ATOC 1060-002
OUR CHANGING ENVIRONMENT

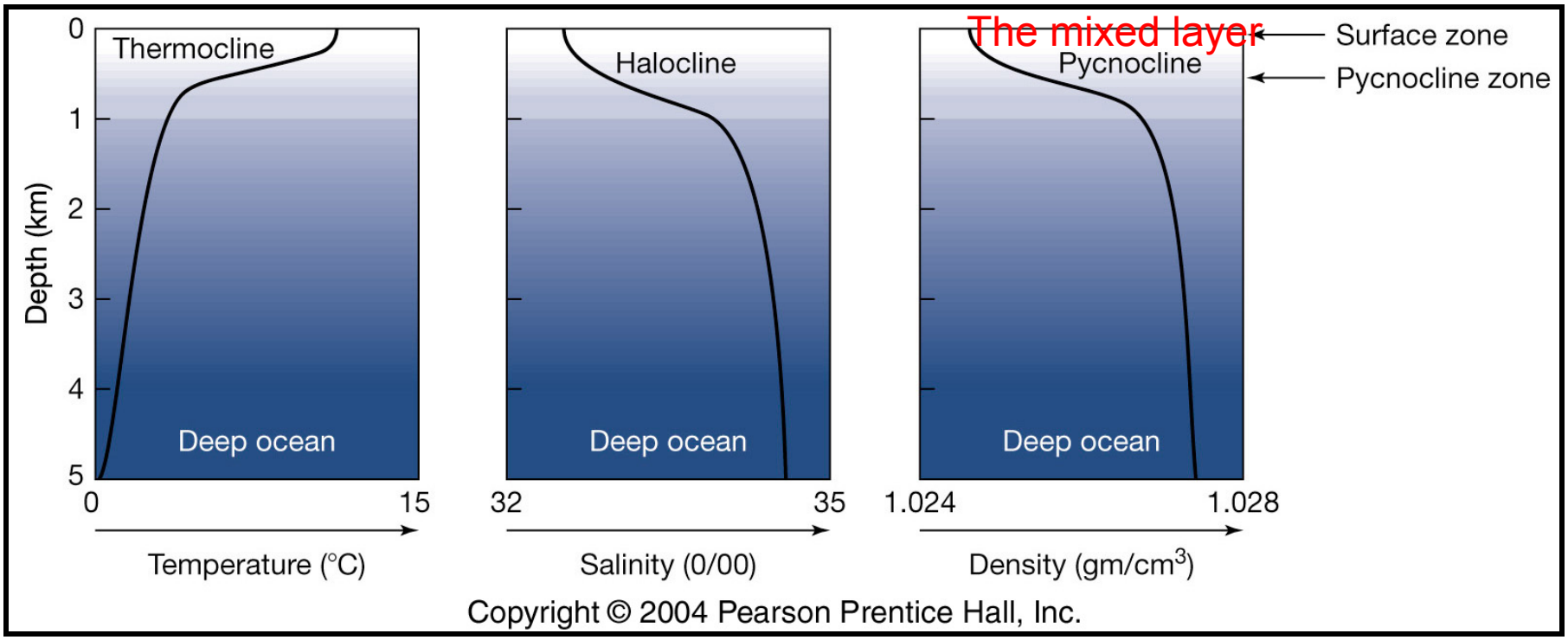
Class 16 (Chp 5)

Objectives of Today's Class: Deep ocean circulation

1. **Deep ocean circulation;**
2. **Thermohaline circulation;**
3. **The thermohaline conveyor belt;**
4. **Ocean circulation and climate.**

1. The deep ocean circulation

Vertical structures: Temperature, salinity and density



Mixed layer: upper 50~100m where Temperature, salinity and density is fairly well mixed
Thermocline: The region where temperature sharply decreases with the increase of depth
Halocline: The region where salinity sharply increases with the increase of depth
Pycnocline: The region where density sharply increases with the increase of depth

Previous classes: Observations: Eastern Pacific

Color: SST; arrows: surface winds

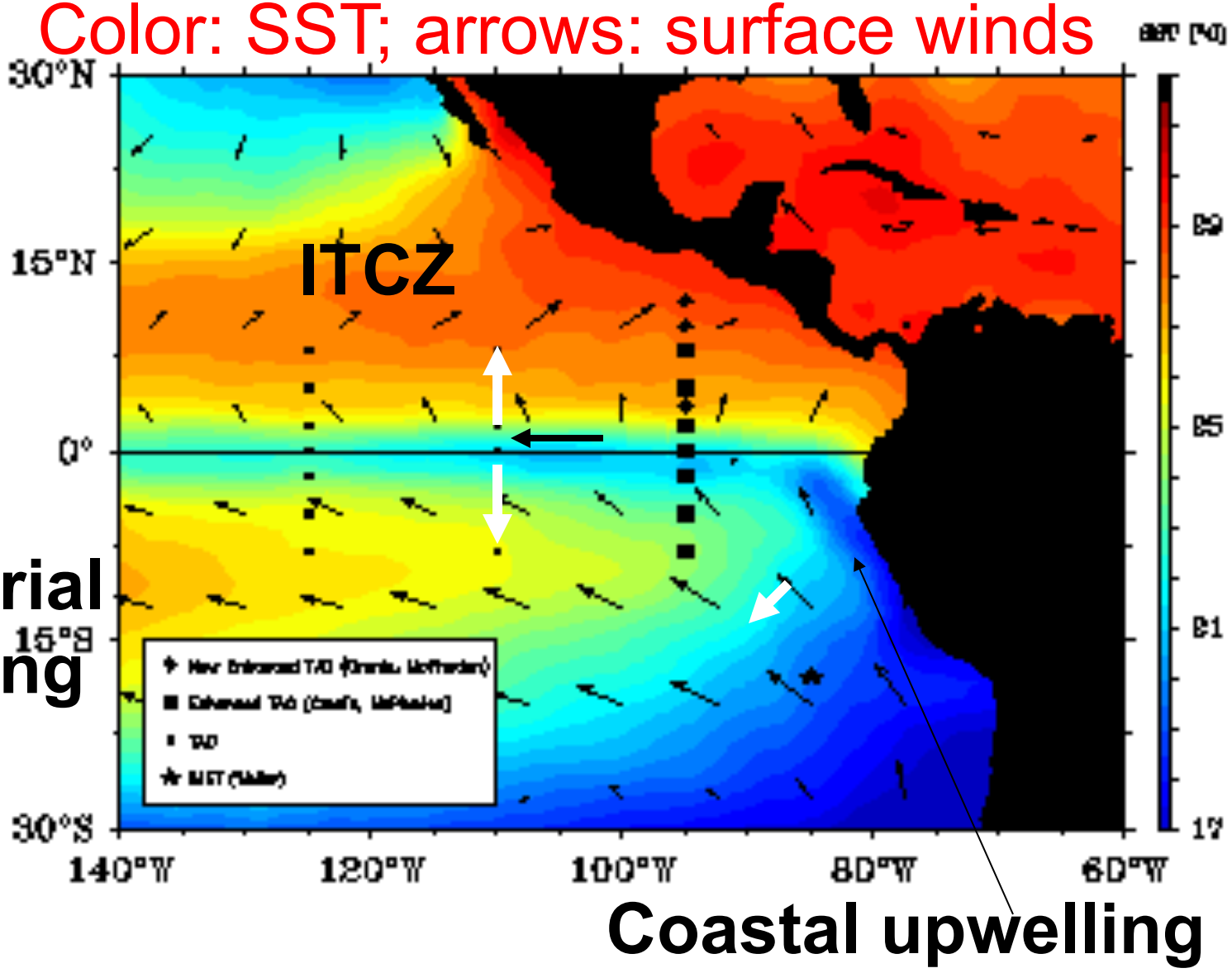
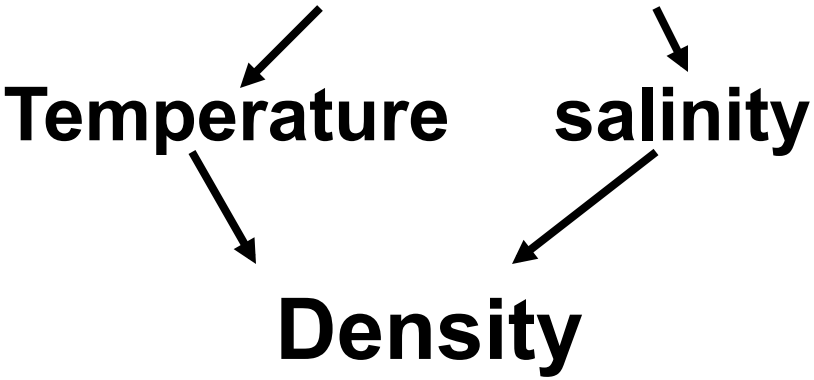


Figure 2

Equatorial upwelling

The circulation of the deep ocean

Surface ocean circulation: wind driven;
Deep ocean circulation: thermalhaline effects;



Differences in water density =>
deep ocean circulation

Salinity of the ocean

Salinity: grams of dissolved materials (salt) in one kg of sea water. .

Salt: major components, Sodium (Na) and chlorine (Cl);

Units: part per thousand (ppt), which is equal to practical salinity unit (psu);

Typical value: 35psu (35g of salt in 1kg of sea water).

TABLE 5-1

Salt Content of the Earth's Oceans

Salt Ion	*Grams per Kilogram (g/kg) of Ion in Seawater*		*Ion by Weight (%)*
Chloride (Cl^-)	18.980	85.6%	55.04
Sodium (Na^+)	10.556		30.61
Sulfate (SO_4^{2-})	2.649		7.68
Magnesium (Mg^{2+})	1.272		3.69
Calcium (Ca^{2+})	0.400		1.16
Potassium (K^+)	0.380		1.10
Bicarbonate (HCO_3^-)	0.140		0.41
Bromide (Br^-)	0.065		0.19
Boric acid (H_3BO_3)	0.026		0.07
Strontium (Sr^{2+})	0.013		0.04
Flouride (F^-)	0.001		0.00
Total	34.482		99.99

Source: PINET, P. R., *Oceanography*, St. Paul, MN: West Publishing Co., 1992.

Where is the salt from?

Hydrological cycle: ocean water evaporated => precipitation over land => rivers carry the materials from breakdown of crustal rocks (weathering) to the ocean (4 billion tons per year).

Is the ocean getting saltier and saltier? No.

Many processes remove salt from the ocean.

a)Evaporation from shallow seas;

b)Biological processes, shells,eventually sediments;

c)Chemical reactions (sea water & newly formed volcanic rocks on the sea floor);

d) Sea spray (deposited on land).

Salinity variation

Millions of years timescale: in = out;

Shorter timescales: salinity varies

a) Regional difference in Evaporation & Precipitation;

b) Sea ice formation & melt;

c) River runoff.

High salinity: Mediterranean Sea, Red Sea, Persian (Arabian) Gulf;

Low salinity: Gulf of Bothnia in the Baltic Sea; Chesapeake Bay: Atlantic US coast.

2. Thermohaline circulation

Depends on temperature(T),salinity(S)

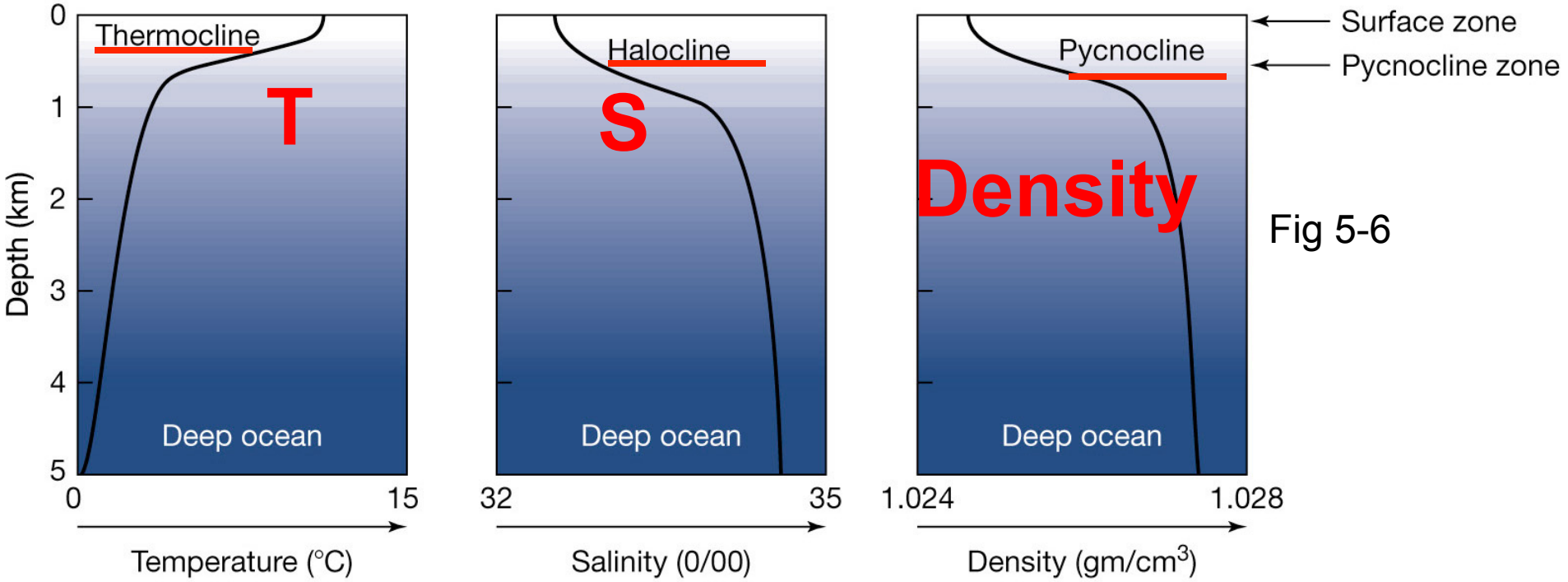


Fig 5-6

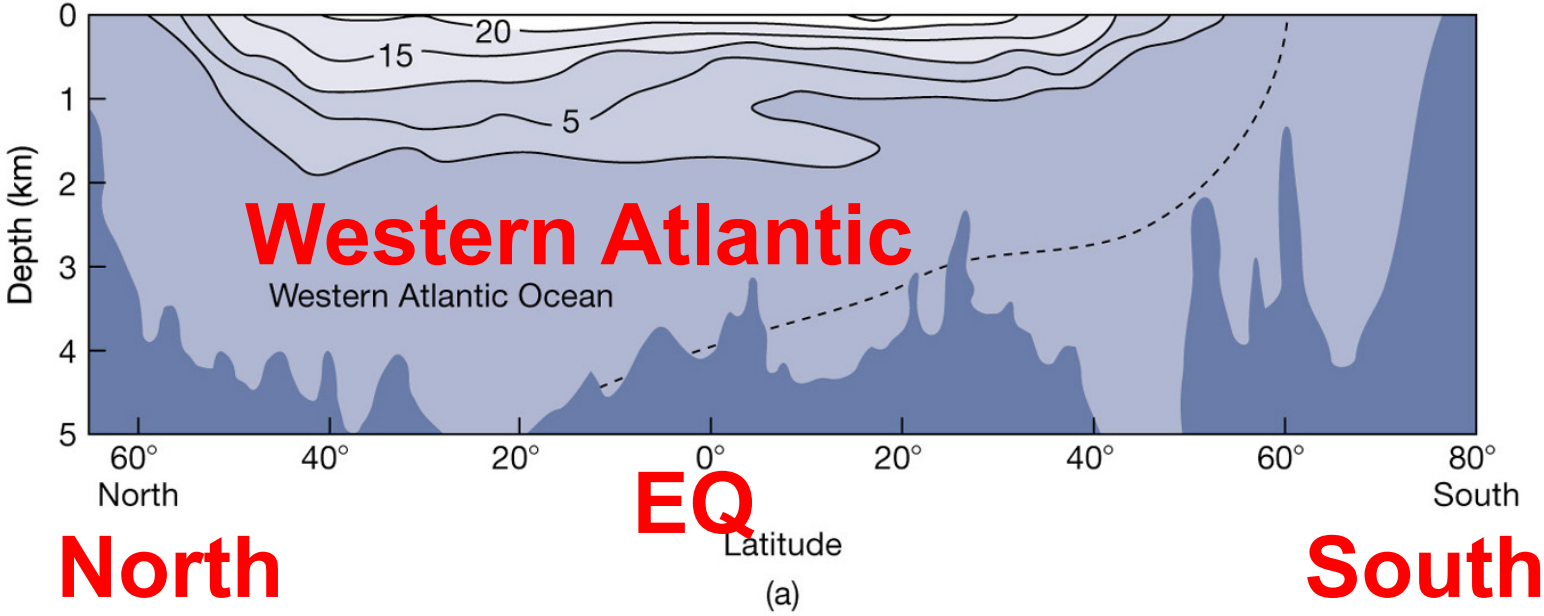
Higher T, lower density;

lower T, higher density;

Higher S, higher density;

lower S, lower density.

Meridional Temperature distribution



North

South

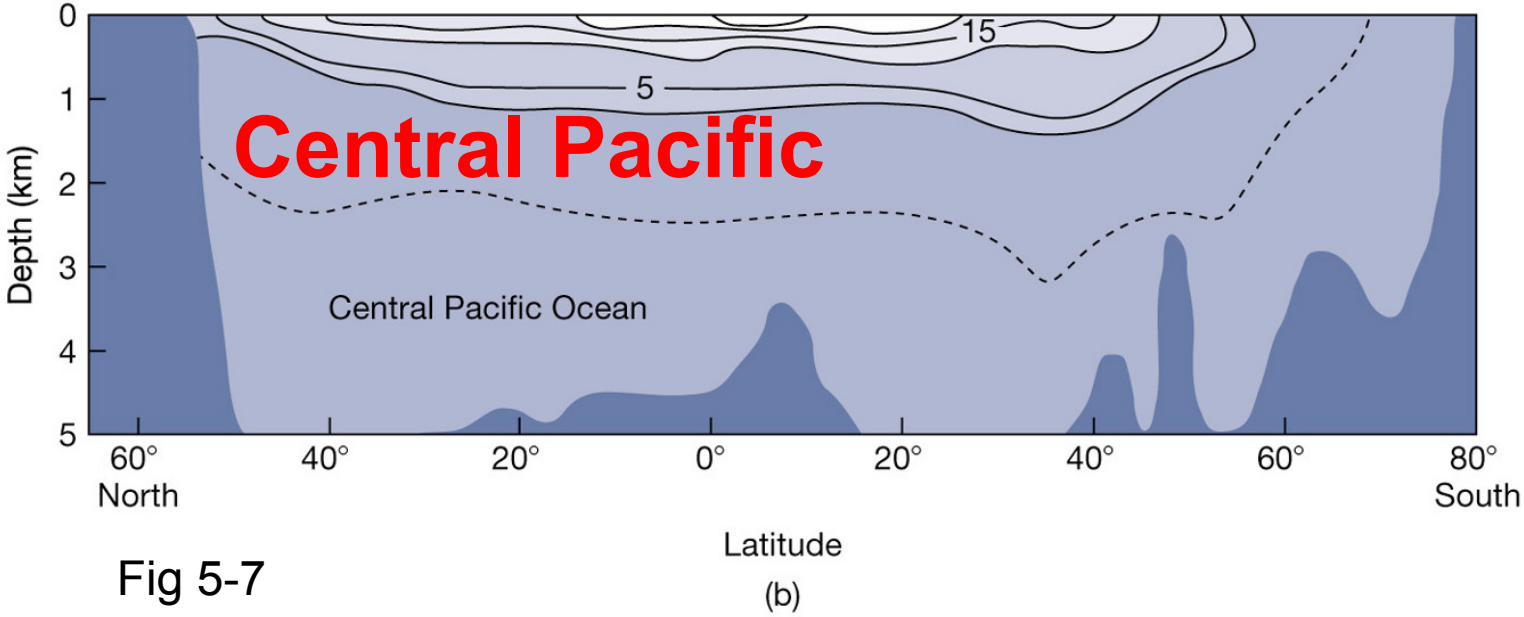
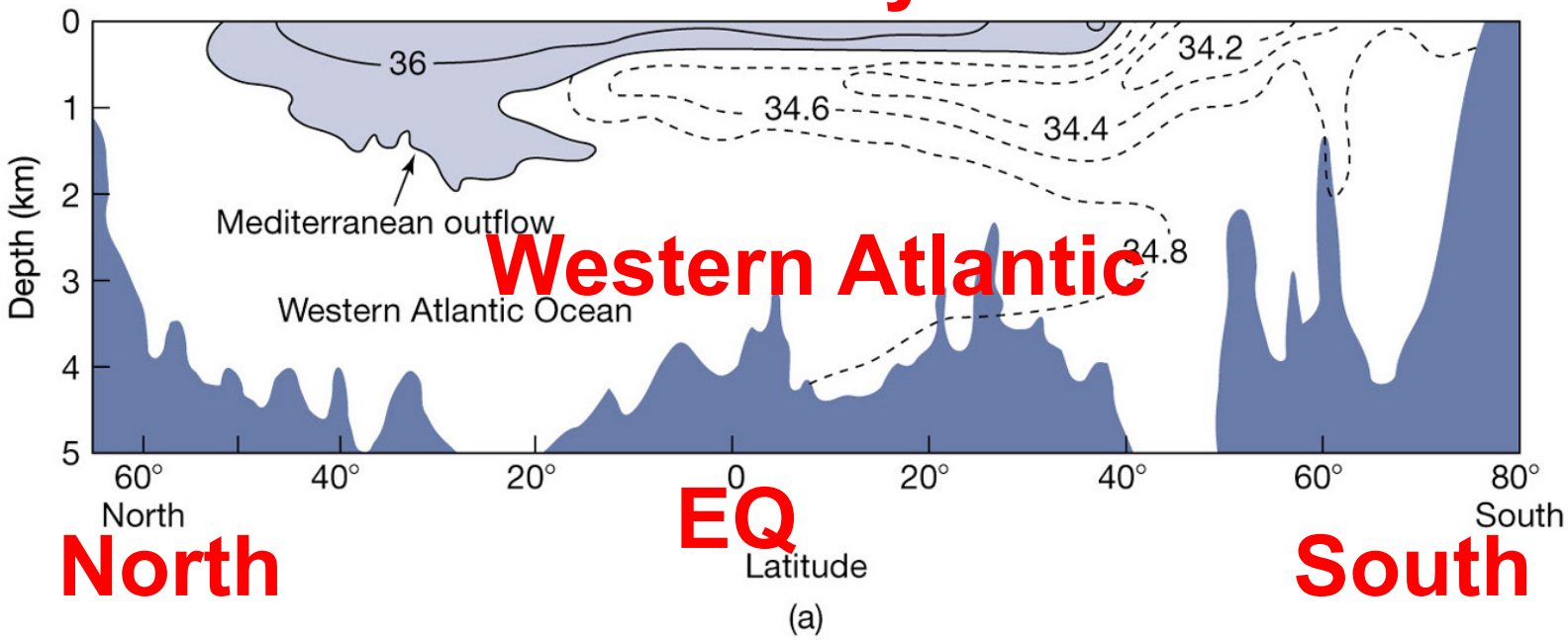


Fig 5-7

Meridional Salinity distribution

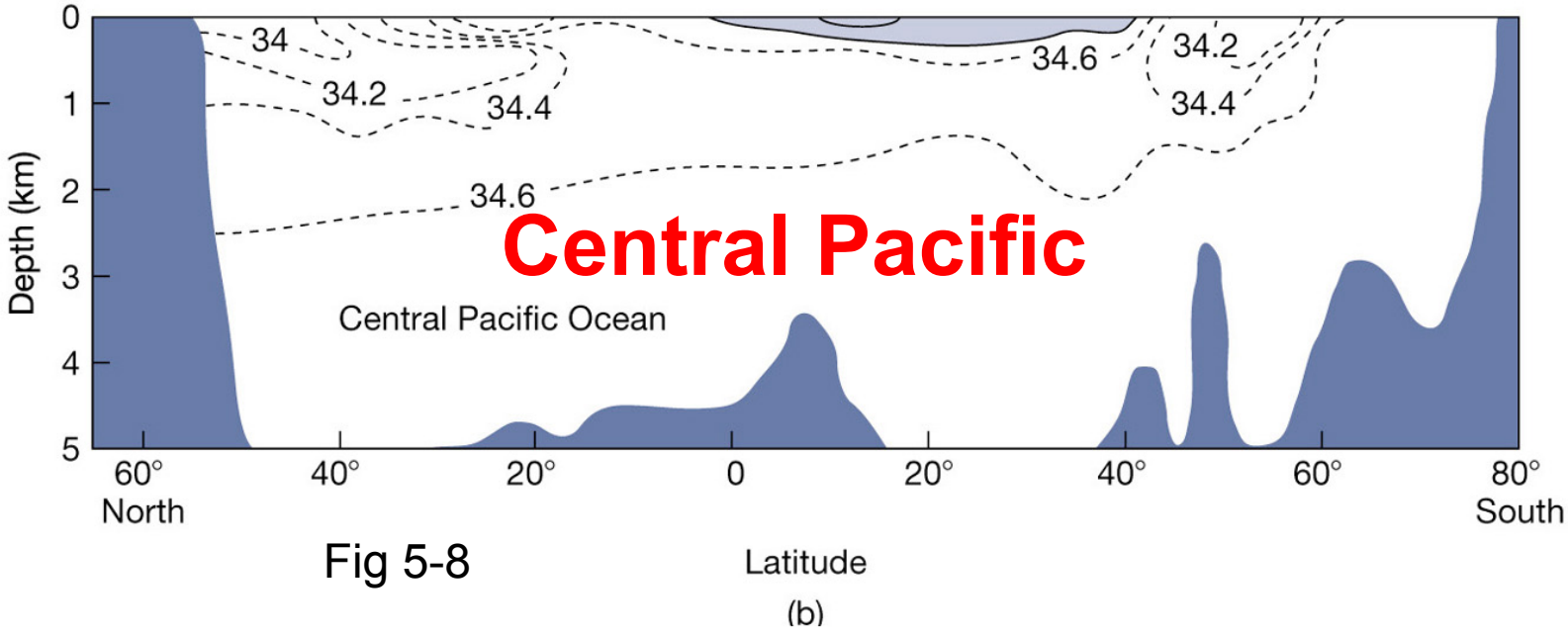


Western Atlantic

North

EQ

South



Central Pacific

Fig 5-8

Bottom water formation

Deep ocean circulation: begins with bottom water formation;

Dense water: cooling; ↗ salinity; sea-ice formation - eject salt ↗ density. (freezing point of sea water is below 0°C; pure water: 0°C).

Bottom-water formation sites

AntArctic Bottom Water (AABW)

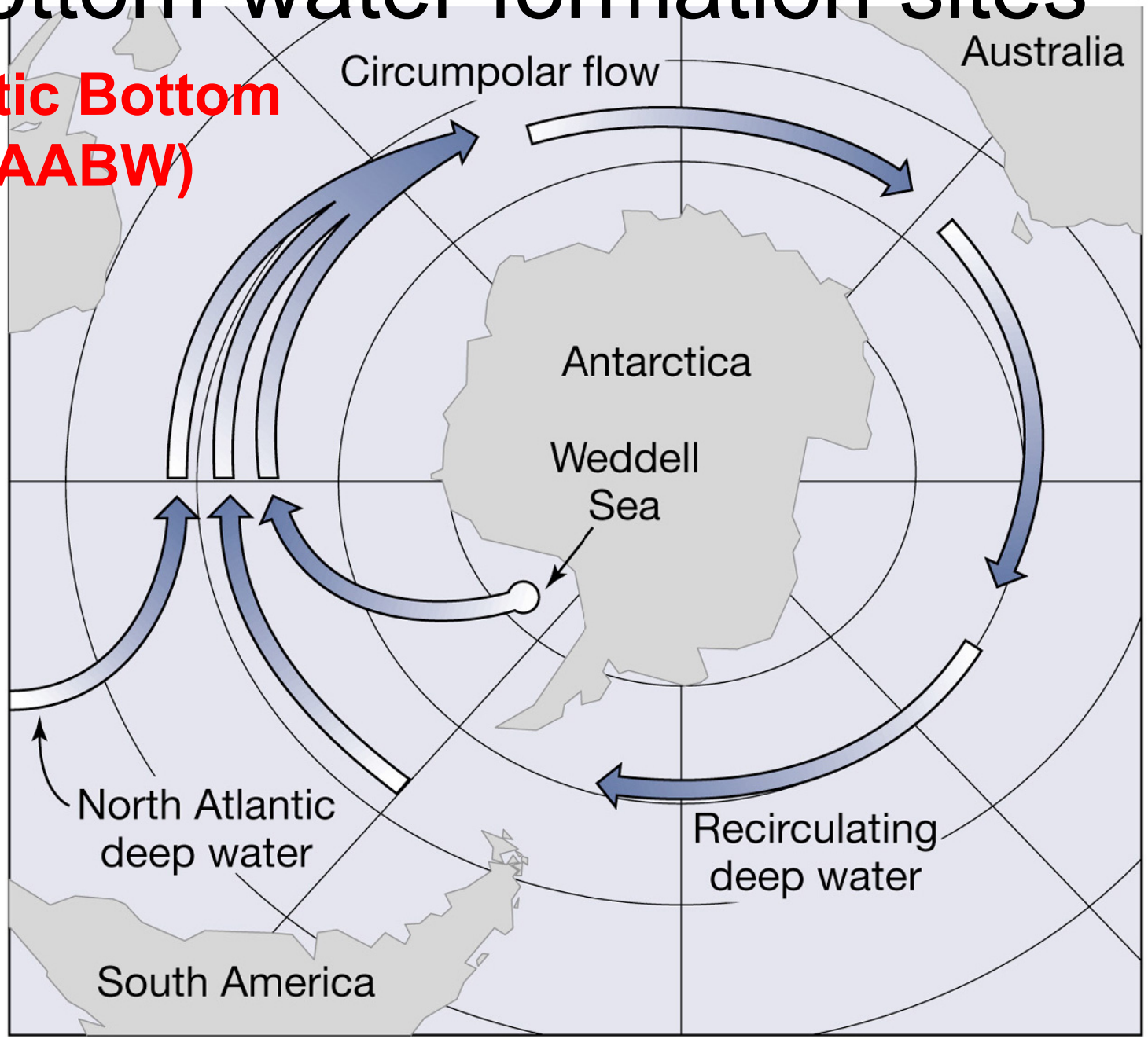


Fig. 5-9

North Atlantic Deep Water (NADW)

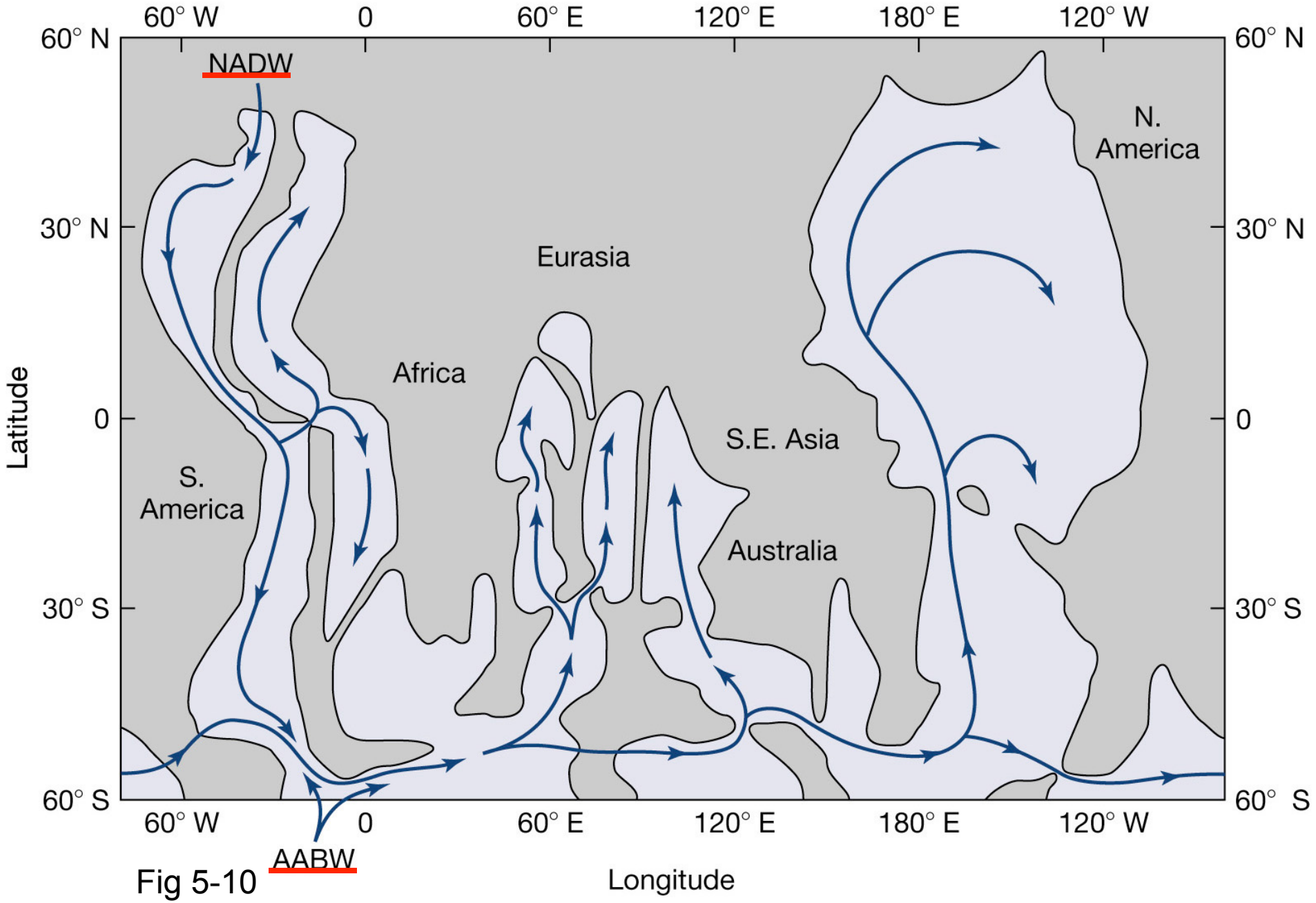
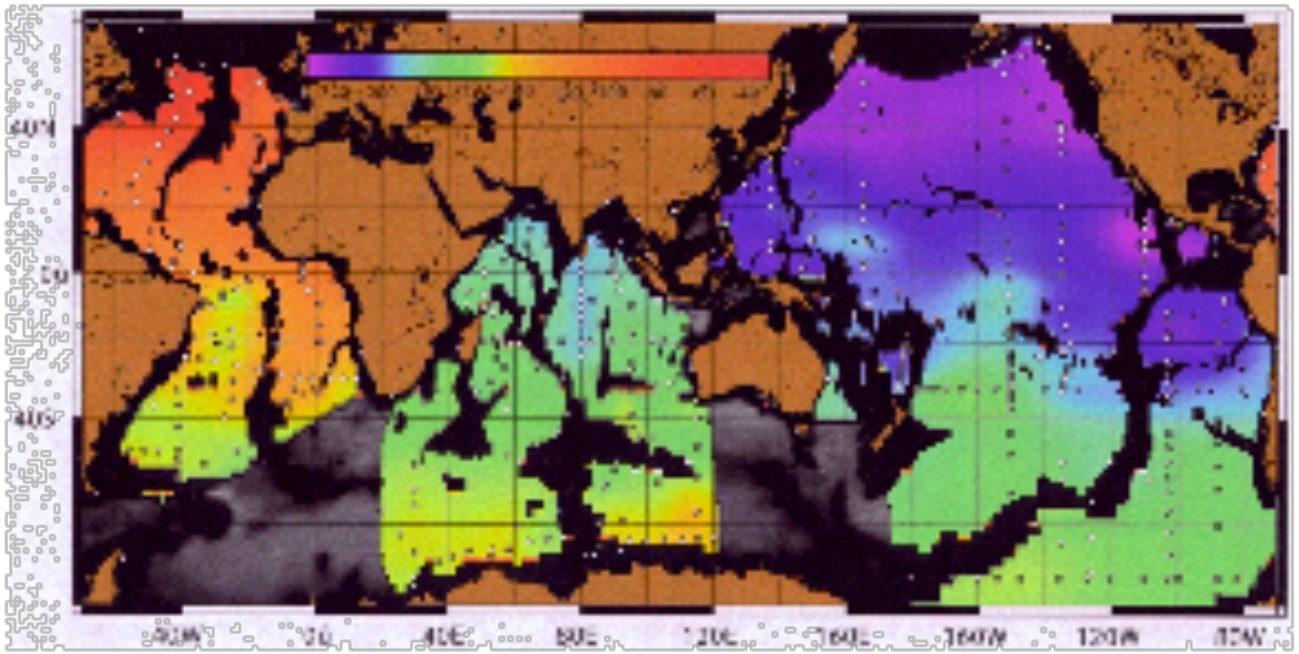


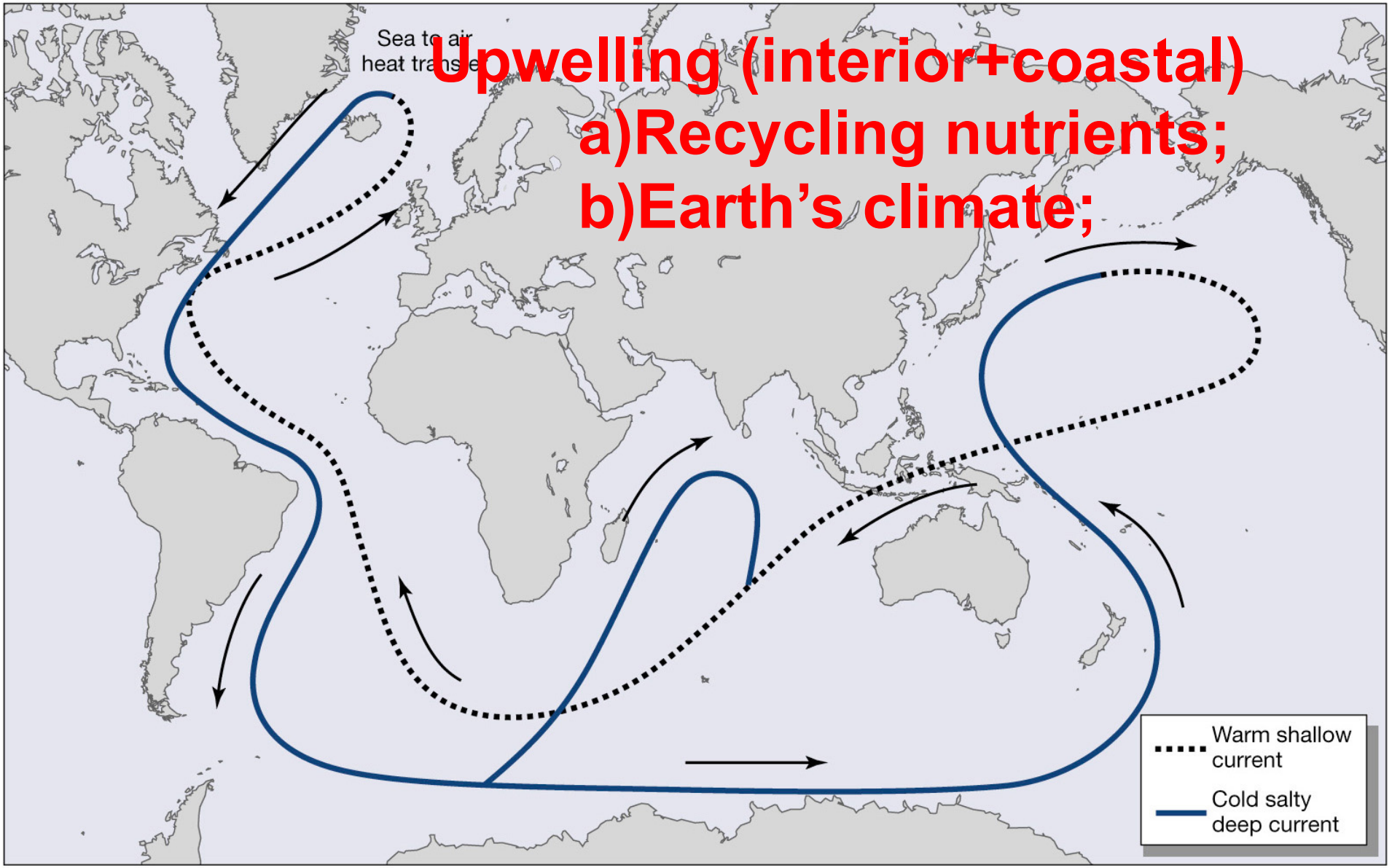
Fig 5-10

Ages of water (^{14}C near bottom)



Red: young water; purple: old water; Time: residence time for deep water: 500 years

3.The Thermohaline Conveyor Belt



Upwelling (interior+coastal)
a)Recycling nutrients;
b)Earth's climate;

Fig 5-12

Salinity effect: North Atlantic, 1000m

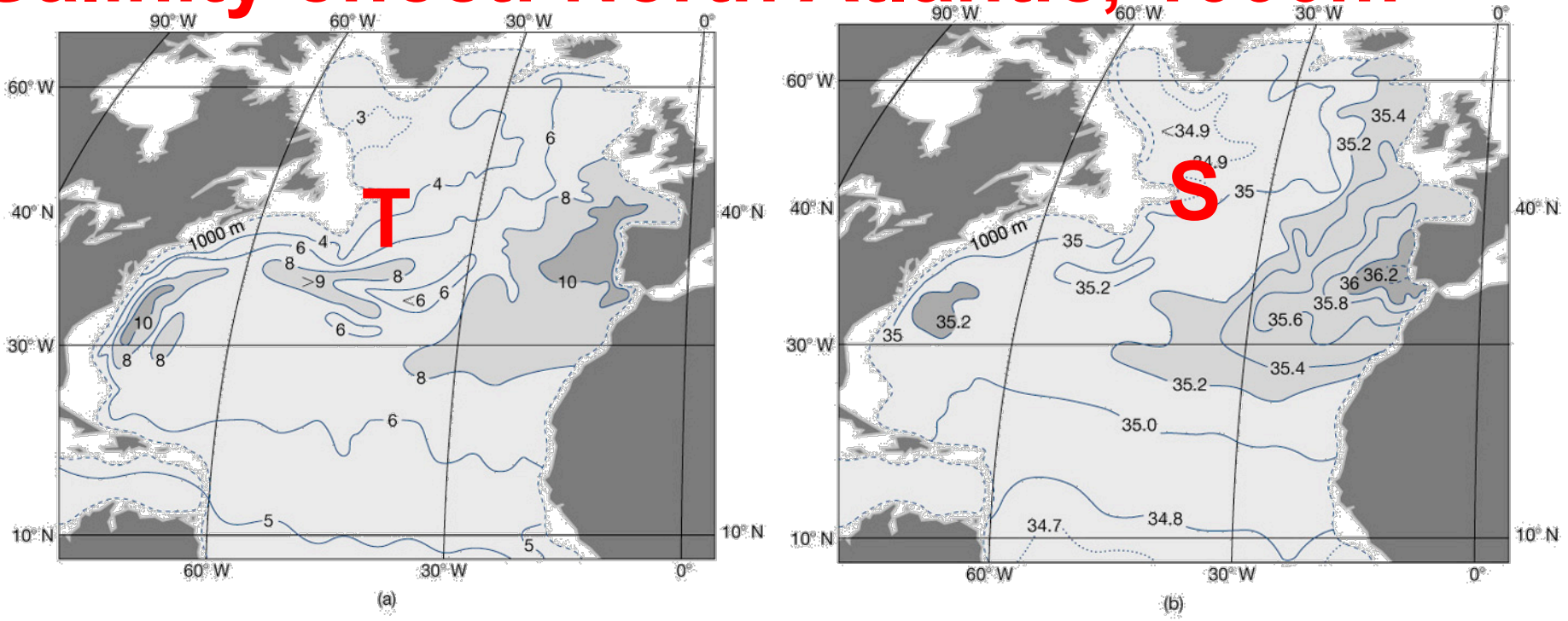


Fig 5-14

High T, High S Mediterranean Sea water

Wind-driven (relatively shallow)+ deep coean circulation; reality more complex;

4. Ocean circulation and climate

NH poleward heat transport

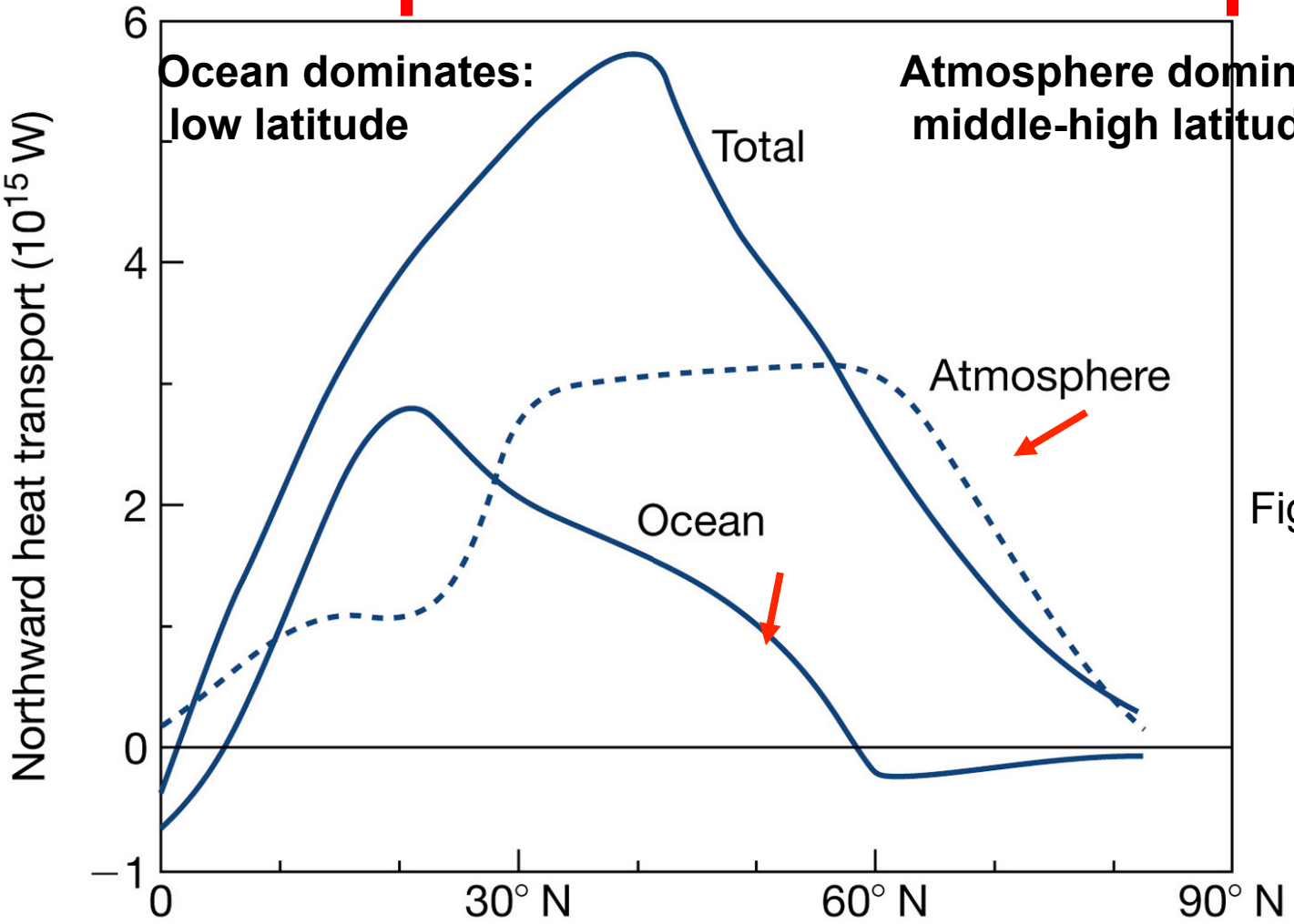


Fig 5-15

heat reservior; long-term climate;

nutrient cycling, CO2 storage.