Ocean Regions

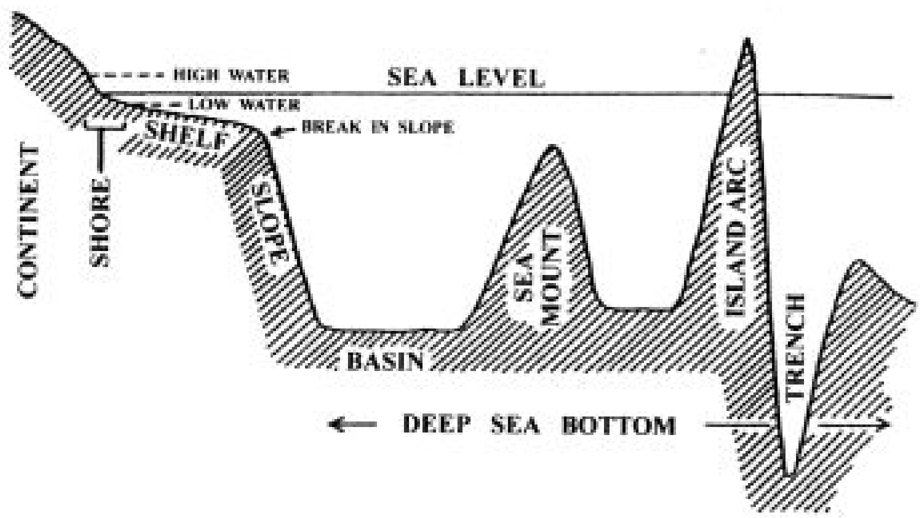
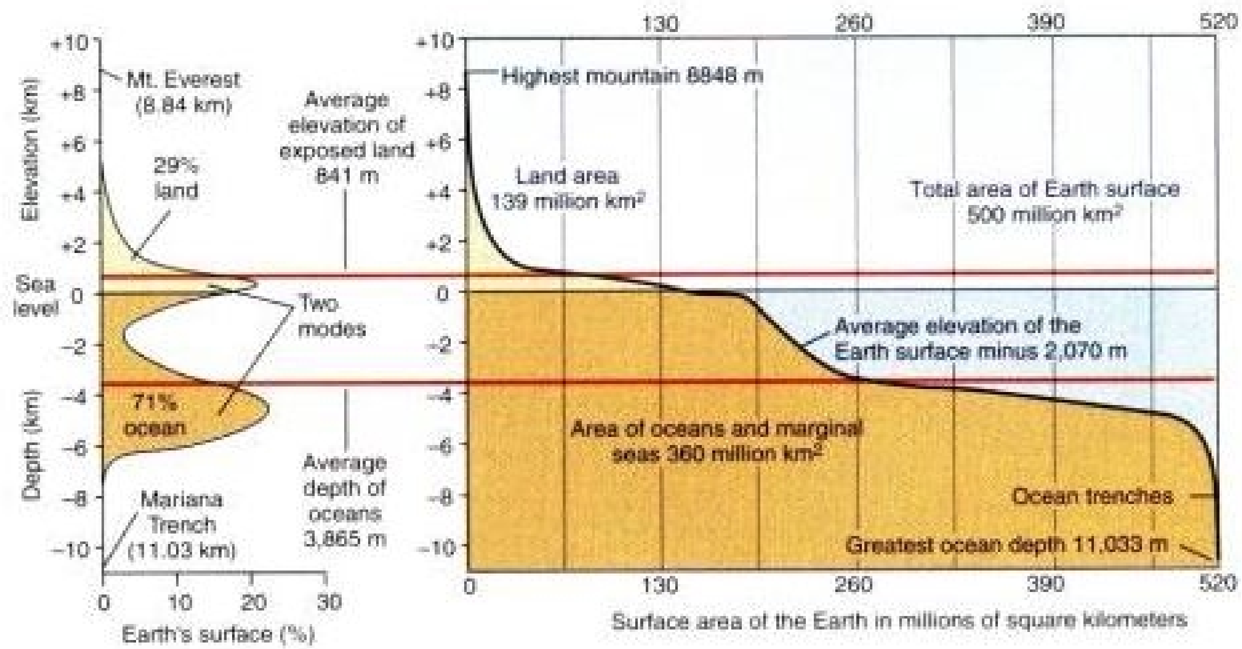
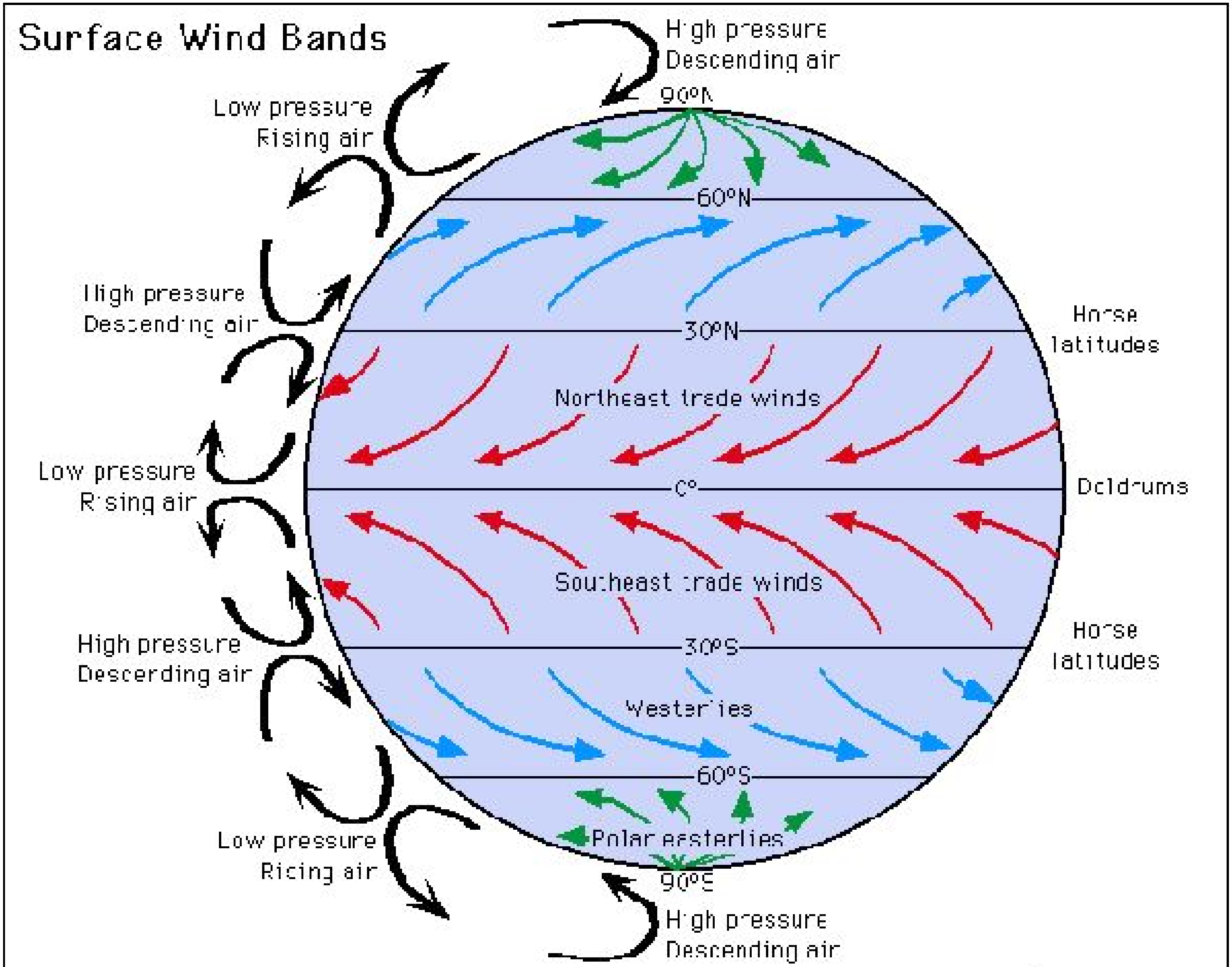


FIGURE 1.2. Structure of the ocean bottom.



Winds



Adapted from Duxbury, Alyn C. and Alison B. Duxbury. *An Introduction to the World's Oceans, 4/e.*
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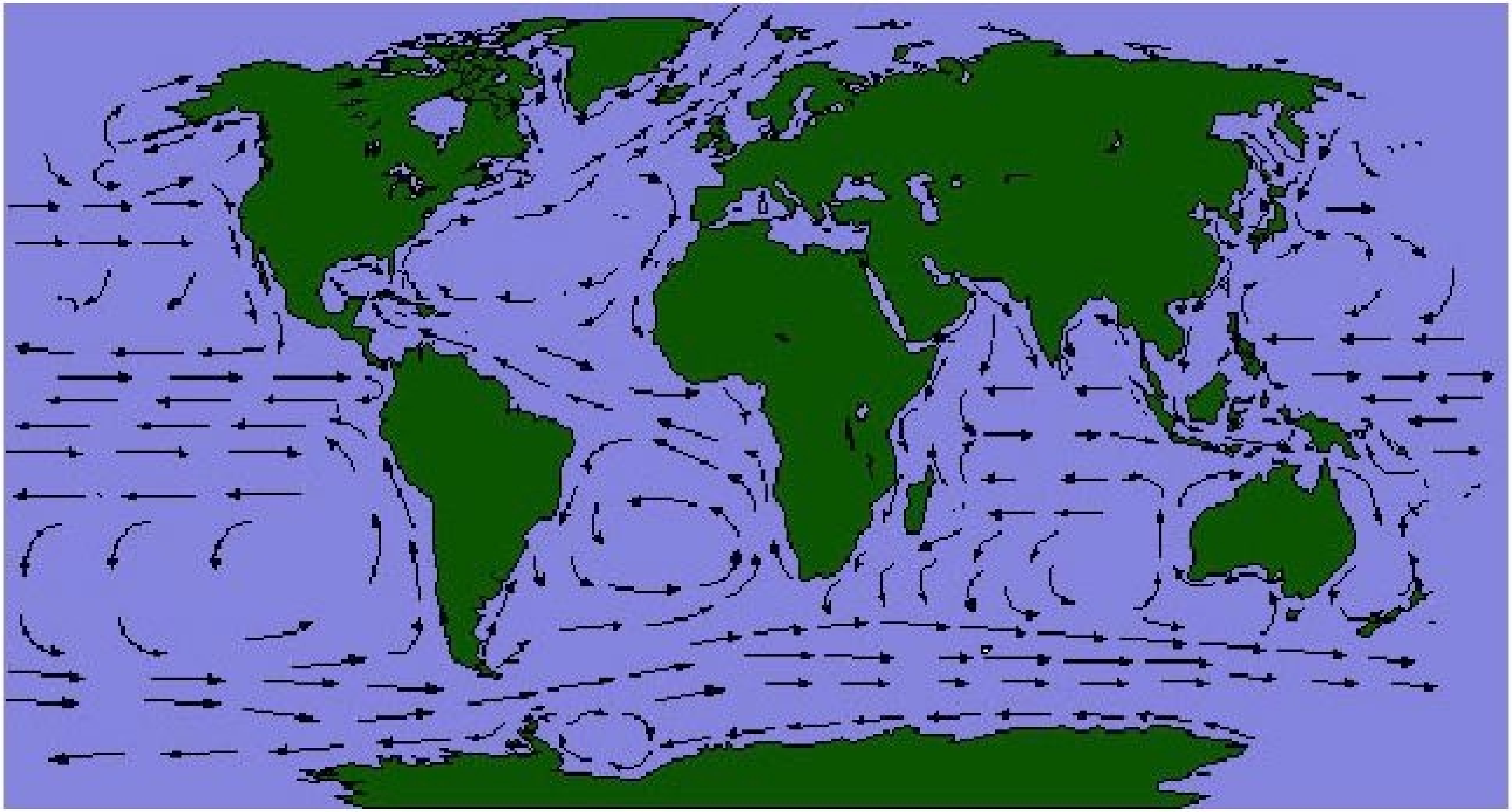
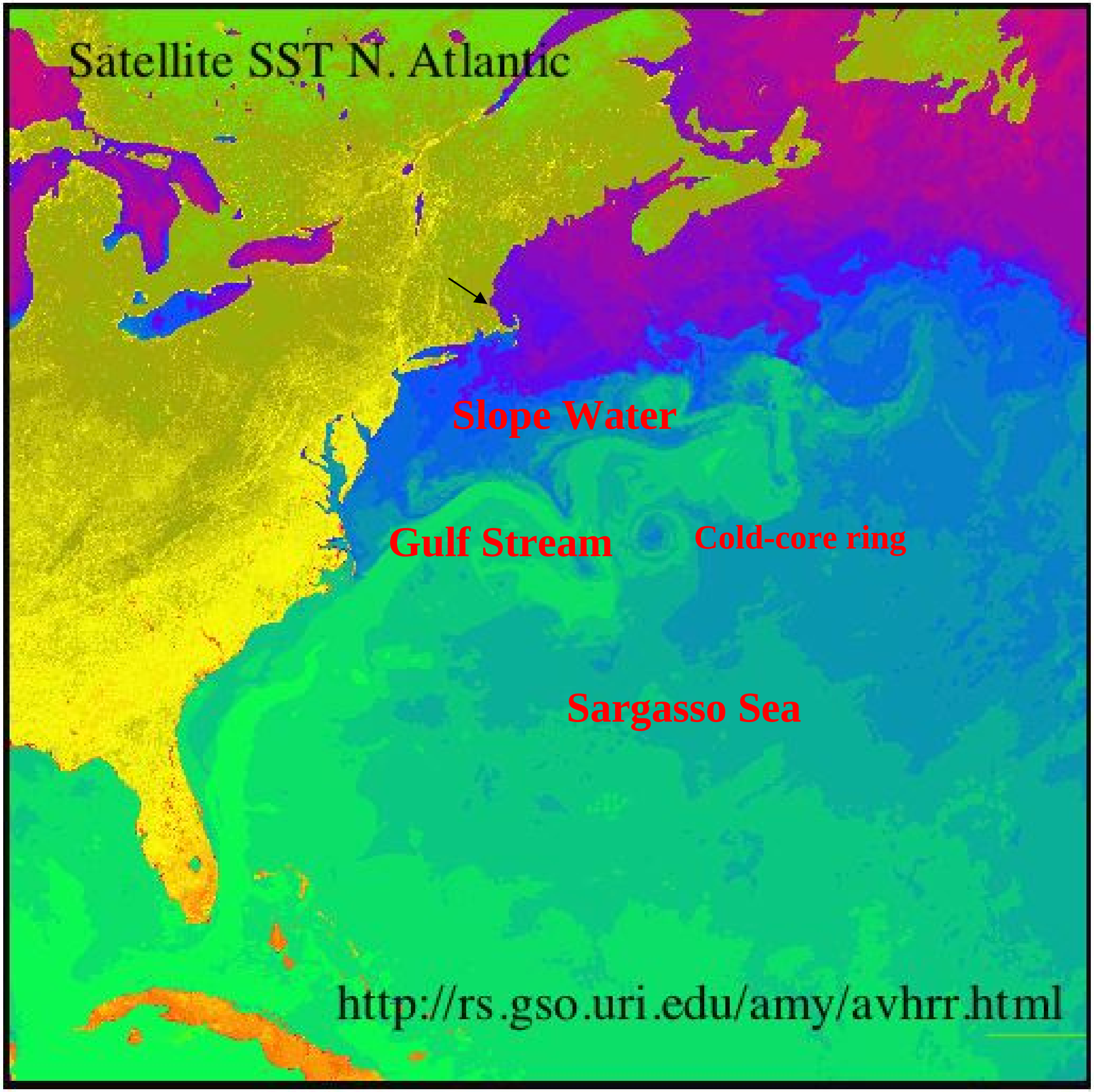
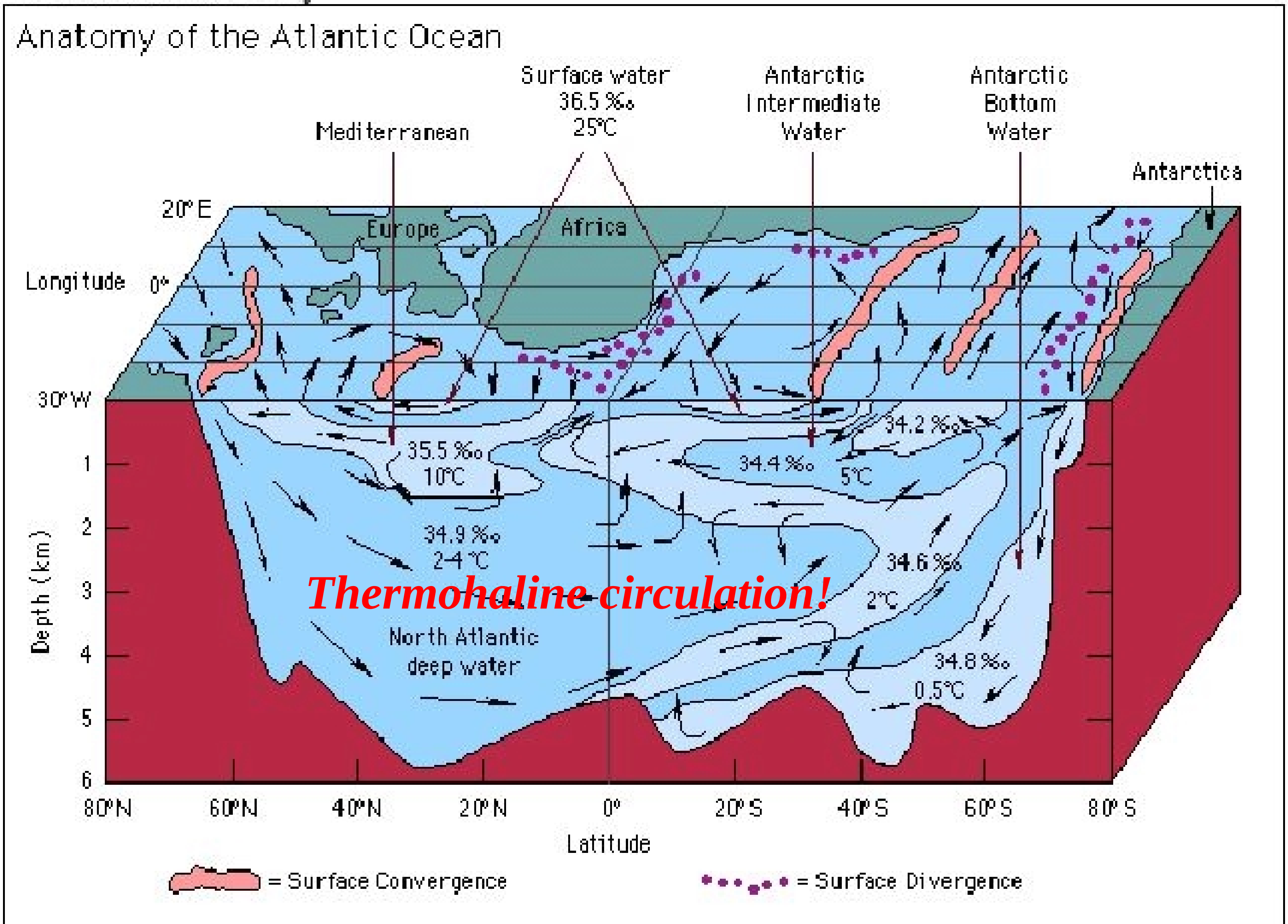
Major Surface Currents ***Wind-Driven!***





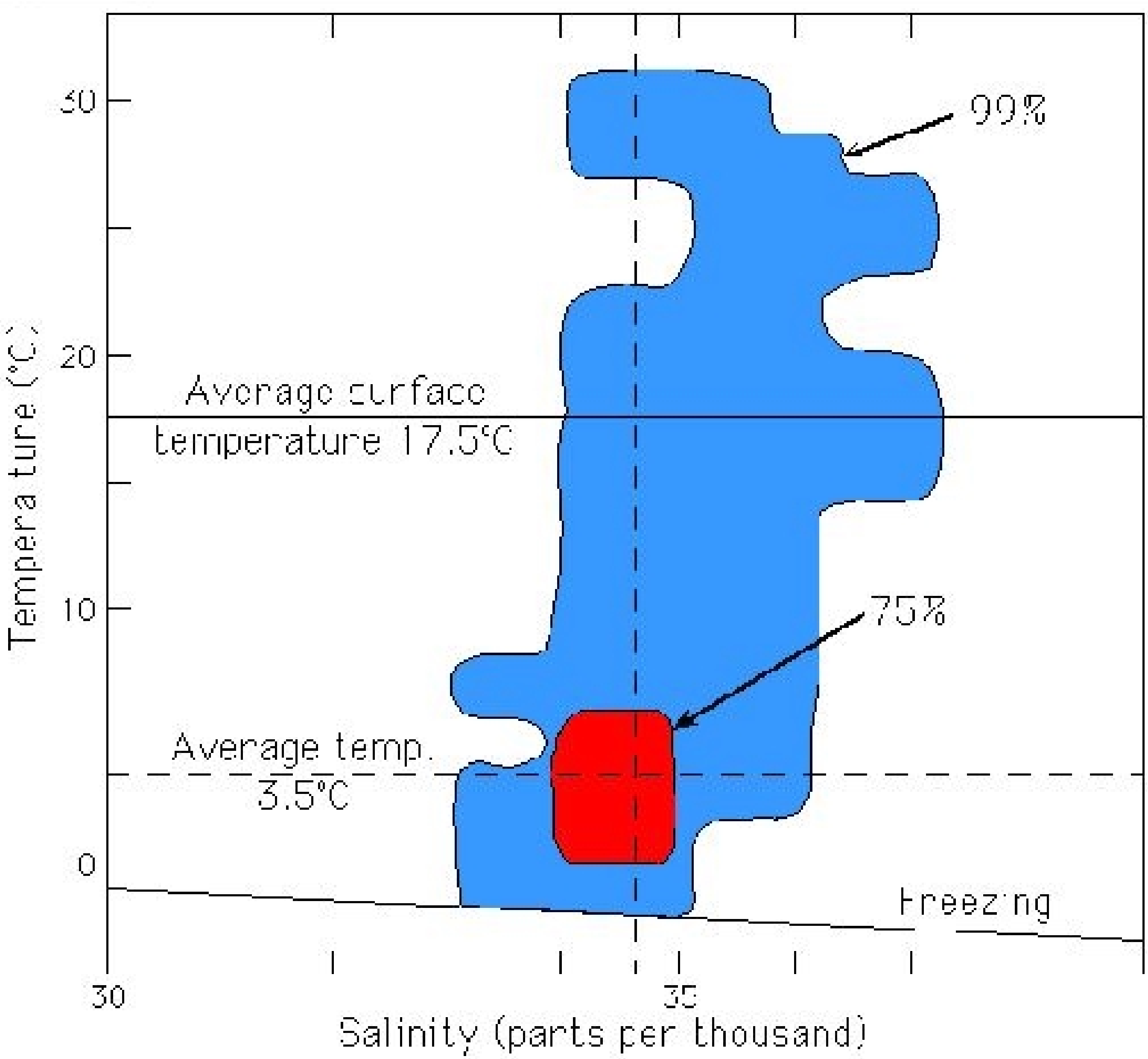
Satellite SST N. Atlantic
Slope Water
Gulf Stream
Cold-core ring
Sargasso Sea
http://rs.gso.uri.edu/amy/avhrr.html

N. Atlantic cut-away



Adapted from Duxbury, Alyn C. and Alison B. Duxbury. *An Introduction to the World's Oceans.* 1994 Wm. C. Brown Publishers.

Global T-S



Temperature and salinity of 99% (75%) of the ocean water are represented by points within the blue (red) area. (After Gross, 1993).

Temperature
Variations

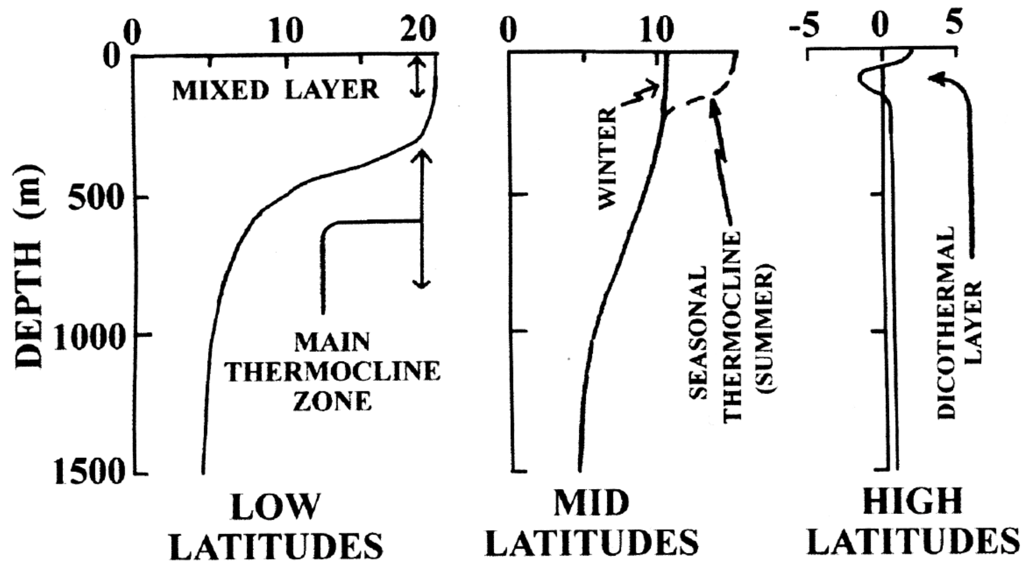


FIGURE 1.7. Typical temperature profiles in the ocean.

Heating/Cooling

Only at surface!

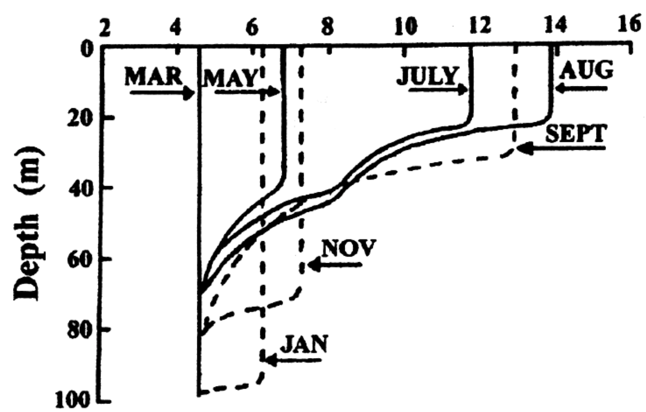


FIGURE 1.8. Growth and decay of the thermocline.

Potential Temperature

Extreme pressure at depth increases ***in situ temperature*** *due to compression (adiabatic heating)*

Potential temperature *is the temperature that would be attained at 1 atm.*

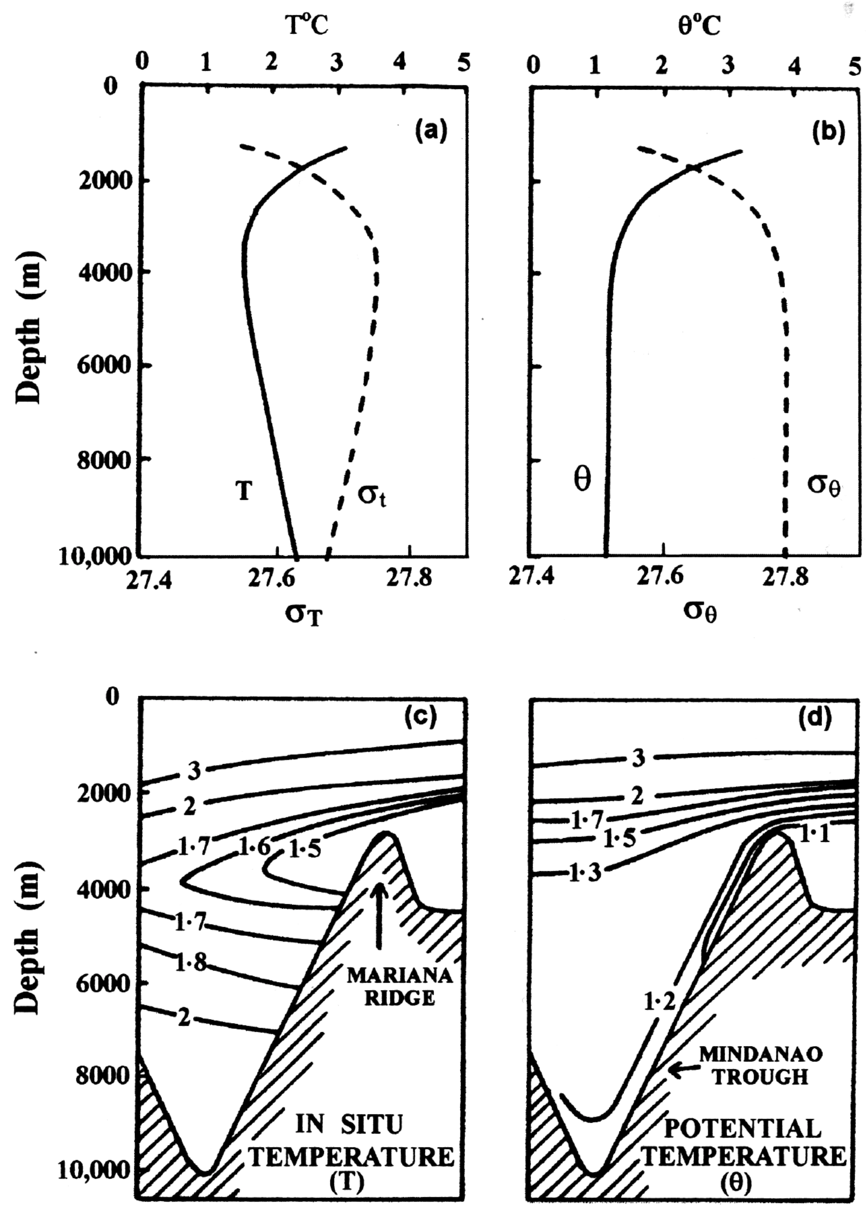
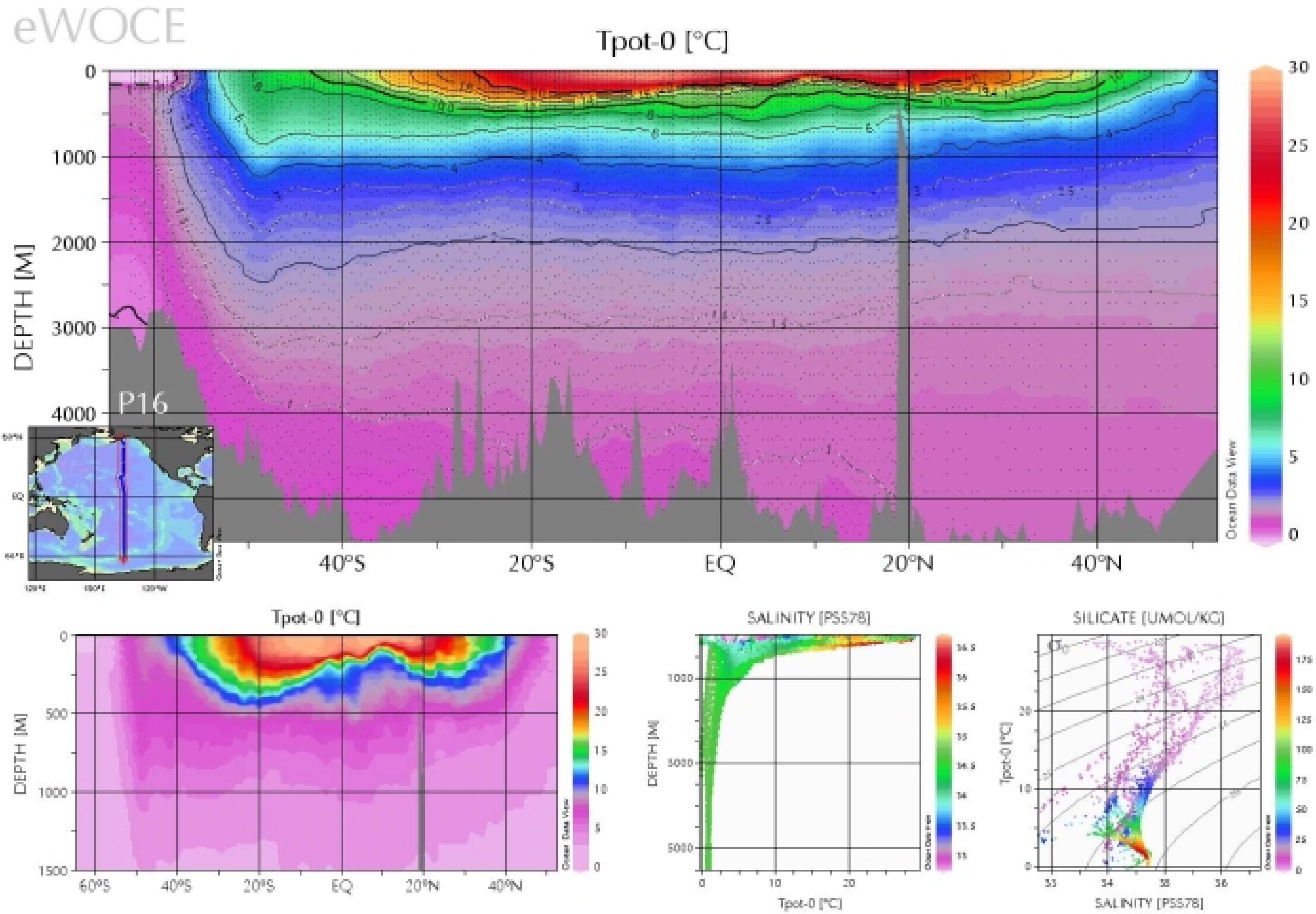


FIGURE 1.9. *In situ* and potential temperature in deep sea trench.


eWOCE
Tpot-0 [°C]
DEPTH [M]
P16
40°S
20°S
EQ
20°N
40°N
Ocean Data View
Tpot-0 [°C]
DEPTH [M]
60°S
40°S
20°S
EQ
20°N
40°N
SALINITY [PSS78]
DEPTH [M]
Tpot-0 [°C]
SILICATE [UMOL/KG]
Tpot-0 [°C]
SALINITY [PSS78]

Salinity Variations

Addition or loss of freshwater occurs only at surface and reflect riverine input near coasts and balance between evaporation and precipitation

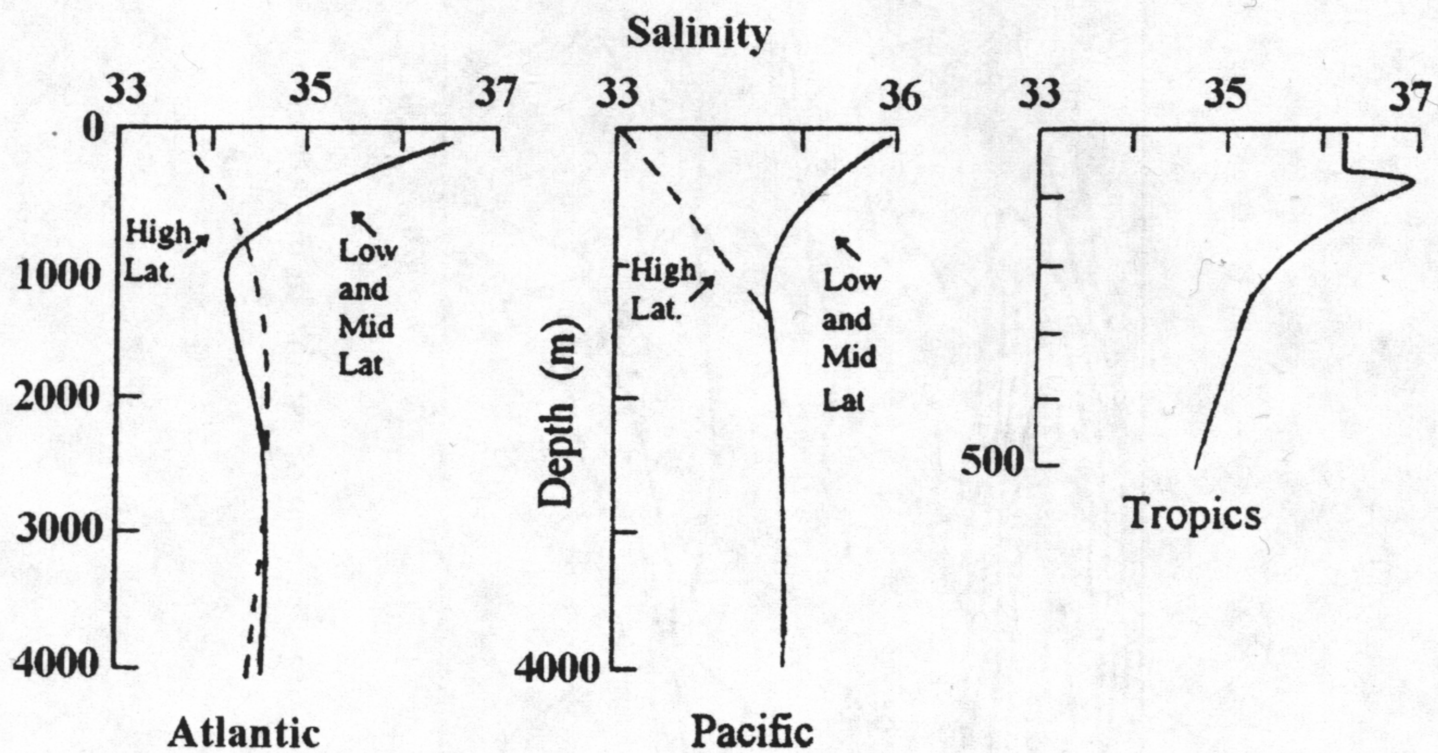
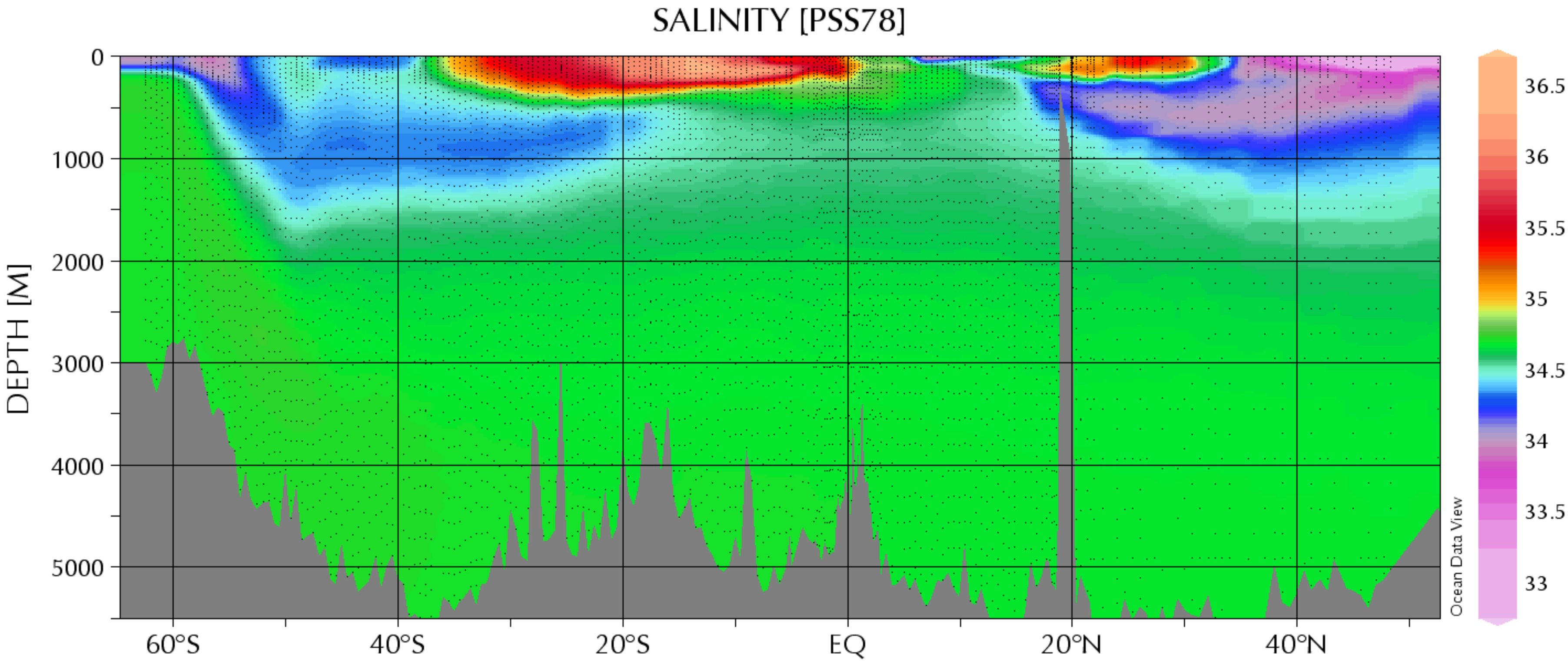


FIGURE 1.15. Typical salinity profiles in the oceans.


SALINITY [PSS78]
DEPTH [M]
0
1000
2000
3000
4000
5000
60°S
40°S
20°S
EQ
20°N
40°N
36.5
36
35.5
35
34.5
34
33.5
33
Ocean Data View

Sigma-Theta Calculation

Density effects:

Increase Temperature:
Reduce Density

Increase Salinity:
Increase Density

$\rho_\eta = [\theta^o/\theta_{ref} - 1] \times 1000$

TABLE 1.4
The International Equation of State for Seawater Kg/m³

$v^P = v^0(1 - P/K)$
$\rho^P = \rho^0[1/(1 - P/K)]$

where: *t is potential temp. (°C)!*

$$\rho^0 = 999.842594 + 6.793952 \times 10^{-2}\,t - 9.095290 \times 10^{-3}\,t^2 + 1.001685 \times 10^{-4}\,t^3 - 1.120083 \times 10^{-6}\,t^4 + 6.536336 \times 10^{-9}\,t^5 + (8.24493 \times 10^{-1} - 4.0899 \times 10^{-3}\,t + 7.6438 \times 10^{-5}\,t^2 - 8.2467 \times 10^{-7}\,t^3 + 5.3875 \times 10^{-9}\,t^4)\,S + (-5.72466 \times 10^{-3} + 1.0227 \times 10^{-4}\,t - 1.6546 \times 10^{-6}\,t^2)S^{3/2} + 4.8314 \times 10^{-4}\,S^2$$

$$K = 19652.21 + 148.4206\,t - 2.327105t^2 + 1.360477 \times 10^{-2}\,t^3 - 5.155288 \times 10^{-5}\,t^4 + S(54.6746 - 0.603459t + 1.09987 \times 10^{-2}\,t^2 - 6.1670 \times 10^{-5}\,t^3) - S^{3/2}(7.944 \times 10^{-2} + 1.6483 \times 10^{-2}\,t - 5.3009 \times 10^{-4}\,t^2) + P[3.239908 + 1.43713 \times 10^{-3}\,t + 1.16082 \times 10^{-4}\,t^2 - 5.77905 \times 10^{-7}\,t^3 + S(2.2838 \times 10^{-3} - 1.0981 \times 10^{-5}\,t - 1.6078 \times 10^{-6}\,t^2) + S^{3/2}(1.91075 \times 10^{-4})] + P2[8.50935 \times 10^{-5} - 6.12293 \times 10^{-6}\,t + 5.2787 \times 10^{-8}\,t^2 + S(-9.9348 \times 10^{-7} + 2.0816 \times 10^{-8}\,t + 9.1697 \times 10^{-10}\,t^2)]$$

Check values:	S	t	P	Kg/m³	K(b)
	35	5°C	0 b	1027.67547	22185.93358
			1000	1069.48914	25577.49819

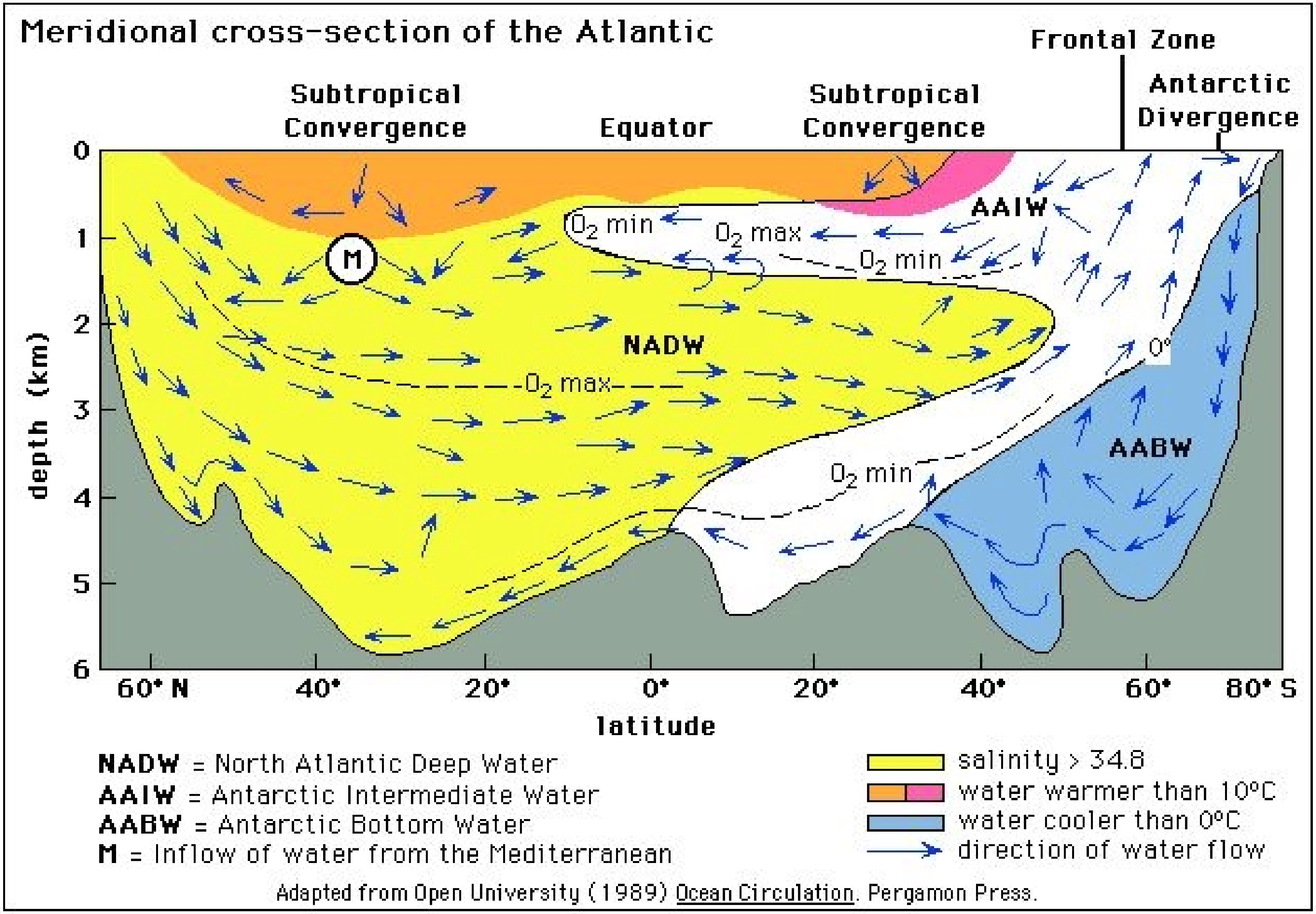
[a] Millero et al., *Deep-Sea Res.,* **27**, 255, 1980; Millero and Poisson, *Deep-Sea Res.,* **28**, 625, 1981.

Major Water Mass Characteristic:

TABLE 4.1
Major Water Masses of the World Ocean

Water mass	*Temperature (°C)*	*Salinity (‰)*
Central water masses		
N. Atlantic water (NAC)	8–19	35.1–36.5
S. Atlantic water (SAC)	6–17	34.7–36.0
W. North Pacific water (NPC)	6–18	34.0–34.9
W. South Pacific water (SPC)	10–17	34.5–35.6
Indian water (IC)	7–16	34.5–35.6
High-latitude surface water masses		
Atlantic subarctic water	4–5	34.6–34.7
Pacific subarctic water	3–6	33.5–34.4
Subantartic water	3–10	33.9–34.7
Antarctic circumpolar water	0–2	34.6–34.7
Intermediate water masses		
Arctic intermediate water (NAI)	3–5	34.7–34.9
N. Pacific intermediate water (NPI)	4–10	34.0–34.5
Antarctic intermediate water (AI)	3–7	33.8–34.7
Mediterranean intermediate water (MI)	6–12	35.3–36.5
Red Sea intermediate water (RSI)	8–12	35.1–35.7
Deep and bottom water masses		
N. Atlantic deep and bottom water (NAD and B)	2–4	34.8–35.1
Antarctic bottom water (AB)	−0.4	34.7

Source: From *The World Ocean: An Introduction to Oceanography*, W. A. Anikouchine and R. W. Sternberg, copyright © 1981 by Prentice Hall, Inc., Englewood Cliffs, NJ, p. 219. Reprinted by permission. After *The Oceans*, H. U. Sverdrup, M. W. Johnson, and R. H. Fleming, copyright © 1941 by Prentice Hall, Inc., Englewood Cliffs, NJ, p. 741. Reprinted by permission.



Atlantic water masses

TS mixing

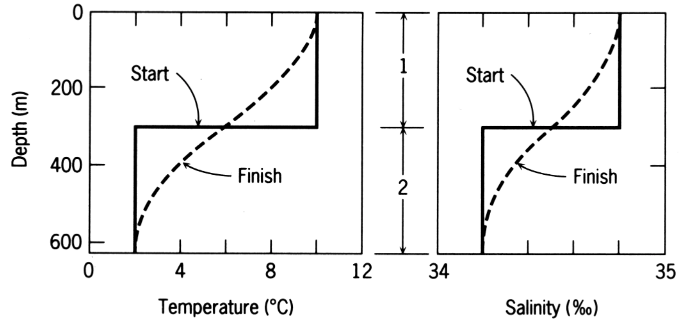


FIGURE 4.10. Conservative mixing of water masses. *Source:* From *Oceanography: A View of the Earth,* 4th ed., M. G. Gross, copyright © 1987 by Prentice Hall, Inc., Englewood Cliffs, NJ, p. 169. Reprinted by permission.

The rate of change in concentration of a conservative solute, C, at some fixed point, x, which is caused by turbulent mixing is given by Fick's Second Law:

$$\frac{\partial[C]}{\partial t} = D_x\left[\frac{\partial}{\partial x}\left(\frac{\partial[C]}{\partial x}\right)\right] = D_x\left[\frac{\partial^2[C]}{\partial x^2}\right] \qquad (4.1)$$

where D_x is the turbulent mixing coefficient for water motion in the x direction.

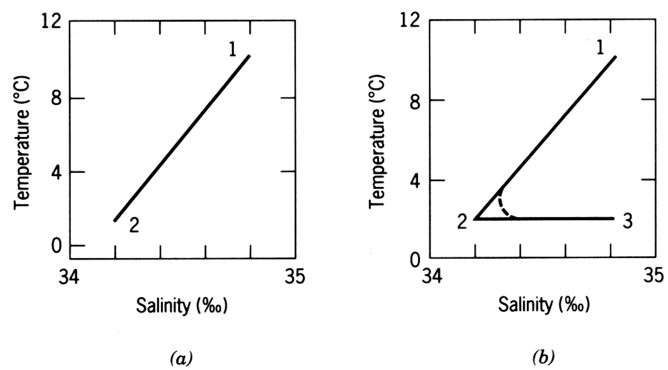
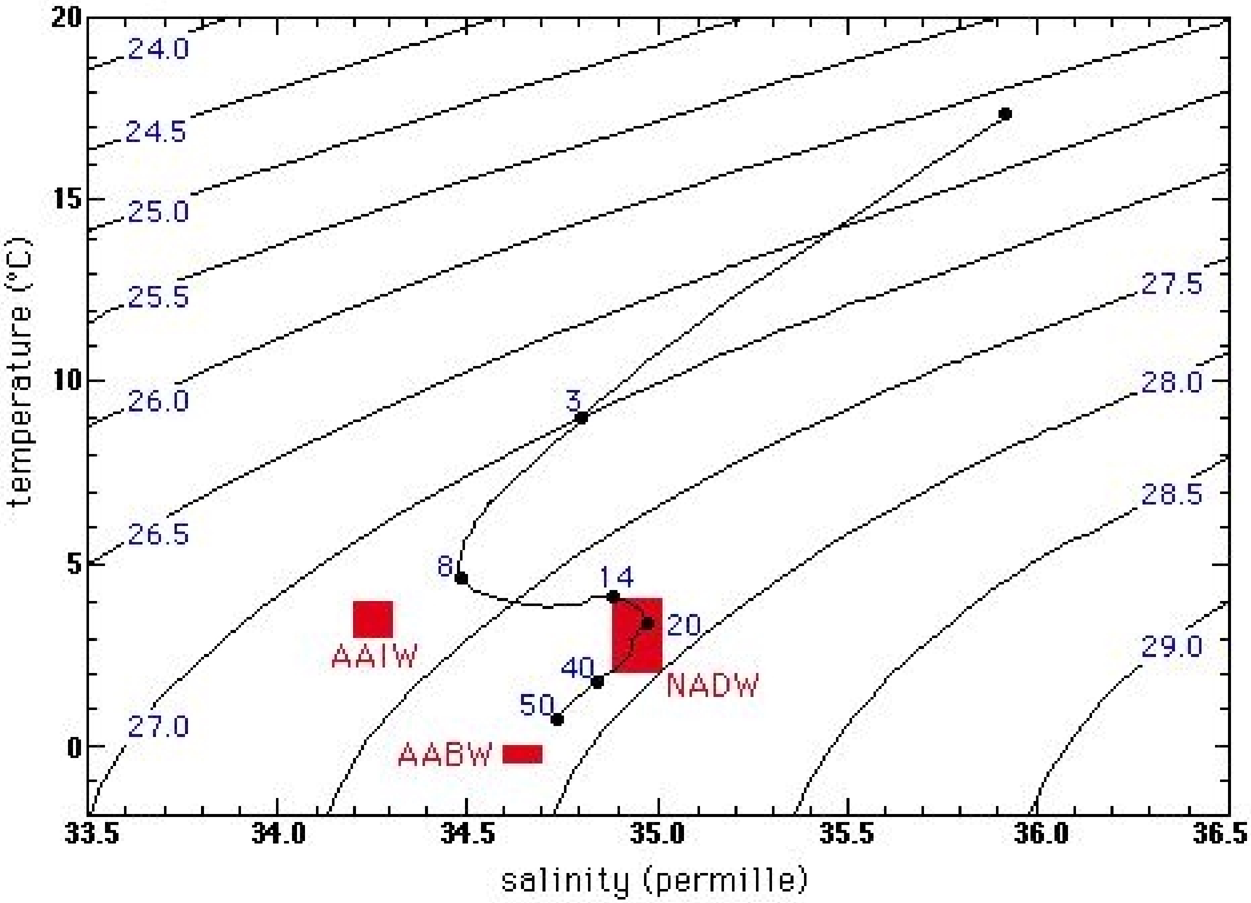


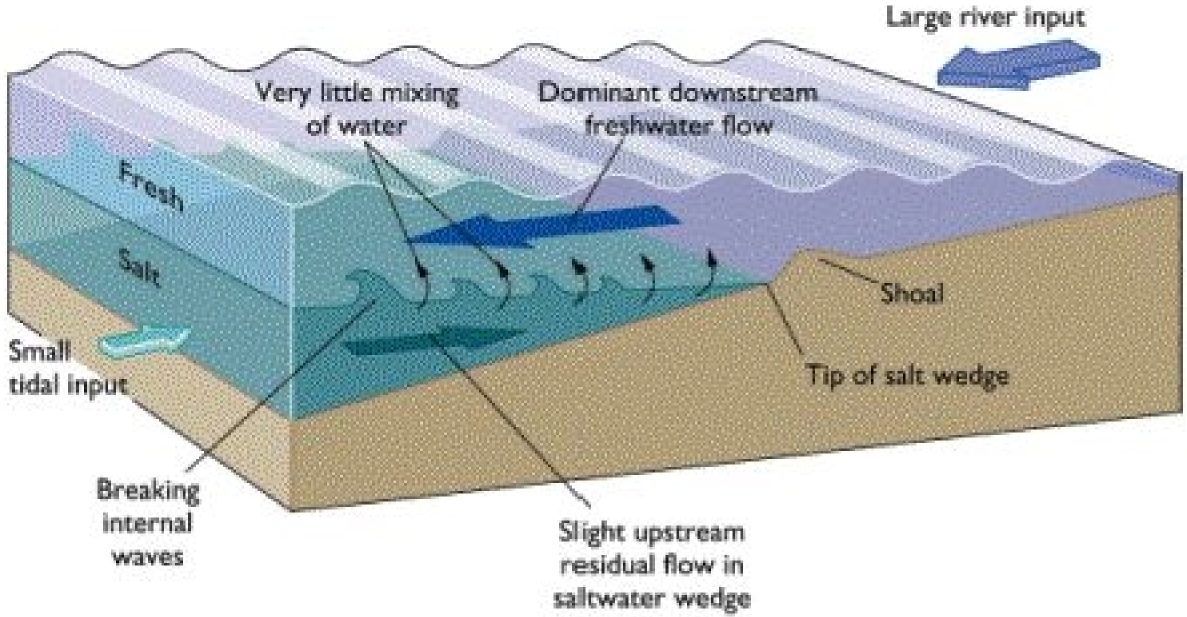
FIGURE 4.11. T–S Diagram indicating the presence of (a) two water masses and (b) multiple water masses. From *Oceanography: A View of the Earth,* 4th ed., M. G. Gross, copyright © 1987 by Prentice Hall, Inc., Englewood Cliffs, NJ, p. 169. Reprinted by permission.

Typical T-S diagram

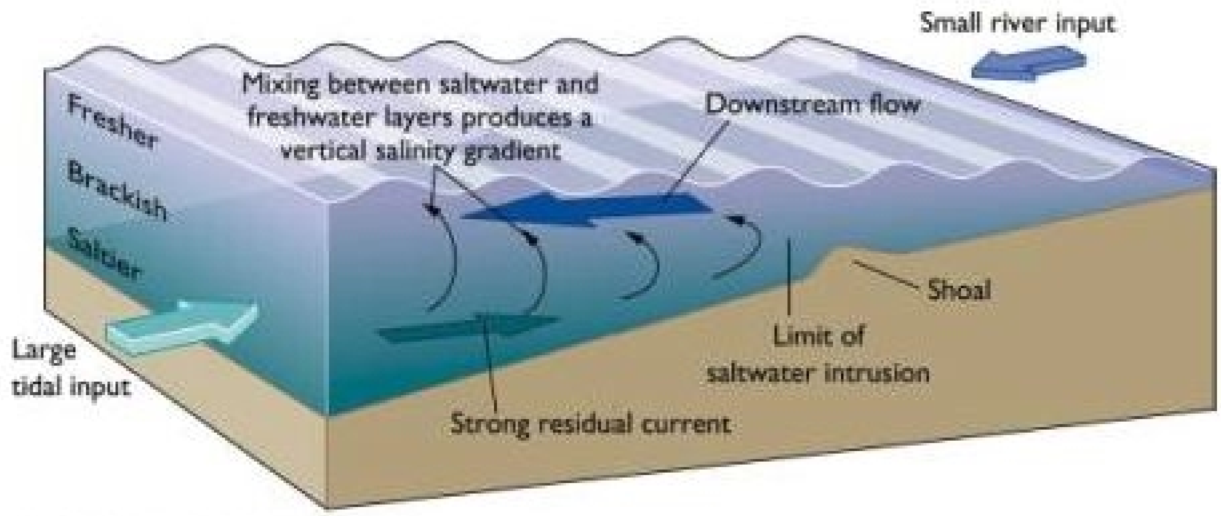


An example of a T-S diagram for observations at depths from 150 m to 5,000 m at 9°S latitude in the Atlantic Ocean. Dots represent individual seawater samples; numbers indicate depths in hundreds of meters. Red boxes represent the major subsurface Atlantic water masses. AABW = Antarctic Bottom Water; NADW = North Atlantic Deep Water; AAIW = Antarctic Intermediate Water.

Estuarine Circulation

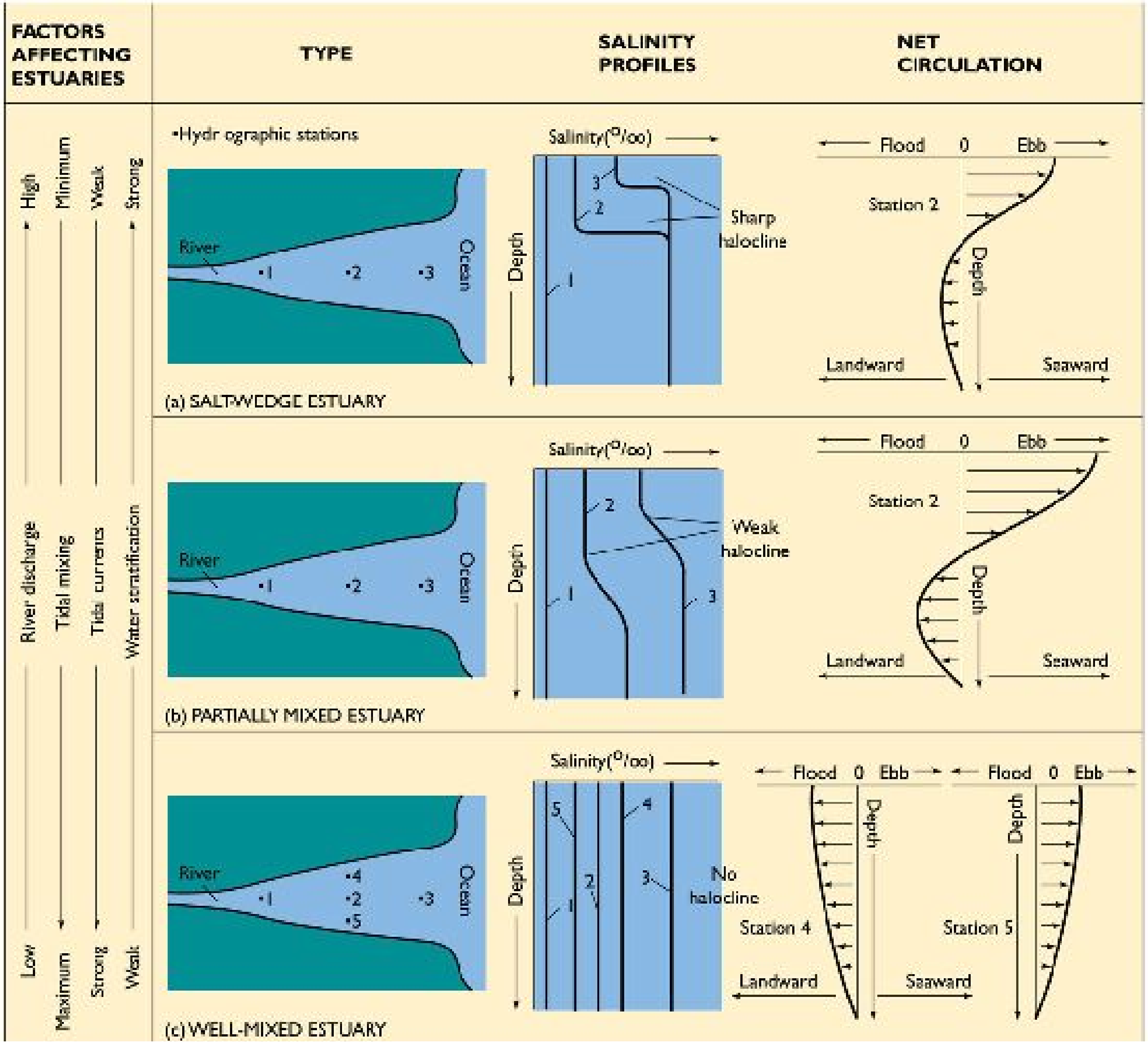


(a) SALT-WEDGE ESTUARY

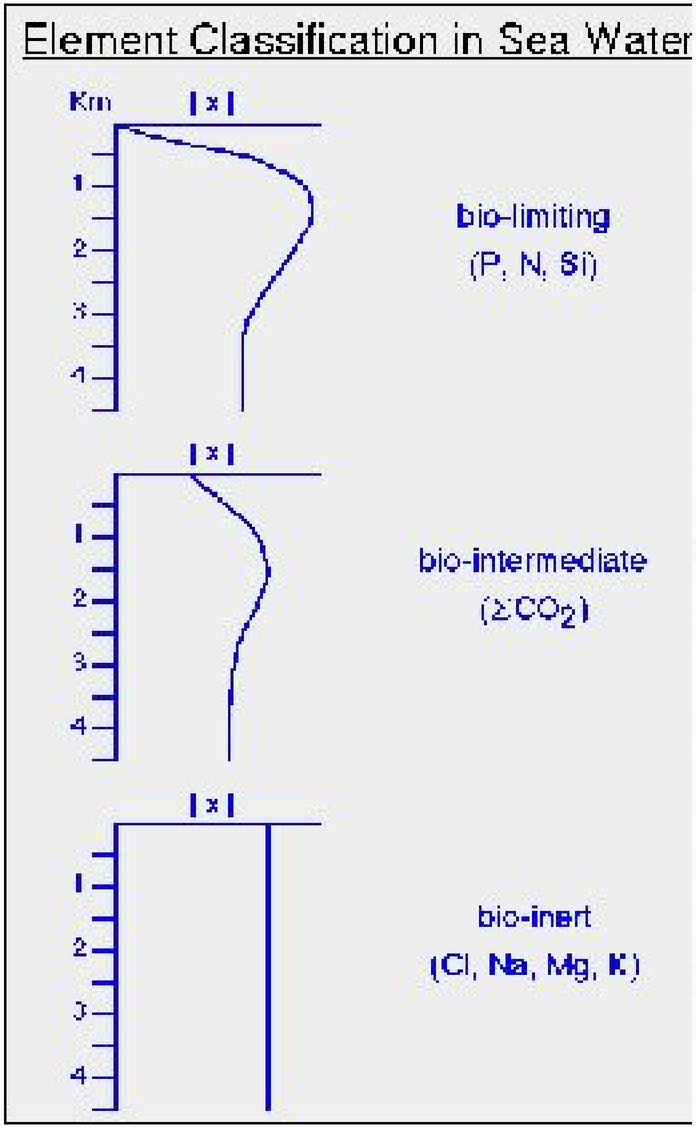


(b) PARTIALLY MIXED ESTUARY

Estuary Types



Element Dist Types



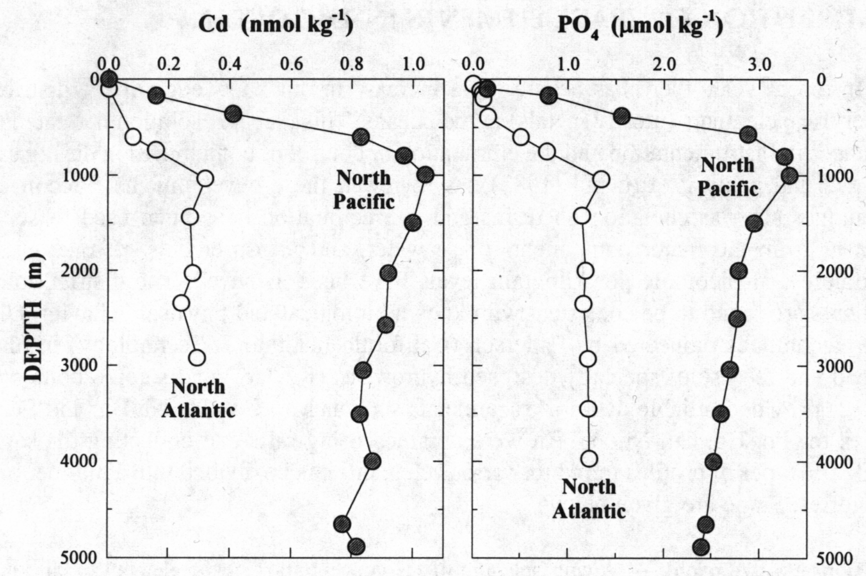


FIGURE 3.6. Profiles of cadmium (Cd) and phosphate (PO_4) in the Atlantic and Pacific Oceans.

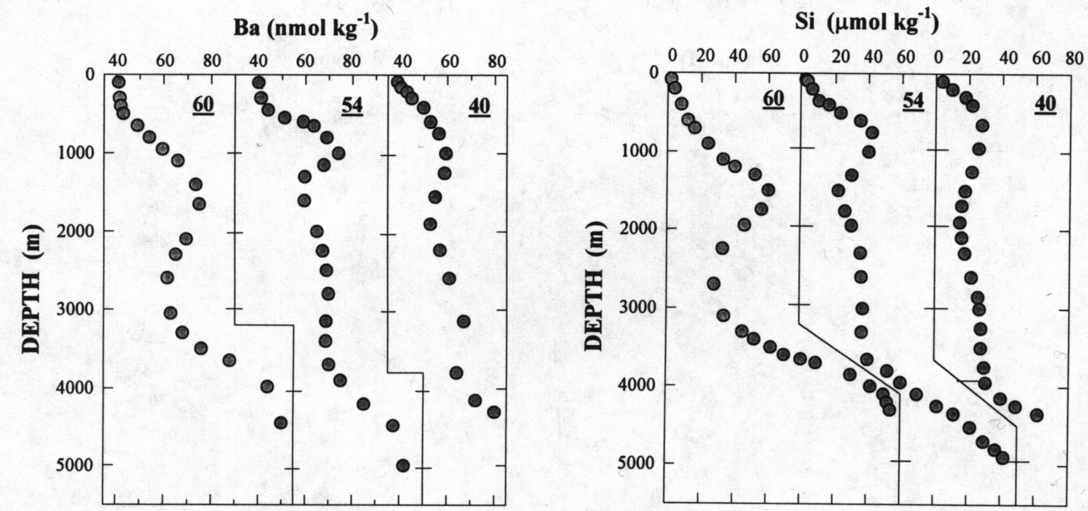


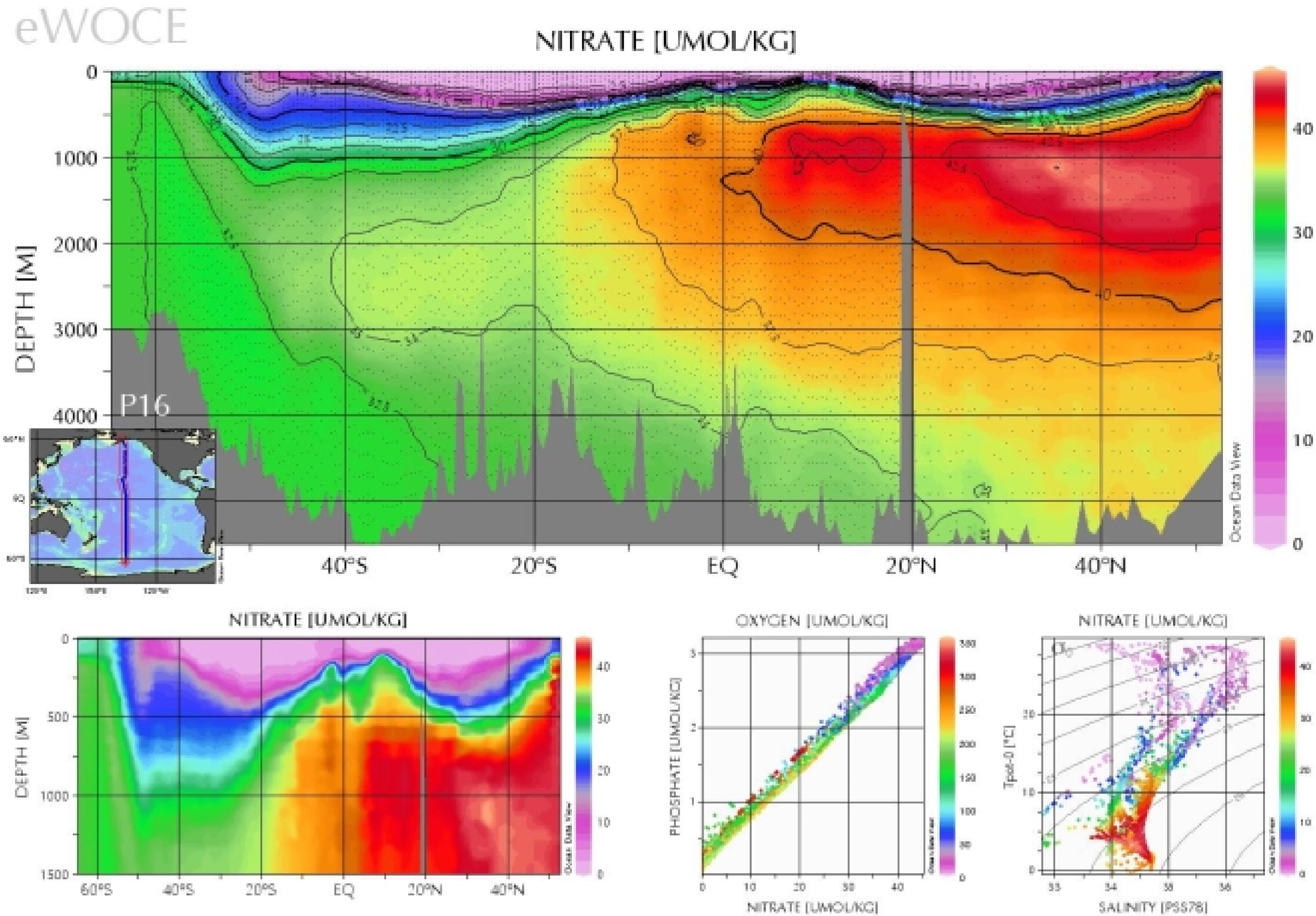
FIGURE 3.7. Comparison of barium (Ba) (a) and silica (Si) (b) profiles in the South Atlantic.

TABLE 3.1
Speciation, Concentration, and Distribution Types of Elements in Ocean Waters

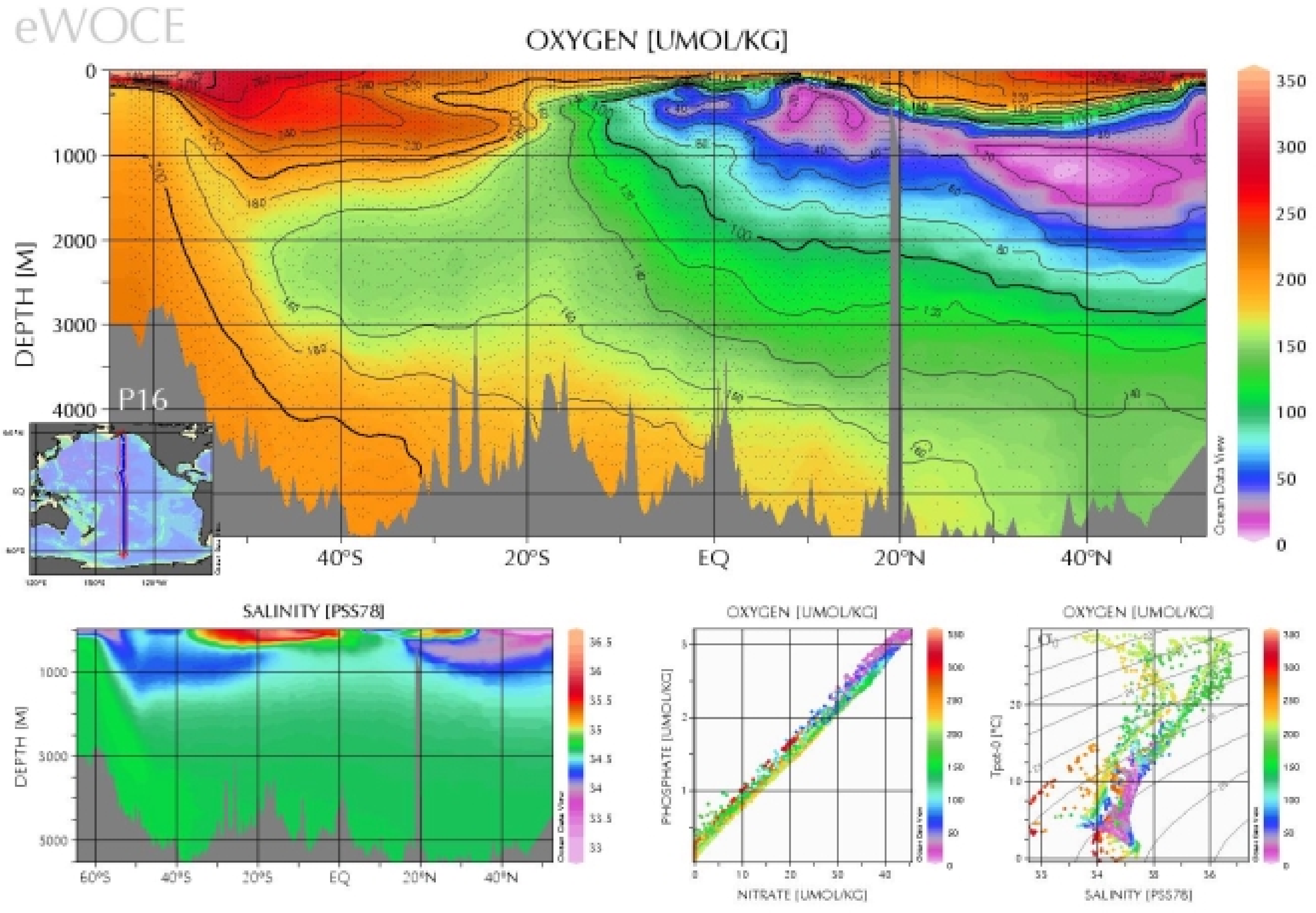
Element	Probable species	Range and ave. concentration	Type of distribution
Li	Li^{+}	25 μM	Conservative
Be	$BeOH^{+}$, $Be(OH)_2$	4–30 pM, 20 pM	Nutrient type
B	$B(OH)_3$, $B(OH)_4$	0.416 mM	Conservative
C	HCO_3^{-}, CO_3^{2-}	2.0–2.5 mM, 2.3 mM	Nutrient type
N	NO_3^{-}, (N_2)	0–45 μM	Nutrient type
F	F^{-}, MgF^{+},CaF^{+}	68 μM	Conservative
Na	Na^{+}	0.468 M	Conservative
Mg	Mg^{2+}	53.2 mM	Conservative
Al	$Al(OH)_4^{-}$, $Al(OH)_3$	5–40 nM, 2 nM	Mid-depth-min.
Si	$Si(OH)_4$	0–180 μM	Nutrient type
P	HPO_4^{2-}, $MgHPO_4$	0–3.2 μM	Nutrient type
S	SO_4^{2-}, $NaSO_4^{-}$, $MgSO_4$	28.2 mM	Conservative
Cl	Cl^{-}	0.546 M	Conservative
K	K^{+}	10.2 mM	Conservative
Ca	Ca^{2+}	10.3 mM	Conservative
Sc	$Sc(OH)_3$	8–20 pM, 15 pM	Surface depletion
Ti	$Ti(OH)_4$	few pM	?
V	HVO_4^{2-}, $H_2VO_4^{-}$	20–35 nM	Surface depletion
Cr	CrO_4^{2-}	2–5 nM, 4 nM	Nutrient type
Mn	Mn^{2+}	0.2–3 nM, 0.5 nM	Depletion at depth
Fe	$Fe(OH)_3$	0.1–2.5 nM, 1 nM	Surface and depth depletion
Co	Co^{2+}, $CoCO_3$	0.01–0.1 nM, 0.02nM	Surface and depth depletion
Ni	$NiCO_3$	2–12 nM, 8 nM	Nutrient type
Cu	$CuCO_3$	0.5–6 nM, 4 nM	Nutrient type, scavenging
Zn	Zn^{2+}, $ZnOH^{+}$	0.05–9 nM, 6 nM	Nutrient type
Ga	$Ga(OH)_4^{-}$	5–30 pM	?
As	$HAsO_4^{2-}$	15–25 nM, 23 nM	Nutrient type
Se	SeO_4^{2-}, SeO_3^{2-}	0.5–2.3 nM,1.7 nM	Nutrient type
Br	Br^{-}	0.84 nM	Conservative
Rb	Rb^{+}	1.4 μM	Conservative
Sr	Sr^{2+}	90 μM	Conservative
Y	YCO_3^{+}	0.15 nM	Nutrient type
Zr	$Zr(OH)_4$	0.3 nM	?
Nb	$NbCO_3^{+}$	50 pM	Nutrient type(?)
Mo	MoO_4^{2-}	0.11 μM	Conservative
Tc	TcO_4^{-}	No stable isotope	?
Ru	?	<0.05 pM	?
Rh	?	?	?
Pd	?	0.2 pM	?
Ag	$AgCl_2^{-}$	0.5–35 pM, 25 pM	Nutrient type
Cd	$CdCl_2^{-}$	0.001–1.1 nM, 0.7 nM	Nutrient type
In	$In(OH)_3$	1 pM	?
Sn	$Sn(OH)_4$	1–12pM, 4 pM	Surface input
Sb	$Sb(OH)_6^{-}$	1.2 nM	?
Te	TeO_3^{2-}, $HTeO_3^{-}$	?	?
I	IO_3^{-}	0.2–0.5 μM, 0.4 μM	Nutrient type
Cs	Cs^{+}	2.2 nM	Conservative
Ba	Ba^{2+}	32–150 nM,100 nM	Nutrient type
La	$LaCO_3^{+}$	13–37 pM, 30 pM	Surface depletion
Ce	$CeCO_3^{+}$	16–26 pM, 20 pM	Surface depletion

TABLE 3.1 (continued)
Speciation, Concentration, and Distribution Types of Elements in Ocean Waters

Element	Probable species	Range and ave. concentration	Type of distribution
Pr	$PrCO_3^{+}$	4 pM	Surface depletion
Nd	$NdCO_3^{+}$	12–25 pM, 10 pM	Surface depletion
Sm	$SmCO_3^{+}$	3–5 pM, 4 pM	Surface depletion
Eu	$EuCO_3^{+}$	0.6–1 pM, 0.9 pM	Surface depletion
Gd	$GdCO_3^{+}$	3–7 pM, 6 pM	Surface depletion
Tb	$TbCO_3^{+}$	0.9 pM	Surface depletion
Dy	$DyCO_3^{+}$	5–6 pM, 6 pM	Surface depletion
Ho	$HoCO_3^{+}$	1.9 pM	Surface depletion
Er	$ErCO_3^{+}$	4–5 pM, 5 pM	Surface depletion
Tm	$TmCO_3^{+}$	0.8 pM	Surface depletion
Yb	$YbCO_3^{+}$	3–5 pM, 5 pM	Surface depletion
Lu	$LuCO_3^{+}$	0.9 pM	Surface depletion
Hf	$Hf(OH)_4$	<40 pM	?
Ta	$Ta(OH)_5$	<14 pM	?
W	WO_4^{2-}	0.5 nM	Conservative
Re	ReO_4^{-}	14–30 pM, 20 pM	Conservative
Os	?	?	?
Ir	?	0.01 pM	?
Pt	$PtCl_4^{2-}$	0.5 pM	?
Au	$AuCl_2^{-}$	0.1–0.2 pM	?
Hg	$HgCl_4^{2-}$	2–10 pM, 5 pM	?
Tl	Tl^{+},TCl	60 pM	Conservative
Pb	$PbCO_3$	5–175 pM, 10 pM	Surface input, depletion at depth
Bi	BiO^{+},$Bi(OH)_2^{+}$	<0.015–0.24 pM	Depletion at depth

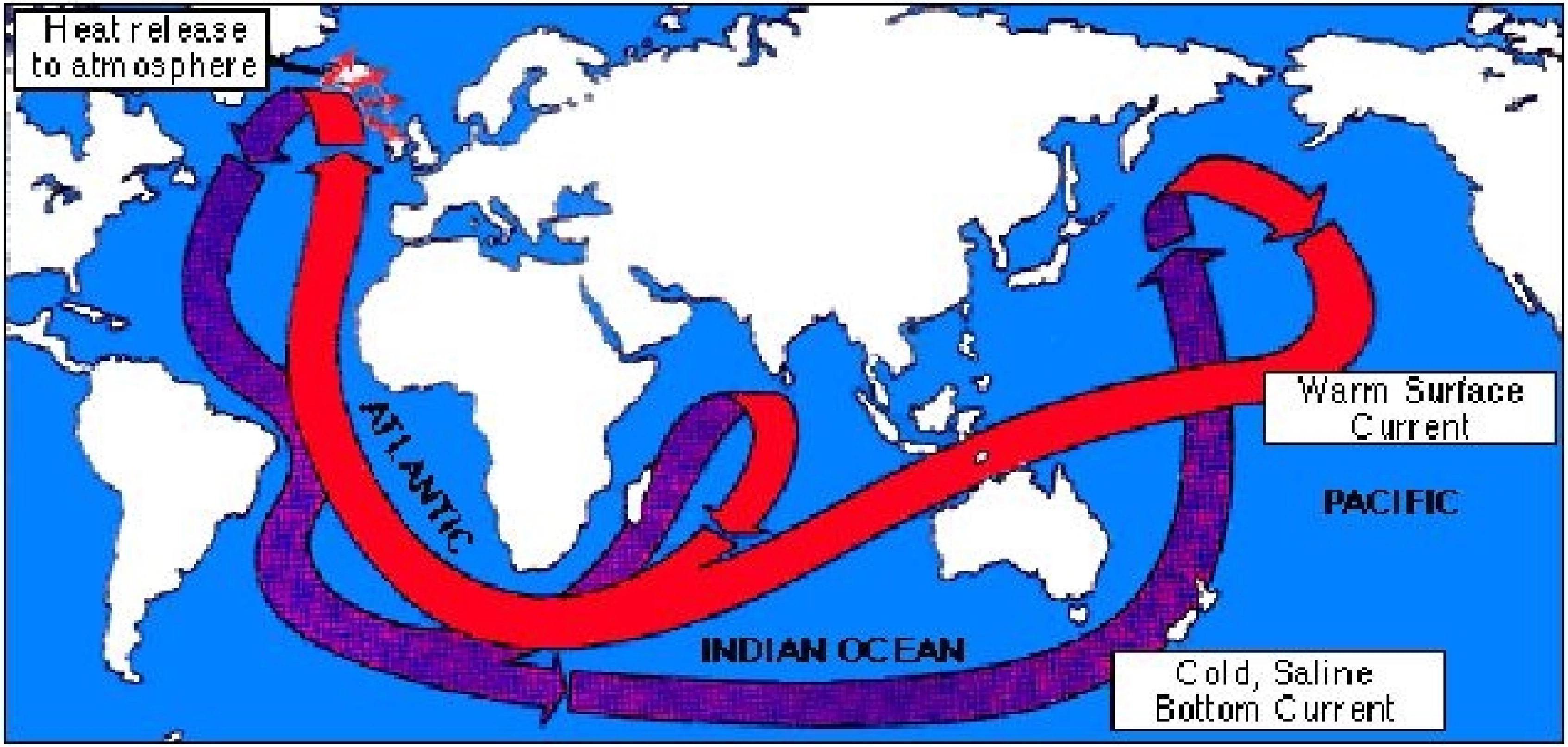


eWOCE
NITRATE [UMOL/KG]
DEPTH [M]
0
1000
2000
3000
4000
40°S
20°S
EQ
20°N
40°N
P16
Ocean Data View
40
30
20
10
0
NITRATE [UMOL/KG]
DEPTH [M]
500
1000
1500
60°S
40°S
20°S
EQ
20°N
40°N
OXYGEN [UMOL/KG]
PHOSPHATE [UMOL/KG]
NITRATE [UMOL/KG]
NITRATE [UMOL/KG]
Tpot-0 [°C]
SALINITY [PSS78]



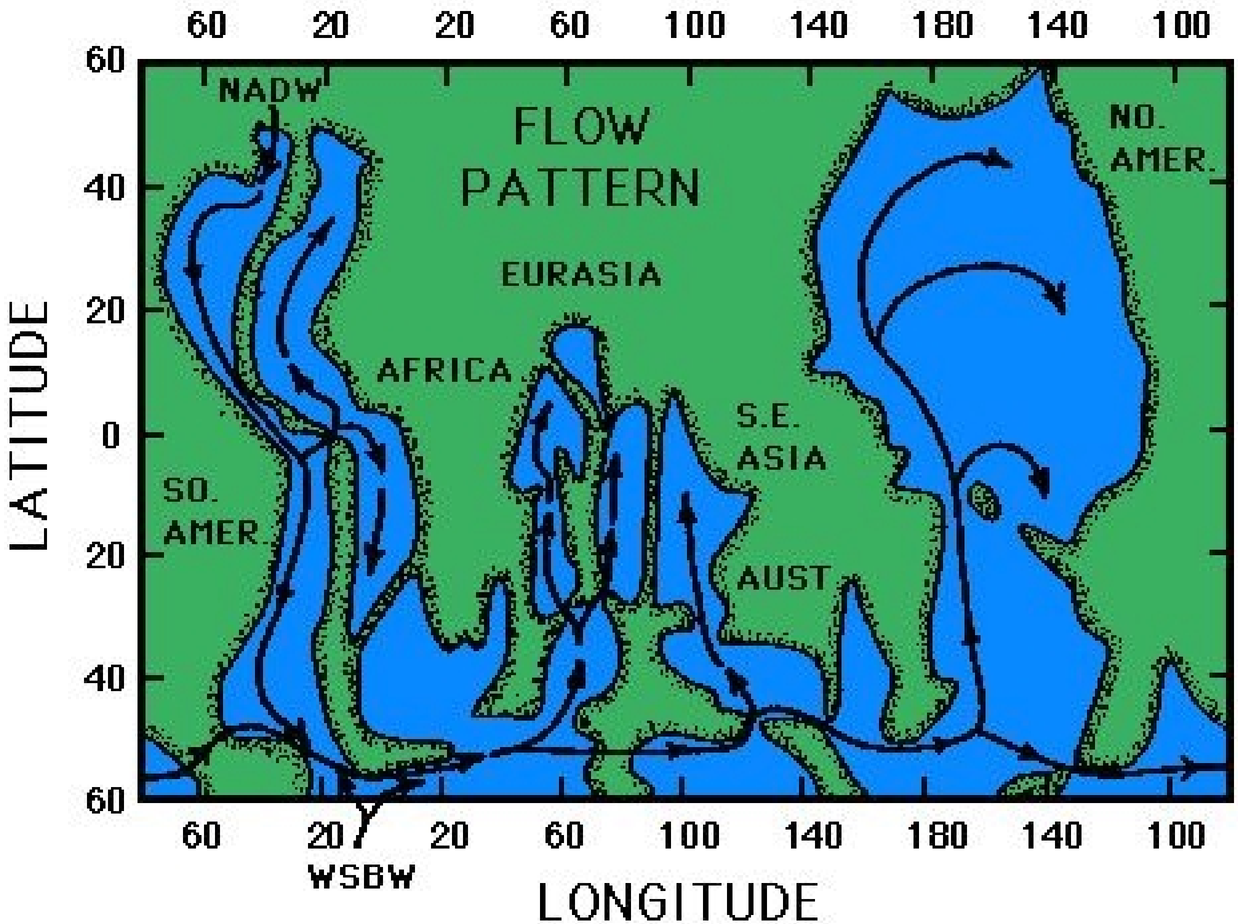
eWOCE
OXYGEN [UMOL/KG]
DEPTH [M]
P16
40°S
20°S
EQ
20°N
40°N
Ocean Data View
SALINITY [PSS78]
DEPTH [M]
60°S
40°S
20°S
EQ
20°N
40°N
OXYGEN [UMOL/KG]
PHOSPHATE [UMOL/KG]
NITRATE [UMOL/KG]
OXYGEN [UMOL/KG]
Tpot-0 [°C]
SALINITY [PSS78]

Ocean Conveyer Belt



The present large-scale ocean current system determines climate to a great extent. The huge "conveyor belt" reacts extremely sensitively to global temperature changes accompanying each increase and decrease in the content of carbon dioxide in the atmosphere. - Broecker

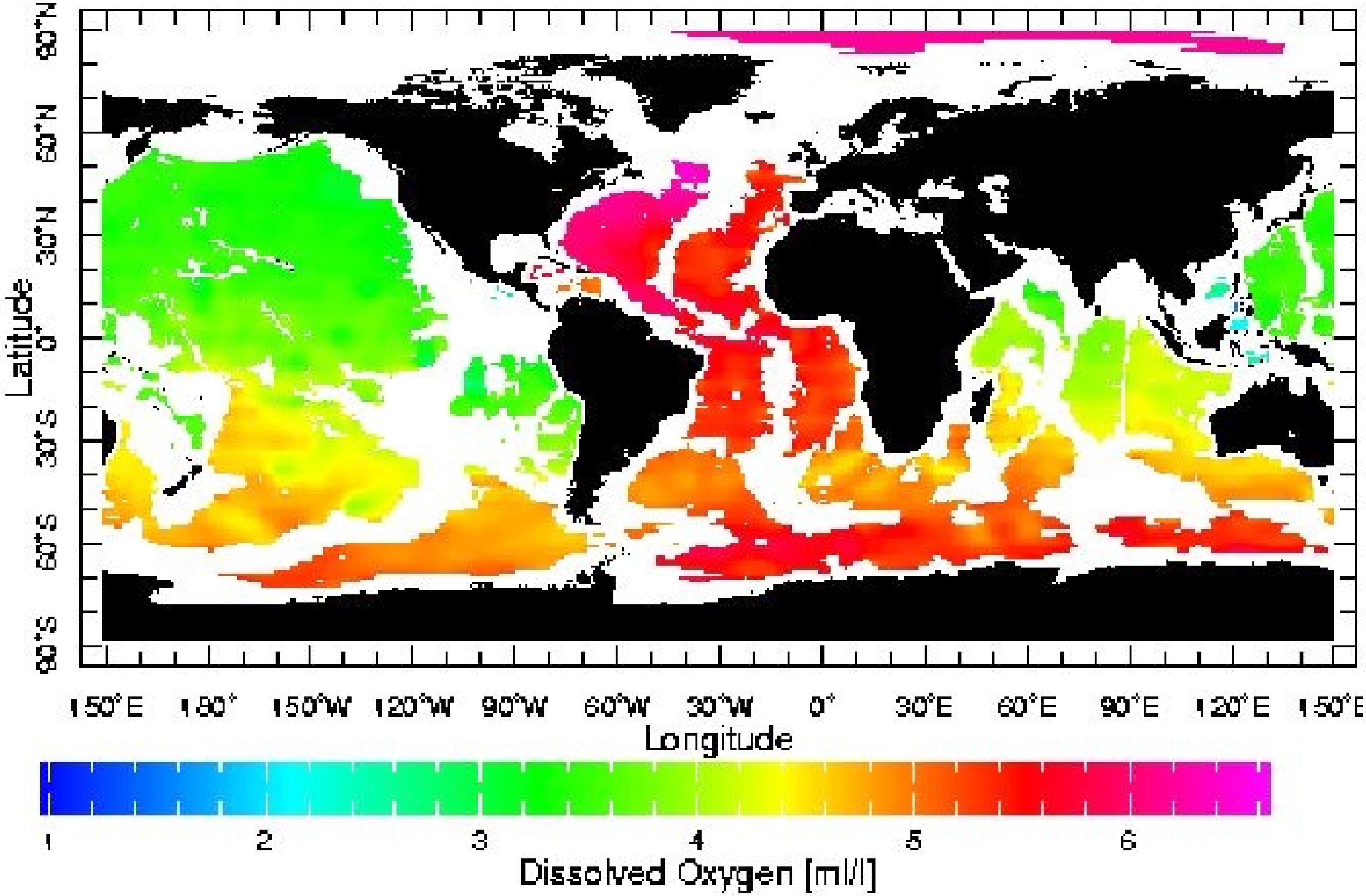
Abyssal Circulation



Flow pattern at a depth of 4000 meters. The major inputs to this horizon are North Atlantic Deep Water (NADW) which enters at the northern end of the western basin of the Atlantic and Weddell Sea Bottom Water (WSBW) which enters from the margin of the Antarctic continent adjacent to the South Atlantic.

From: Broecker, Wallace S. and Tsung-Hung Peng. Tracers in the Sea,

Deep
O2



90°N
60°N
30°N
0°
30°S
60°S
90°S
Latitude
150°E
180°
150°W
120°W
90°W
60°W
30°W
0°
30°E
60°E
90°E
120°E
150°E
Longitude
1
2
3
4
5
6
Dissolved Oxygen [ml/l]

Deep
Phosphate