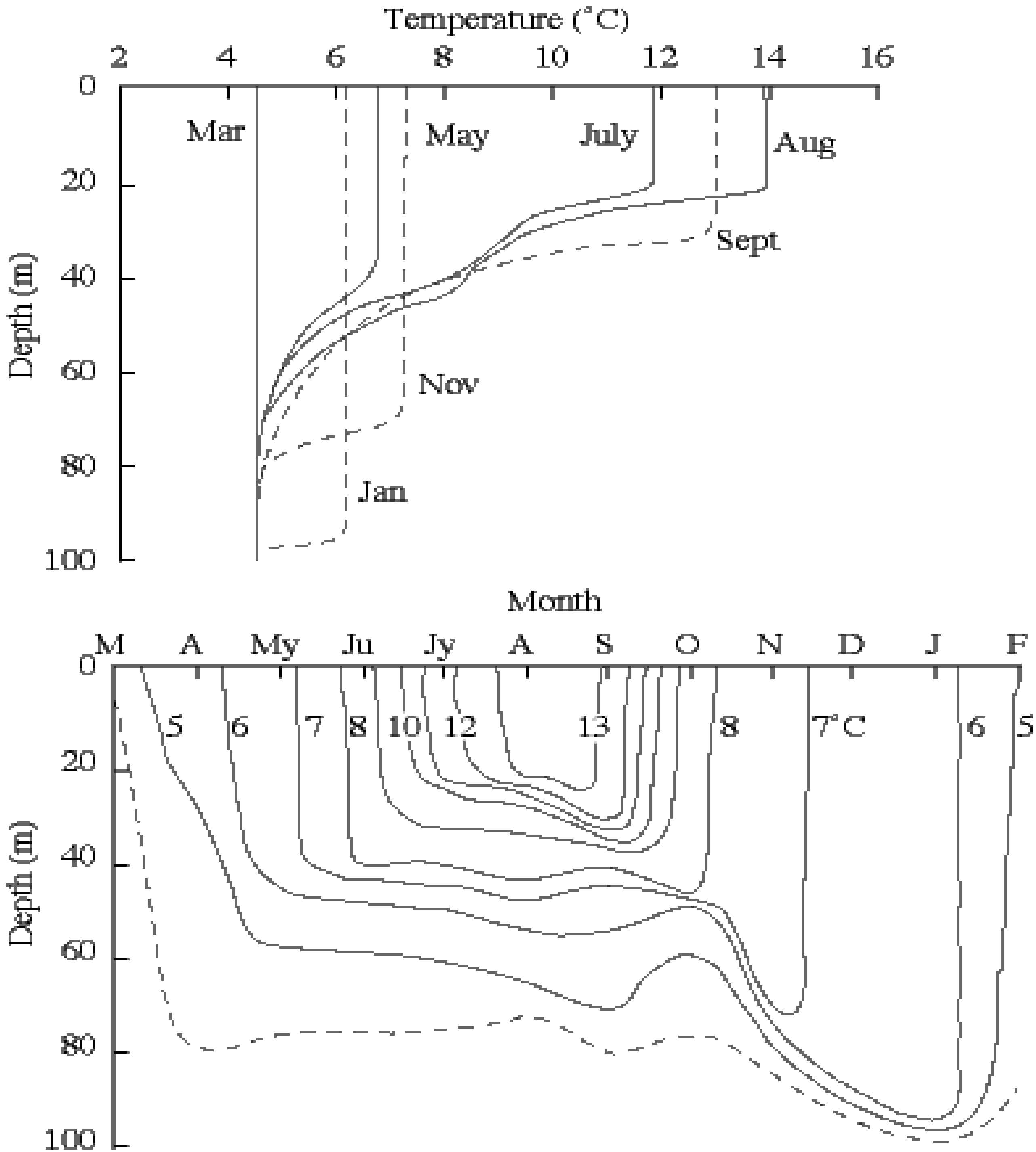

Sea Surface Temperature (C)
SST analysis for 00Z 19 OCT 04
8.26
8.71
25.7
29.2
30.2
27.5
−2.0
1.0
4.0
7.0
10
13
16
19
22
25
28
31
32

Atlantic temperature section (0 – 6000 m)



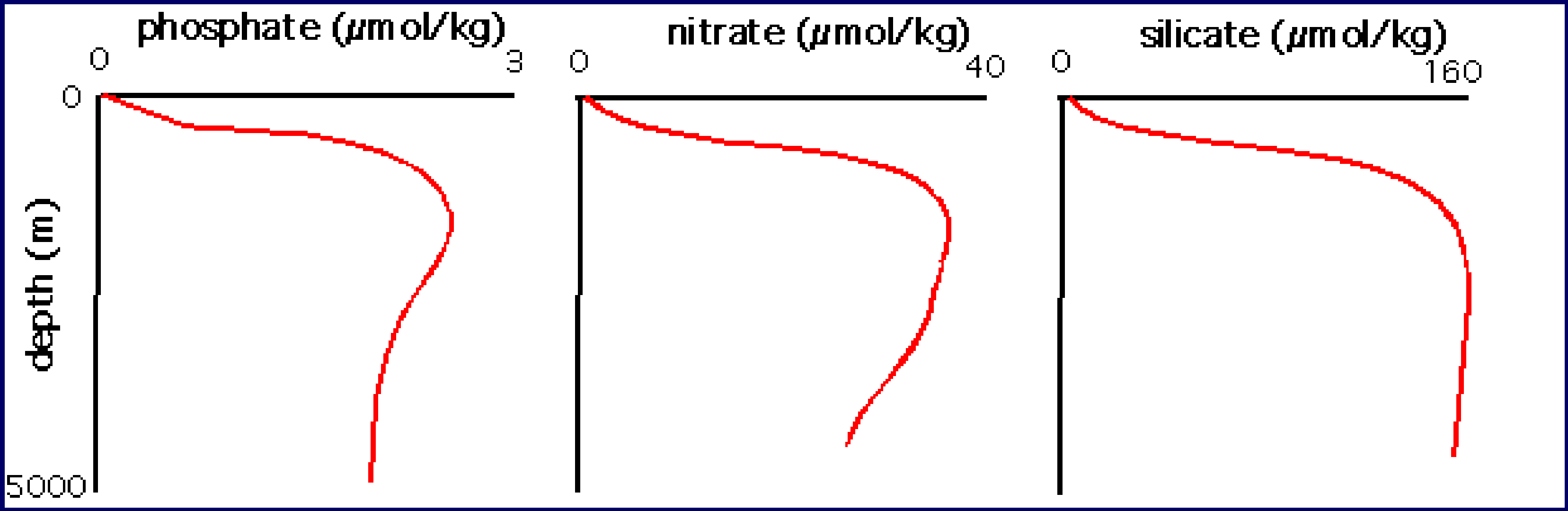
Typical Temperature Profiles




Temperature (°C)
2
4
6
8
10
12
14
16
0
20
40
60
80
100
Depth (m)
Mar
May
July
Aug
Sept
Nov
Jan
Month
M
A
My
Ju
Jy
A
S
O
N
D
J
F
5
6
7
8
10
12
13
8
7°C
6
5

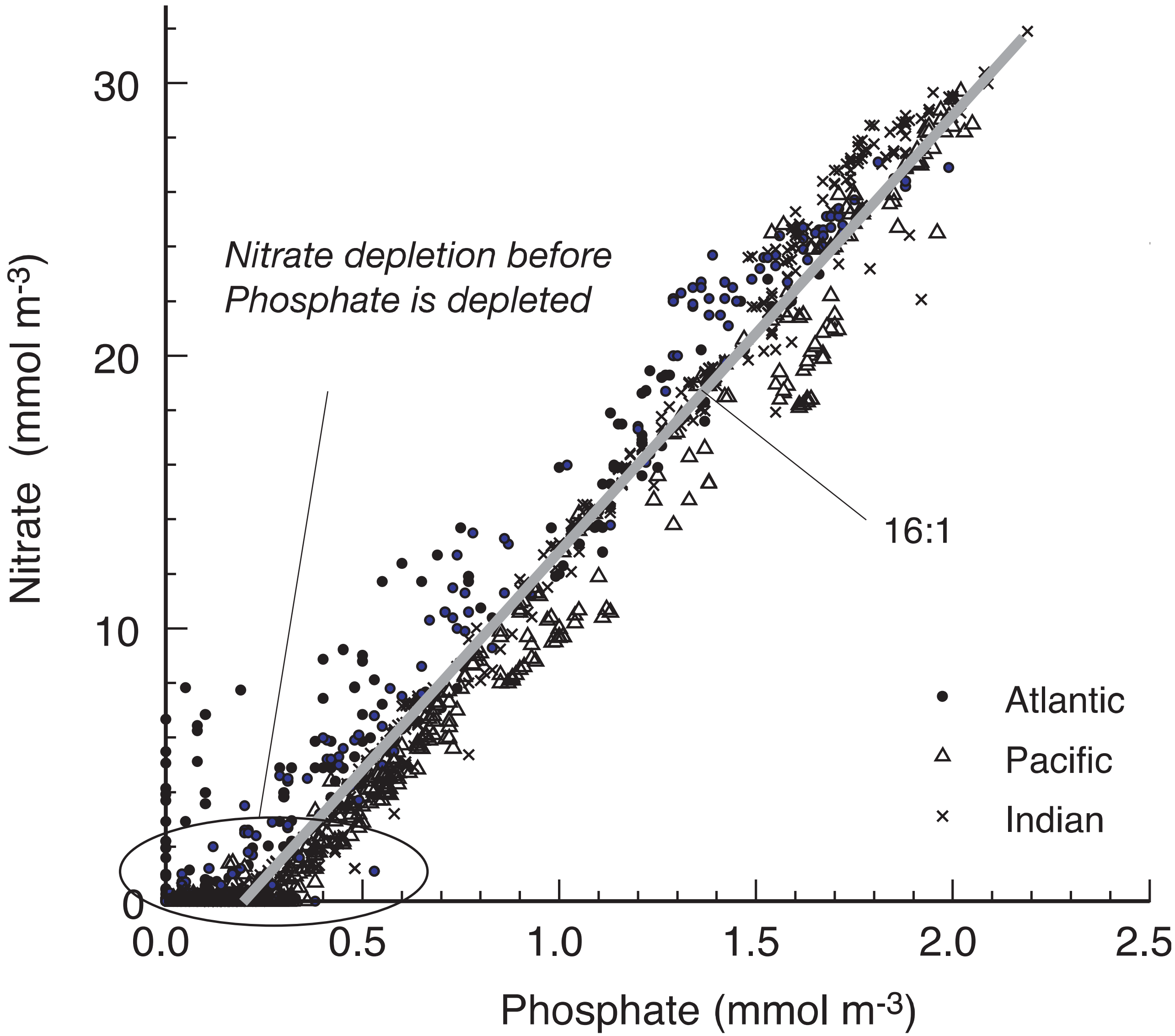
Nutrient elements

Nutrient elements (e.g., P, N, Si) are depleted in surface waters by biological production, and returned to deep waters by decomposition/respiration of sinking material



Mixing back up to surface waters is restricted by density contrast (stratification) and the depth to which wind-driven mixing can penetrate

חנקן וזרחן בחומר אורגני מאוקיאנוסים שונים המראים יחס של 1:16



The Modified Redfield Equation

→

PHOTOSYNTHESIS

$106CO_2 + 122H_2O + 16HNO_3 + H_3PO_4 =$

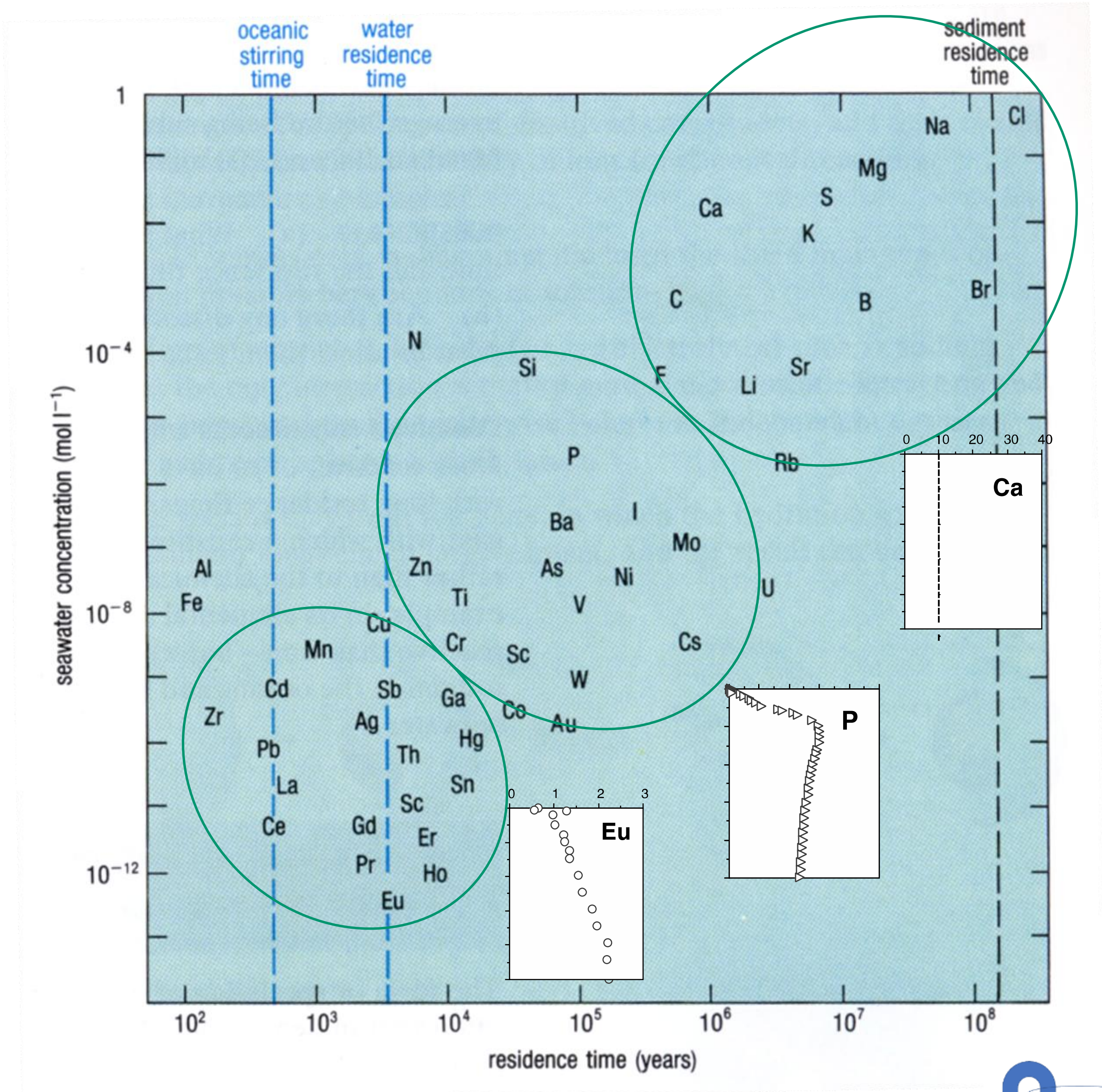
←

RESPIRATION

$= (CH_20)_{106}(NH_3)_{16} (H_3PO_4) + 138O_2$

C:N:P=106:16:1

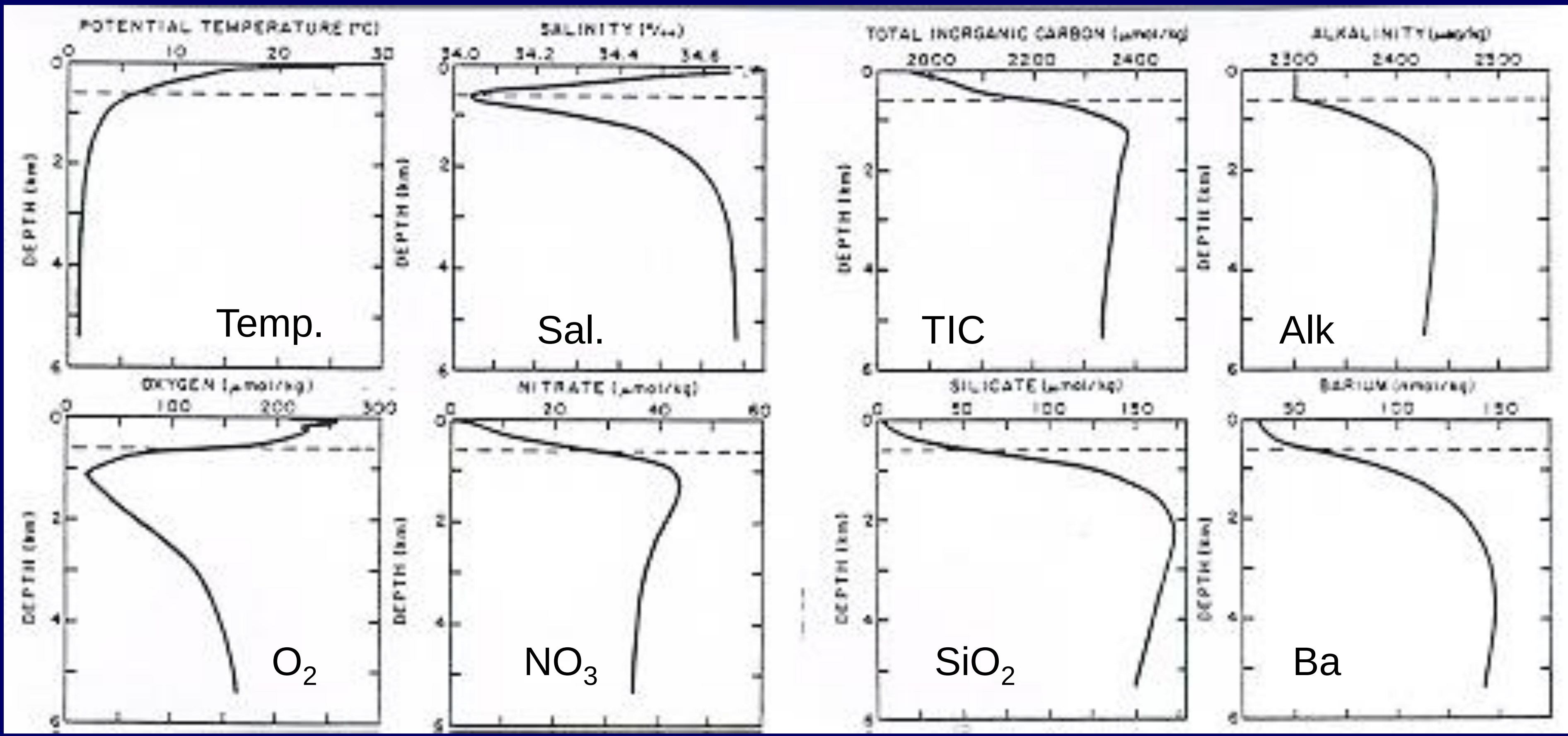
Fe= 0.0075



oceanic stirring time
water residence time
sediment residence time
1
10−4
10−8
10−12
seawater concentration (mol l−1)
10²
10³
10⁴
10⁵
10⁶
10⁷
10⁸
residence time (years)
Na
Cl
Mg
S
Ca
K
C
B
Br
N
Si
F
Li
Sr
Rb
P
Ba
I
Mo
Al
Fe
Zn
As
Ni
Ti
V
U
Cu
Cr
Sc
Cs
Mn
W
Cd
Sb
Ga
Co
Zr
Ag
Au
Hg
Pb
Th
La
Sn
Sc
Ce
Gd
Er
Pr
Ho
Eu
0
10
20
30
40
Ca
P
0
1
2
3
Eu

100 ליטר

Nutrients in the ocean



Principle Drivers are Marine Organisms!!
Phytoplankton (and Zooplankton)

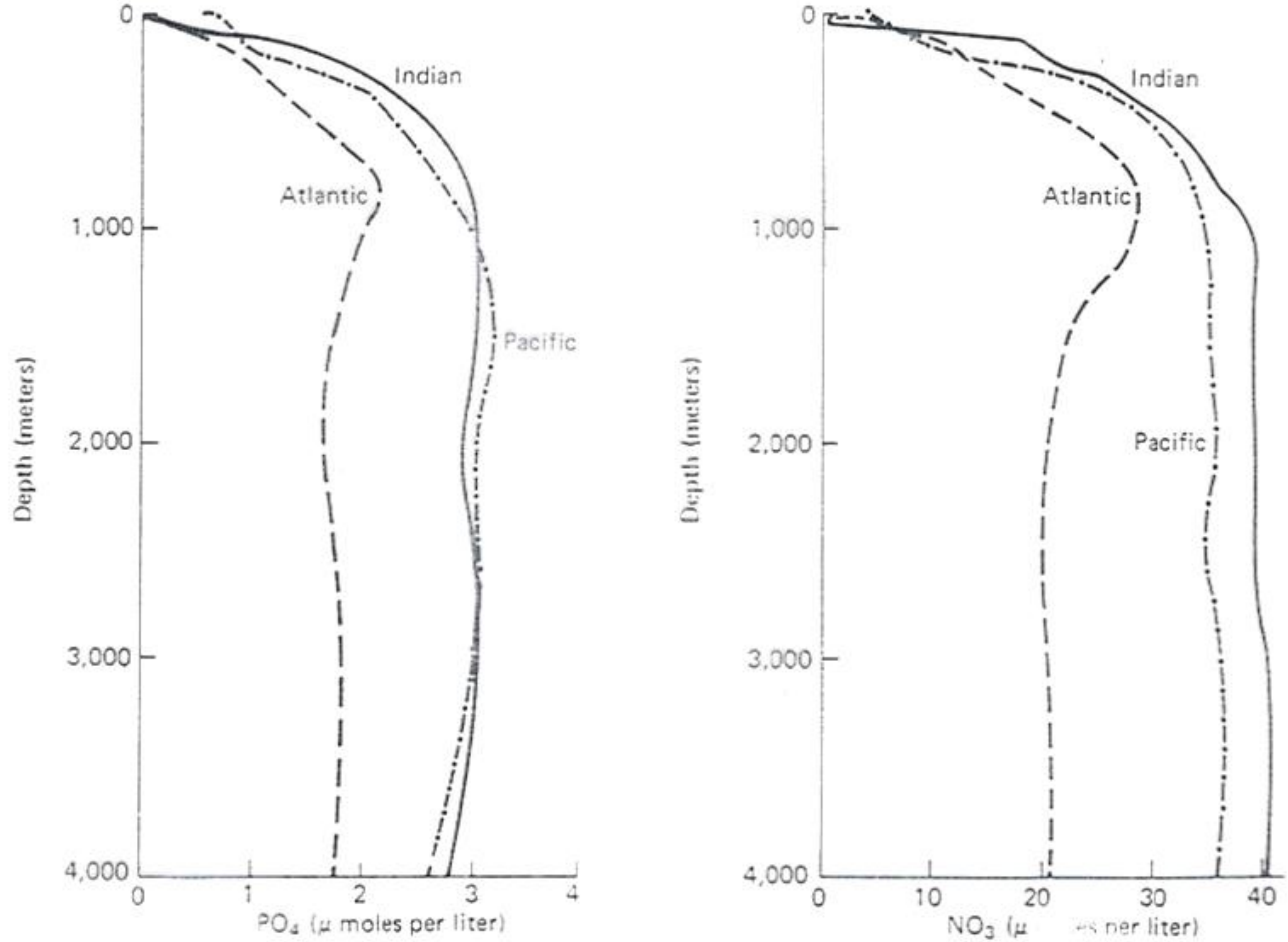
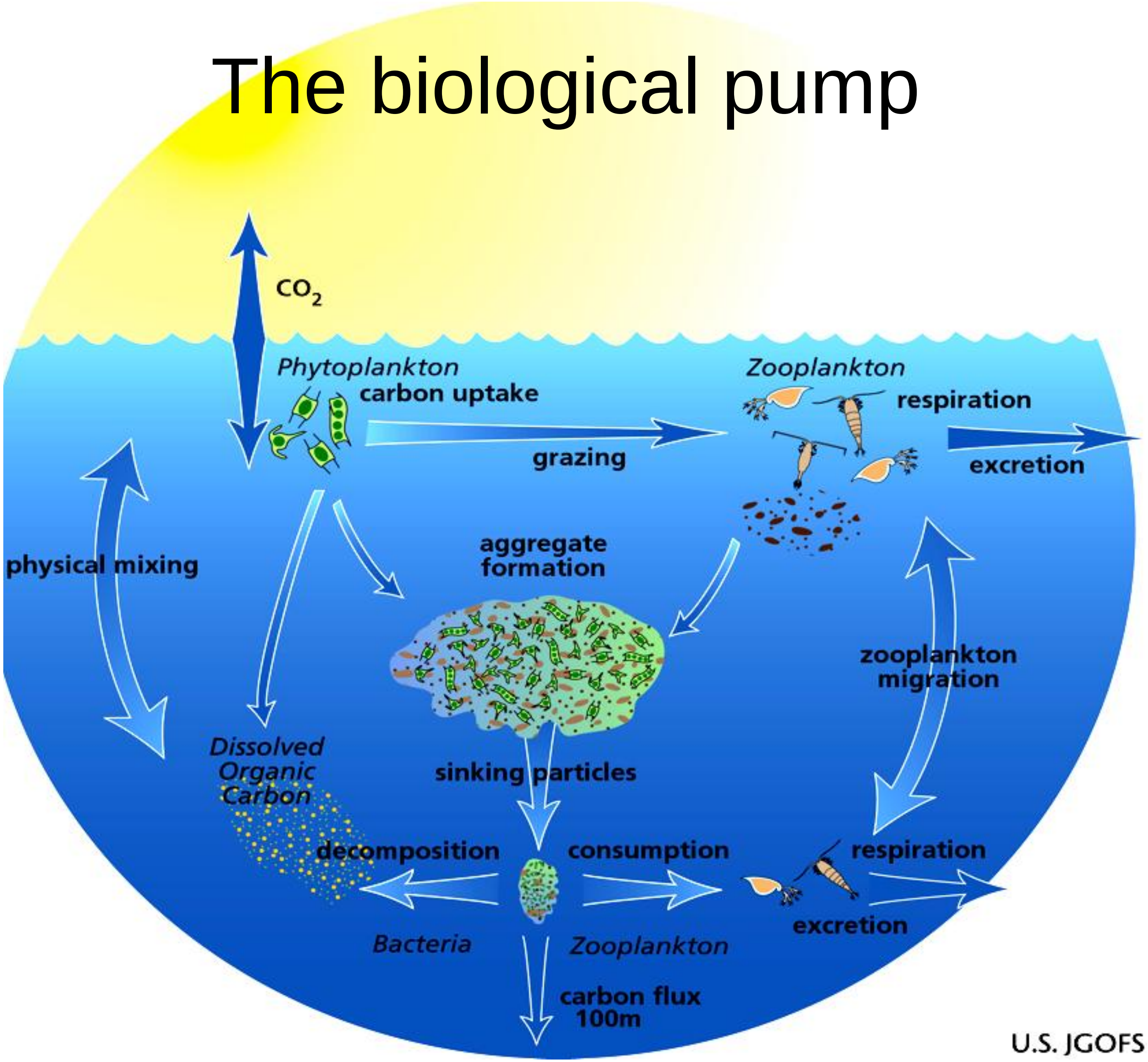
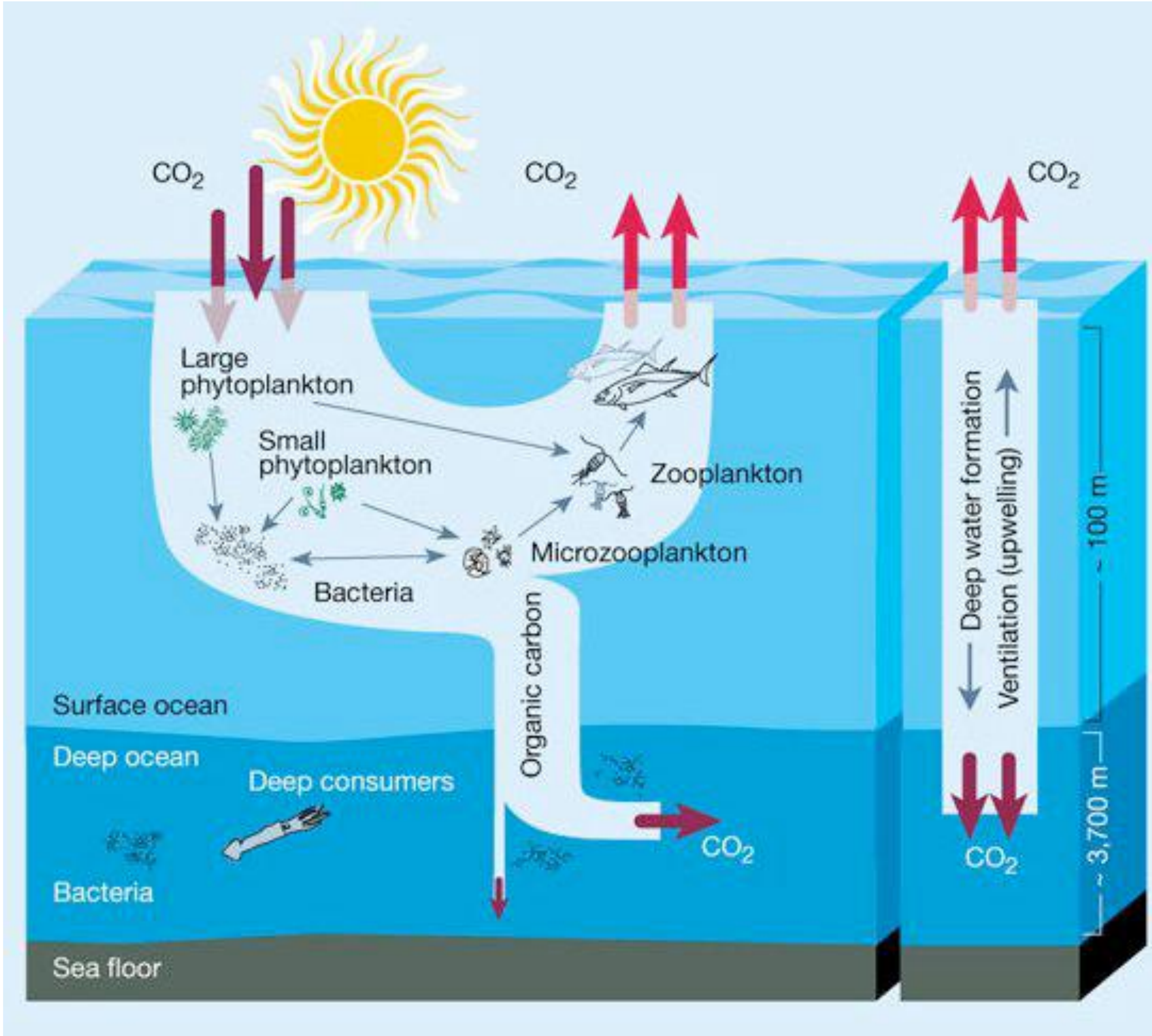


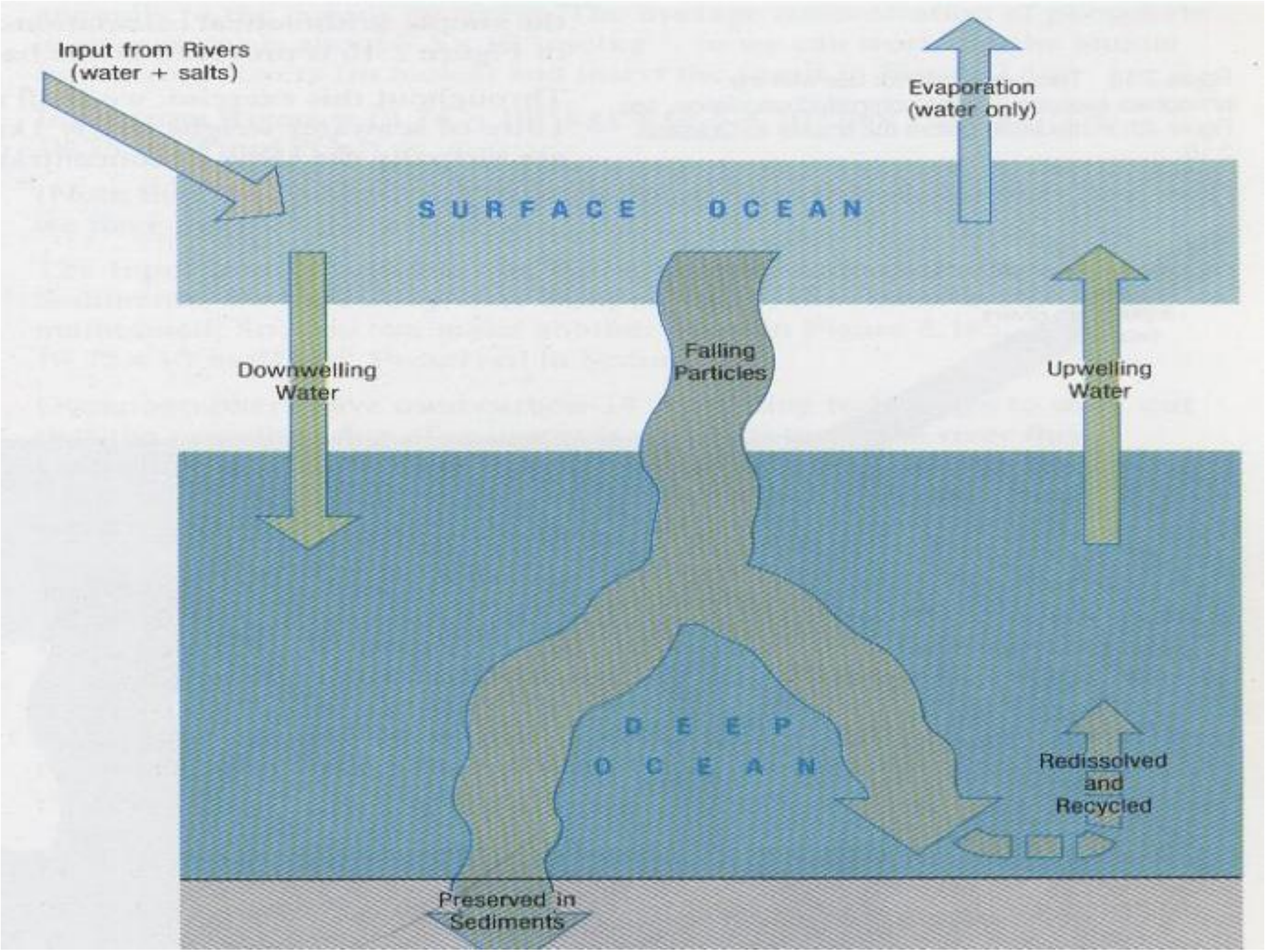
FIGURE 9.2 Vertical distributions of the nutrient components, phosphate and nitrate, in typical water columns in the Atlantic, Pacific, and Indian Oceans. (After Sverdrup, Johnson, and Fleming, 1942).

The biological pump





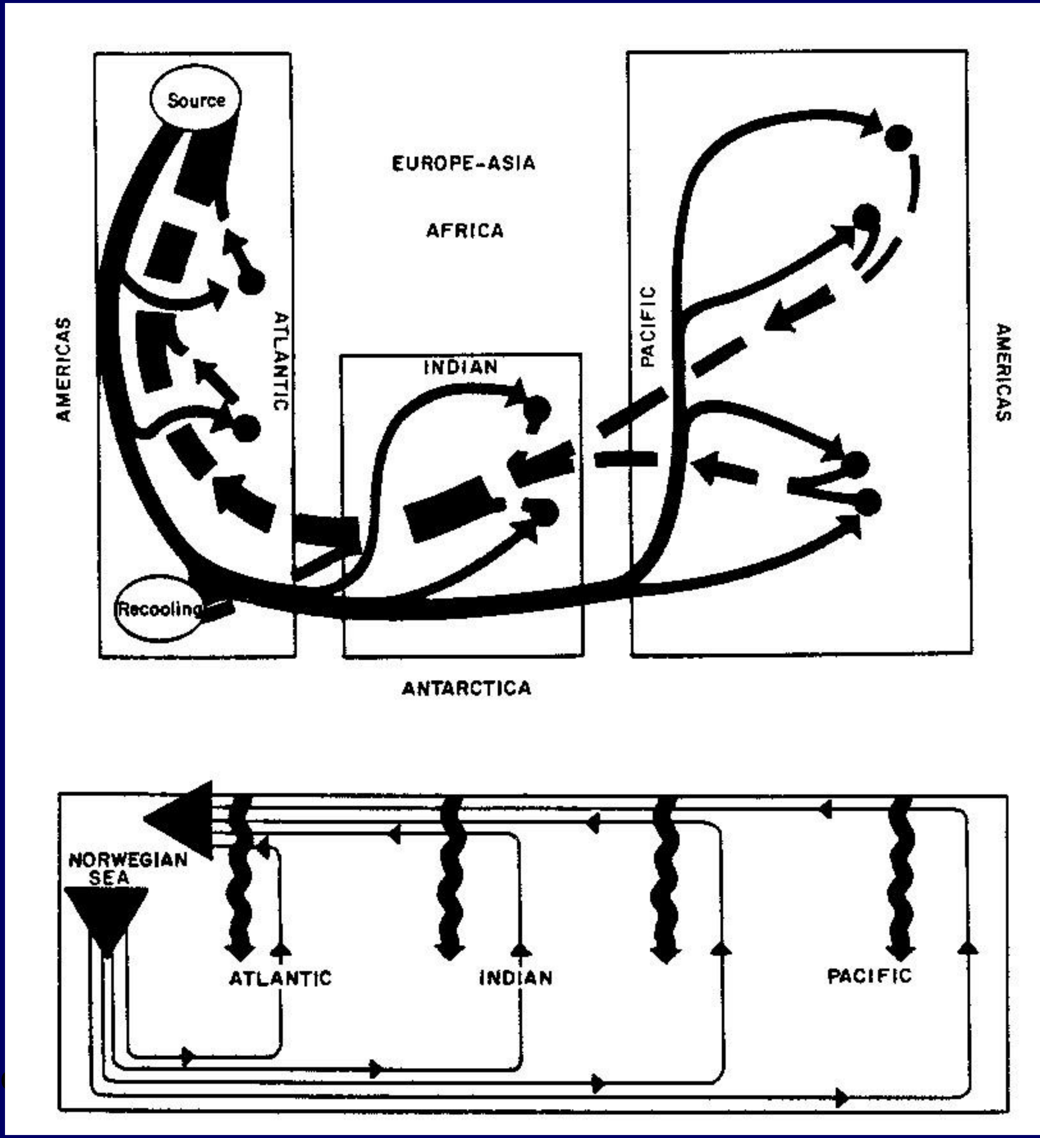
CO2
CO2
CO2
Large phytoplankton
Small phytoplankton
Zooplankton
Microzooplankton
Bacteria
Organic carbon
Deep water formation
Ventilation (upwelling)
~ 100 m
~ 3,700 m
Surface ocean
Deep ocean
Deep consumers
CO2
CO2
Bacteria
Sea floor


Input from Rivers
(water + salts)
Evaporation
(water only)
SURFACE OCEAN
Downwelling
Water
Falling
Particles
Upwelling
Water
DEEP
OCEAN
Redissolved
and
Recycled
Preserved in
Sediments

Spatial distributions of properties

As deep water flows from the North Atlantic to the Indian and Pacific Oceans, it continually receives a “rain” of particulate material from the overlying surface waters

Consumption of this material by bacteria, etc. adds nutrients and CO_2, and depletes oxygen from deep waters, along the flow pathway

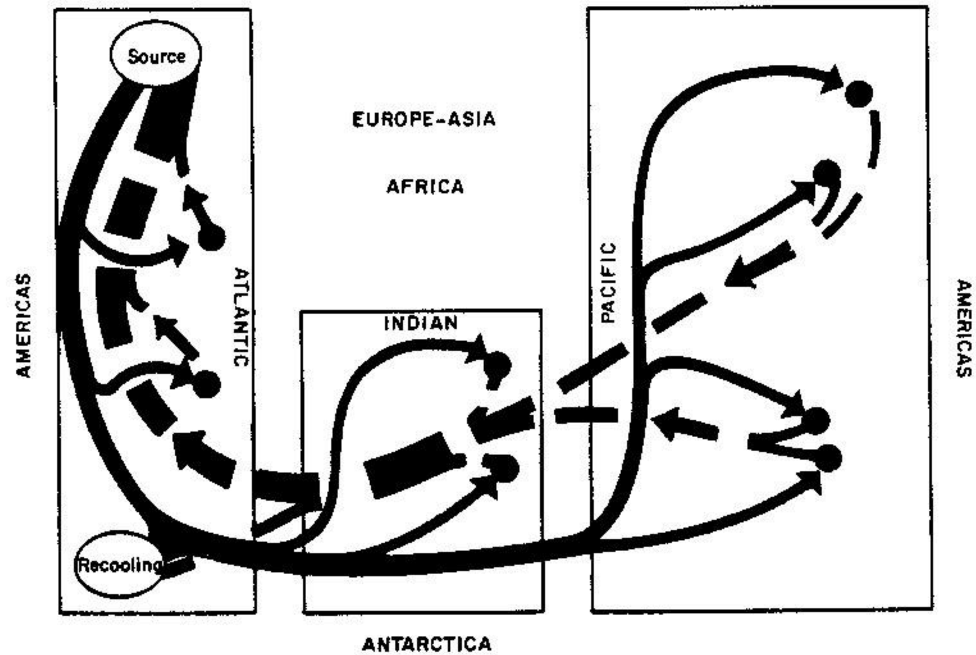


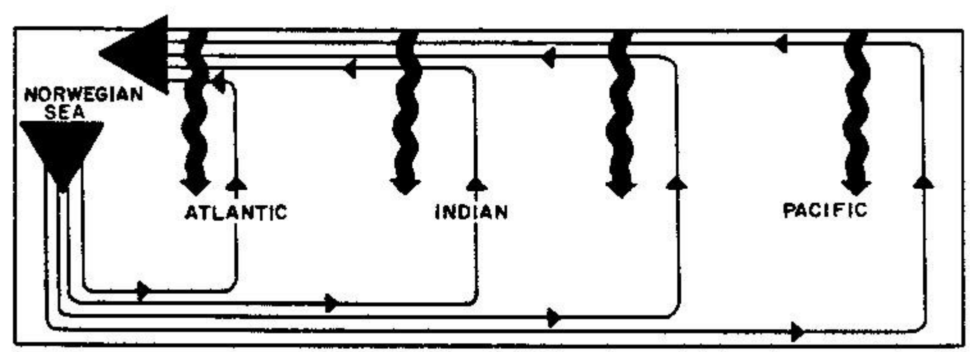
Bro

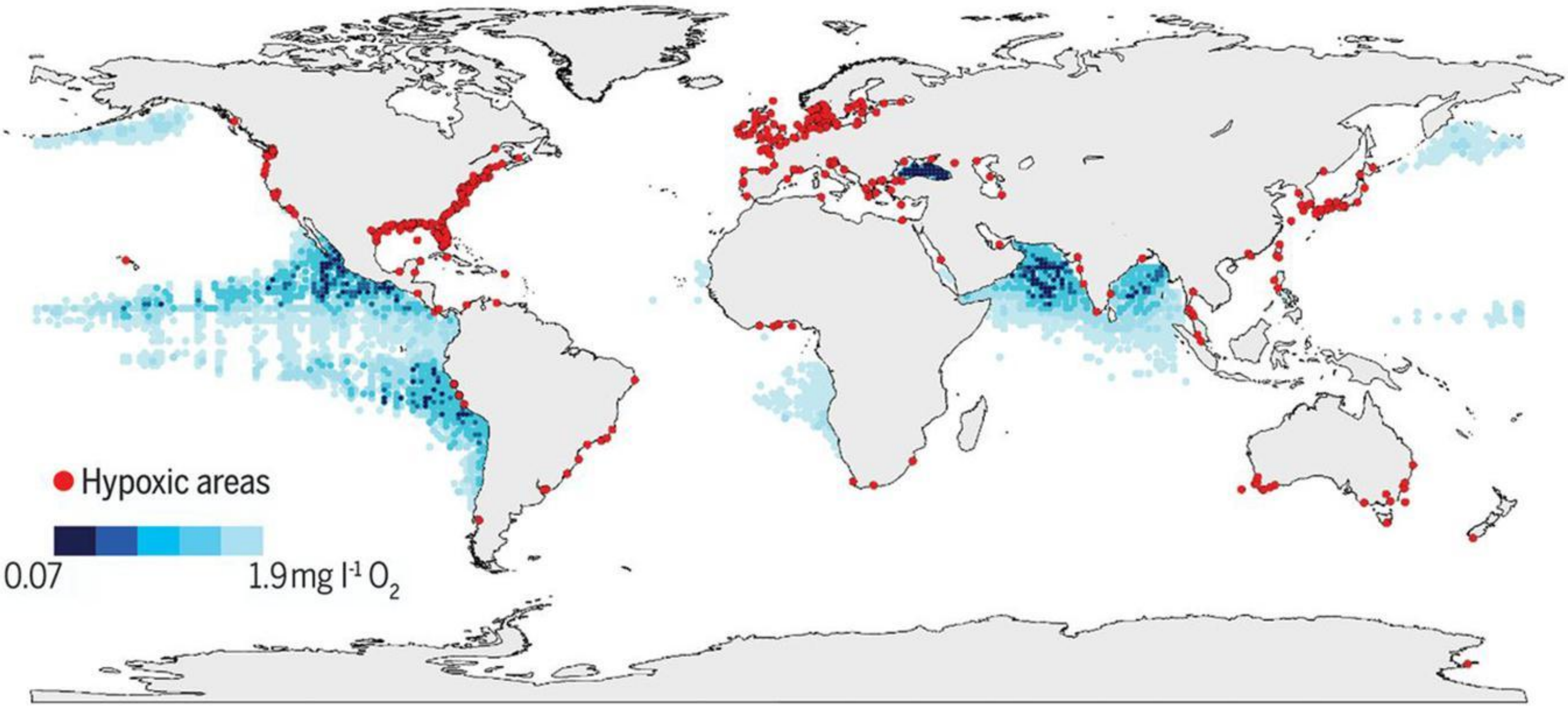
Broecker scheme

$$\text{Ratio} = \frac{(C_{deep} - C_{surface})\ \text{PACIFIC}}{(C_{deep} - C_{surface})\ \text{ATLANTIC}}$$

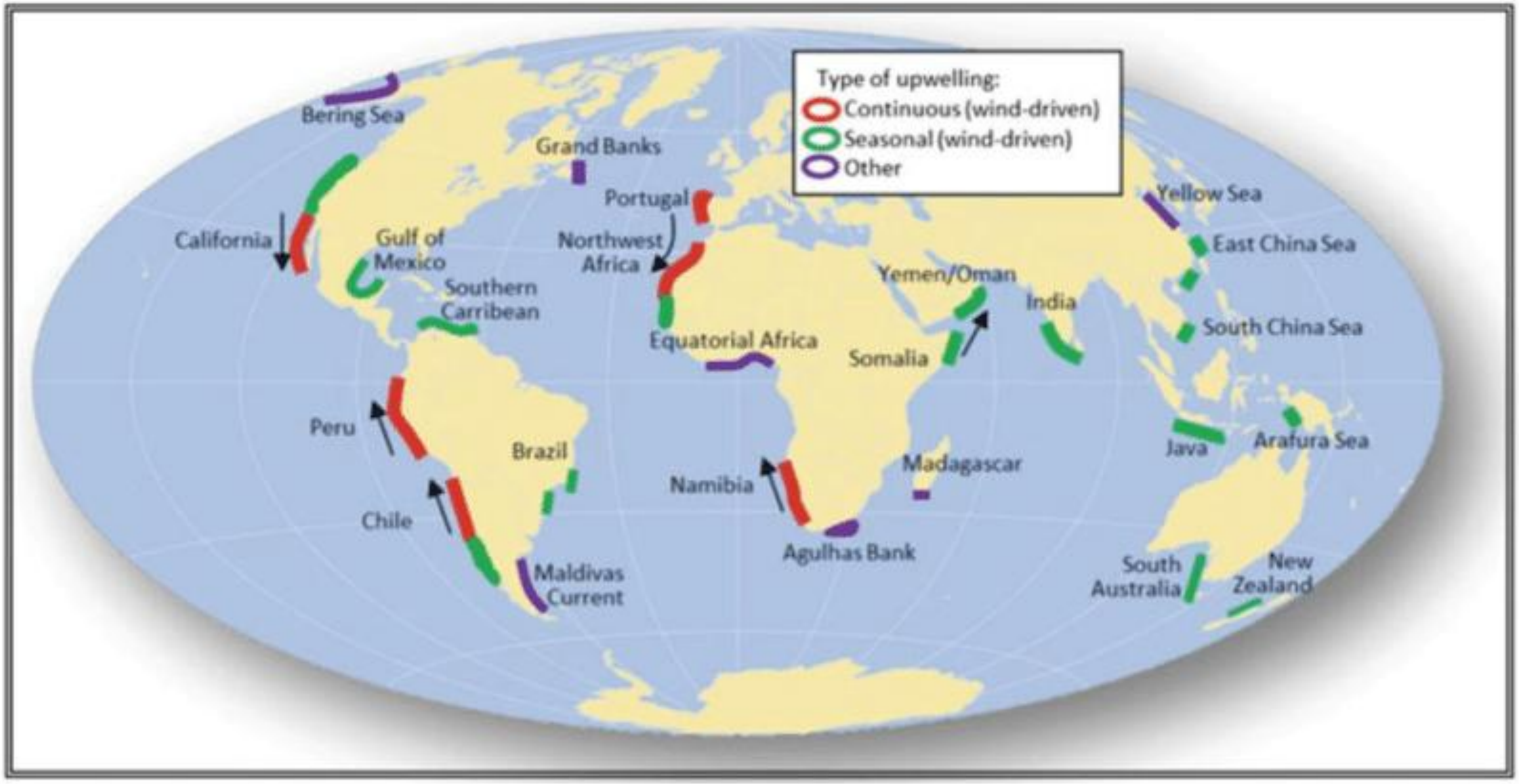
ELEMENT	Ratio
N(NO3^{--})	2
P	2
C	3
SI	5
Ba	7

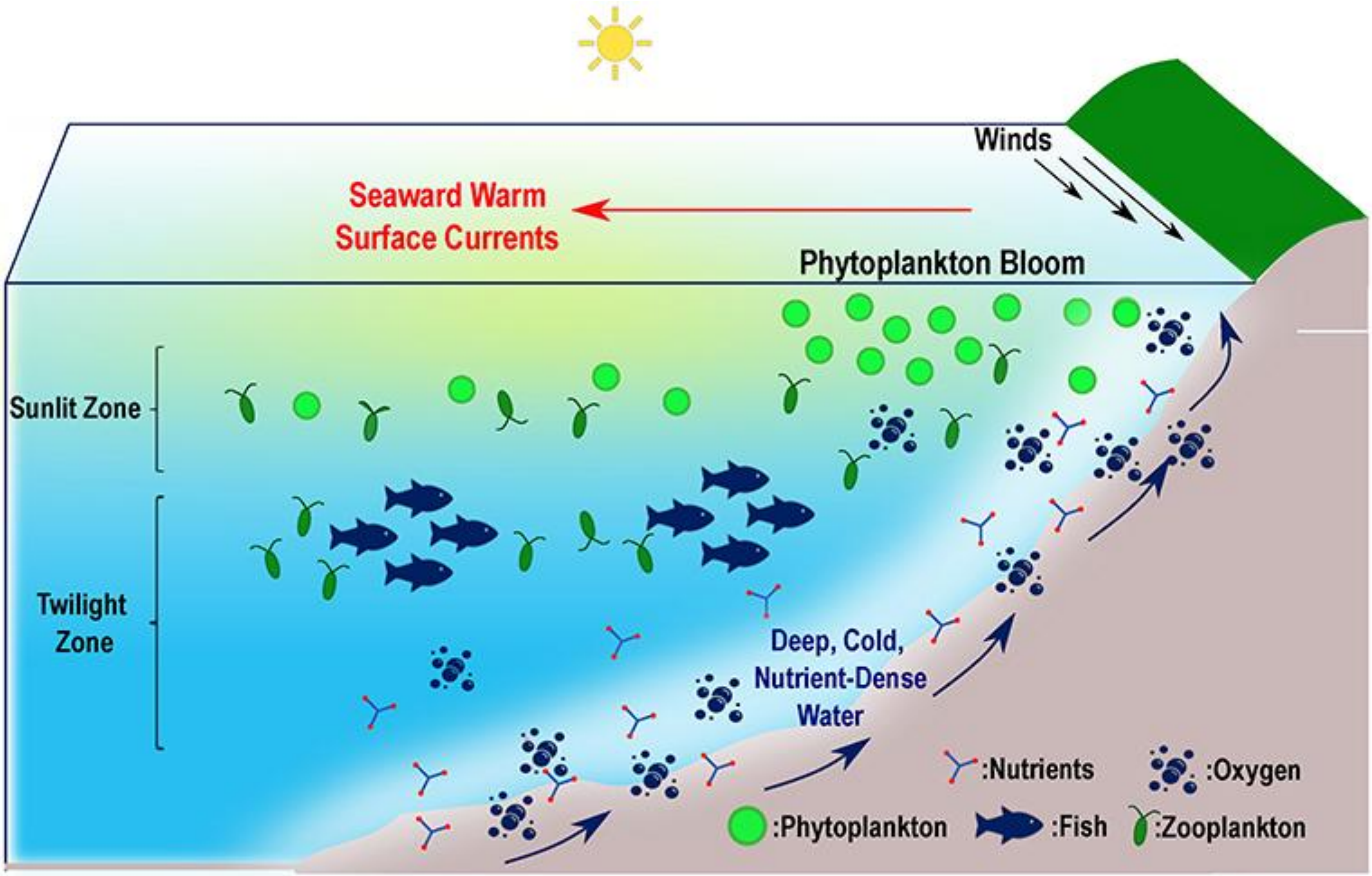





Hypoxic areas
0.07
1.9mg l-1 O2

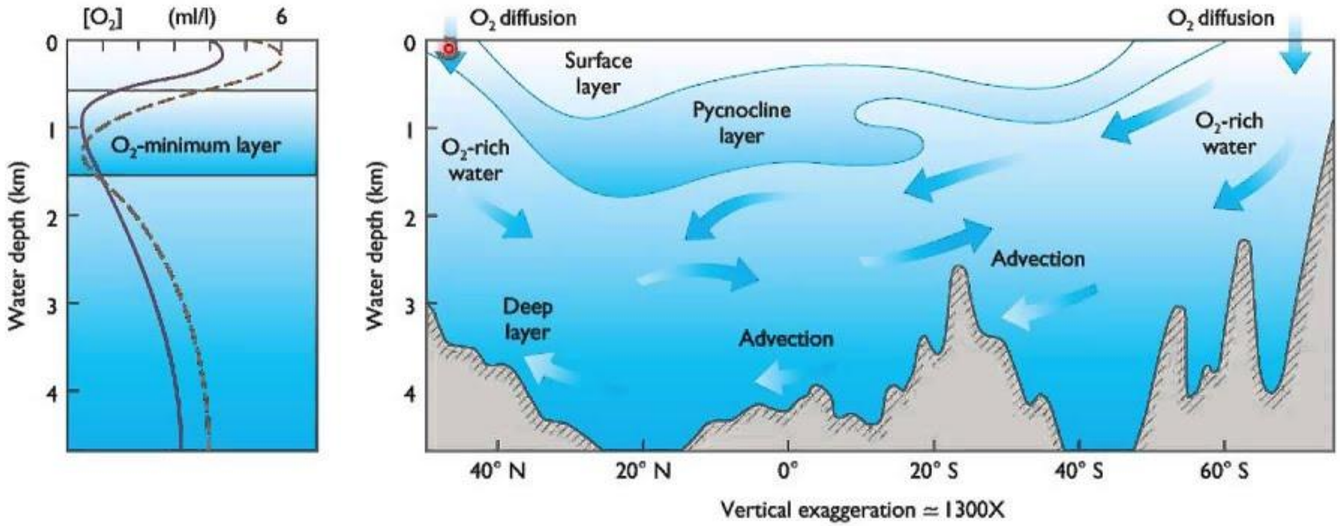
Upwelling regions in the ocean





Winds
Seaward Warm
Surface Currents
Phytoplankton Bloom
Sunlit Zone
Twilight
Zone
Deep, Cold,
Nutrient-Dense
Water
:Nutrients
:Oxygen
:Phytoplankton
:Fish
:Zooplankton

Oxygen in the Ocean

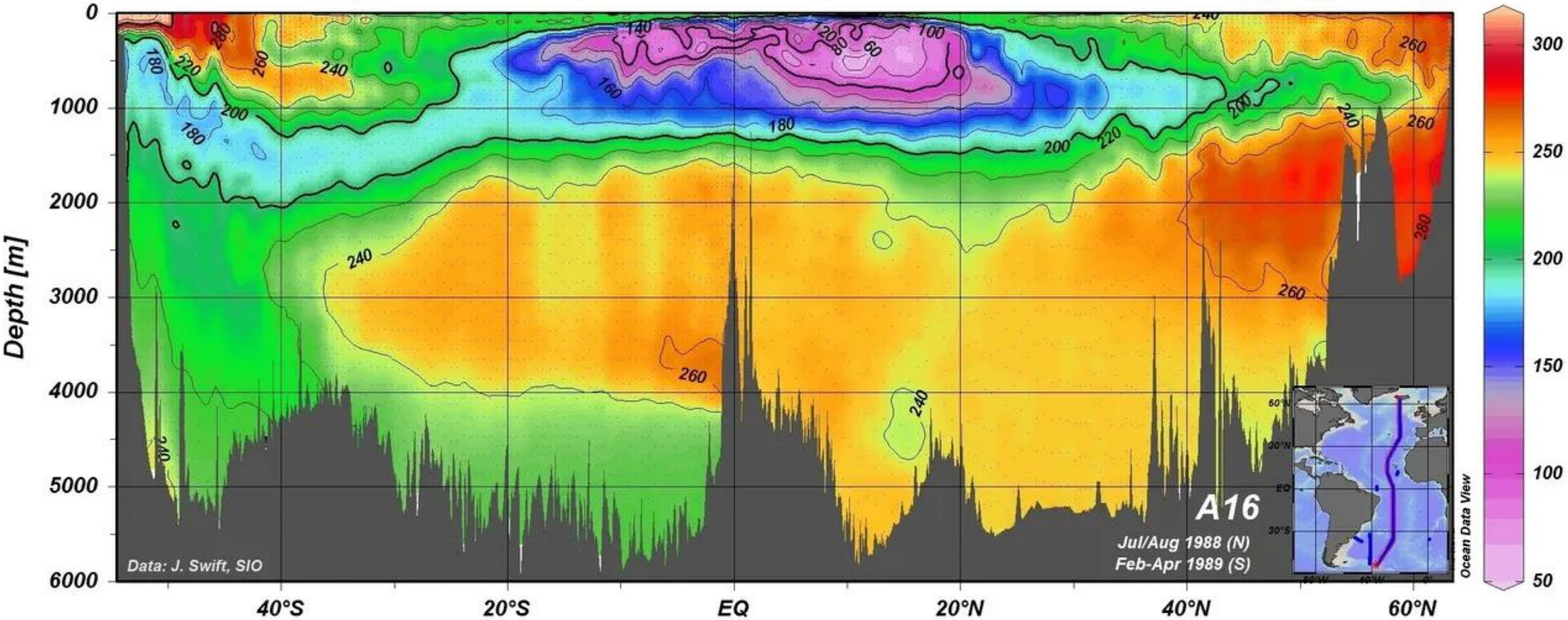


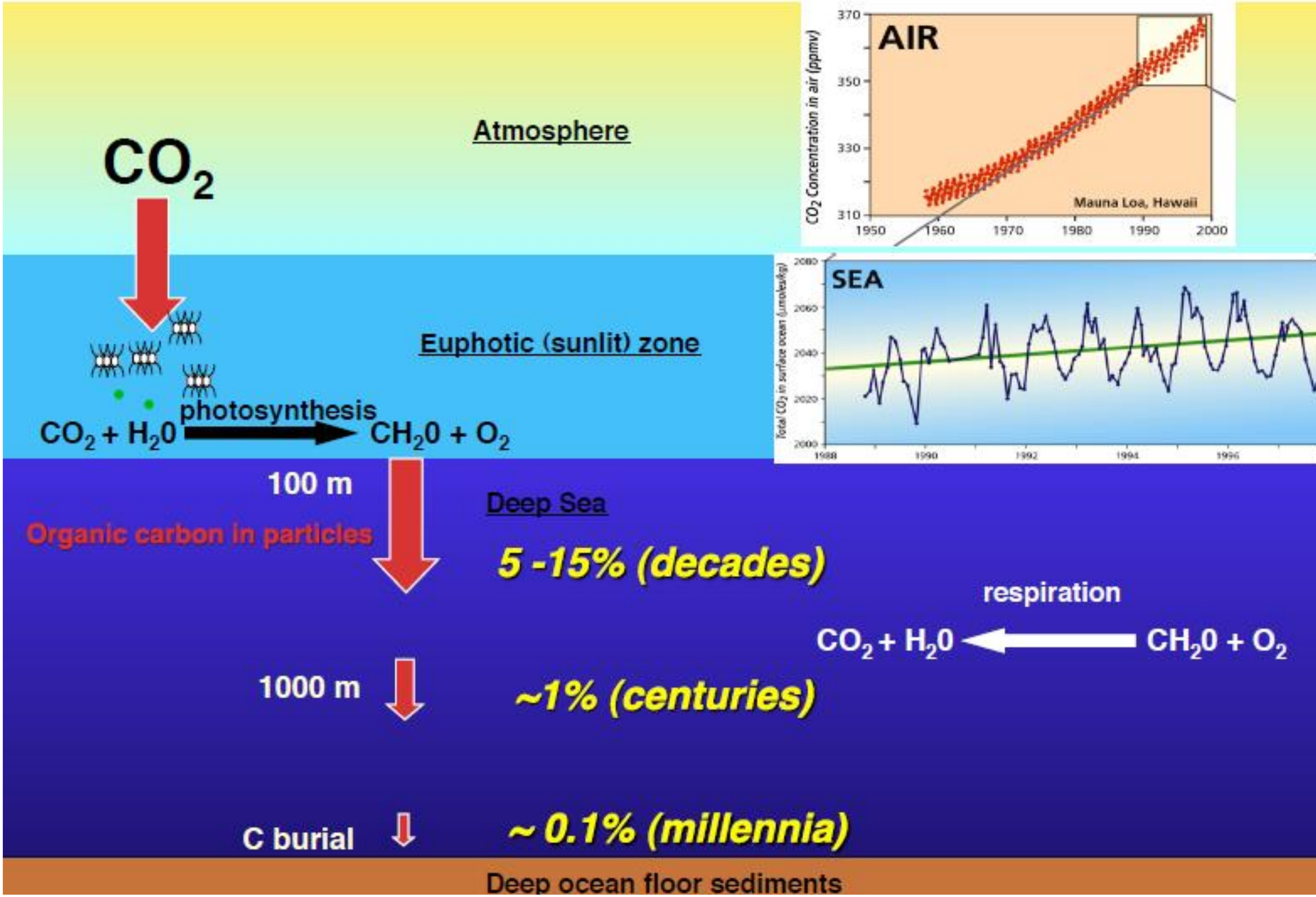
(a) VERTICAL O_2 PROFILES IN THE ATLANTIC OCEAN

(b) O_2-ADVECTION PATTERN IN THE ATLANTIC OCEAN

05.17: (a) Vertical O2 Profiles in the Atlantic Ocean
(b) O2 Advection Pattern in the Atlantic Ocean.

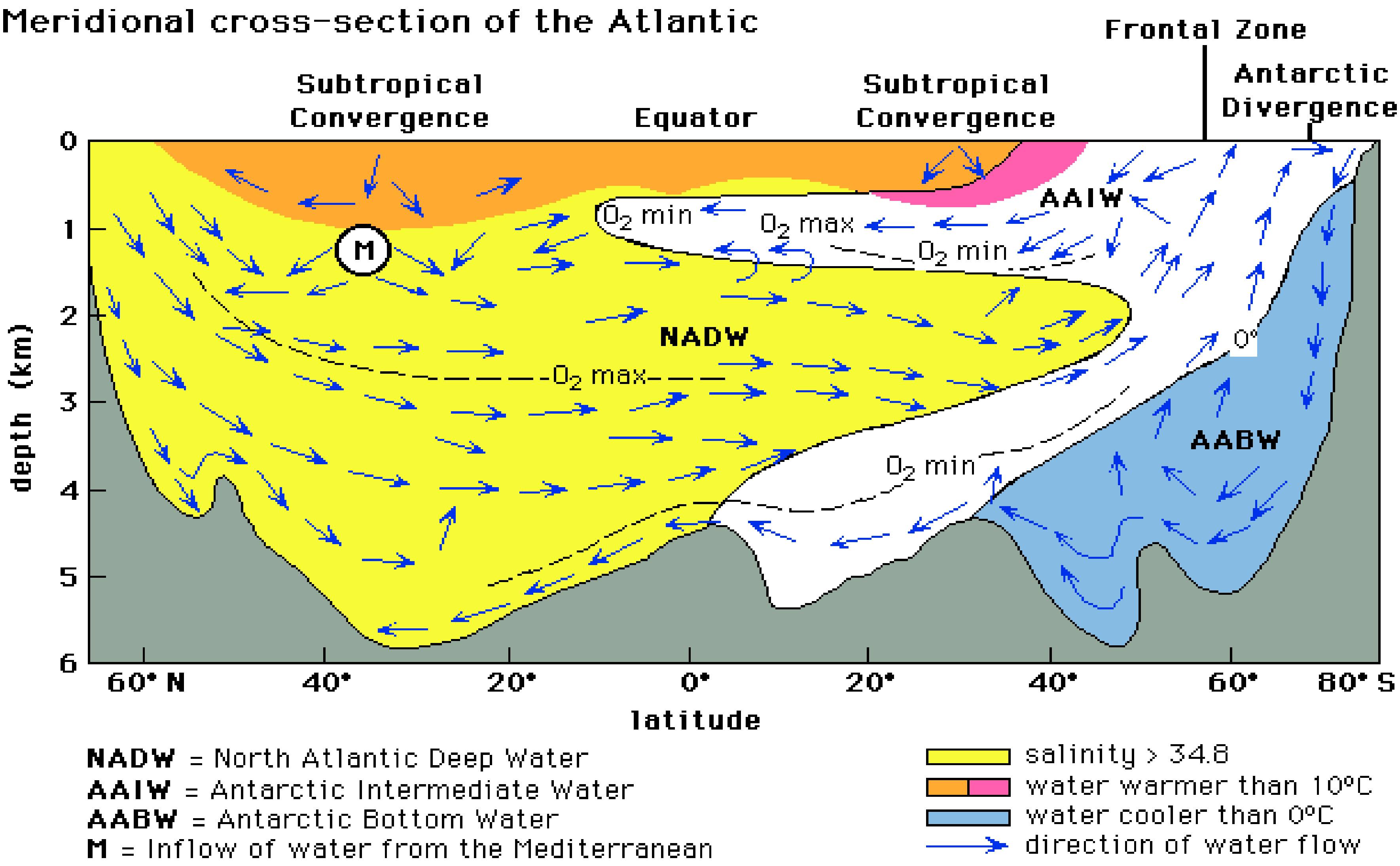
eWOCE atlas by R. Schlitzer, A16 Section, Atlantic Ocean Oxygen [µmol/kg]



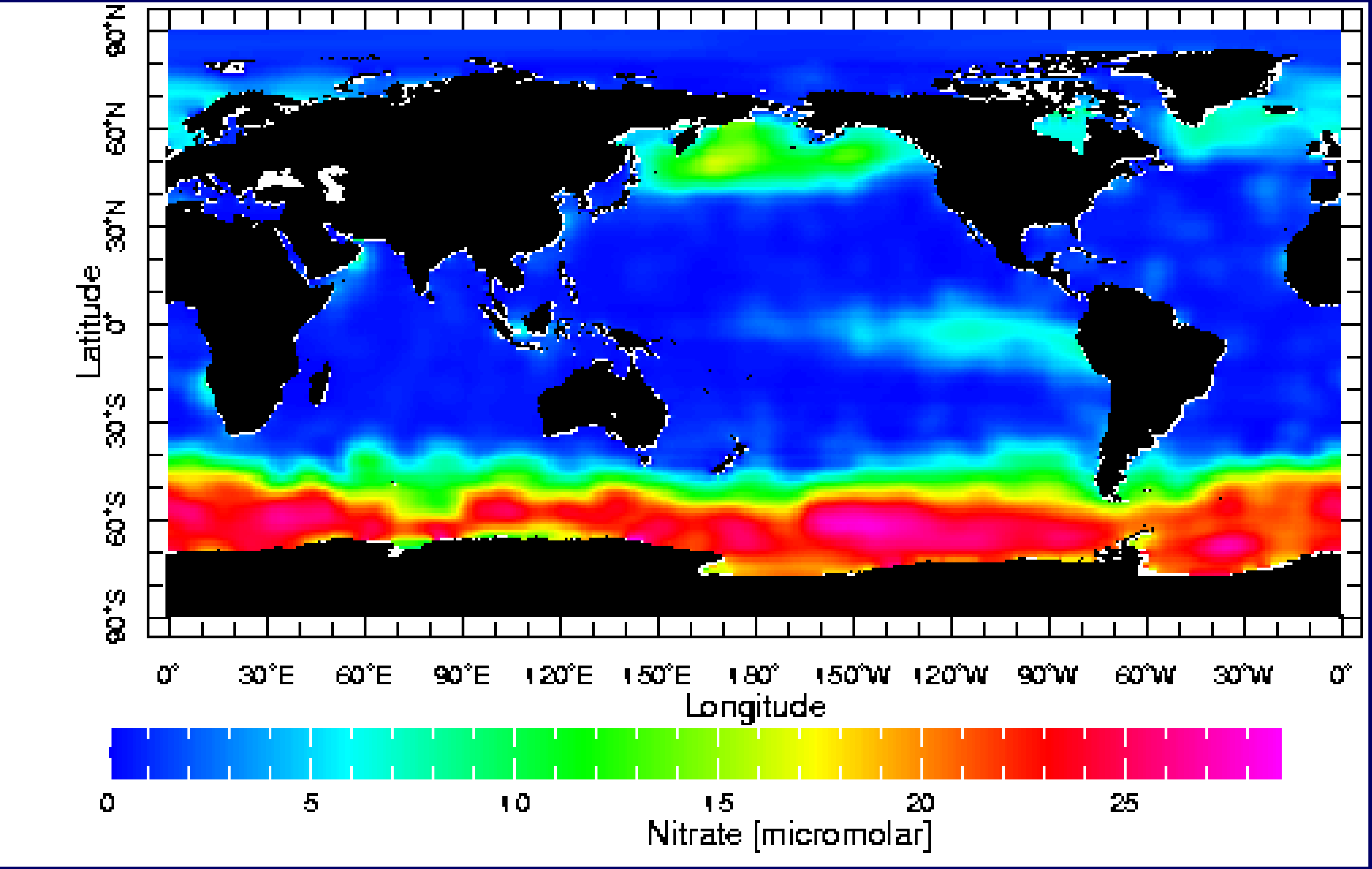

Atmosphere
CO_2
AIR
370
350
330
310
1950
1960
1970
1980
1990
2000
CO_2 Concentration in air (ppmv)
Mauna Loa, Hawaii
SEA
2080
2060
2040
2020
2000
1988
1990
1992
1994
1996
Euphotic (sunlit) zone
photosynthesis
$CO_2 + H_20 \rightarrow CH_20 + O_2$
100 m
Organic carbon in particles
Deep Sea
5 -15% (decades)
respiration
$CO_2 + H_20 \leftarrow CH_20 + O_2$
1000 m
~1% (centuries)
C burial
~ 0.1% (millennia)
Deep ocean floor sediments

Western Atlantic water masses

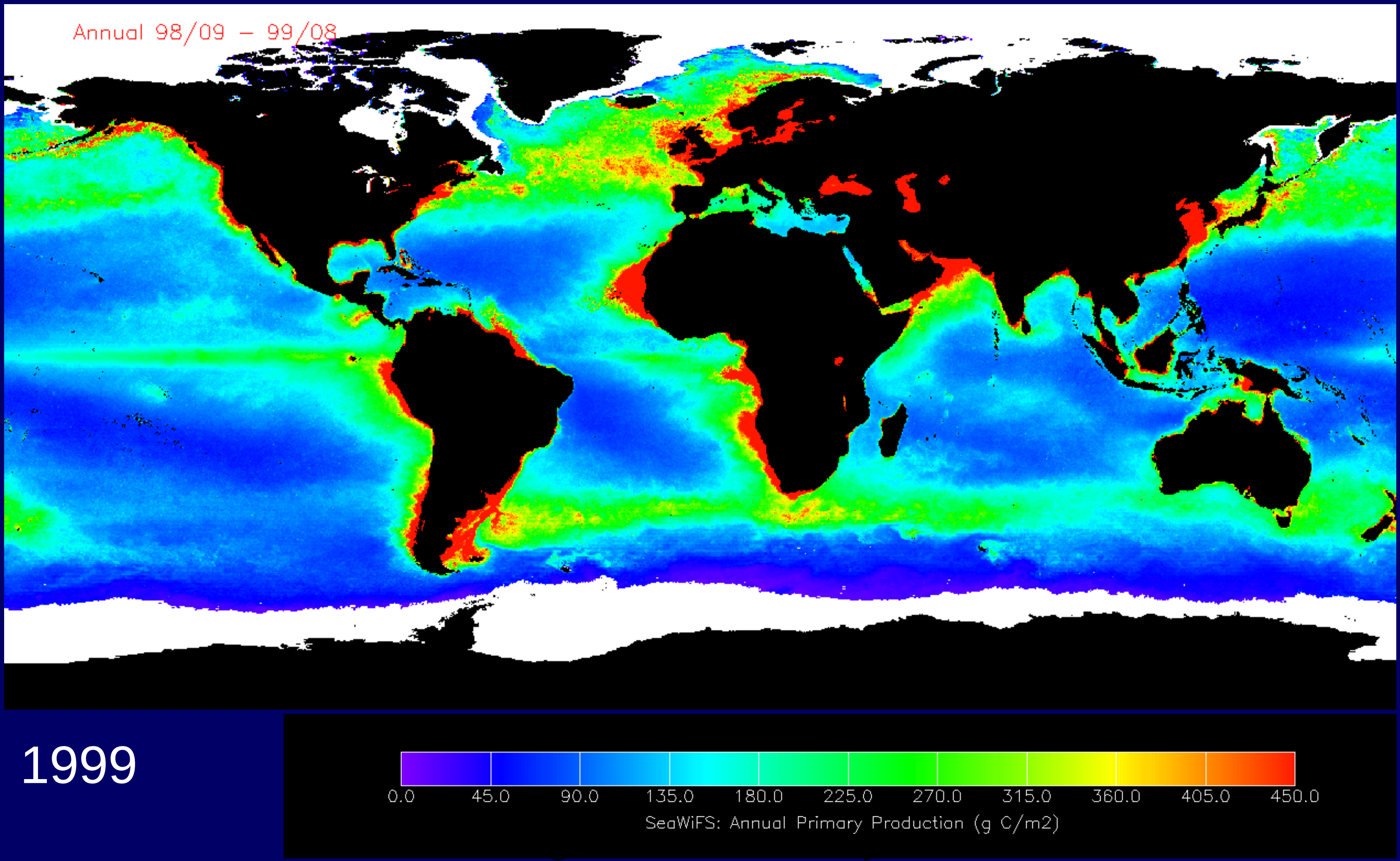
N S



Surface distribution of nitrate



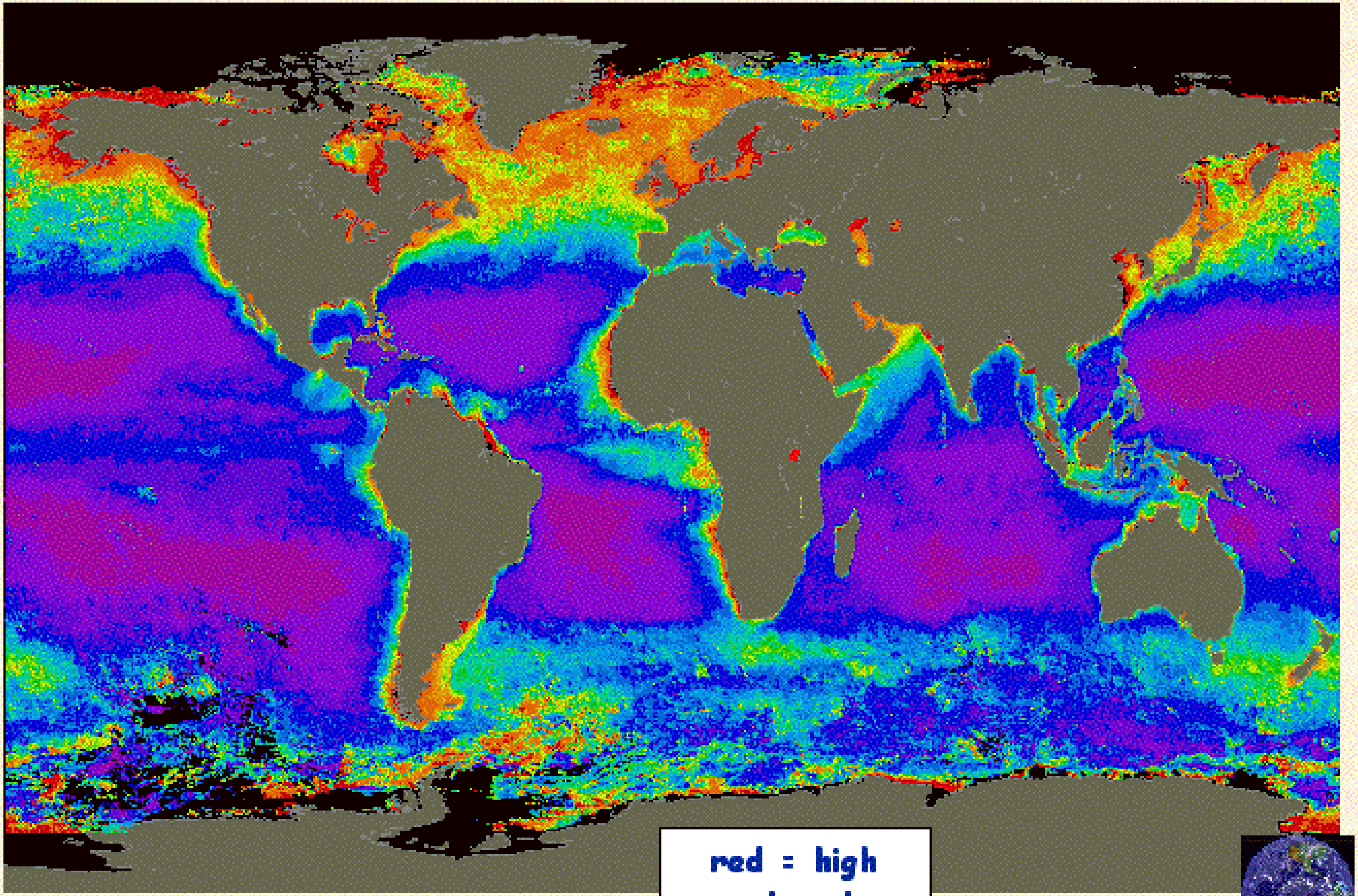
Surface water productivity

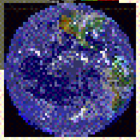


1999

Productivity Study

Global Annual Primary Production:





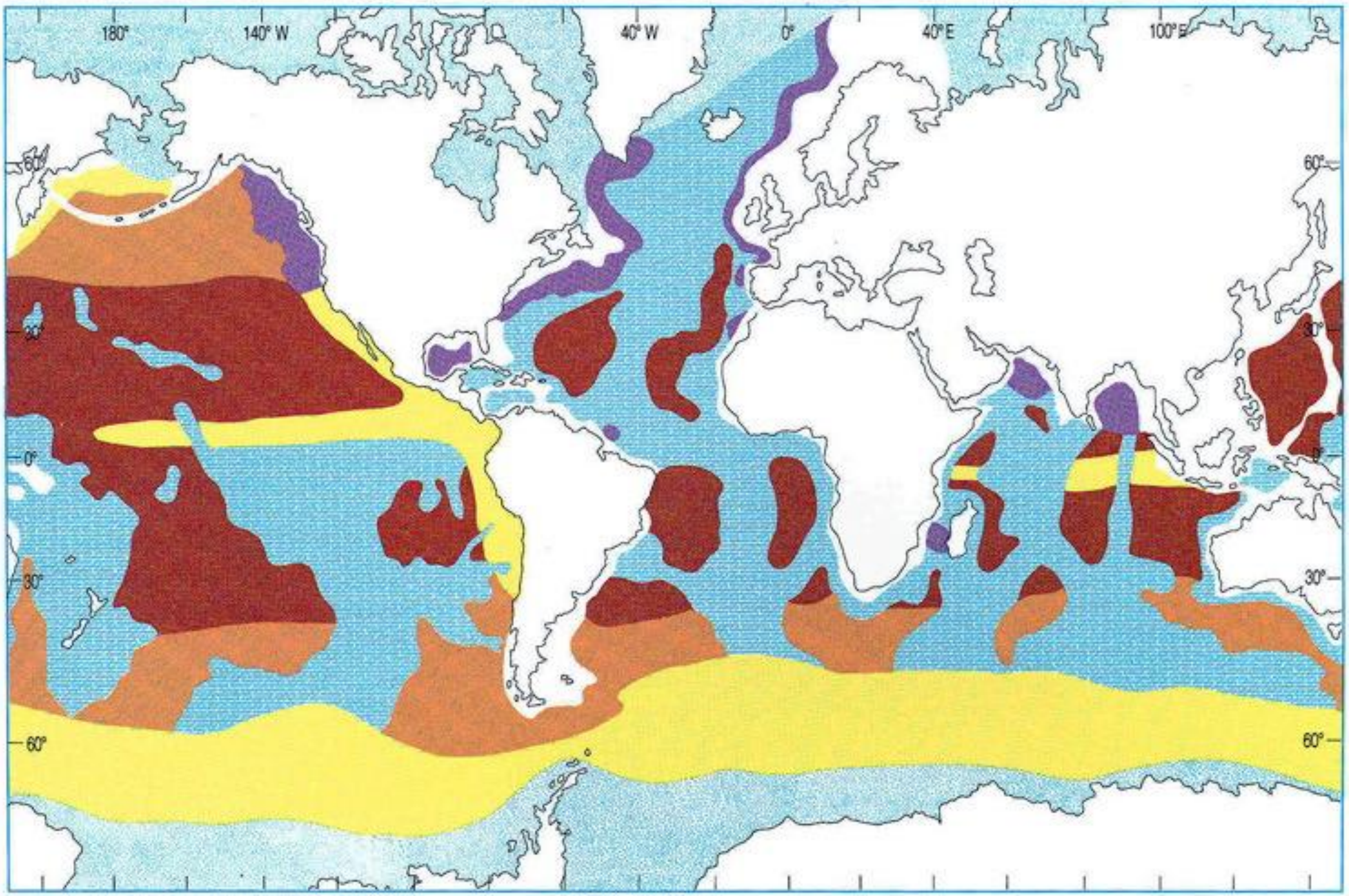


Figure 1.4 Distribution of dominant sediment types on the floor of the present-day oceans. Note that red clays are also terrigenous sediments.

End of 2nd lecture