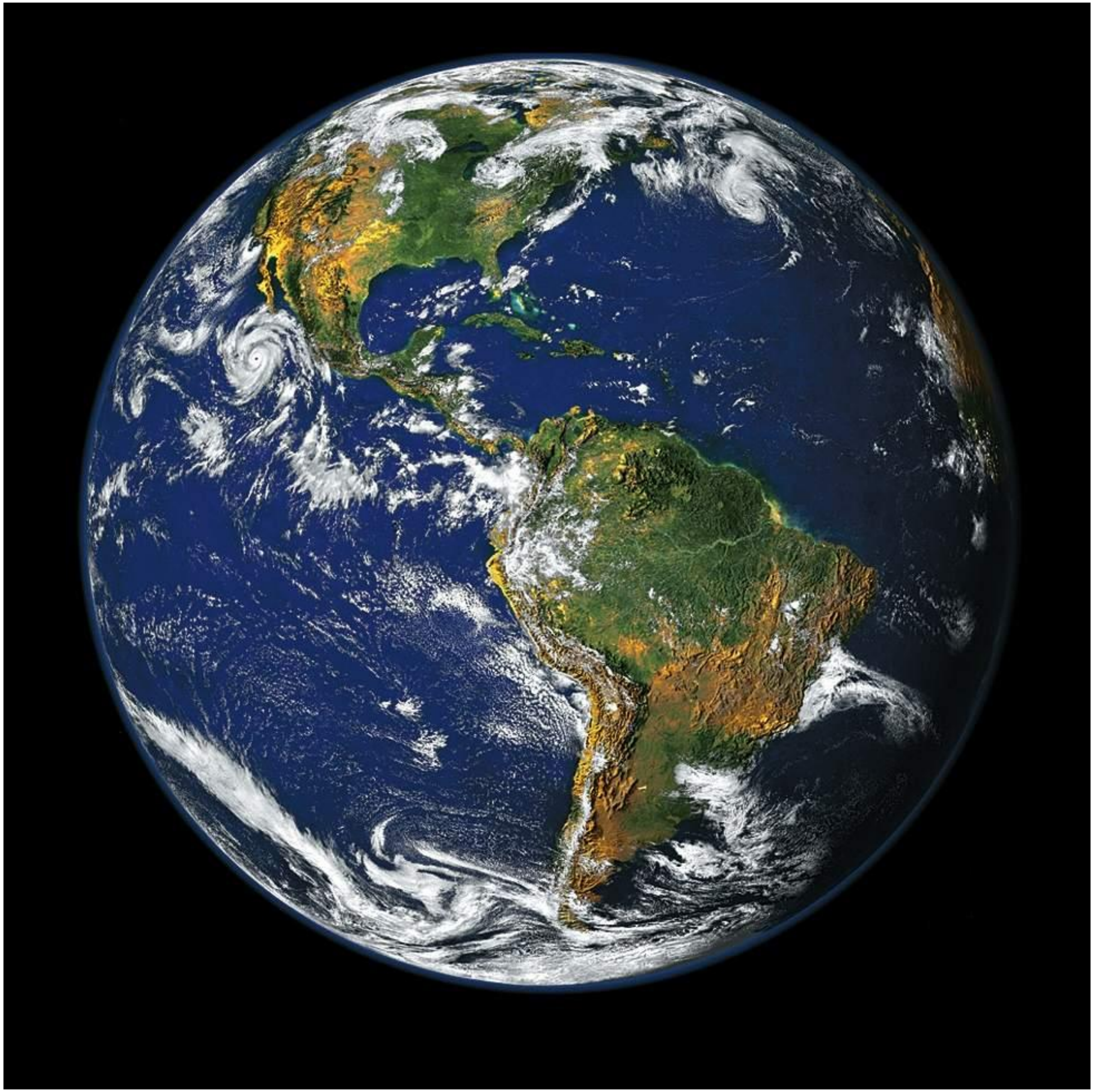
Introduction to marine biogeochemistry Fano 2025

Jonathan Erez, The Hebrew University of Jerusalem, Israel

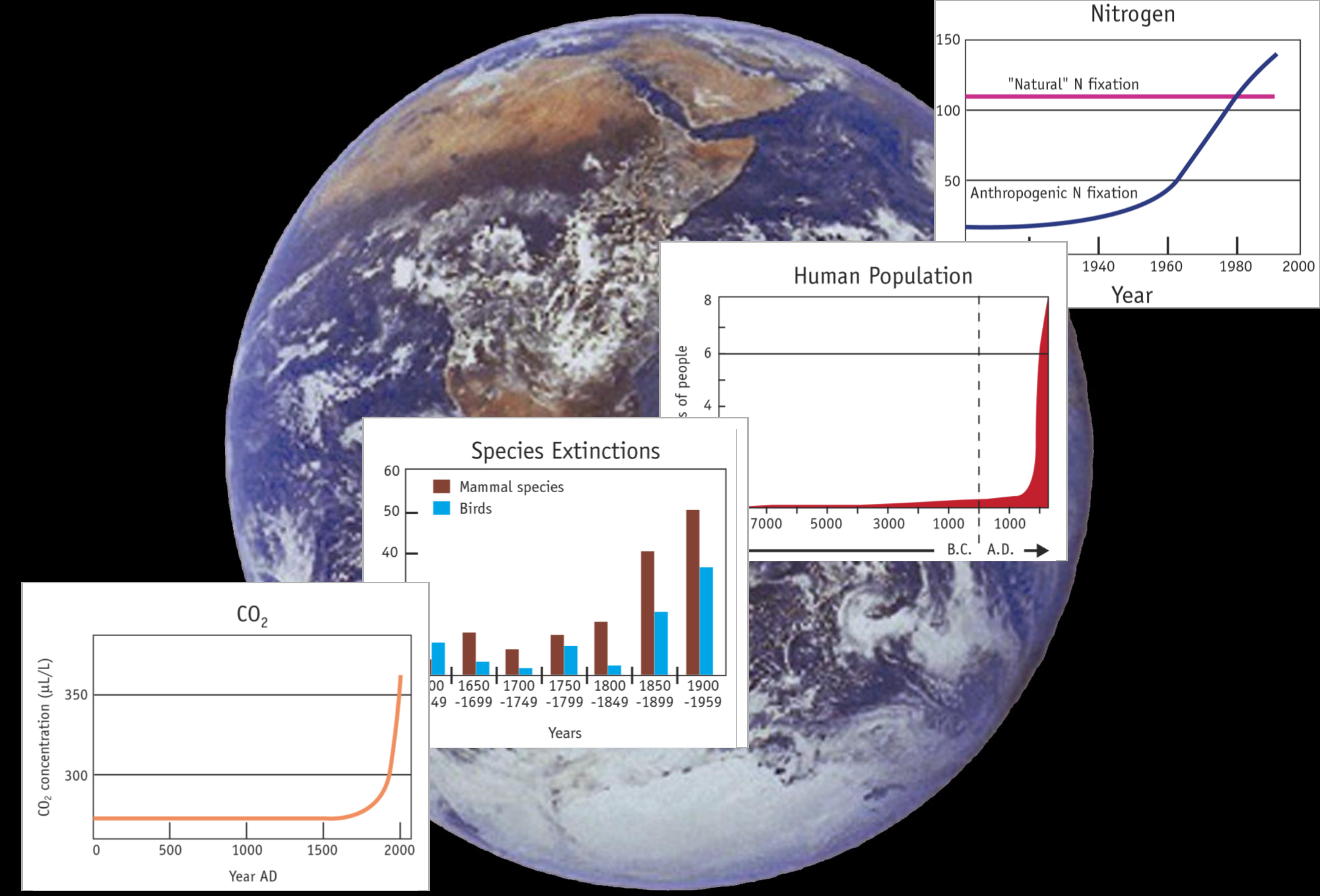
- Ocean basins, elements cycling and salinity, thermocline, ocean circulation 1.15hr. 15 min. break (14:30-16:00)
- Biological oceanography: Nutrients, oxygen, productivity, food web, vertical fluxes, bottom processes 45. min. (16:00-16:45)
- Global and ocean carbon cycle, carbonate chemistry, pH, alkalinity, DIC, ocean acidification 1. hr including 5min break (16:45-17:45)
- Coral reefs, ocean acidification bleaching 45min (17:45-18:30)



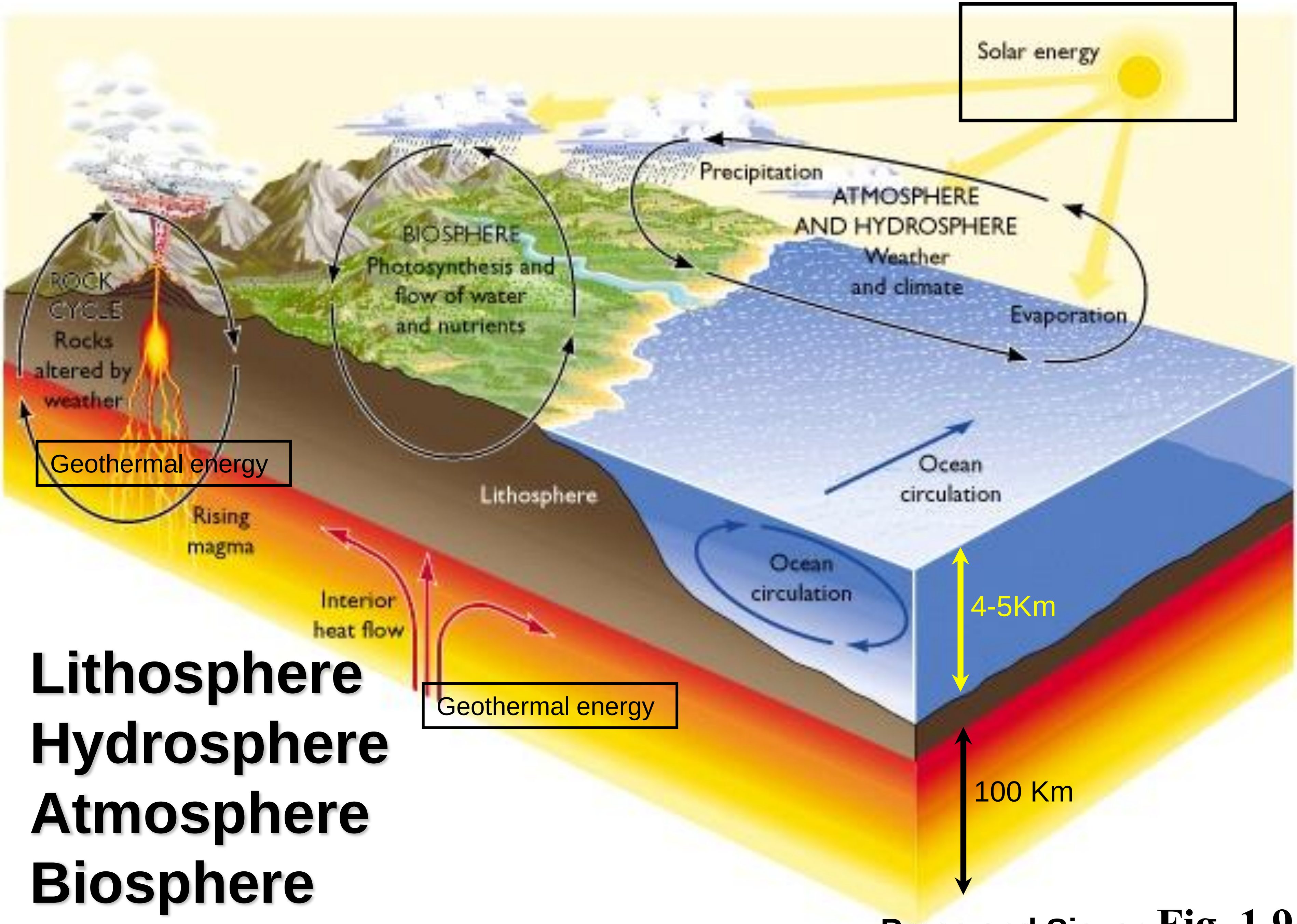
Earth from space: 2/3 is covered by ocean.

Land is concentrated in the Northern hemisphere

The atmosphere is circulating above land and sea



Source Moore



Lithosphere
Hydrosphere
Atmosphere
Biosphere

Press and Siever Fig. 1.9

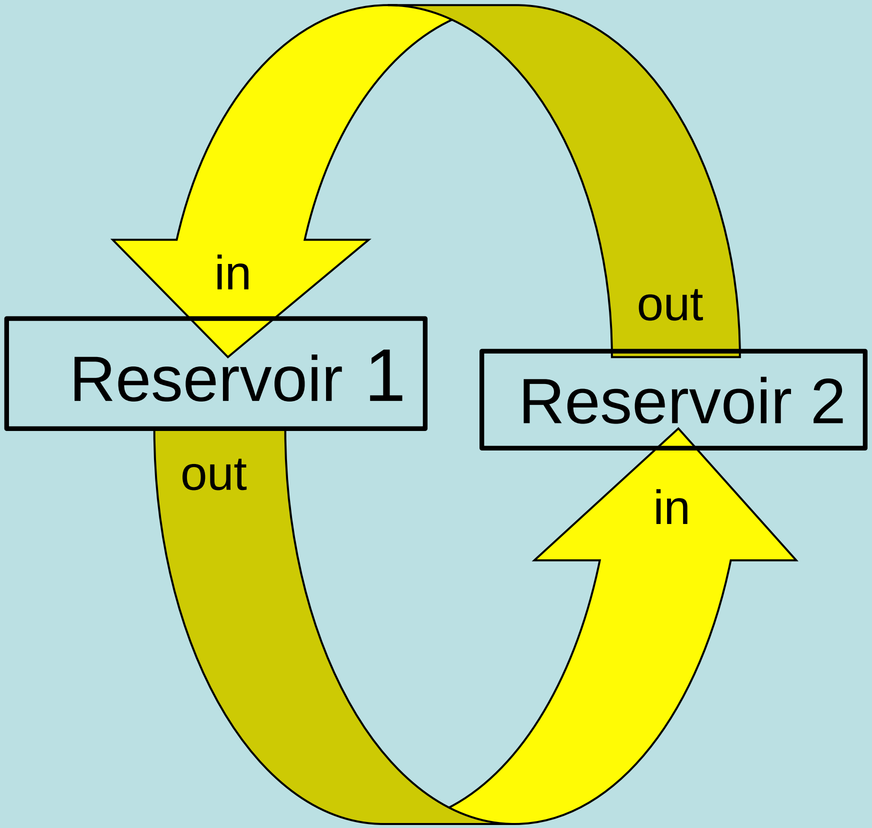
Cyclic and vectorial phenomena

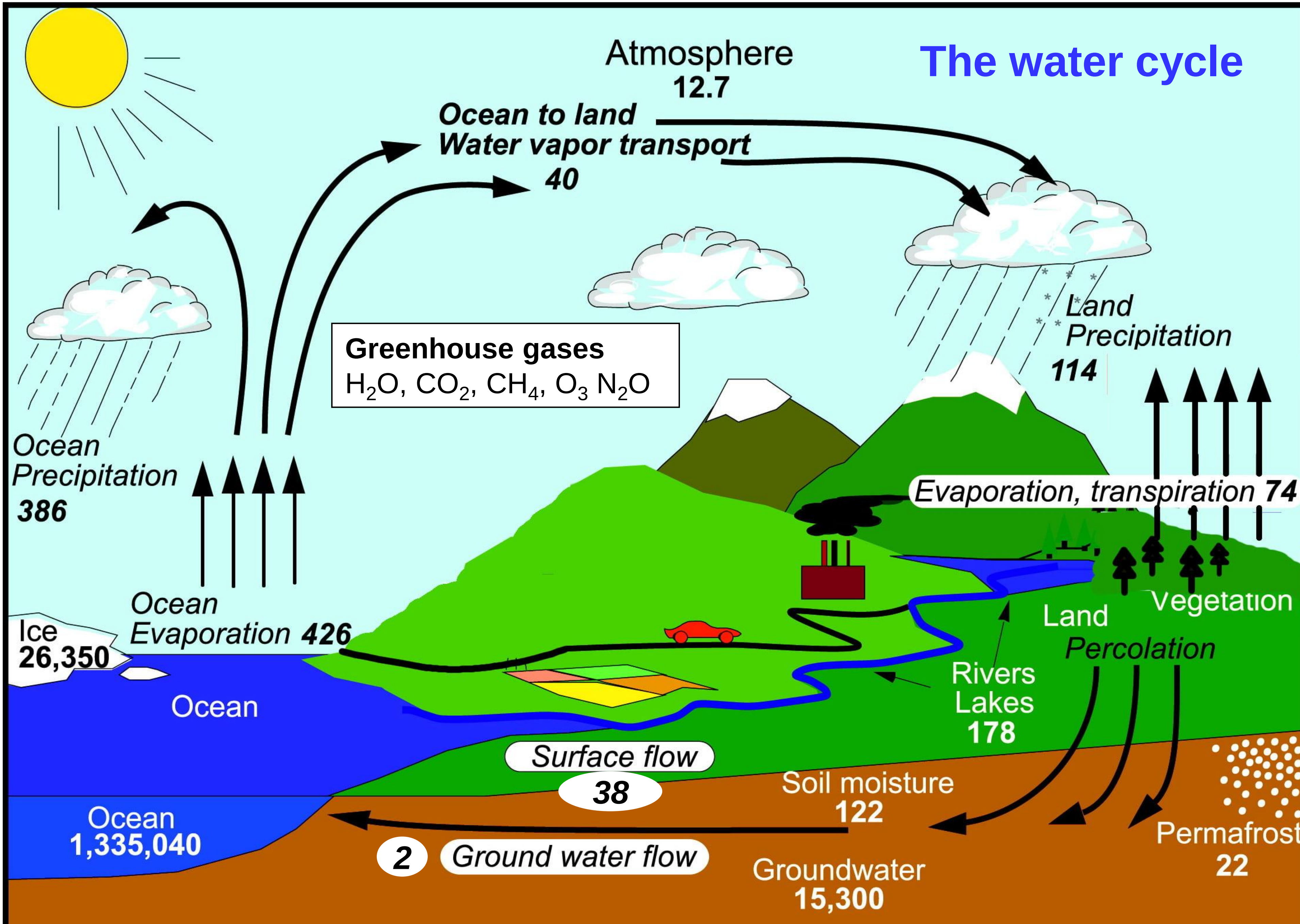
- **Cyclic**
- Orbital cycles (day night, lunar, year, Milankovich cycles)
- Climatic cycles (interaction of the above with ocean and land: seasons, glacial cycles)
- Geological Geochemical and Biological cycles (Ocean circulation, plate tectonics)
- **Vectorial**
- Creation of the universe (elements, stars) 14 Giga Yr
- Segregation of elements on Earth 4.5 Giga Yr
- Biological evolution 3.8 Giga Yr
- Man and its influence ? 2 Mega Yr

- Mega= 10^6 Giga= 10^9 Tera= 10^{12} Peta=10^{15}

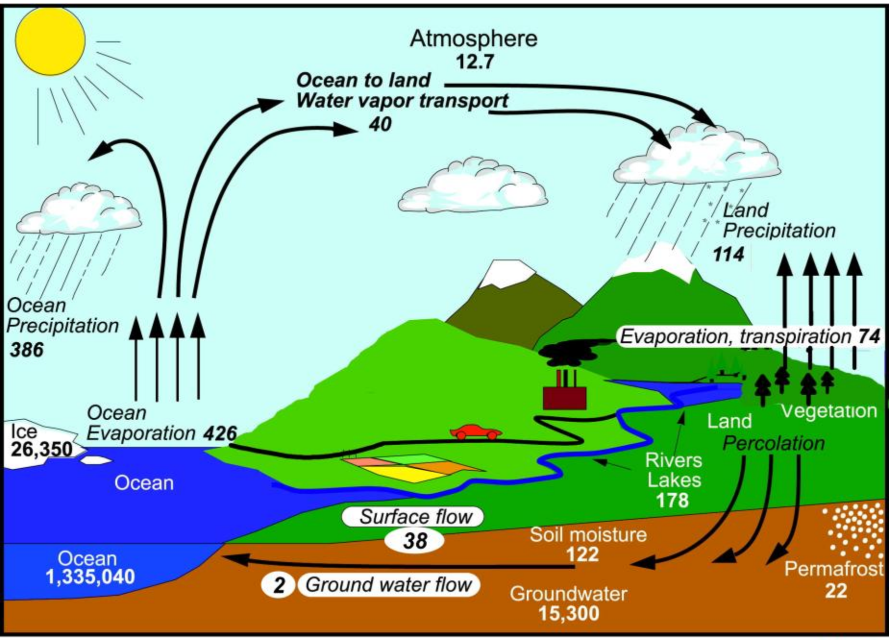
The Biogeochemical Cycles

- Reservoirs
- Fluxes
- Processes





Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges *1990s



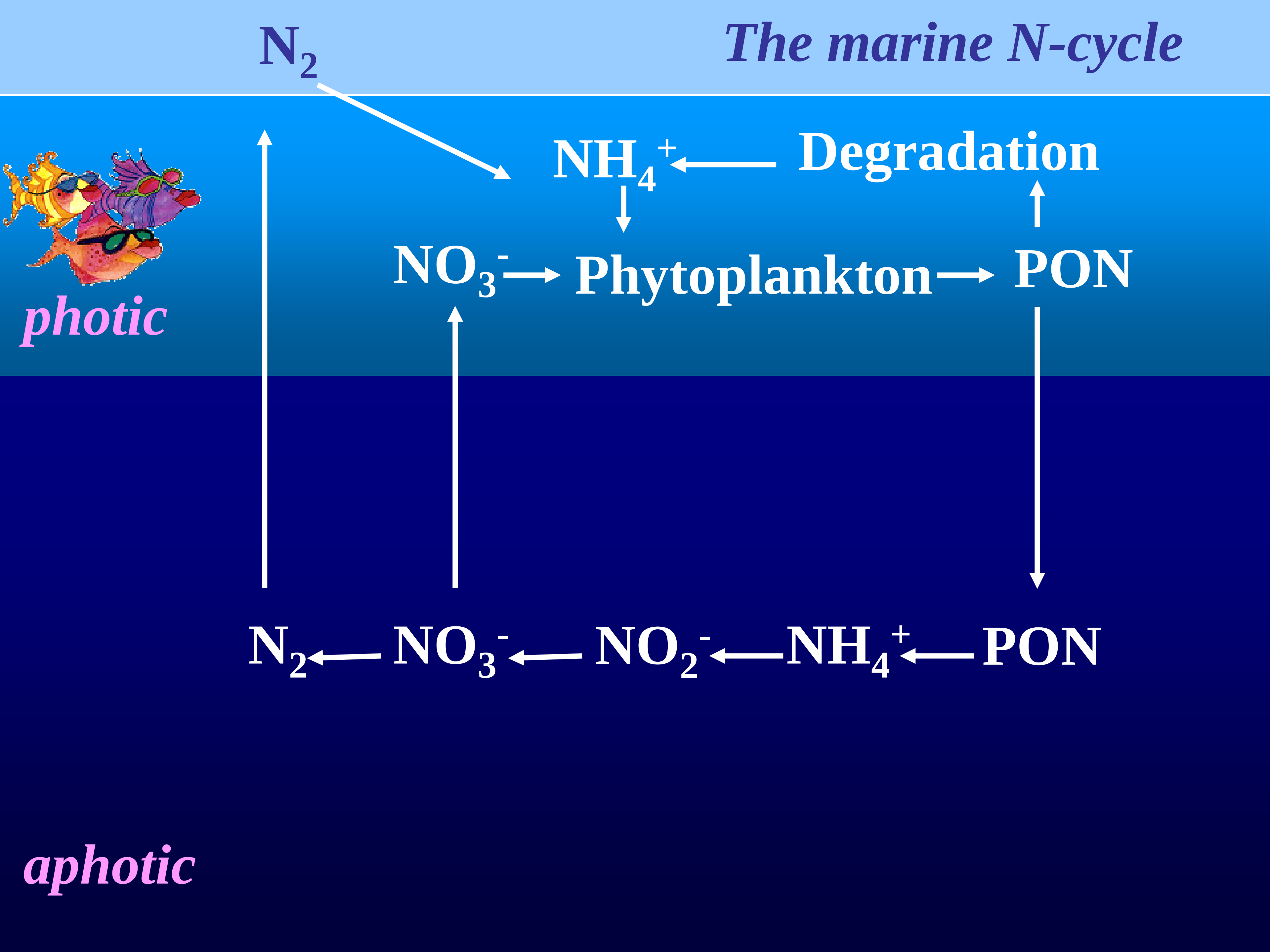
Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges *1990s

10^3 Km^3 = 10^{12} m^3 = Tera m^3

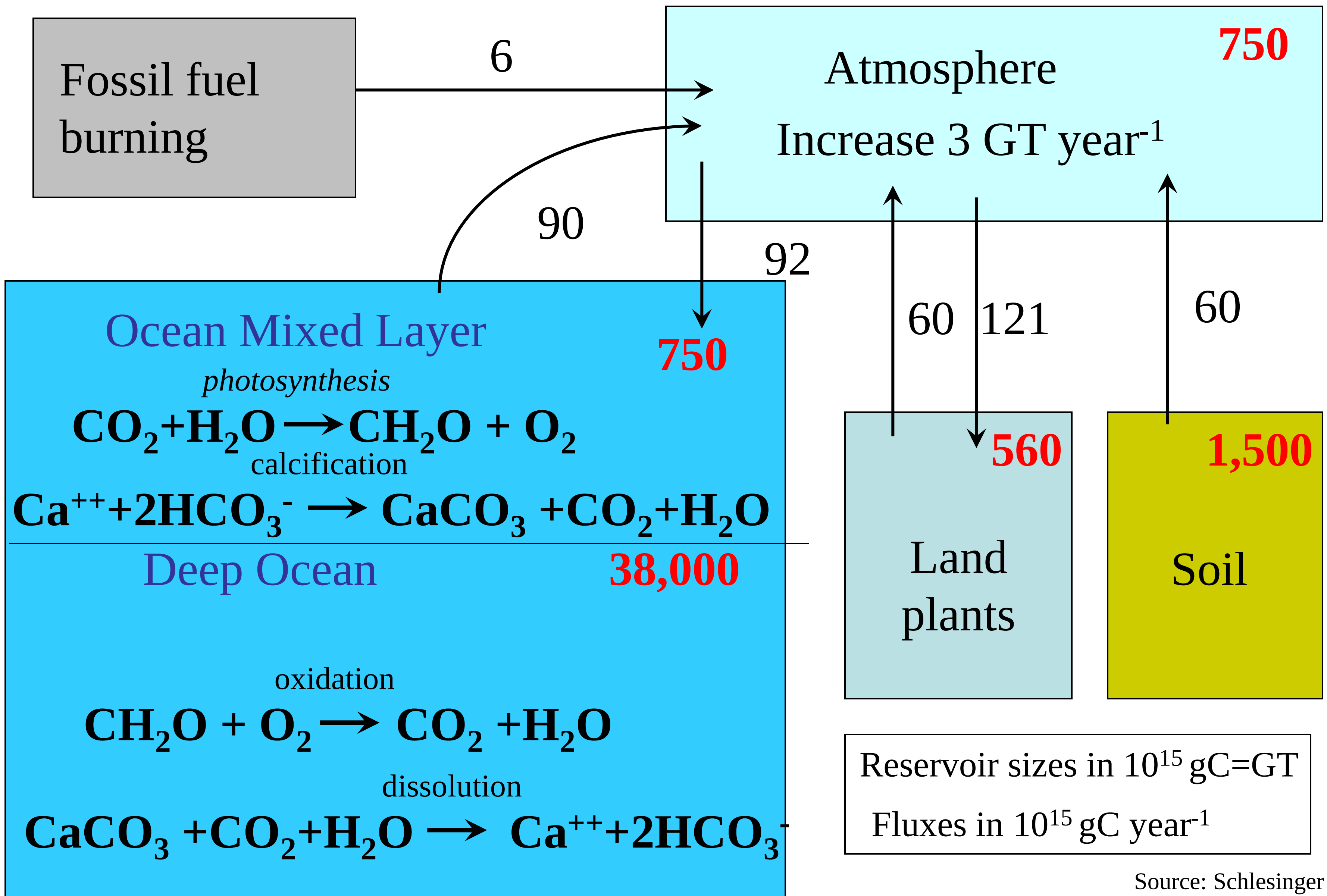
Some simple calculations

(rounded numbers)

Reservoir	resevoir size 10^3 Km^3	process rate 10^3 Km^3/Yr	residence time (Yr)
Ocean	1,340,000	(evaporation) 430	3000
Water on land	16,000	(flow to ocean) 115	140
glacial Ocean	1,290,000		
Ice during glacial	40,000	Glaical cycle 0.35	
groundwater	16,000	(flow to ocean) 2	8000


The marine N-cycle
N2
NH4+
Degradation
NO3-
Phytoplankton
PON
photic
N2
NO3-
NO2-
NH4+
PON
aphotic

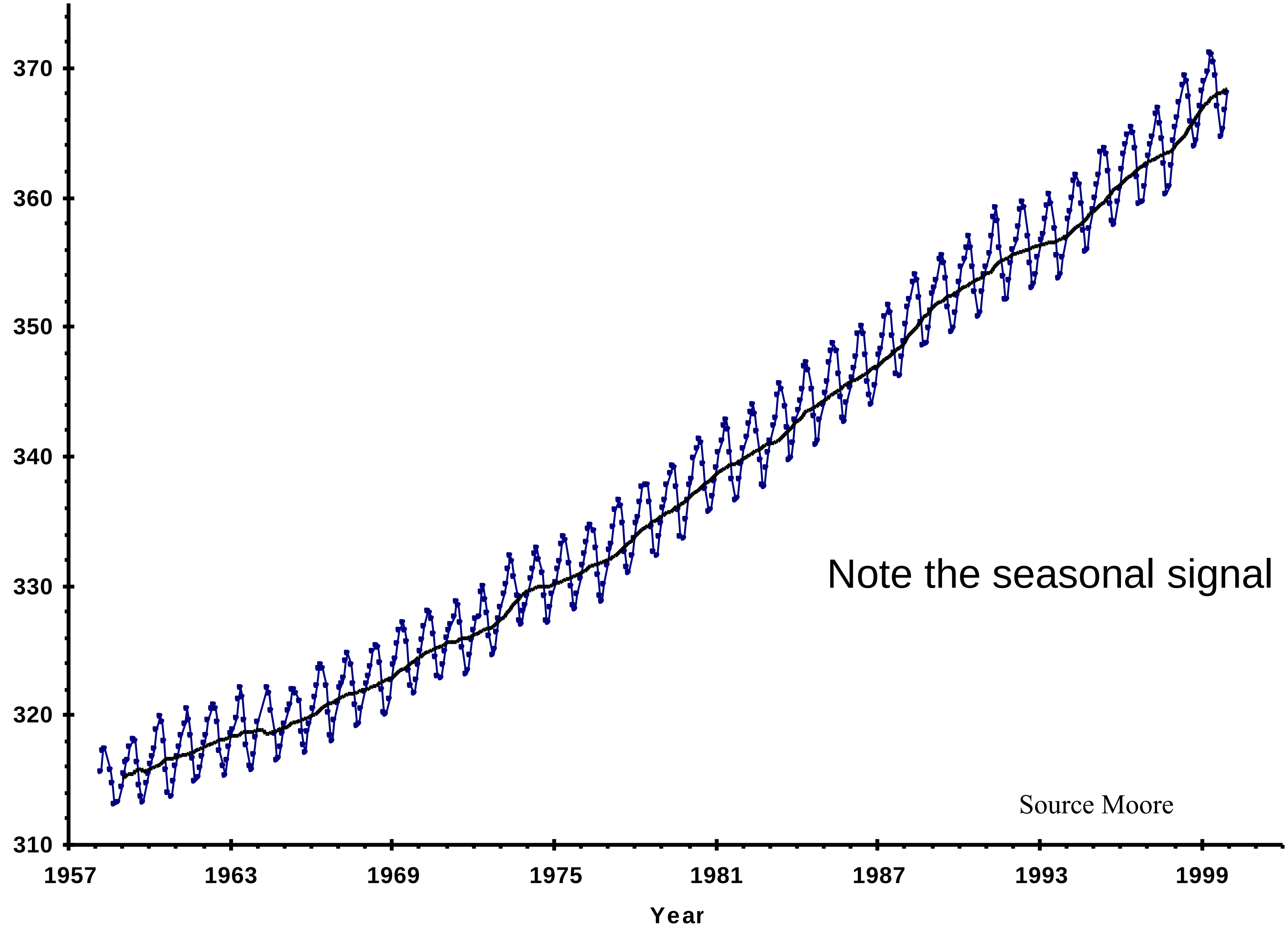
MODIFIED MODEL OF THE GLOBAL CARBON CYCLE



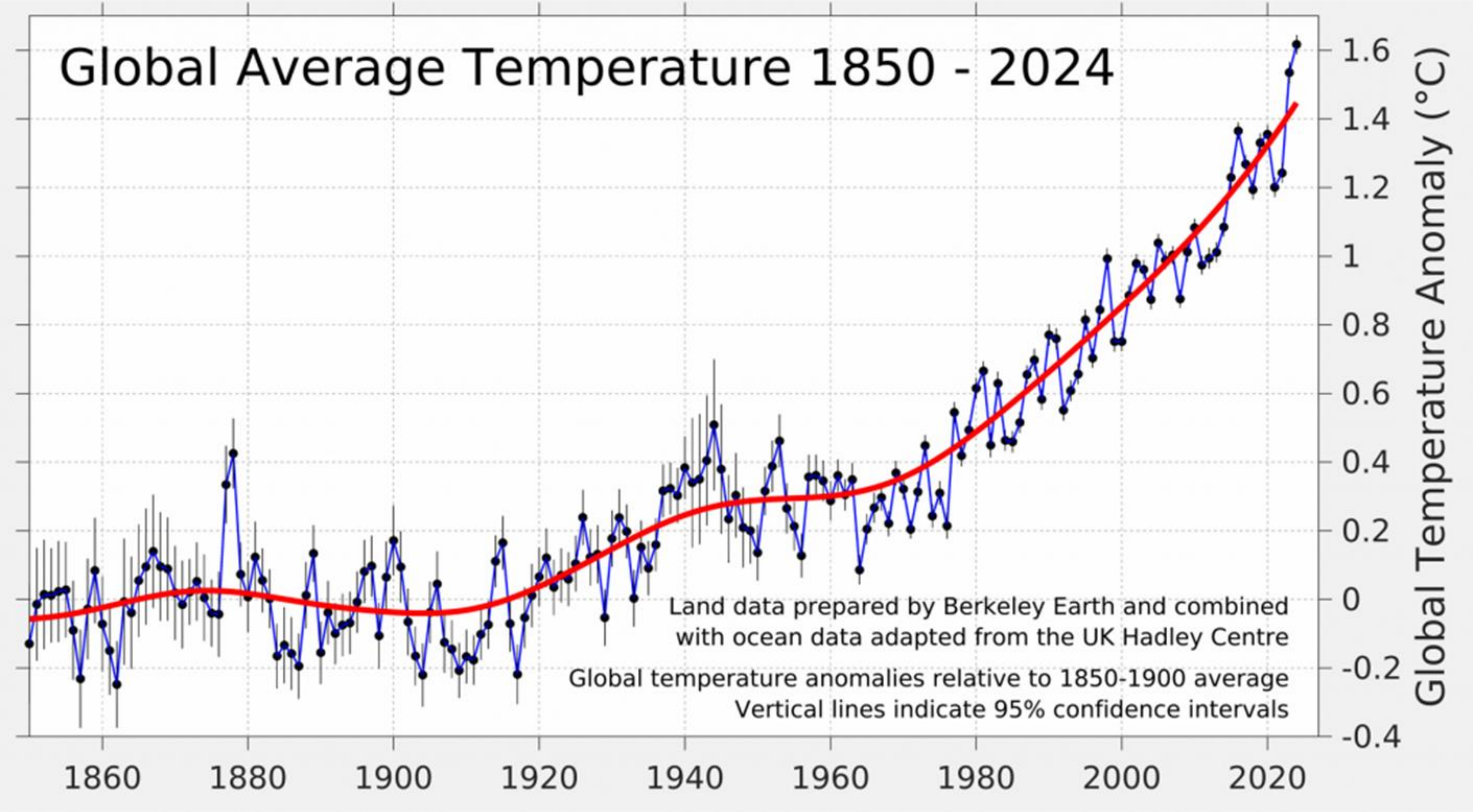
Source: Schlesinger 1997

Mauna Loa Monthly Carbon Dioxide Record:

Keeling Record 1958 - 1999

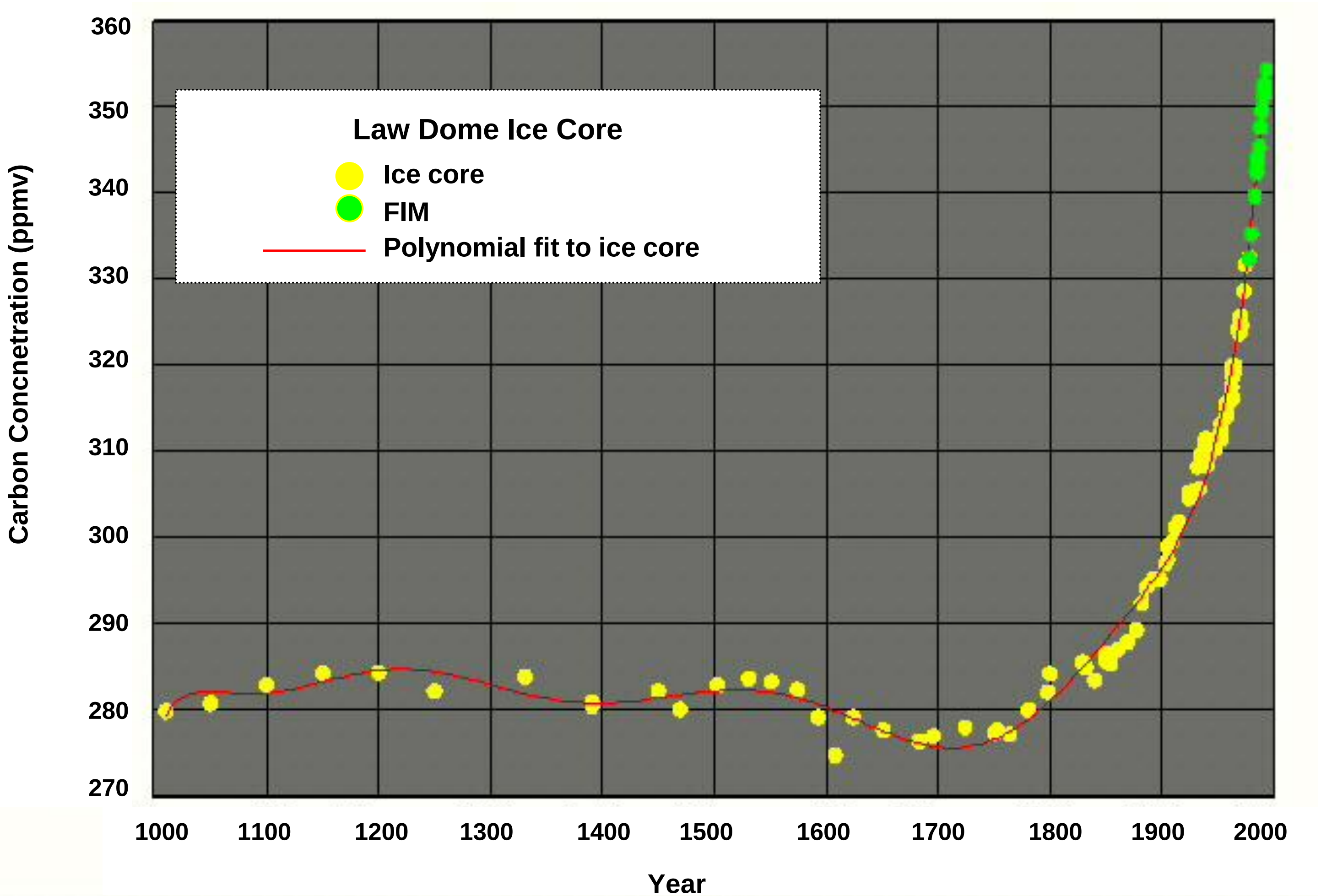


Source (with thanks from everyone): C.D. Keeling and T.P. Whorf



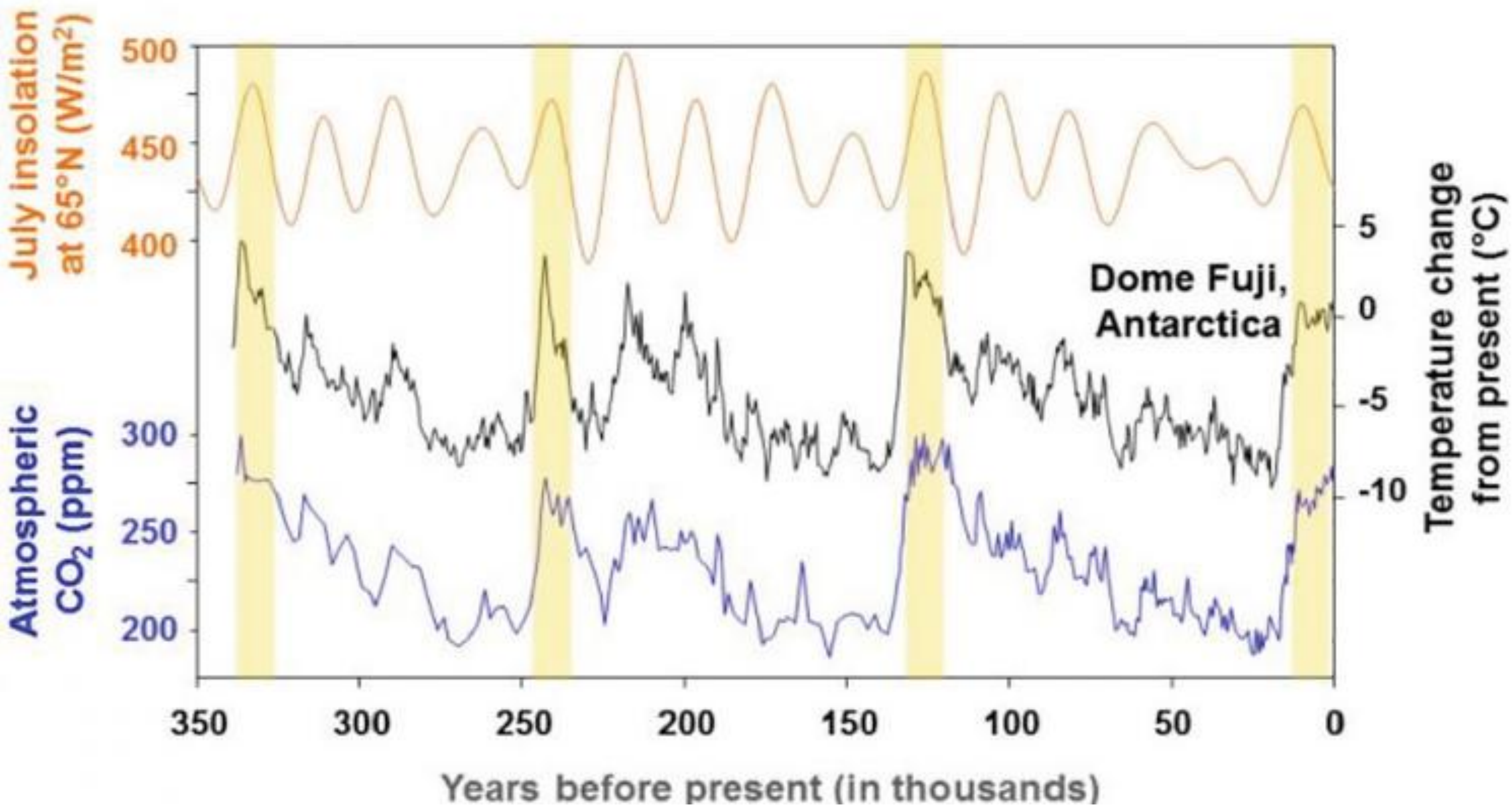
Global Average Temperature 1850 - 2024
Land data prepared by Berkeley Earth and combined with ocean data adapted from the UK Hadley Centre
Global temperature anomalies relative to 1850-1900 average
Vertical lines indicate 95% confidence intervals
Global Temperature Anomaly (°C)
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1860
1880
1900
1920
1940
1960
1980
2000
2020

Historical Atmospheric Carbon Concentration for the Last 1000 Years Extracted from the Law Dome Ice Core



Source Moore

Source: Etheridge, *et.al.*, Petit, *et.al.*


July insolation at 65°N (W/m²)
500
450
400
Atmospheric CO₂ (ppm)
300
250
200
Dome Fuji, Antarctica
Temperature change from present (°C)
5
0
-5
-10
350
300
250
200
150
100
50
0
Years before present (in thousands)

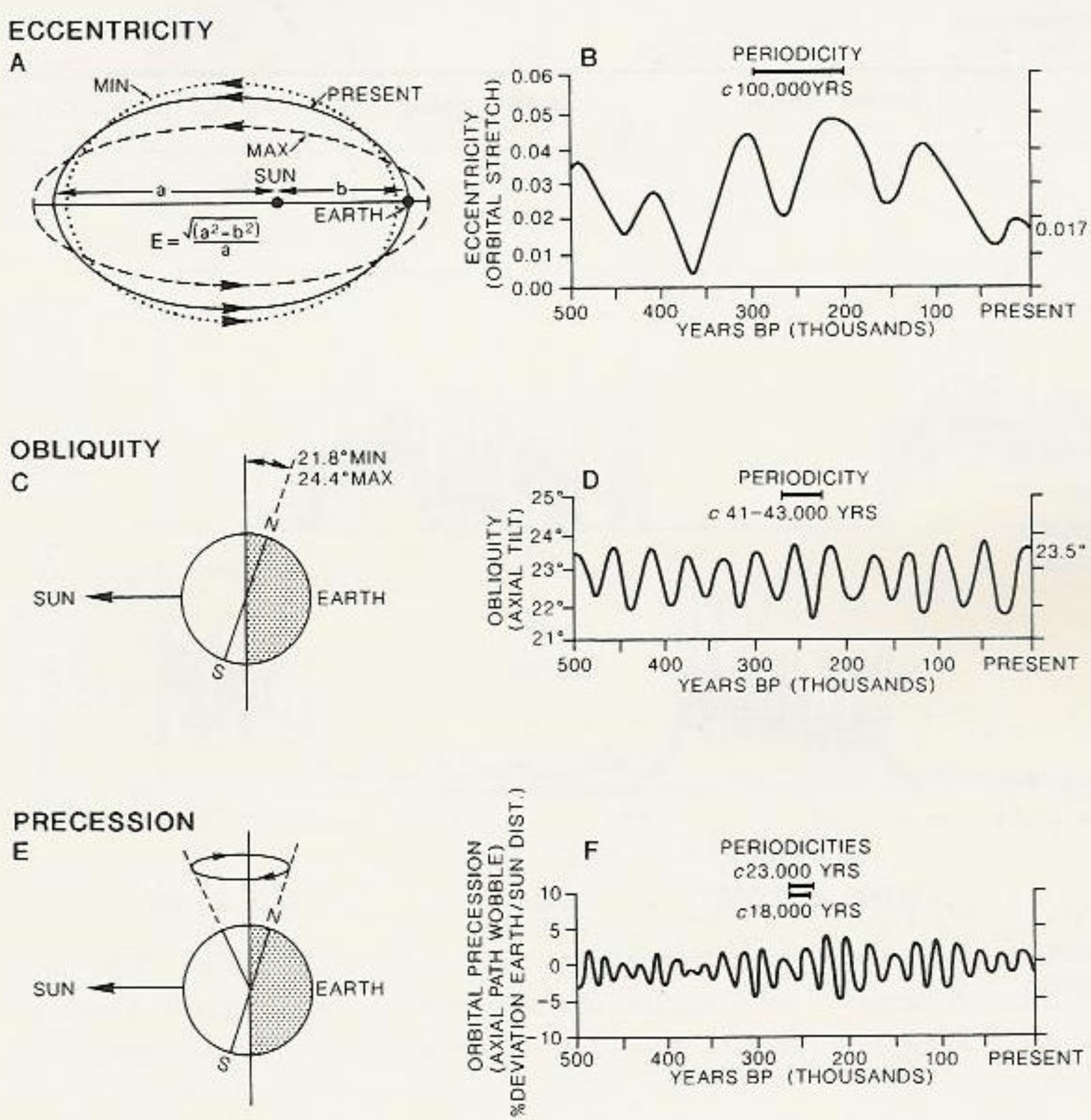
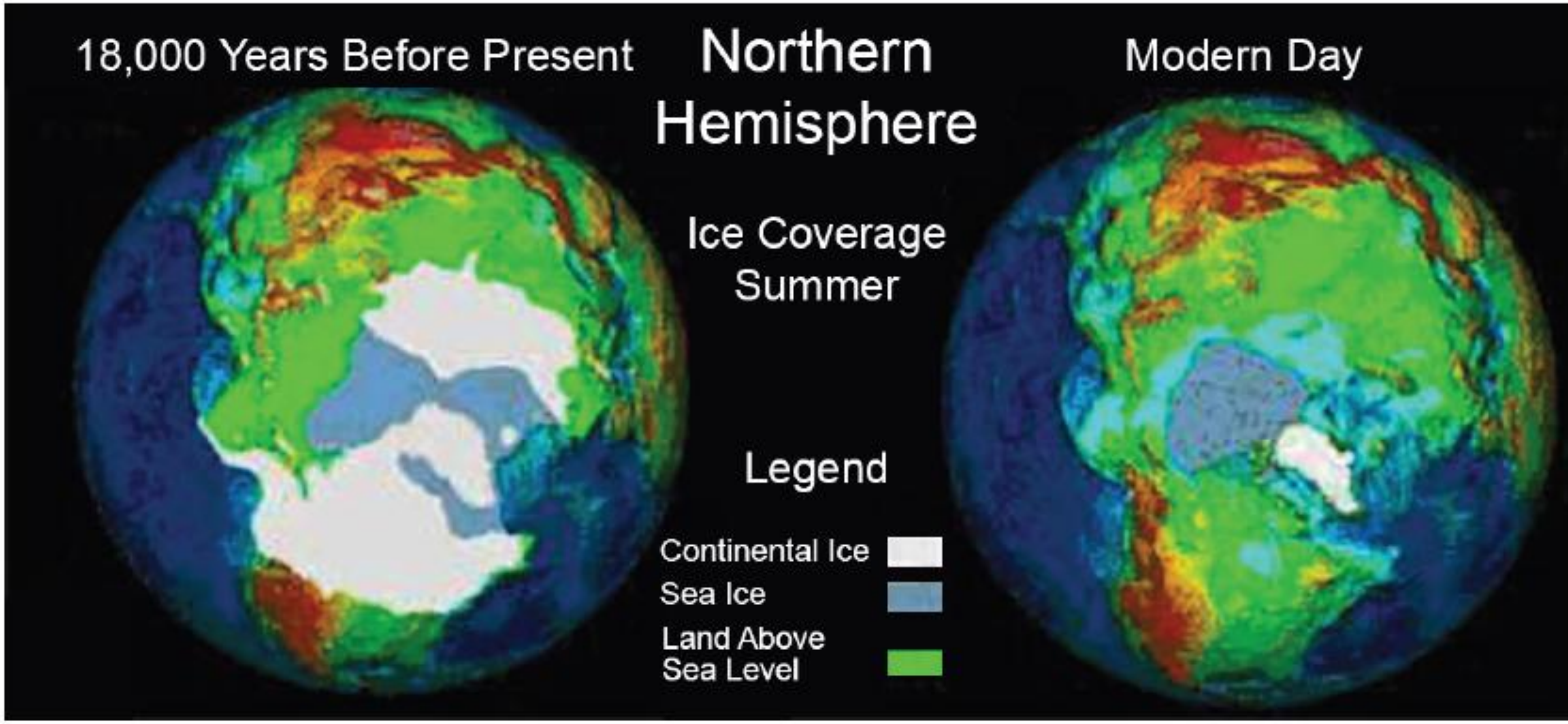


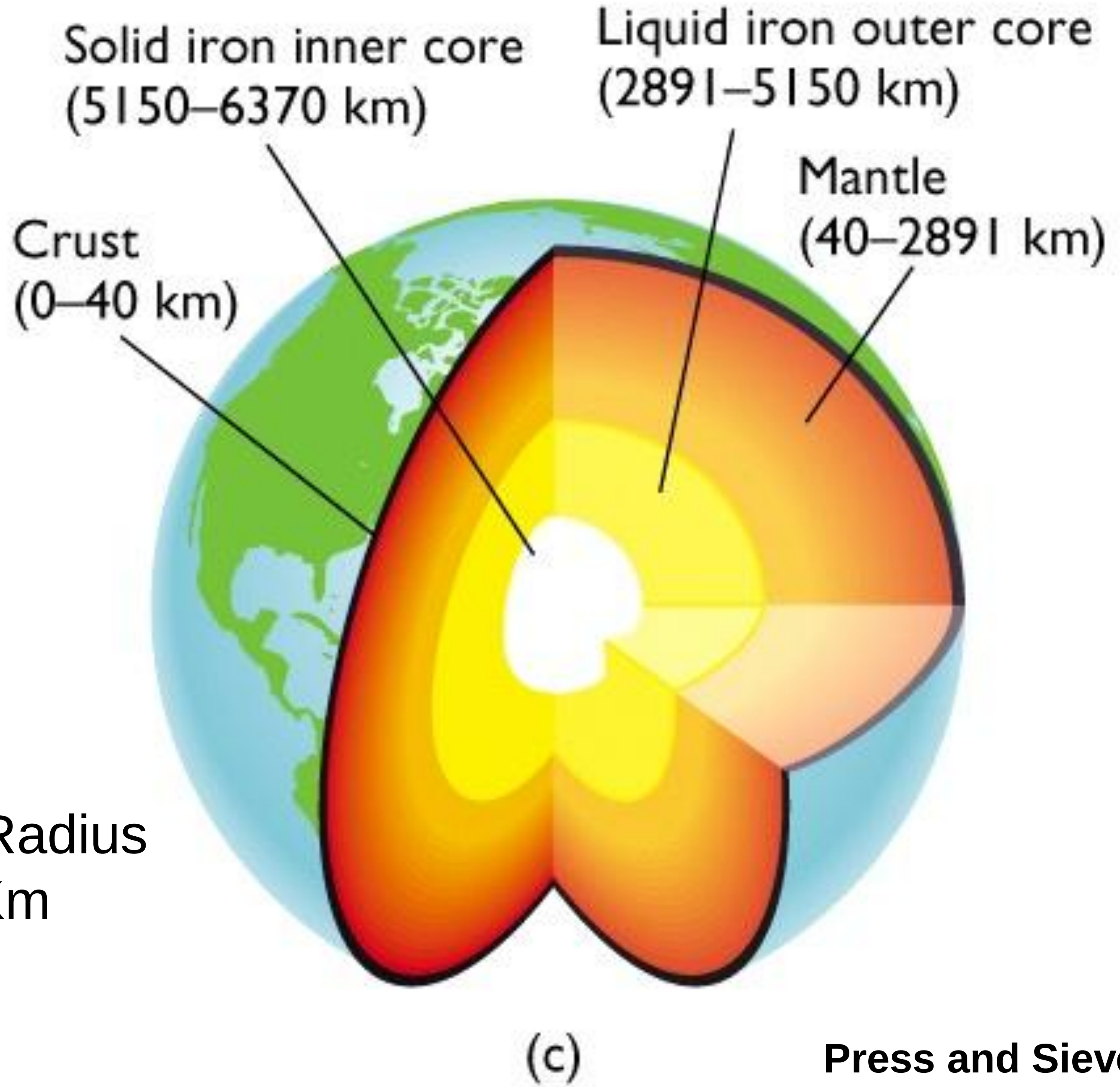
Figure 11.3 The astronomical (orbital) effects on the solar irradiance and their time scales over the past 500,000 years. A and B: Eccentricity or orbital stretch; C and D: Obliquity or axial tilt; E and F: Precession or axial path wobble.

Sources: Partly after Broecker and Van Donk 1970, and Henderson-Sellers and McGuffie 1984. B, D and F: from *Review of Geophysics and Space Physics* **8**, 1970. Reproduced by kind permission of the American Geophysical Union.


18,000 Years Before Present
Northern Hemisphere
Modern Day
Ice Coverage Summer
Legend
Continental Ice
Sea Ice
Land Above Sea Level

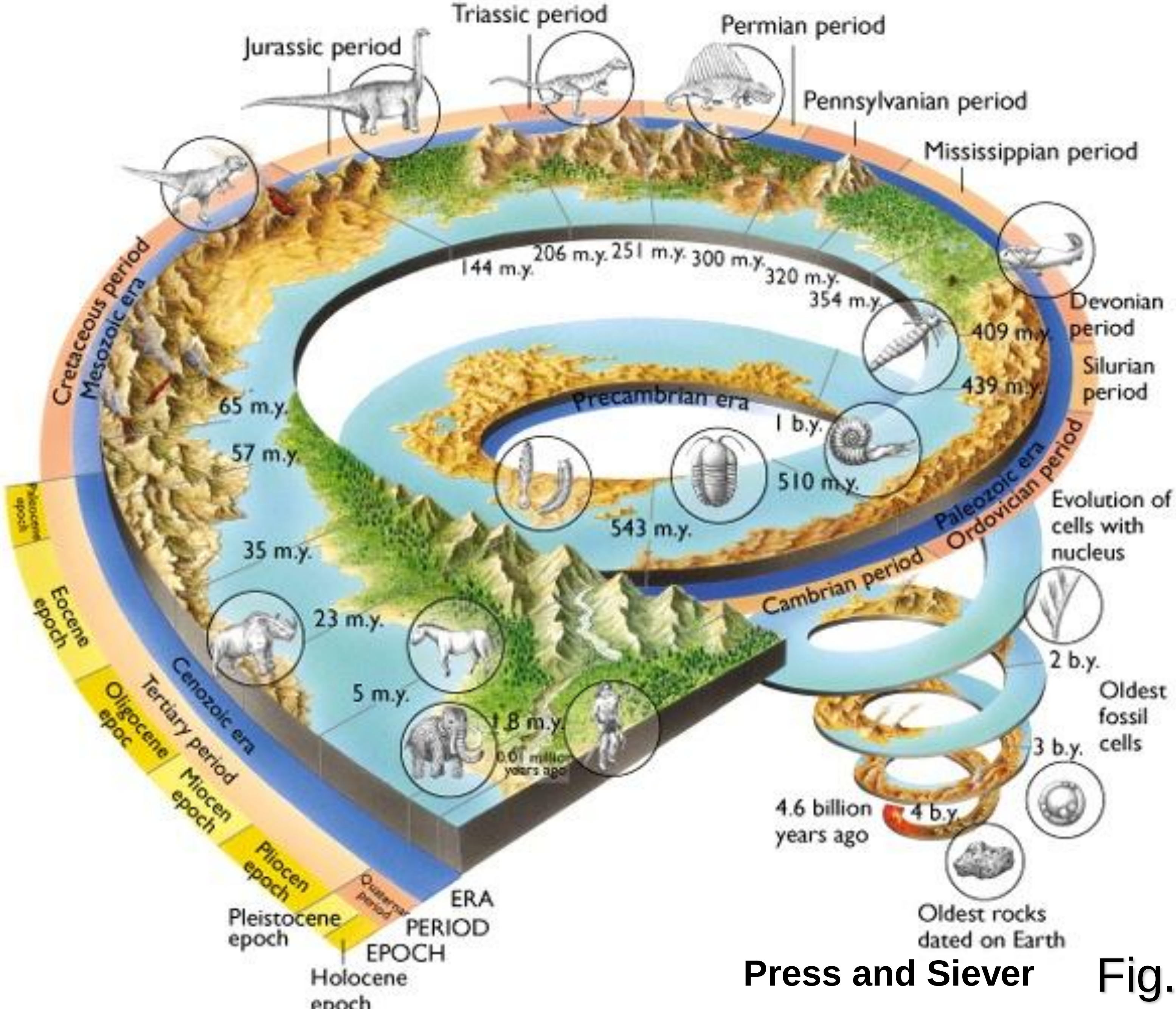
Vectorial processes

- Creation of the universe (elements, stars) 14 Giga Yr
- Segregation of elements on Earth 4.5 Giga Yr
- Biological evolution 3.8 Giga Yr
- Man and its influence ? 2 Mega Yr

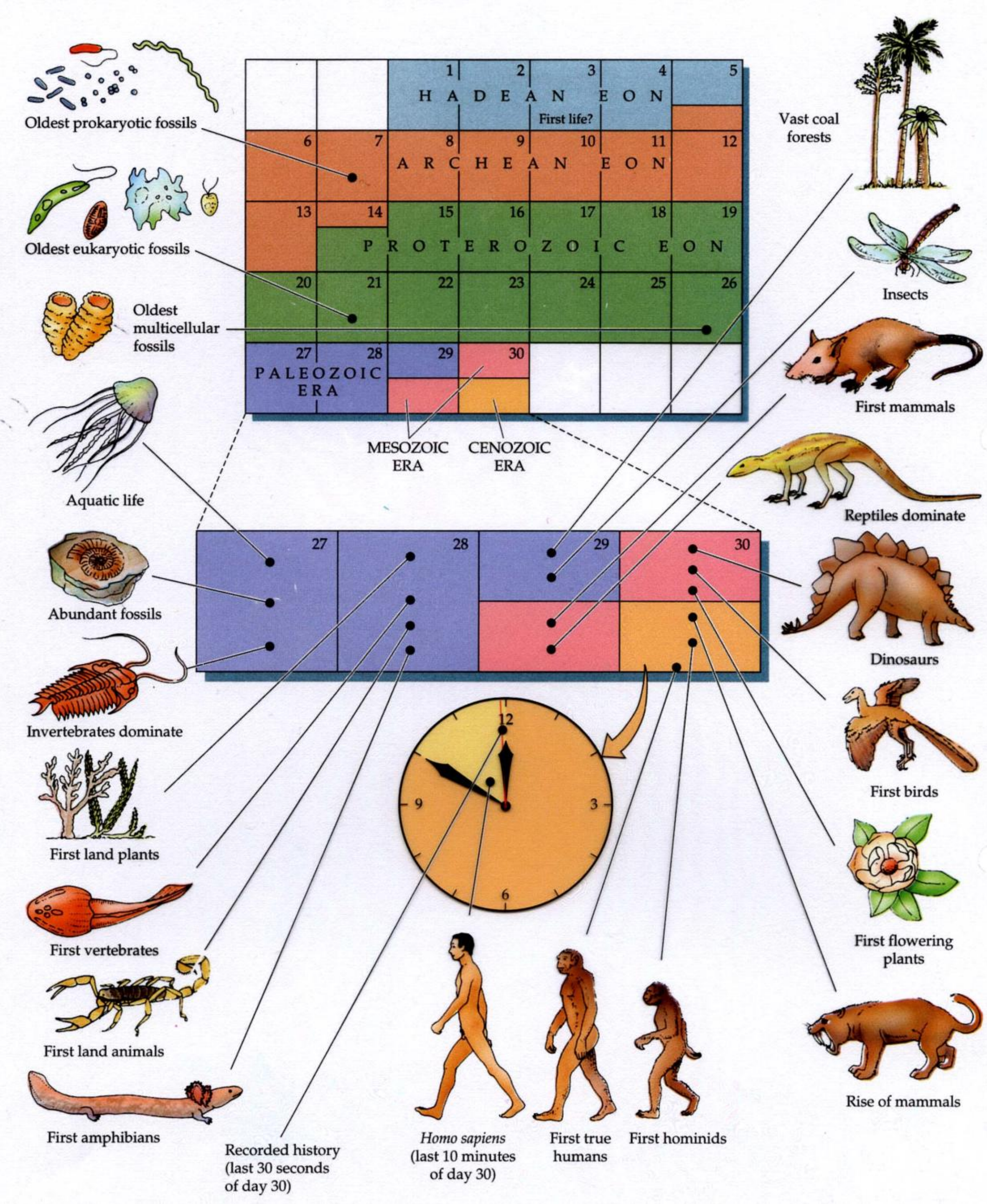


Earth Radius
6400 Km

Press and Siever **Fig. 1.6c**

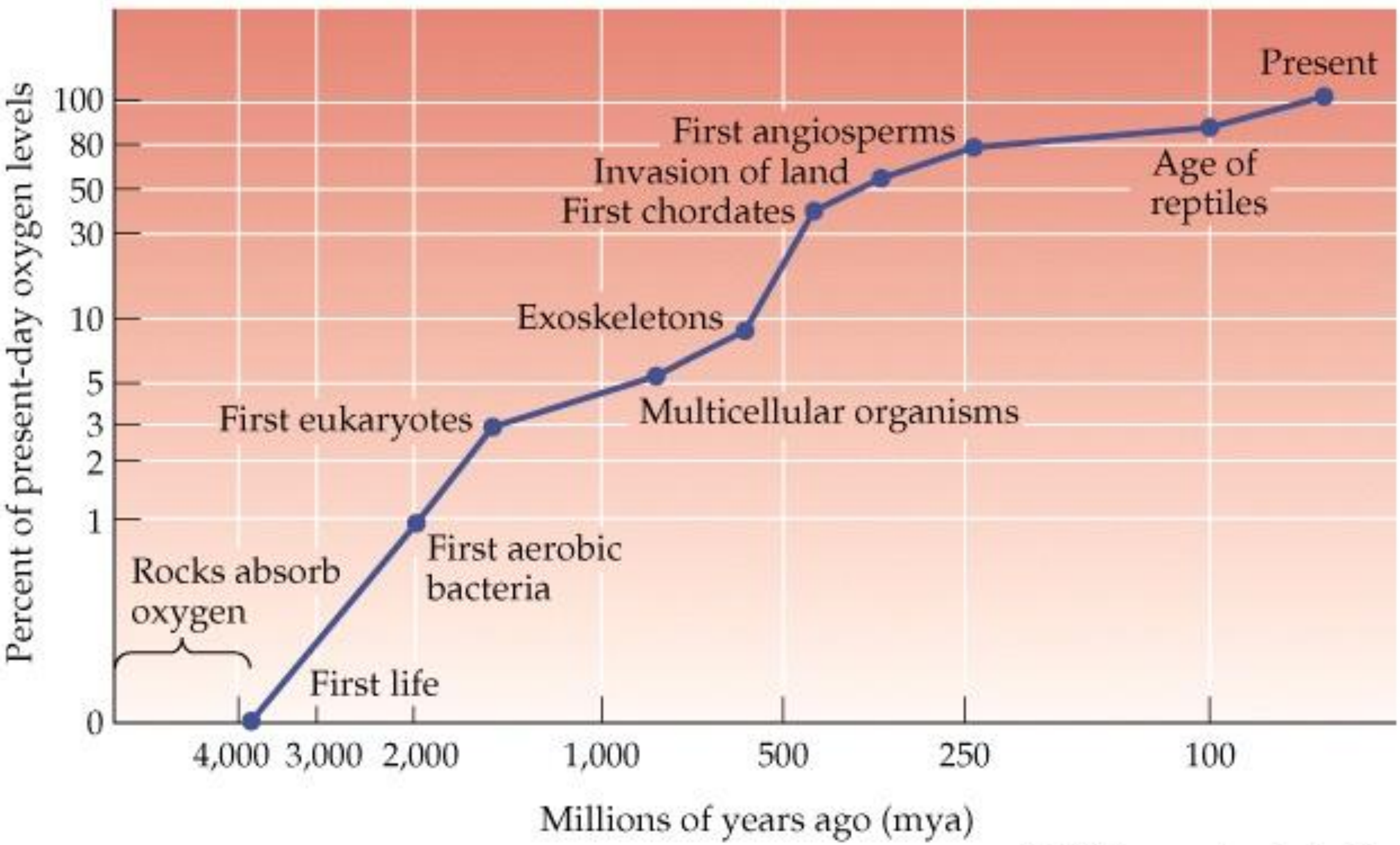


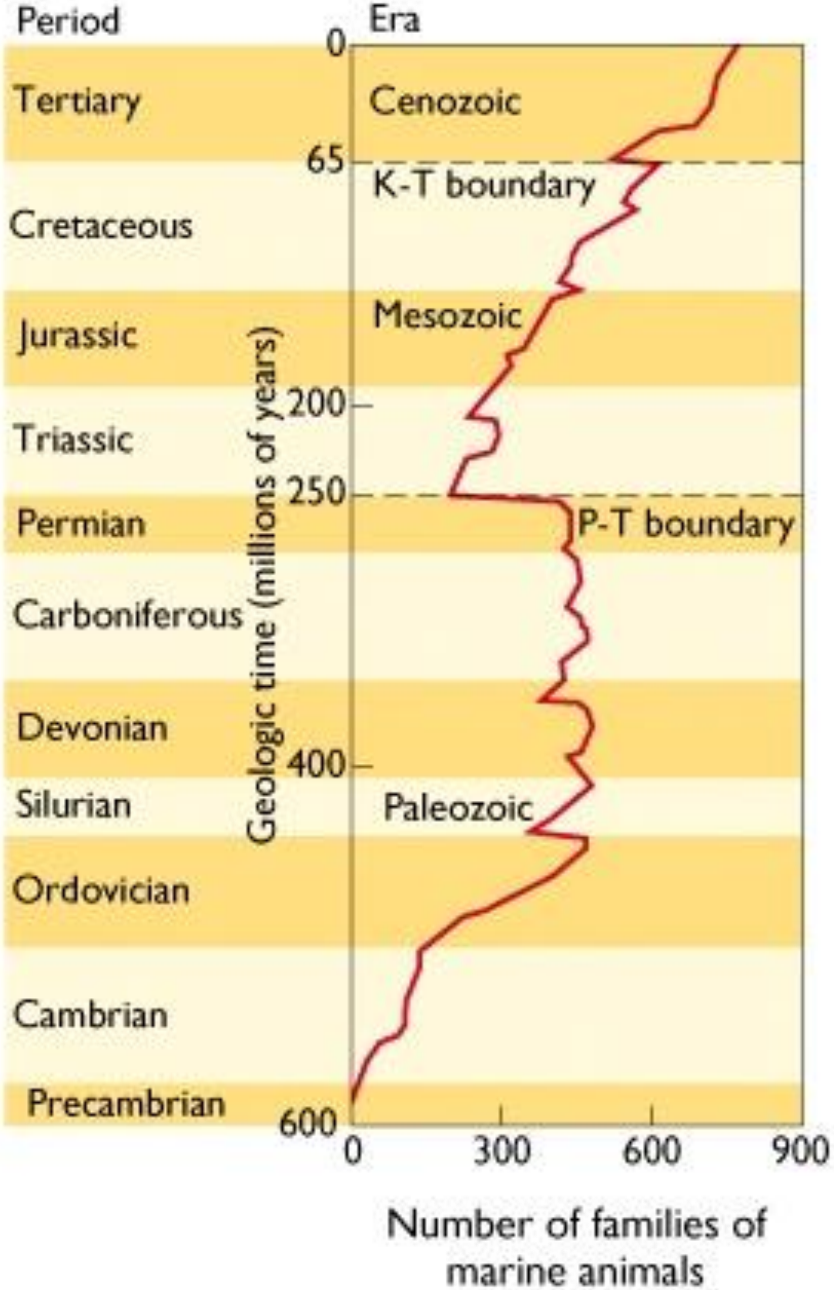
Press and Siever Fig. 9.18



Geologic Time Scale

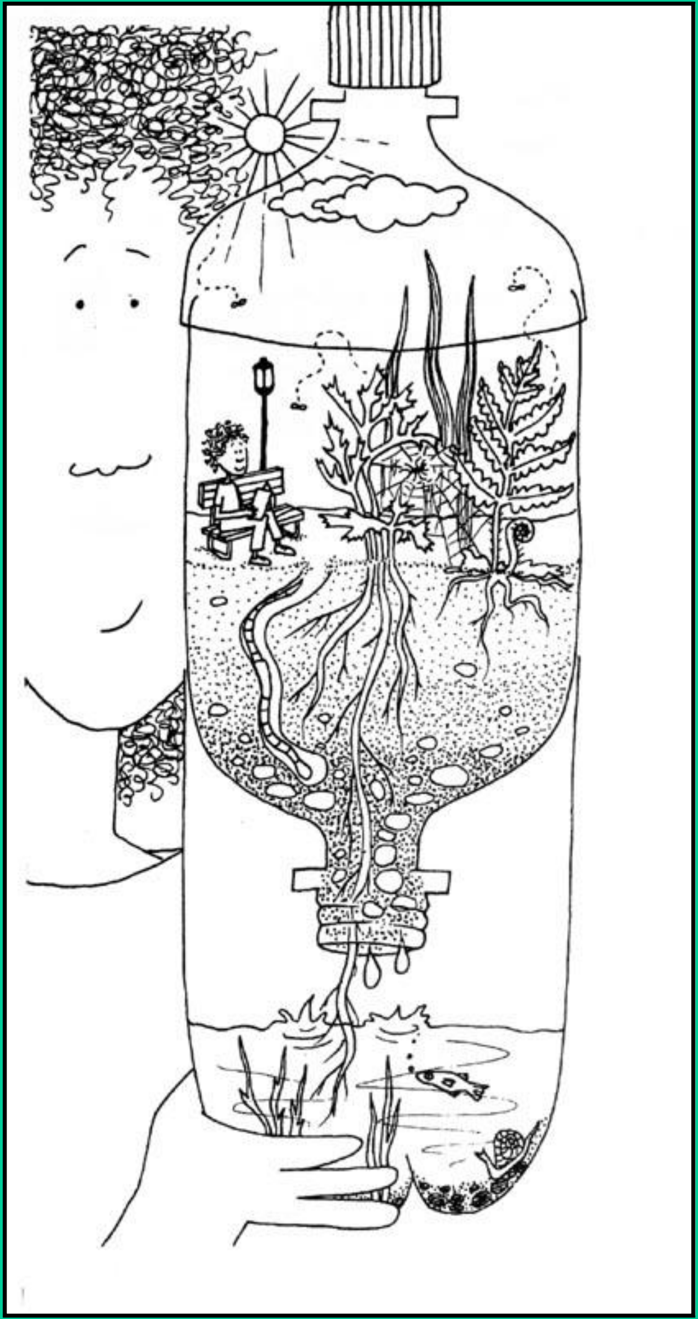
Eon	Era	Period	Epoch	Age(my)
Phanerozoic (Visible Life)	Cenozoic (Recent Life) (Age of Mammals)	Quaternary	Holocene	0.01
			Pleistocene	1.6
		Tertiary	Pliocene	5.3
			Miocene	23.7
			Oligocene	36.6
			Eocene	57.8
			Paleocene	66.4
	Mesozoic (Middle Life) (Age of Reptiles)	Cretaceous		144
		Jurassic		208
		Triassiac		245
	Paleozoic (Ancient Life)	Permian		286
		Pennsylvanian		320
		Mississippian		360
		Devonian		408
		Silurian		438
		Ordovician		505
		Cambrian		570
Proter-ozoic (Early Life)	Oldest Known Life			2500
Archean	Oldest Known Rocks			3900
Hadean	Age of the Earth			4600


Percent of present-day oxygen levels
100
80
50
30
10
5
3
2
1
0
Present
First angiosperms
Invasion of land
First chordates
Age of reptiles
Exoskeletons
Multicellular organisms
First eukaryotes
First aerobic bacteria
Rocks absorb oxygen
First life
4,000
3,000
2,000
1,000
500
250
100
Millions of years ago (mya)



Marine Life During the Phanerozoic Eon

Press and Siever **Fig. 23.10**



James Lovelock
1970's

Ecosystems and the Gaia Hypothesis

Life and its evolution create environmental conditions that support the existence of life in ecosystems.

Examples: Oxygen, CO_2, and temperature and chlorophyl

Gaia Hypothesis(es)

- Life has greatly affected the planetary environment

- This alteration has allowed life to persist

- The Earth is a "super-organism" - Life controls the environment in a fashion that is equivalent to the way an organism controls its various systems

- Evolution?

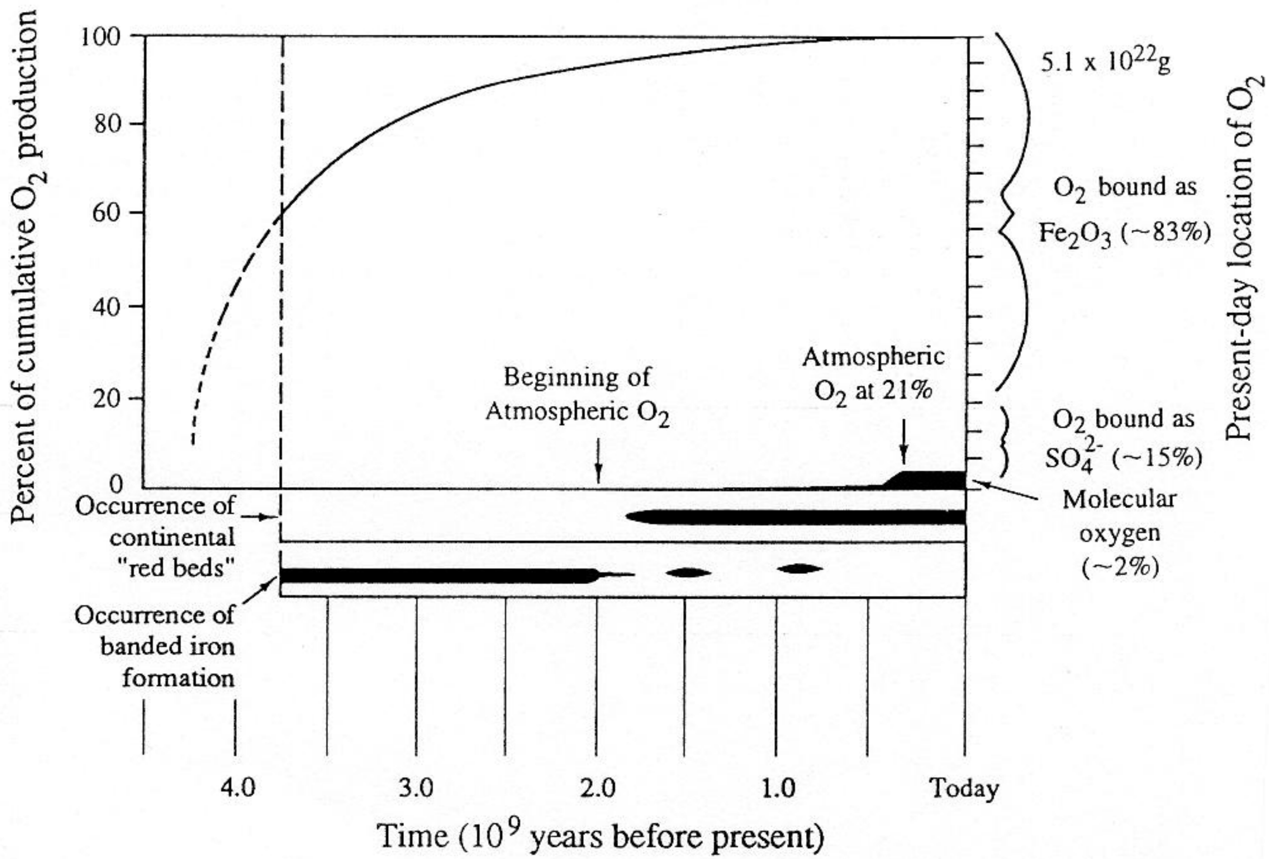
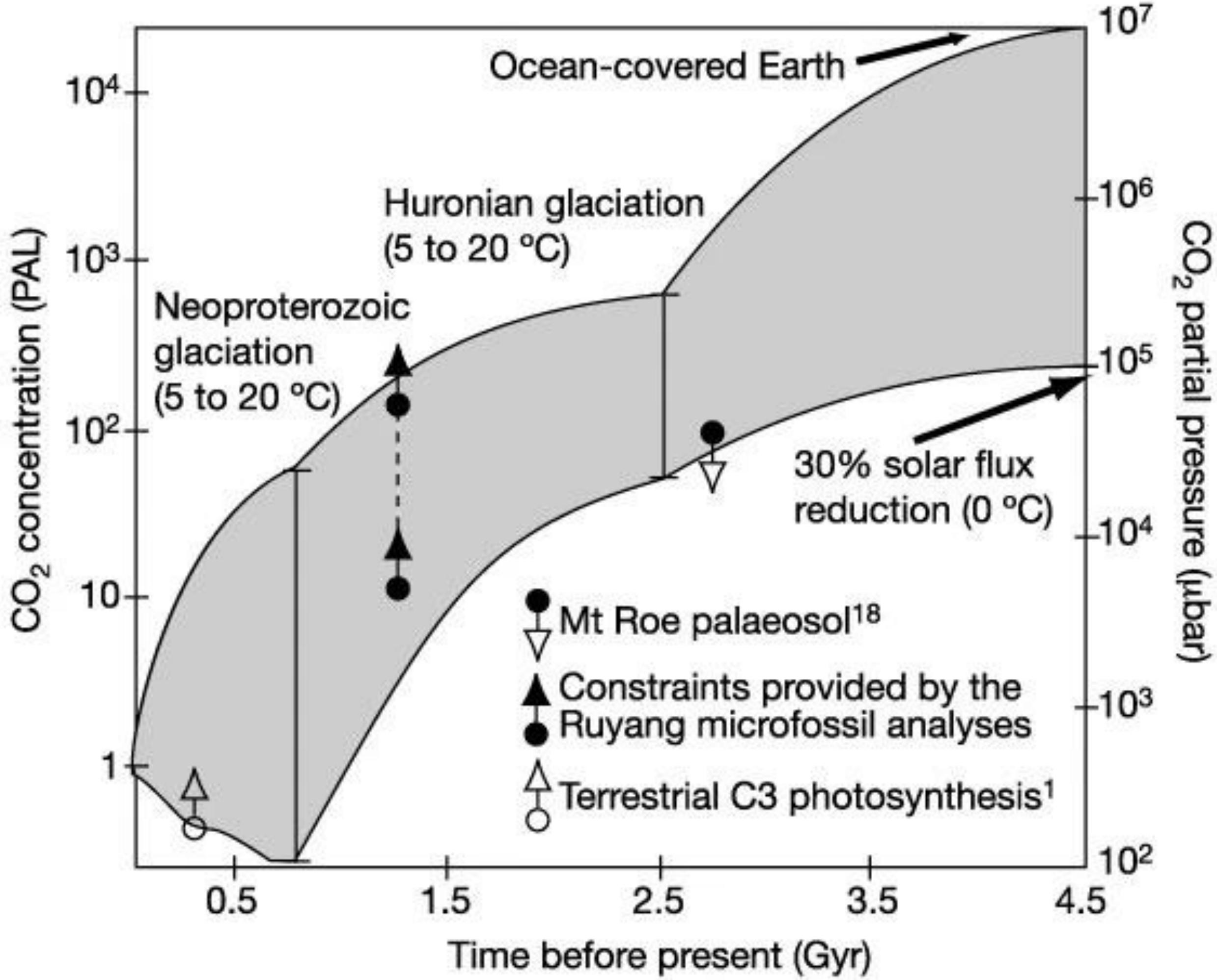
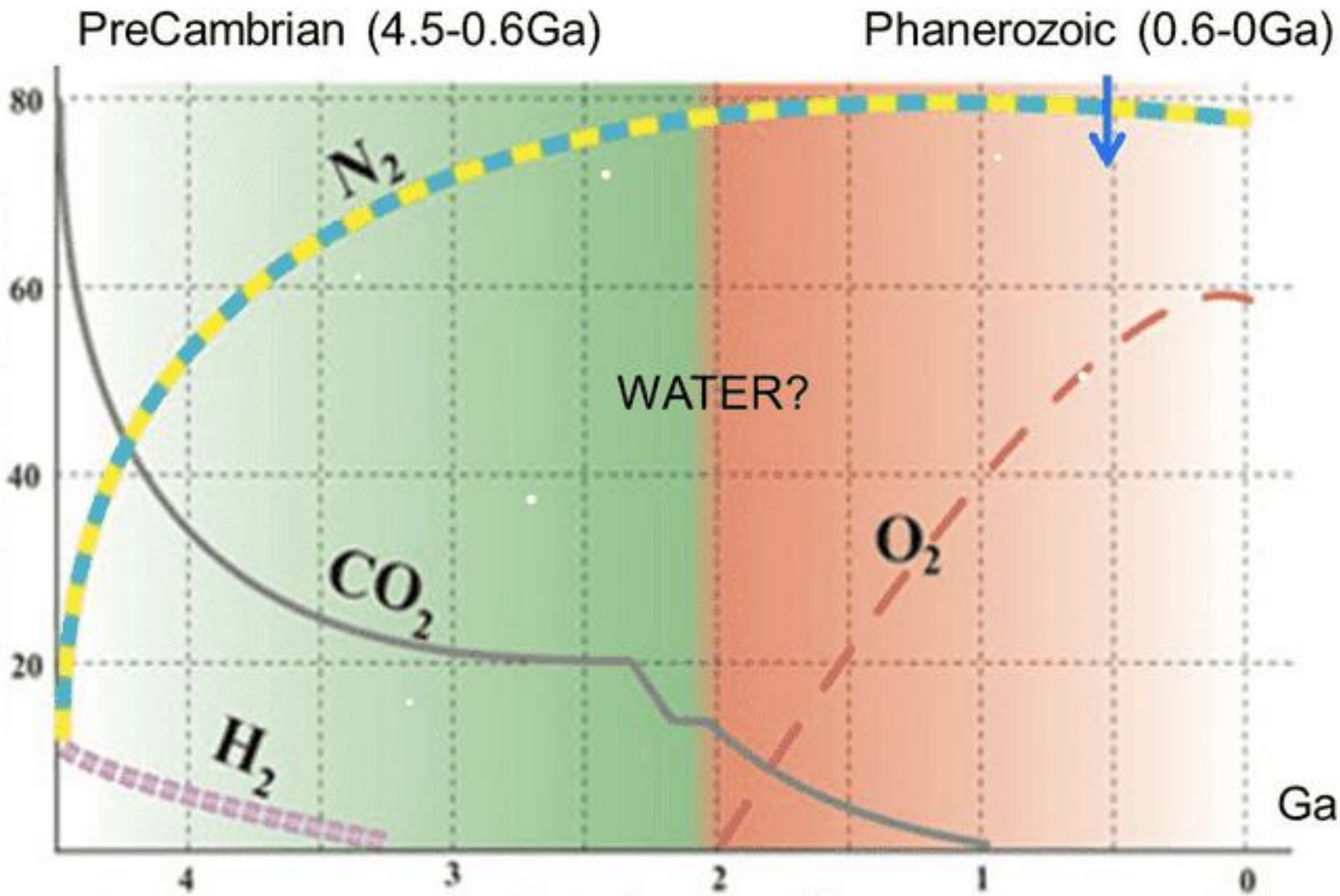


Figure 2.7 Cumulative history of O_2 released by photosynthesis through geologic time. Of more than 5.1×10^{22} g of O_2 released, about 98% is contained in seawater and sedimentary rocks, beginning with the occurrence of Banded Iron Formations at least 3.5 billion years ago (bya). Although O_2 was released to the atmosphere beginning about 2.0 bya, it was consumed in terrestrial weathering processes to form Red Beds, so that the accumulation of O_2 to present levels in the atmosphere was delayed to 400 mya. Modified from Schidlowski (1980).



Shaded area, modelled in ref. 1. Empirical constraints for Archaean (from Mt Roe palaeosol)18 and middle Proterozoic (this study) atmospheric levels are indicated. The two connected upward-pointing arrows at 1.4 Gyr ago relate to estimates based on the possible V/S of D. delicata (see text). After ref. 1.

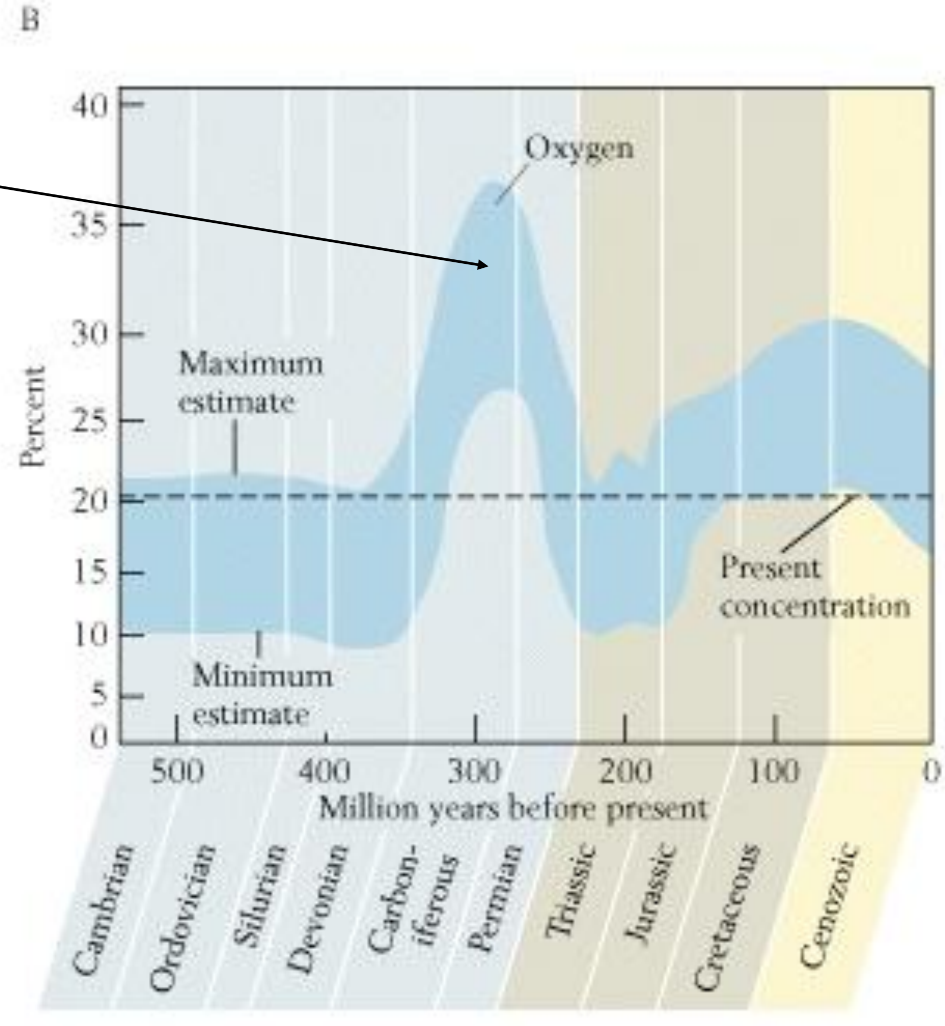


Cumulative % of Earth atmosphere

Historical trends in atmospheric O_2

Carboniferous peak in abundance of oxygen

Large amount of buried organic matter means less oxygen being used in organic decay (oxidation)

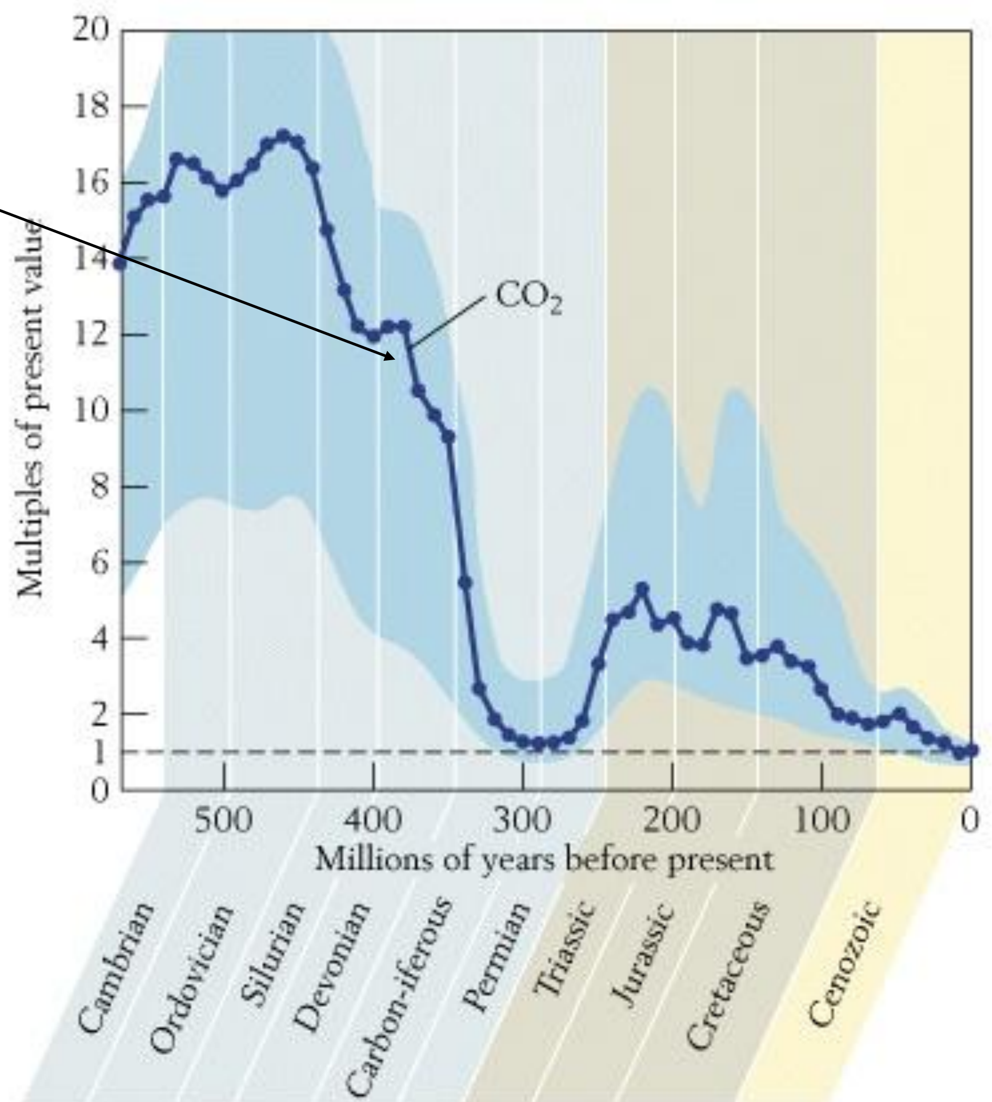


Historical trends in atmospheric CO_2

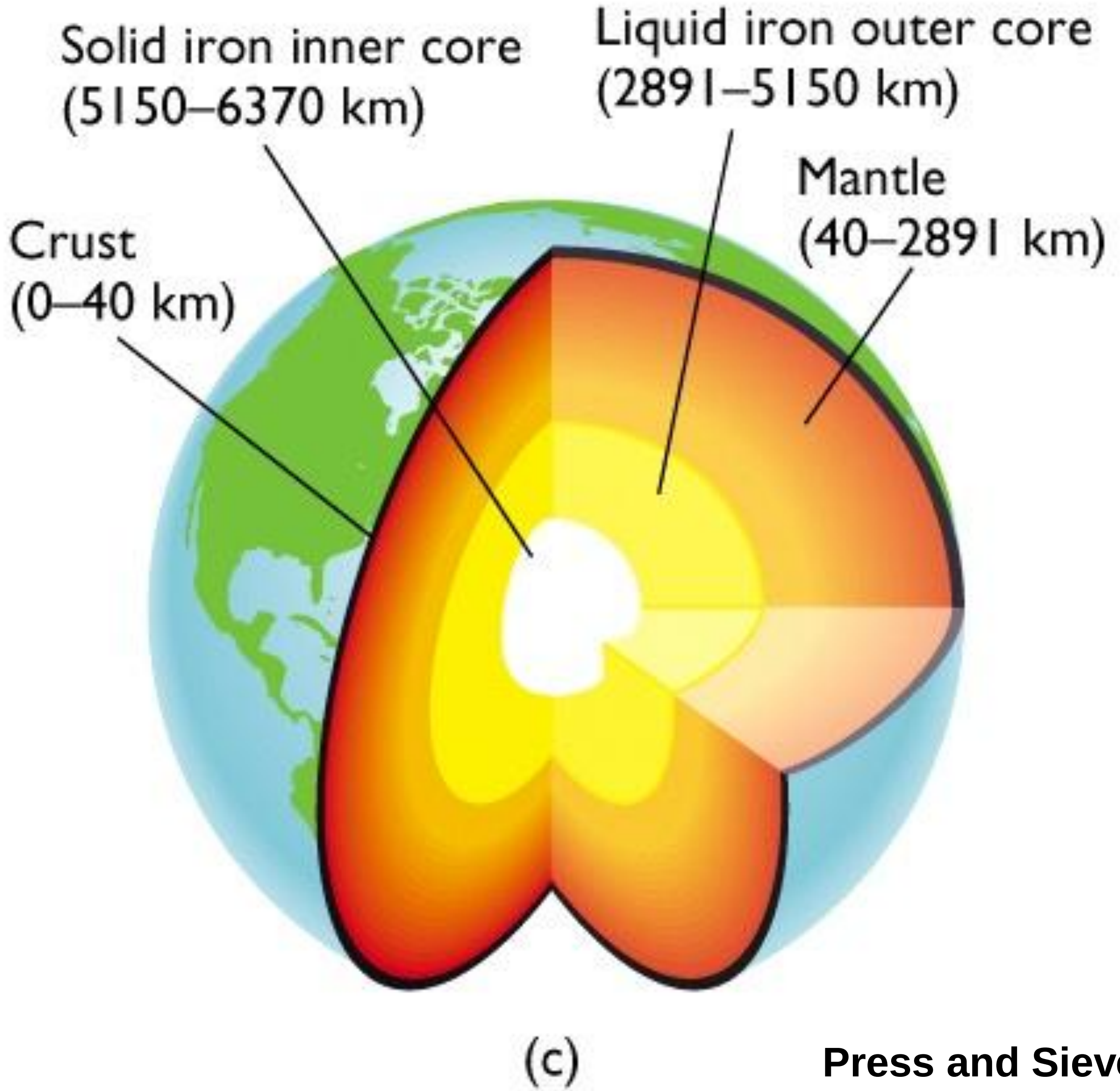
Devonian decline in abundance of CO_2

Diversification of land plants caused increase in rates of mineral weathering processes, which consume CO_2

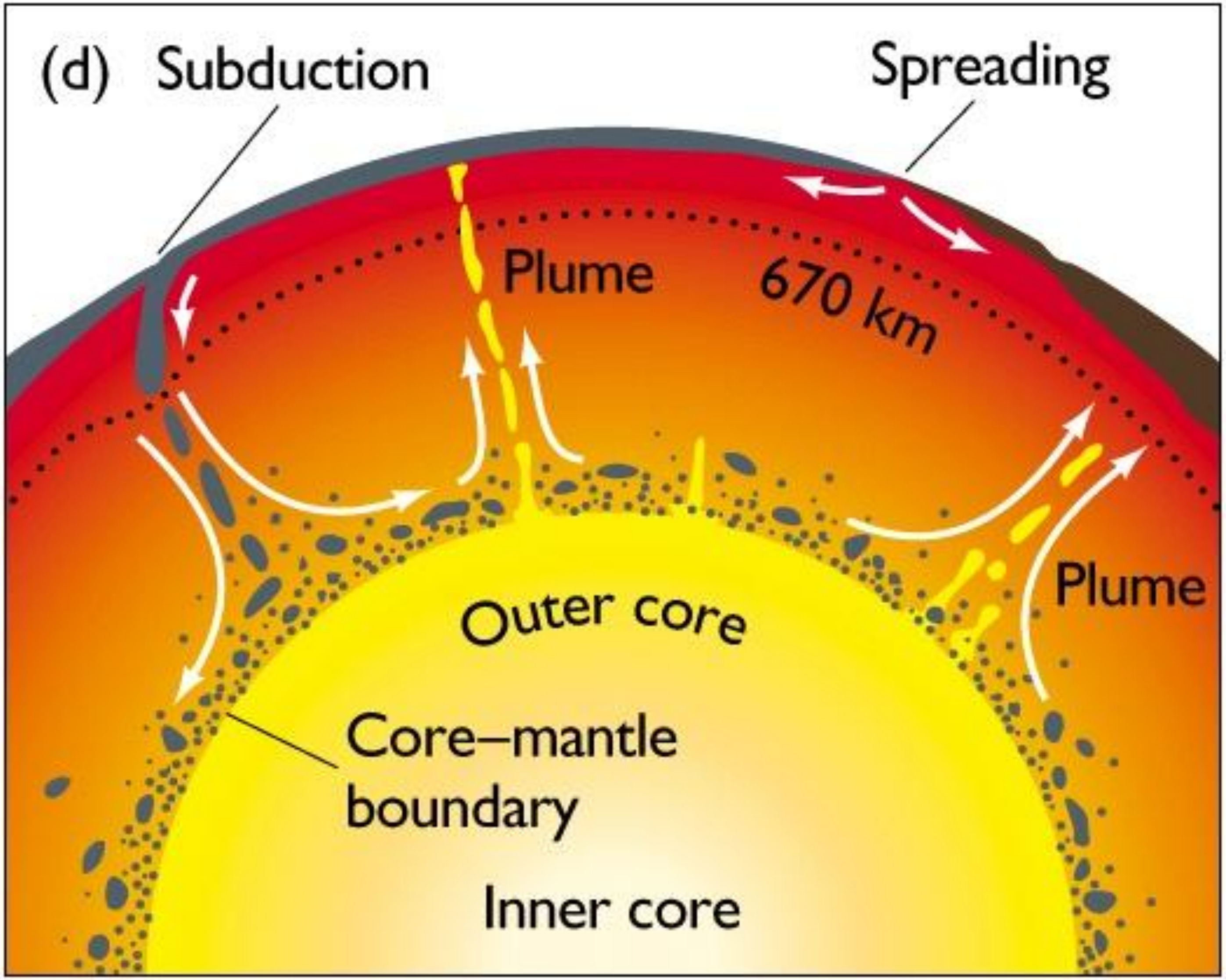
Decline in atmospheric CO_2 may have led to global cooling



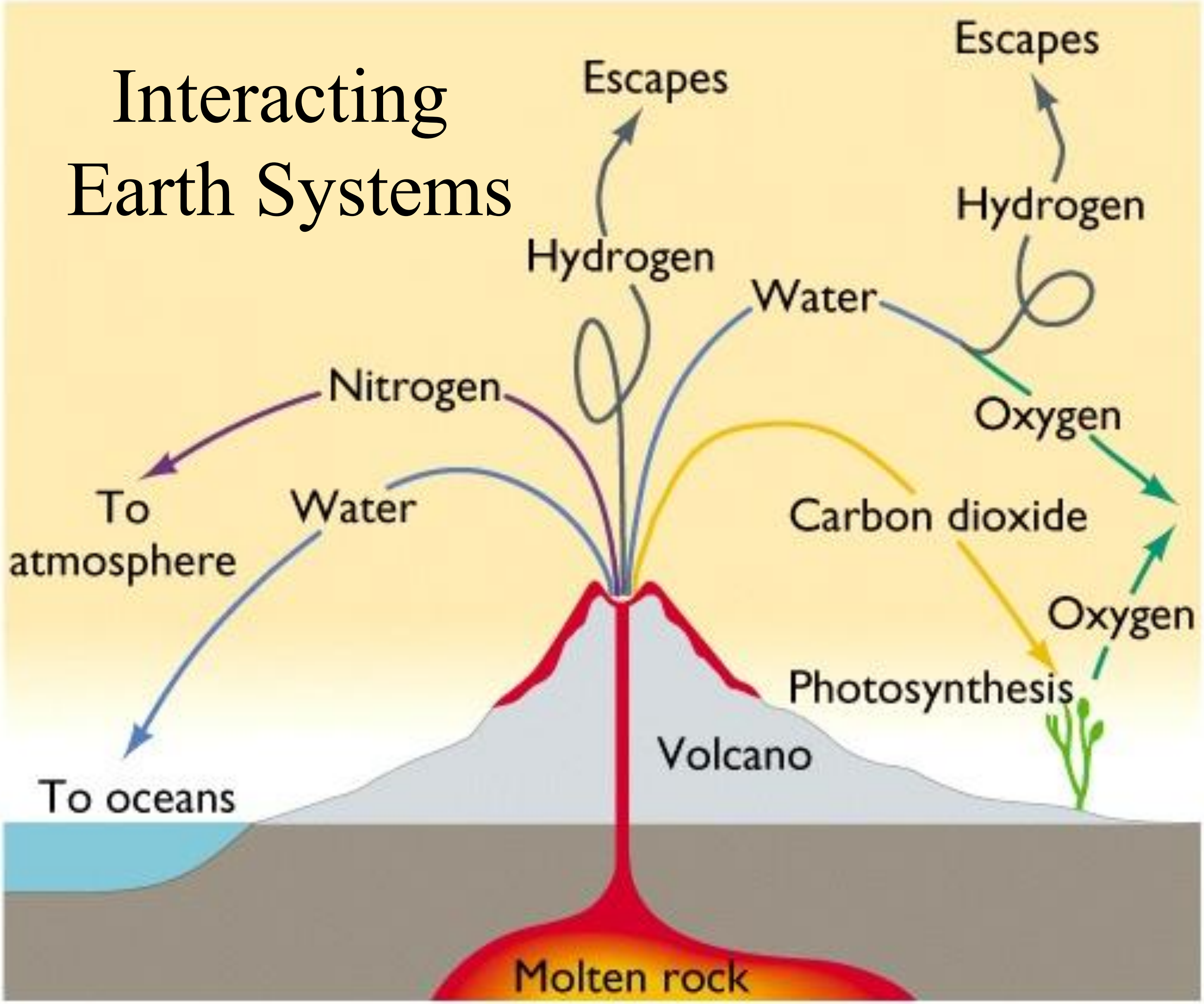
The ocean basins



Press and Siever **Fig. 1.6c**

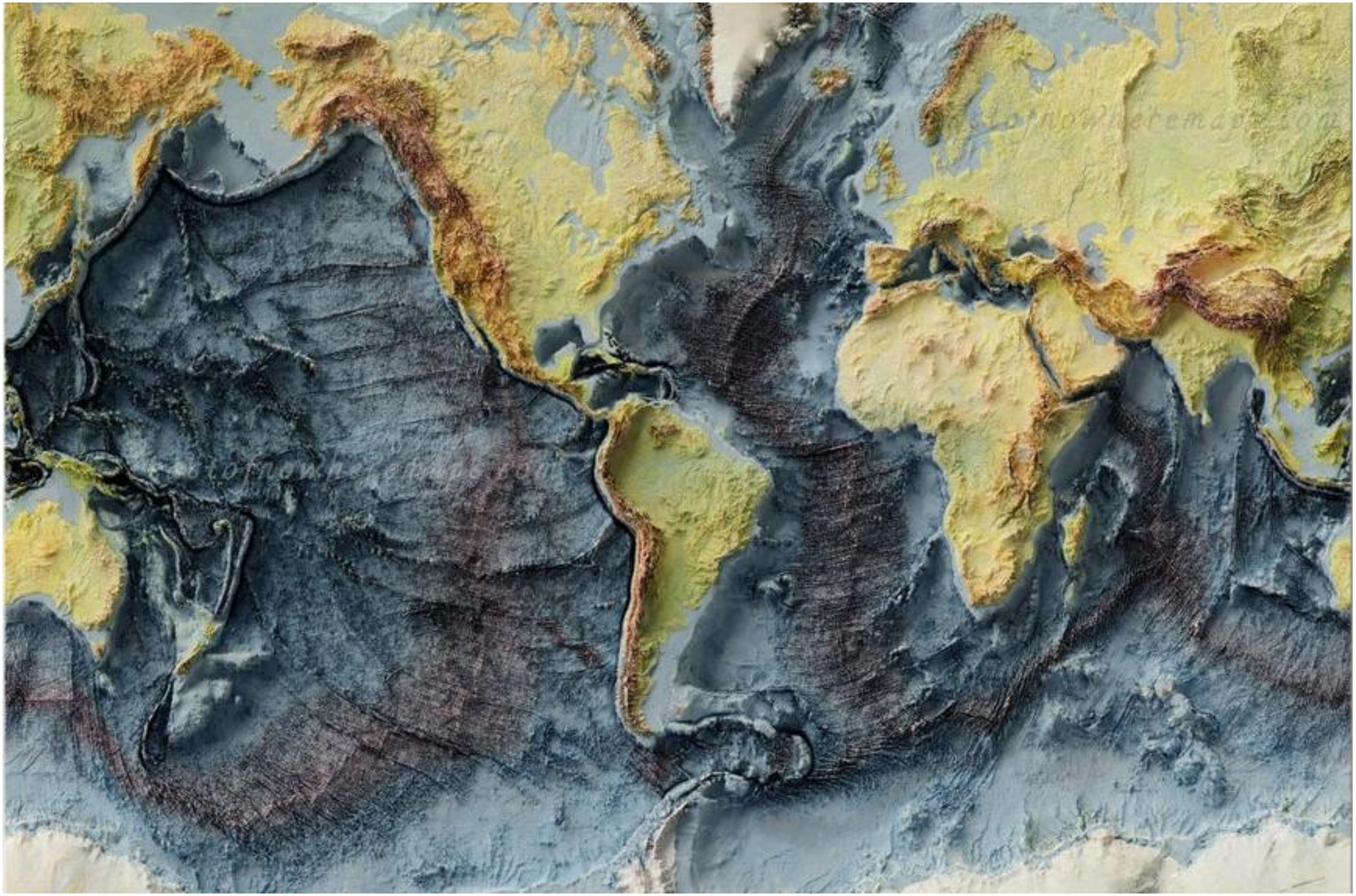


Press and Siever **Fig. 20.25d**

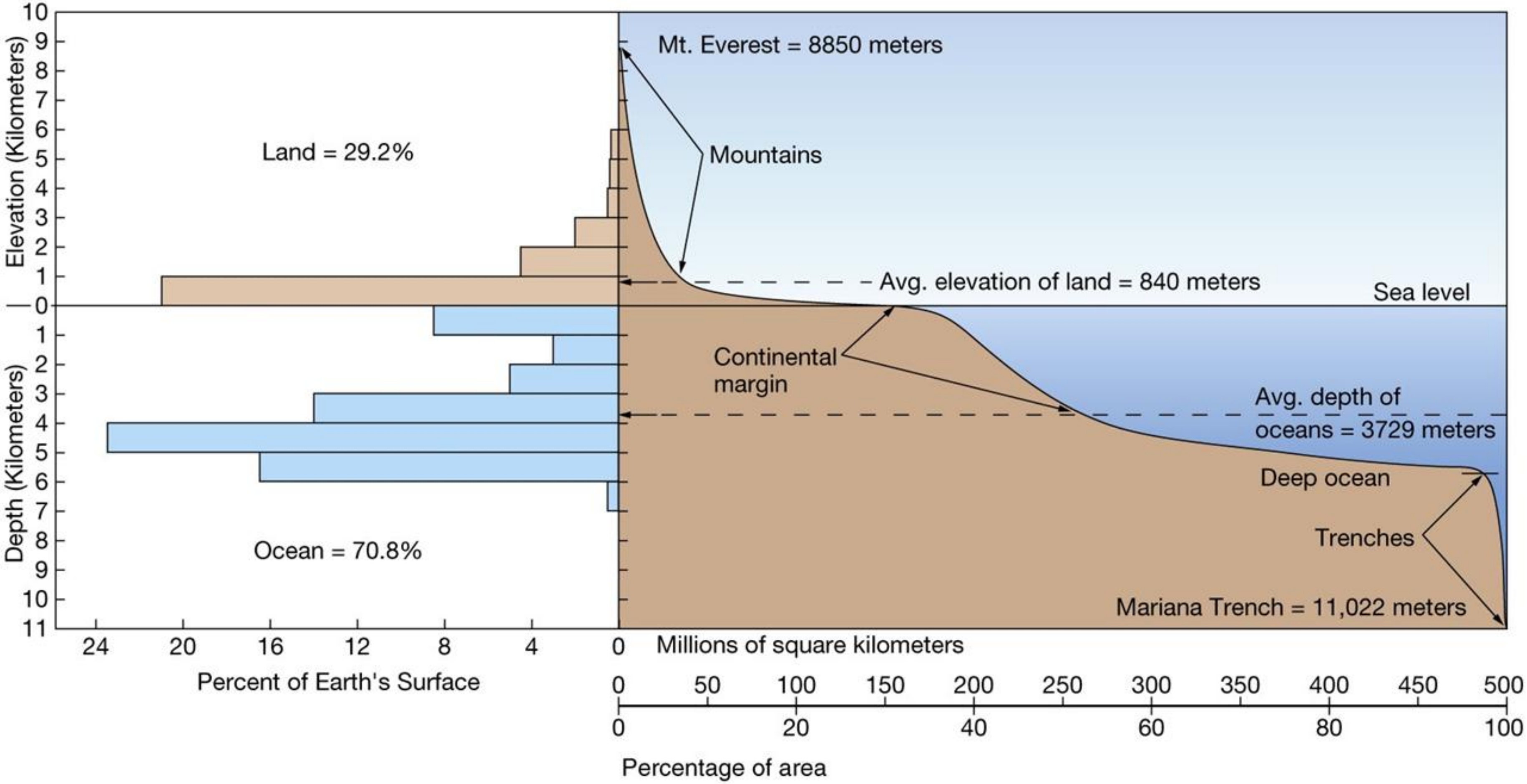


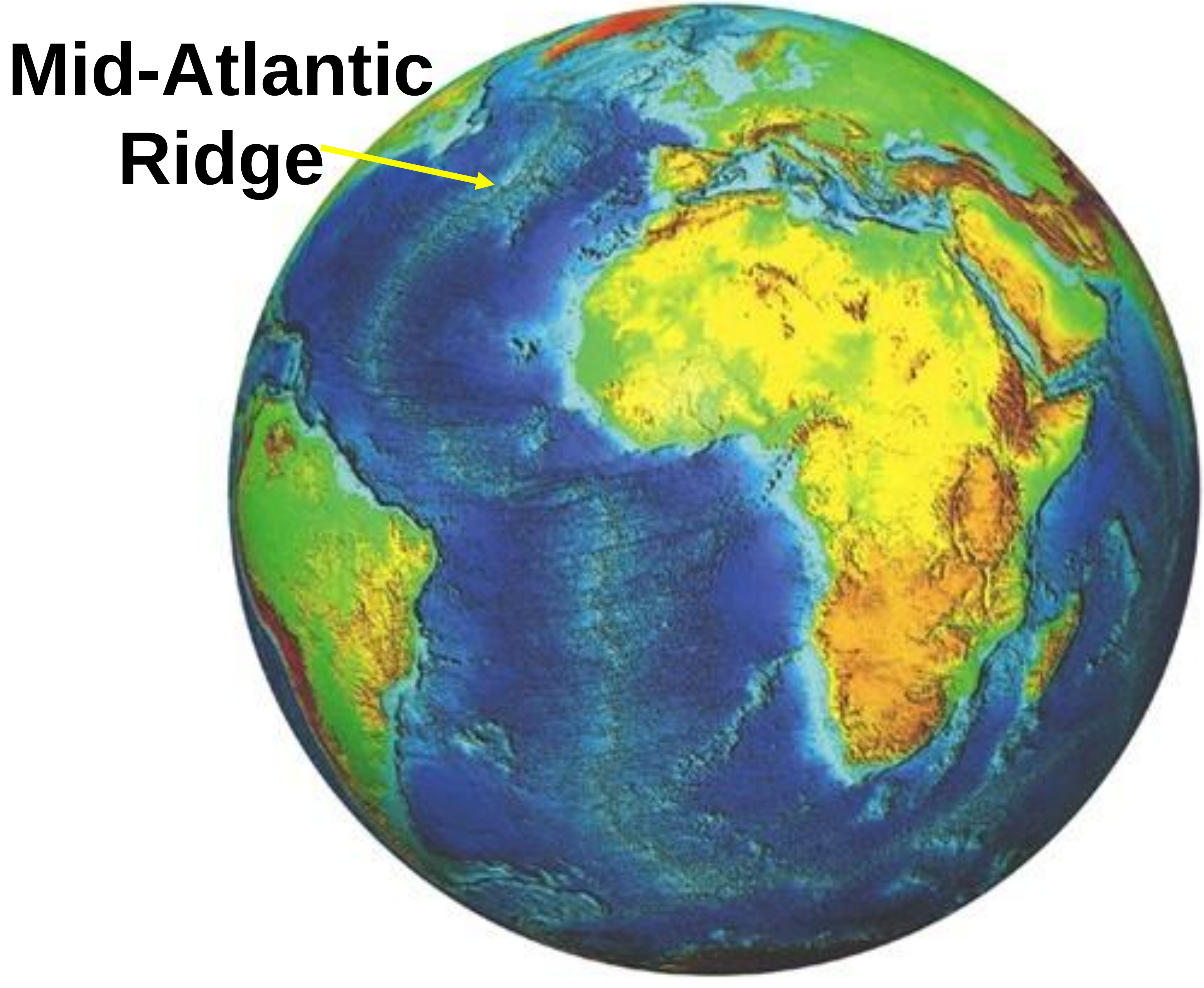
Press and Siever Fig. 1.8

Why the topography of ocean and land look this?



Earth hypsometry

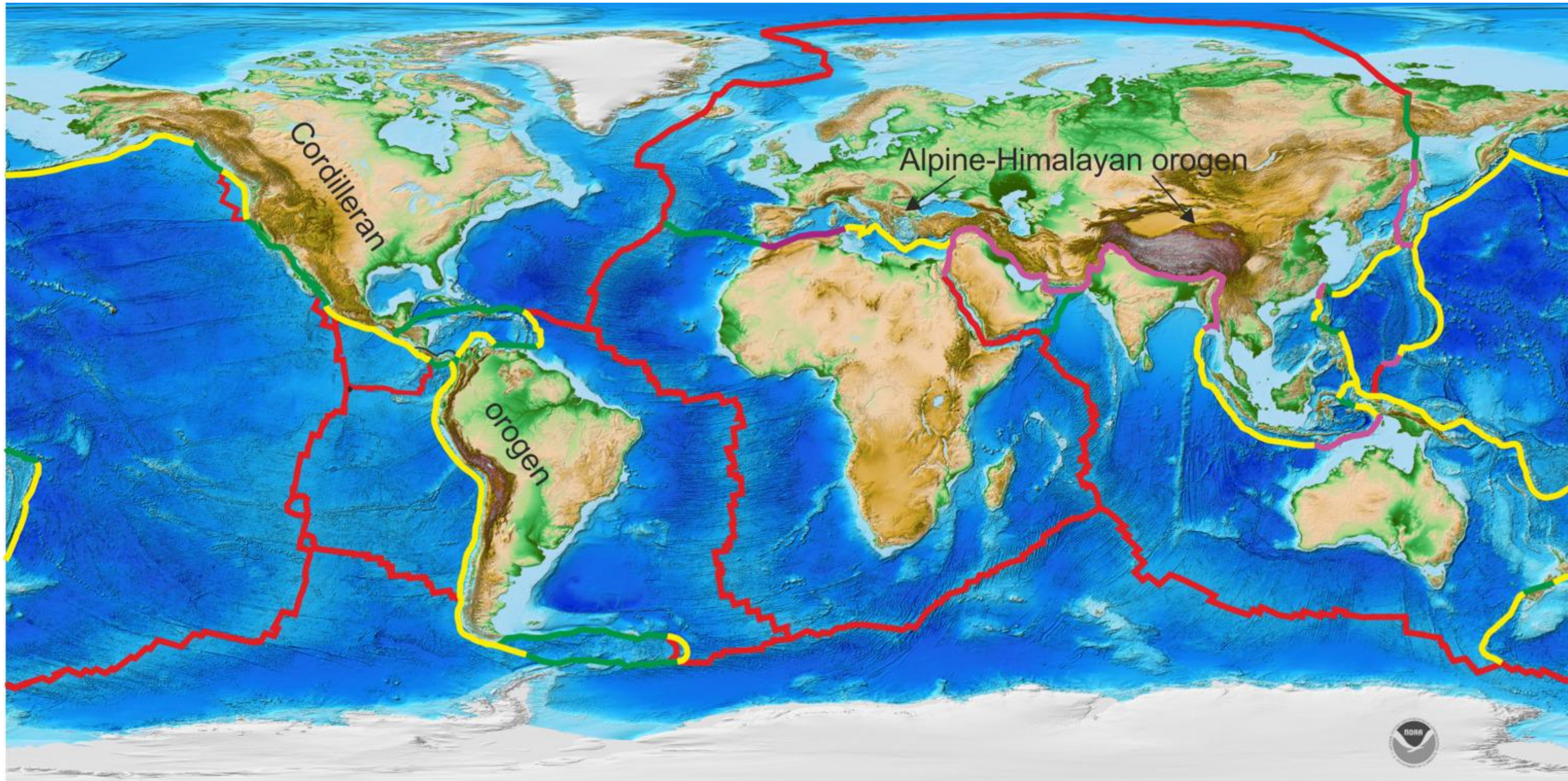




Peter W. Sloss, NOAA-NESDIS-NGDC

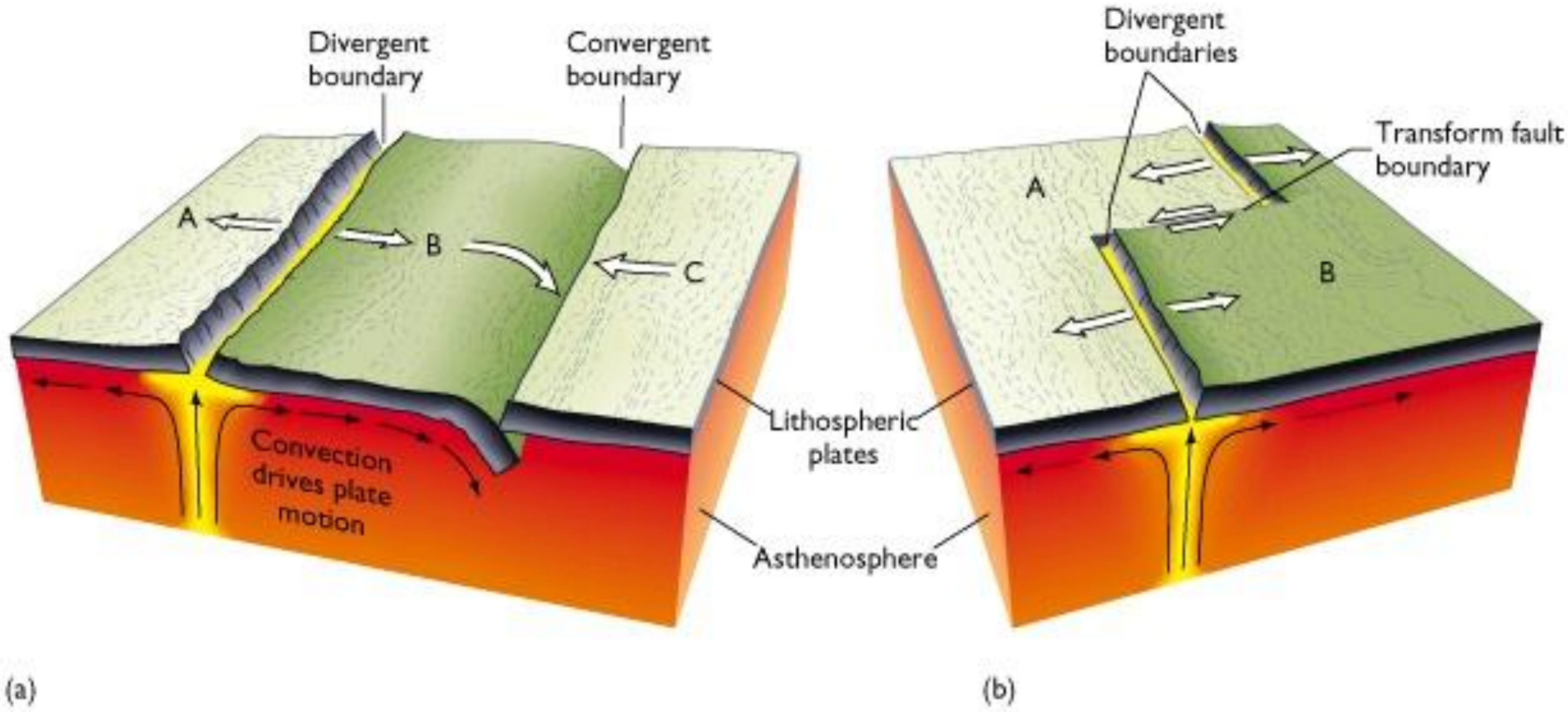
Press and Siever

Plate boundaries



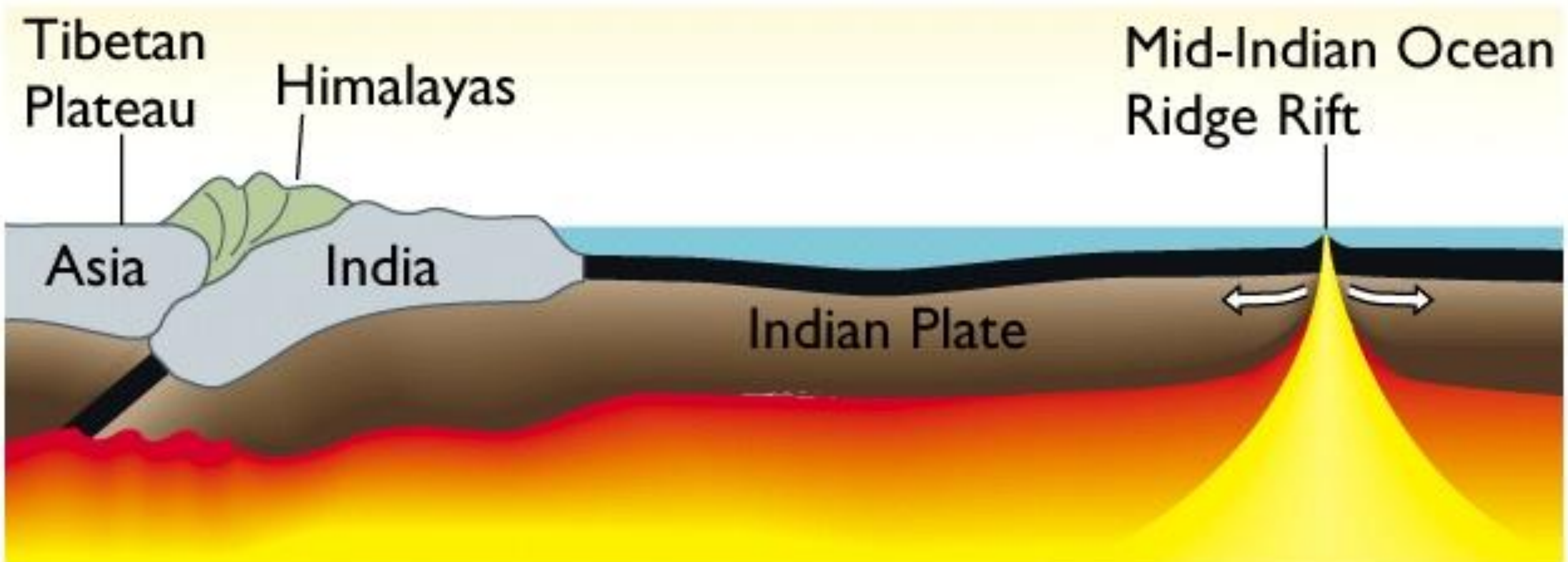
extensional Spreading — Strike-slip — Subduction — Collision

Three Types of Plate Boundaries



Press and Siever **Fig. 1.14**

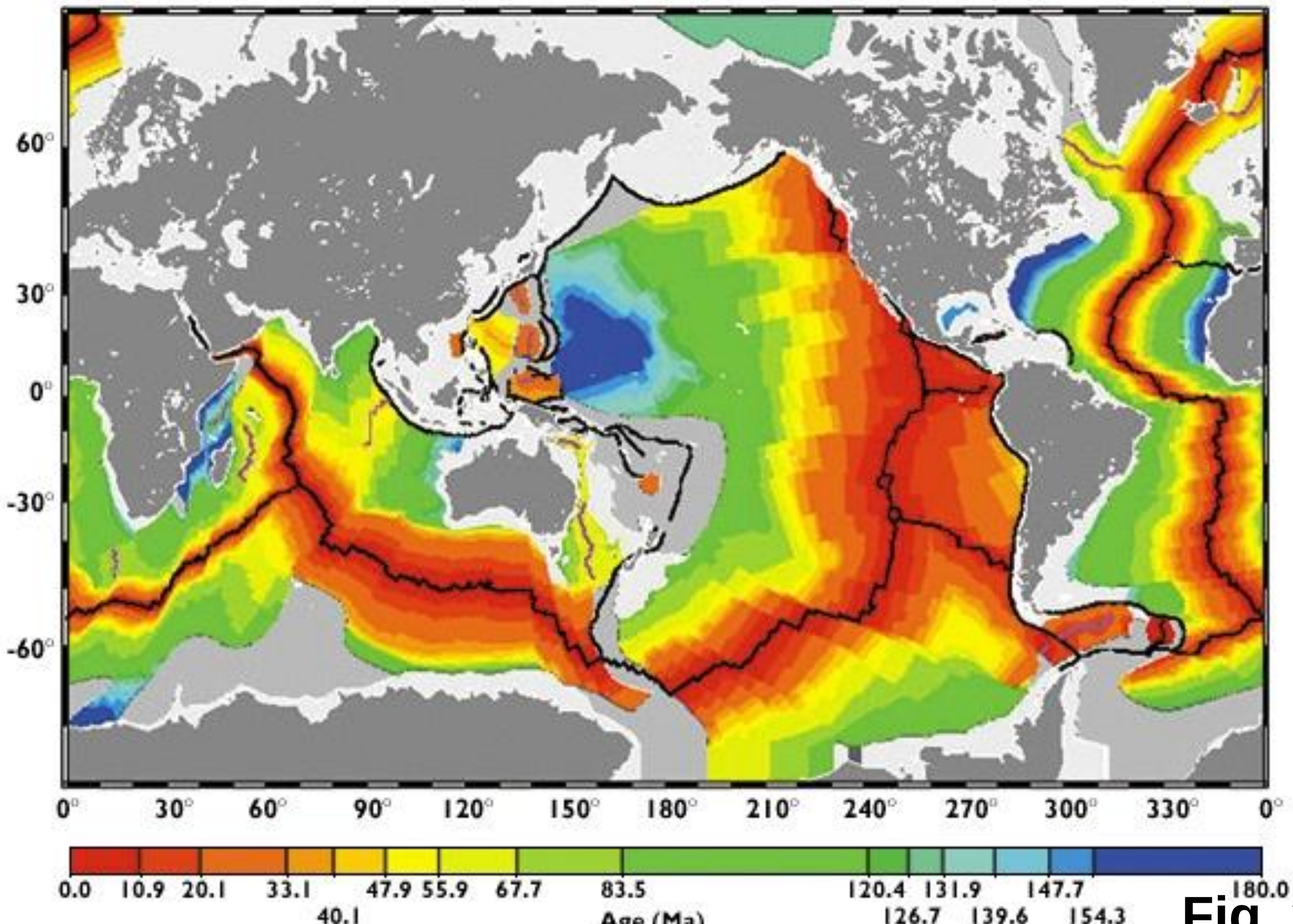
Continent–Continent Convergent Boundary



(d)

Press and Siever **Fig. 20.d**

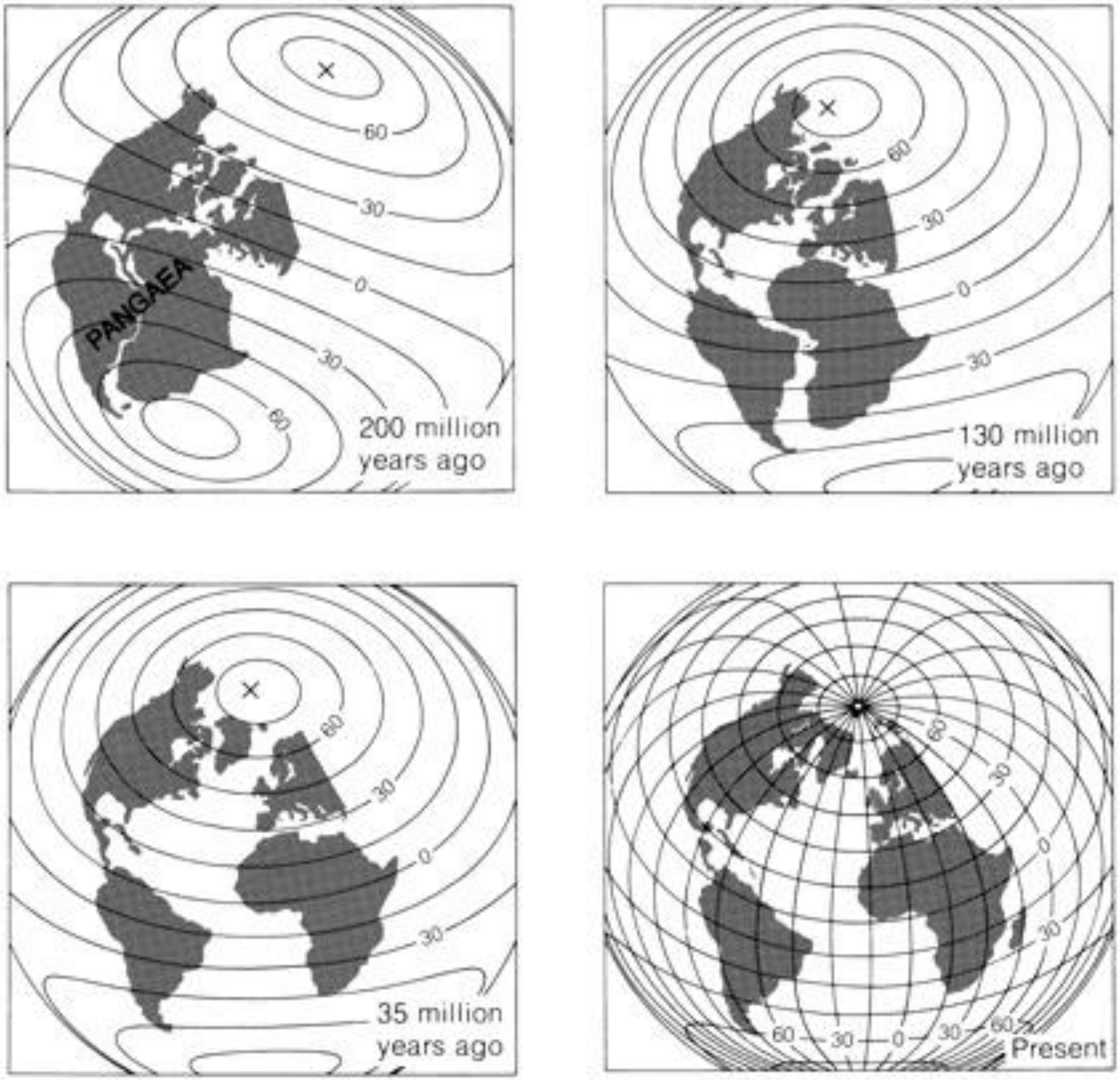
Age of Seafloor Crust



R. Dietmar Muller, 1997

Fig. 20.11
Press and Siever

Opening of the Atlantic by Plate Motion



After Phillips & Forsyth, 1972

× = Ancient geographic pole

Press and Siever

Fig. 20.13

Rates of plate motion

Mostly obtained from magnetic

anomalies on seafloor

Fast spreading: 10 cm/year

Slow spreading: 3 cm/year

- The residence time of an oceanic plate
- of 4000 km is 40 My (fast) or 120 My (slow)

Press and Siever

Geochemical Carbon Cycle

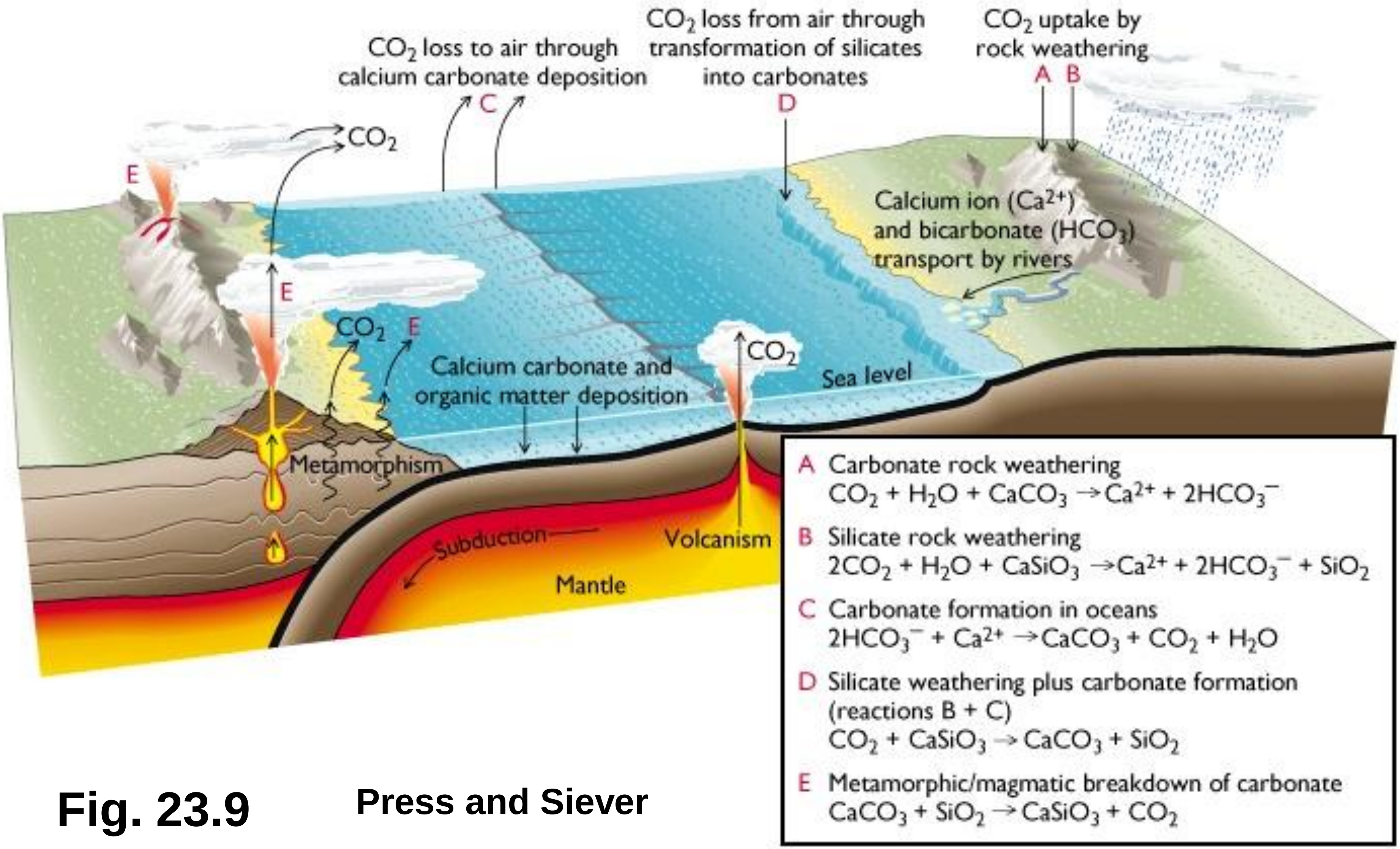


Fig. 23.9 **Press and Siever**

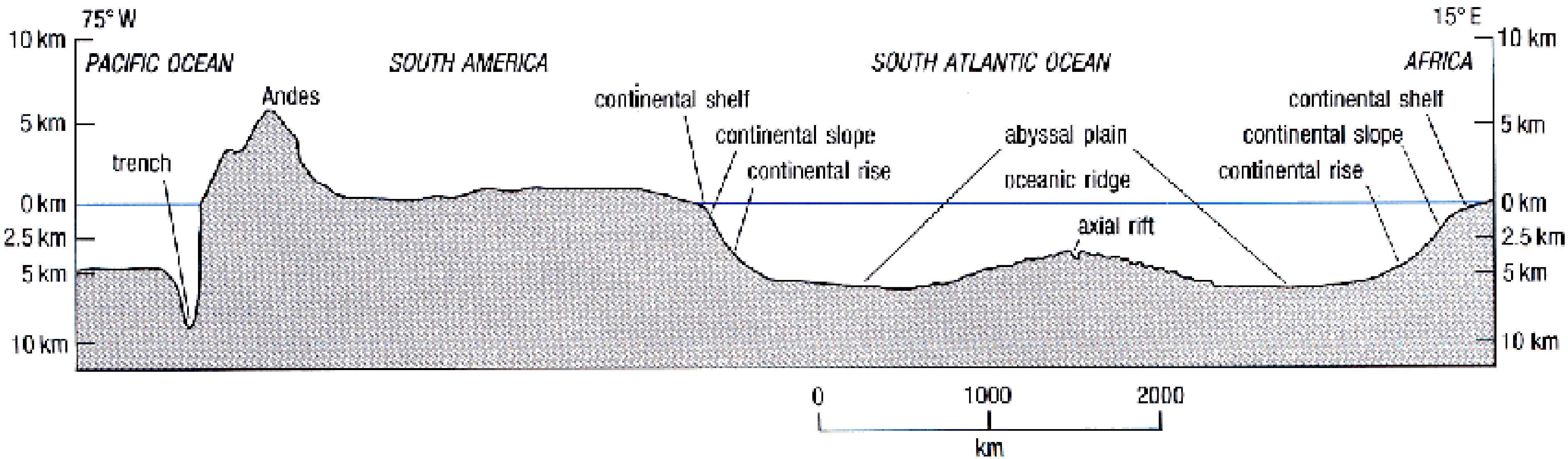


Fig. 7 An example cross-section to show the surface of the Earth between South America and Africe. Vertical exaggeration x 100.

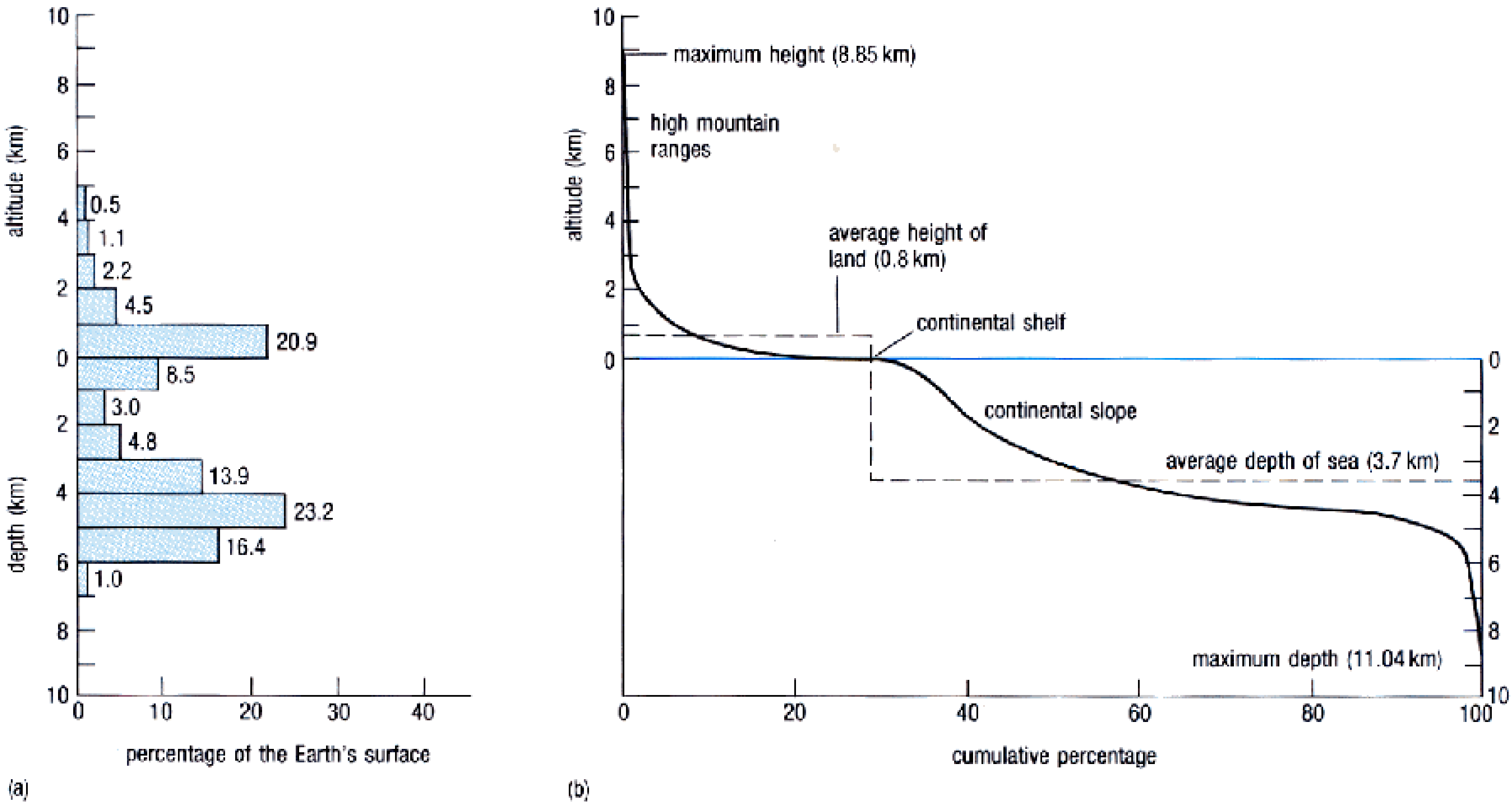
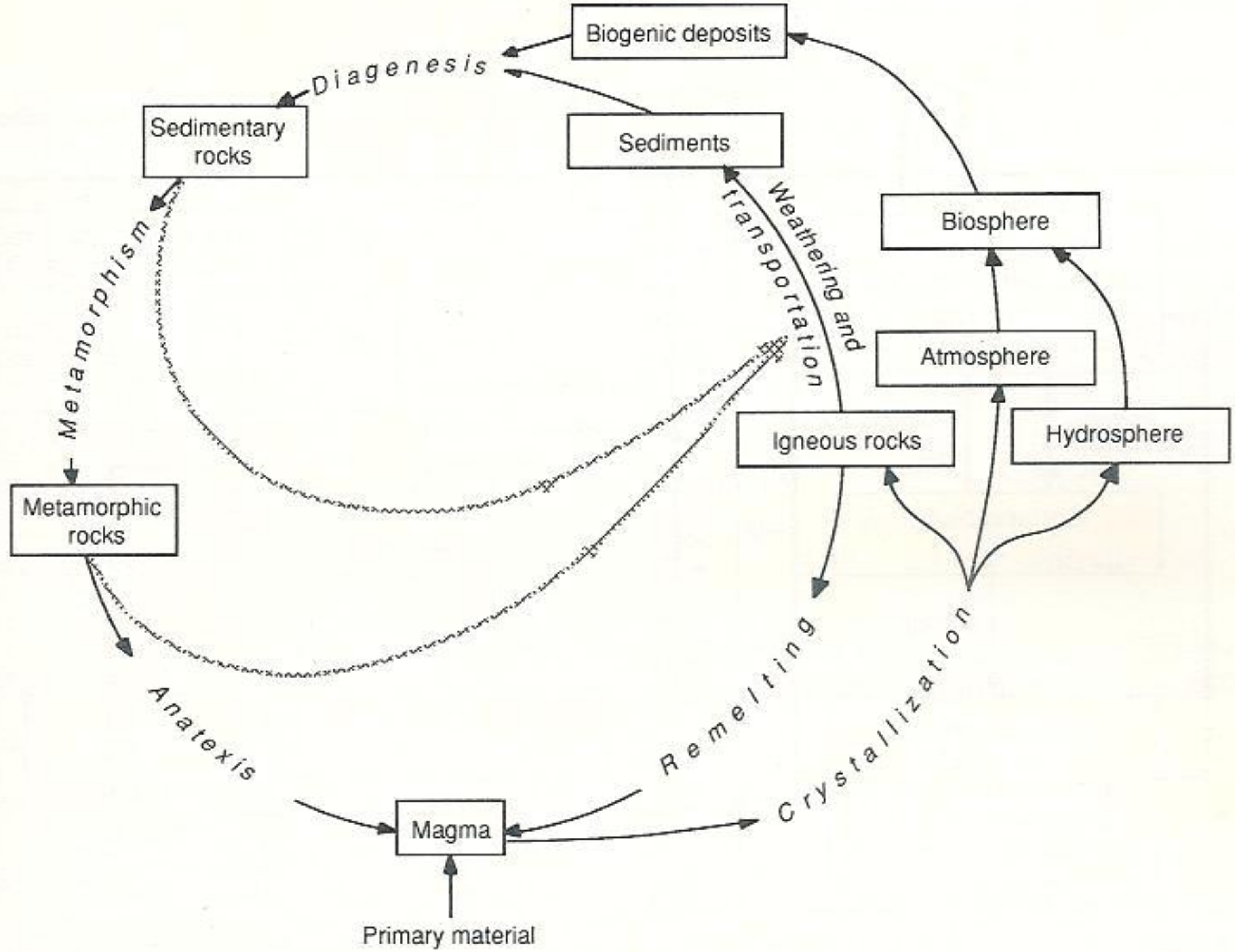


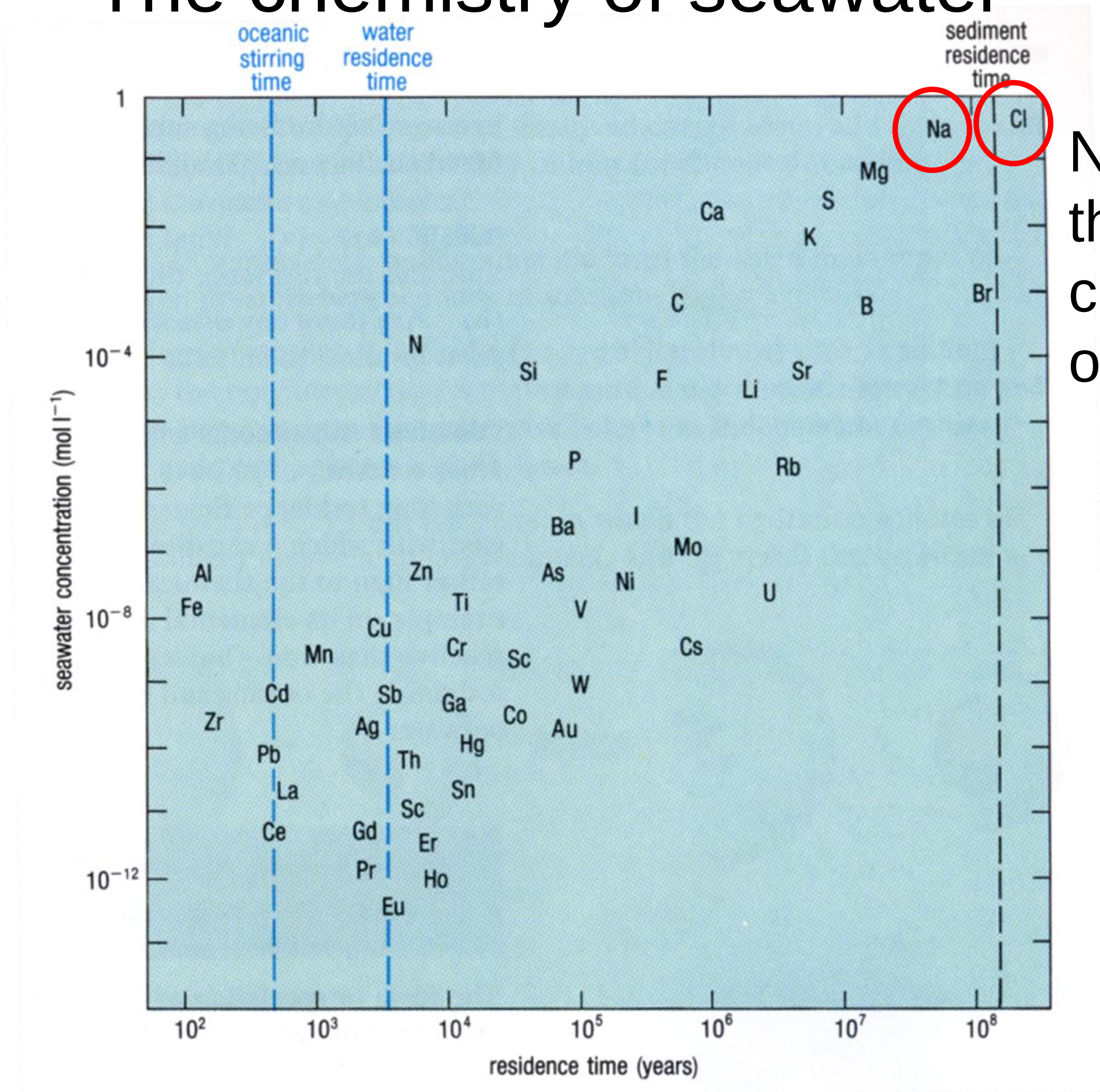
Fig. 8 The distribution of levels on the Earth's surface. (a) A histogram showing the actual frequency distribution. (b) A cumulative-frequency (hypsographic) curve based on (a). This is not a profile of the Earth's surface but a curve of percentages of the Earth's surface that lie above, below or within any given level.



I The geochemical cycle showing the flux of material between various reservoirs in the geosphere. Adapted fr (1984) with the permission of John Wiley and Sons, Inc.

The chemistry of seawater

Concentration in SW mole/L



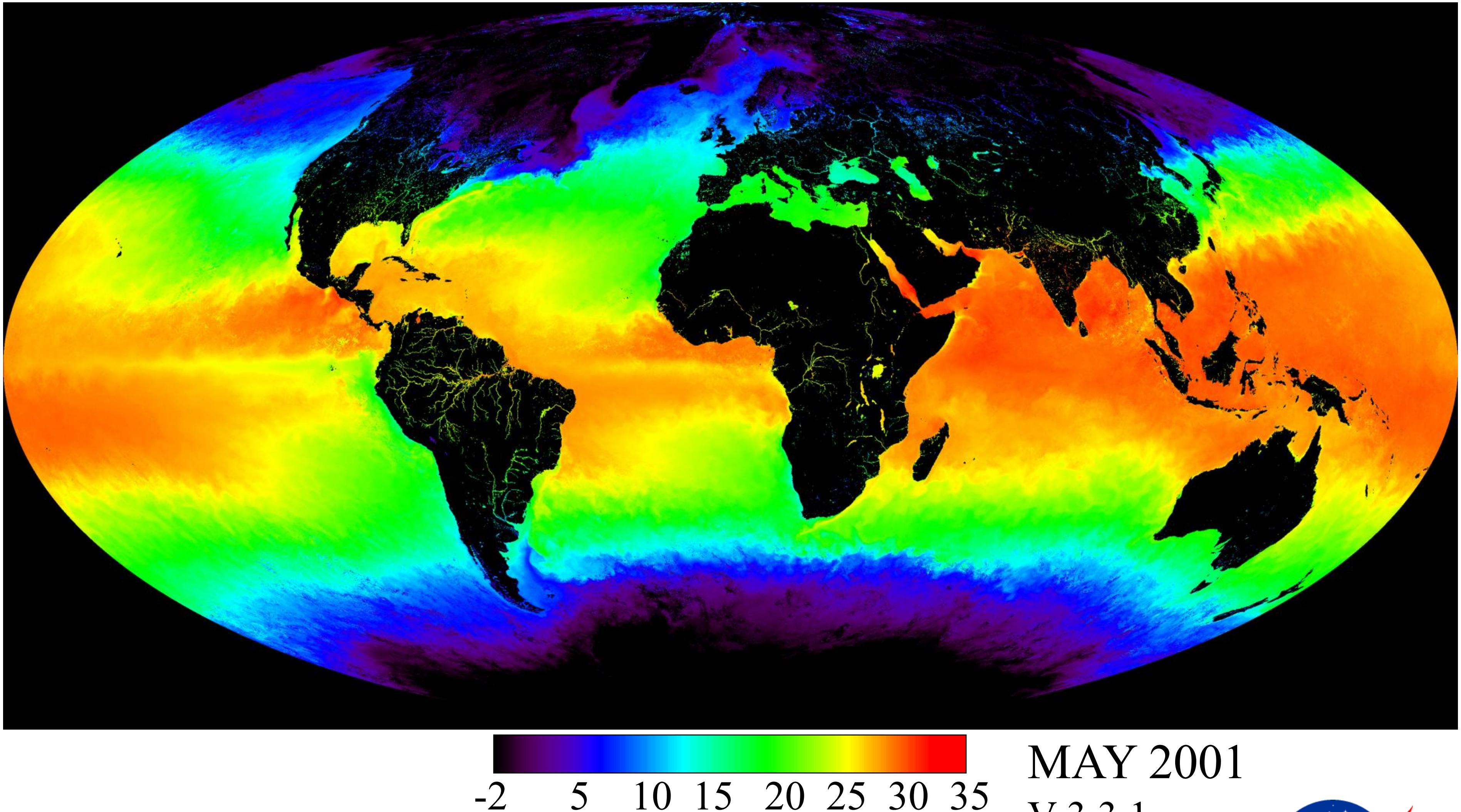
Na and Cl are the main constituents of SW

The residence time of the elements in SW (Yr)

Drivers of ocean circulation

- Sun radiation: poles to equator gradients
- Atmosphere circulation (waves, surface currents, storms)
- Earth rotation, Coriolis Force, conservation of energy
- Temperature, salinity, ice, density gradients
- Tides: Earth Moon Sun (gravity)
- Continuity (mass preservation)
- Configuration of continents vs oceans

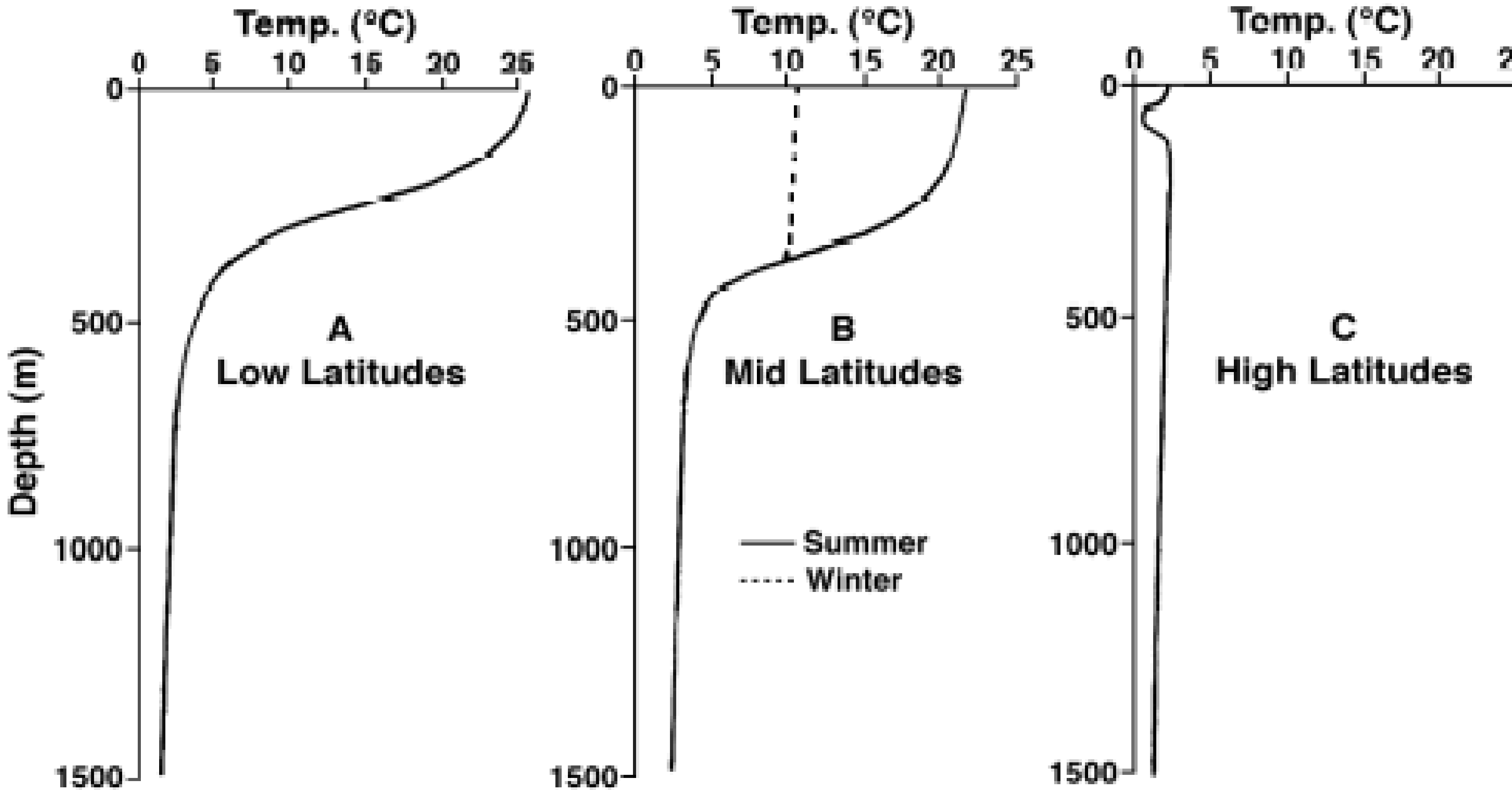
TERRA MODIS NIGHTTIME 4μm SST

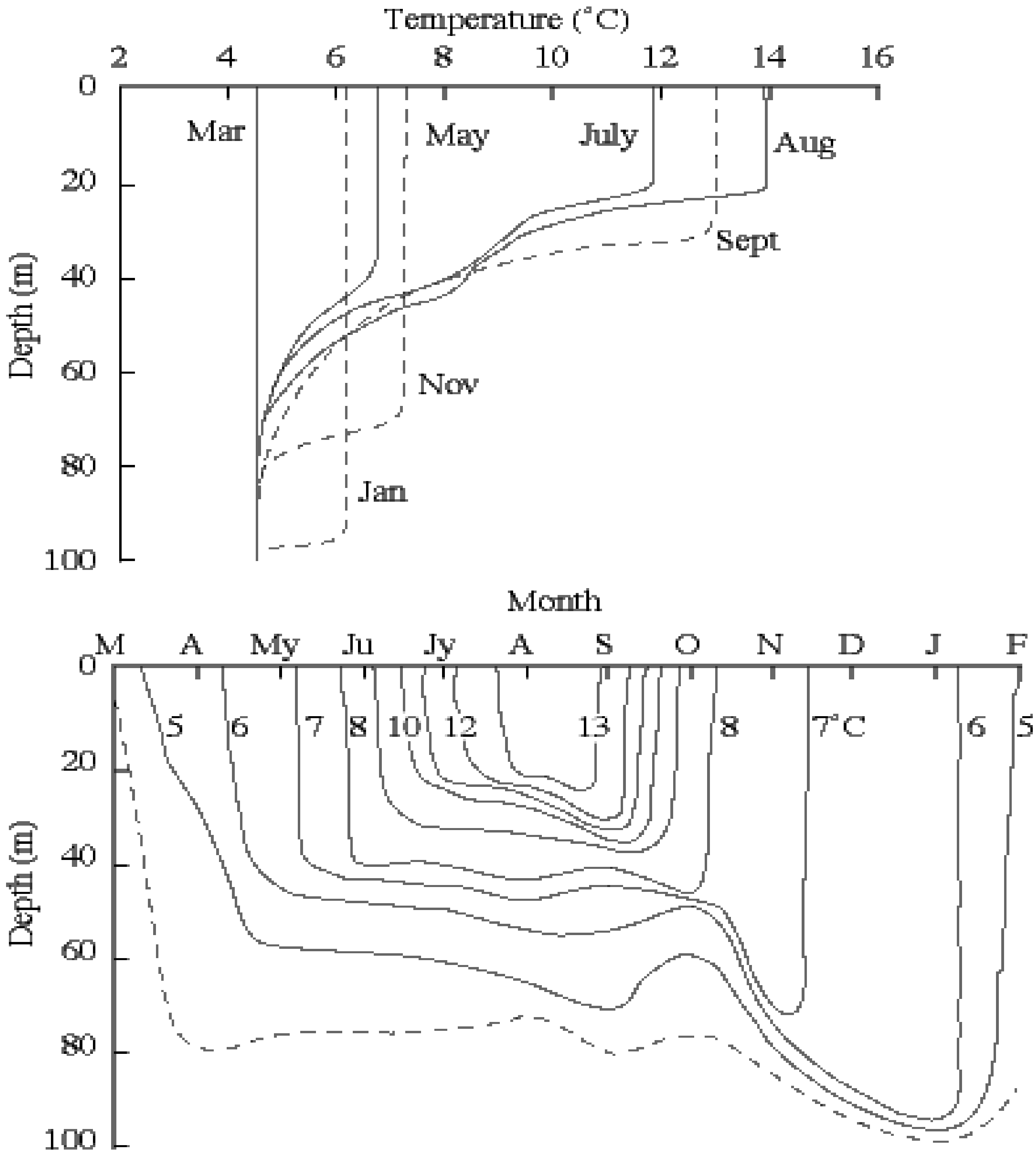


MAY 2001
V 3.3.1

MODIS/OCEAN GROUP
GSFC, RSMAS

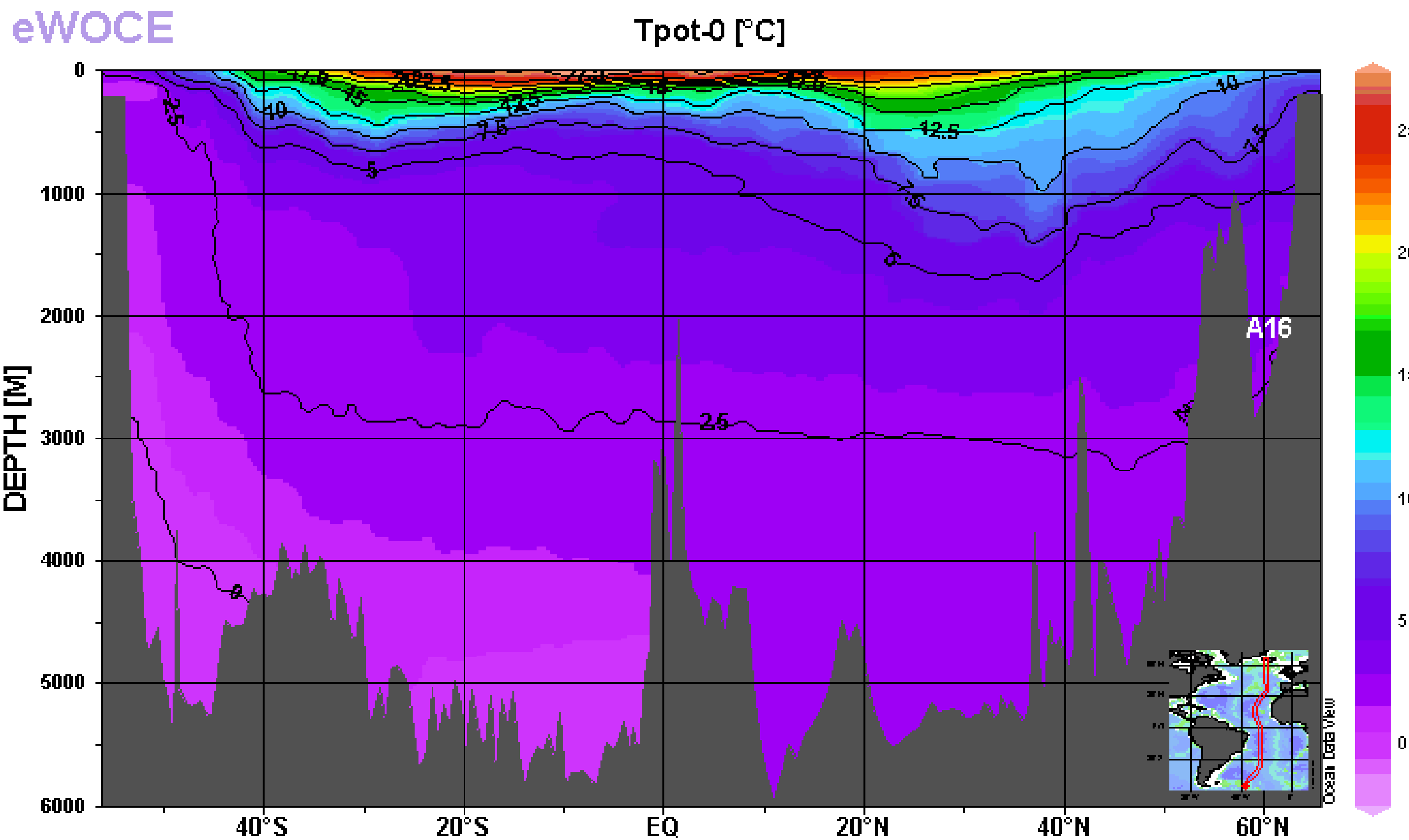
Typical Temperature Profiles



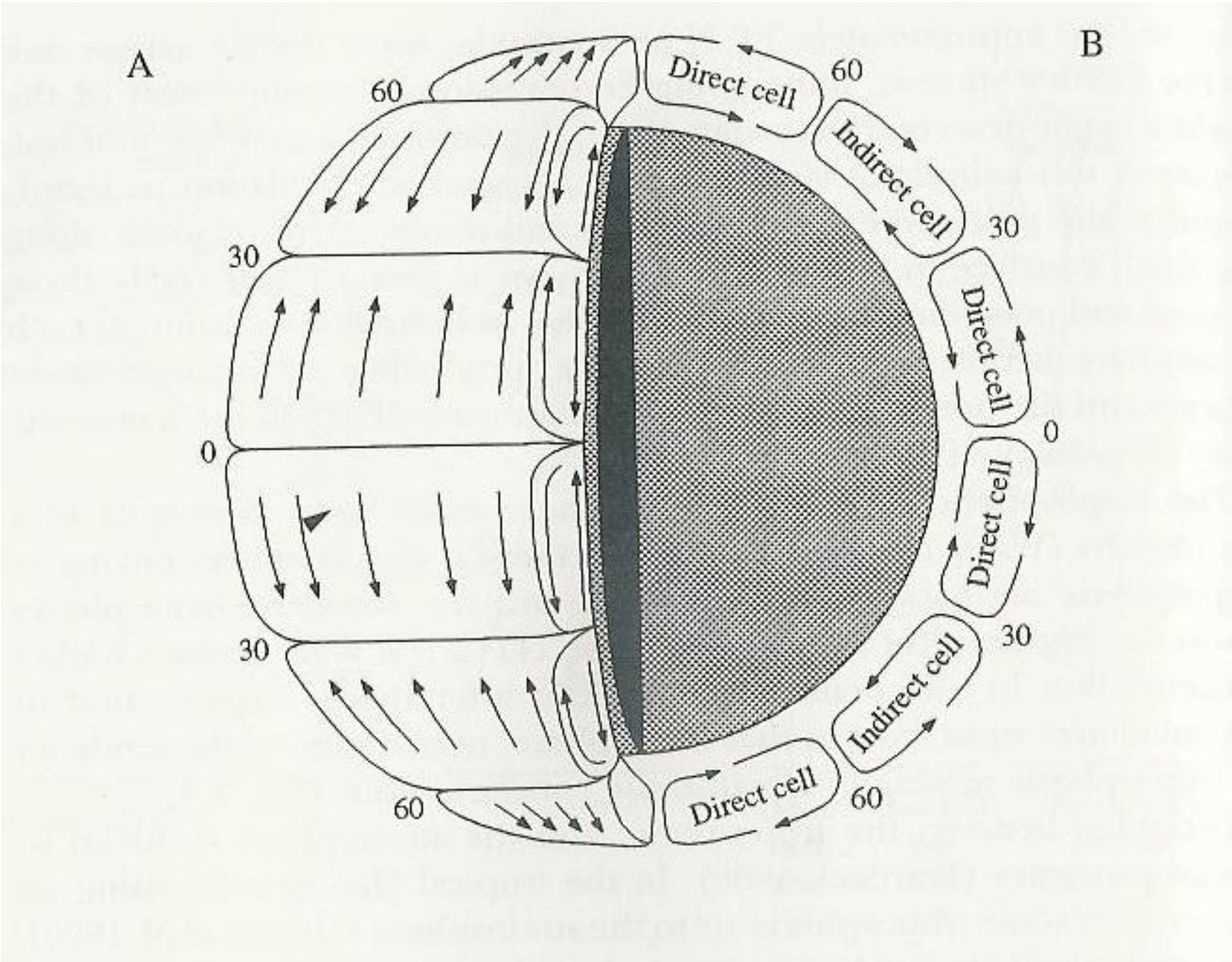


Temperature (°C)
2
4
6
8
10
12
14
16
0
20
40
60
80
100
Depth (m)
Mar
May
July
Aug
Sept
Nov
Jan
Month
M
A
My
Ju
Jy
A
S
O
N
D
J
F
0
20
40
60
80
100
Depth (m)
5
6
7
8
10
12
13
8
7°C
6
5

Atlantic temperature section (0 – 6000 m)



Atmosphere circulation



Atmosphere circulation

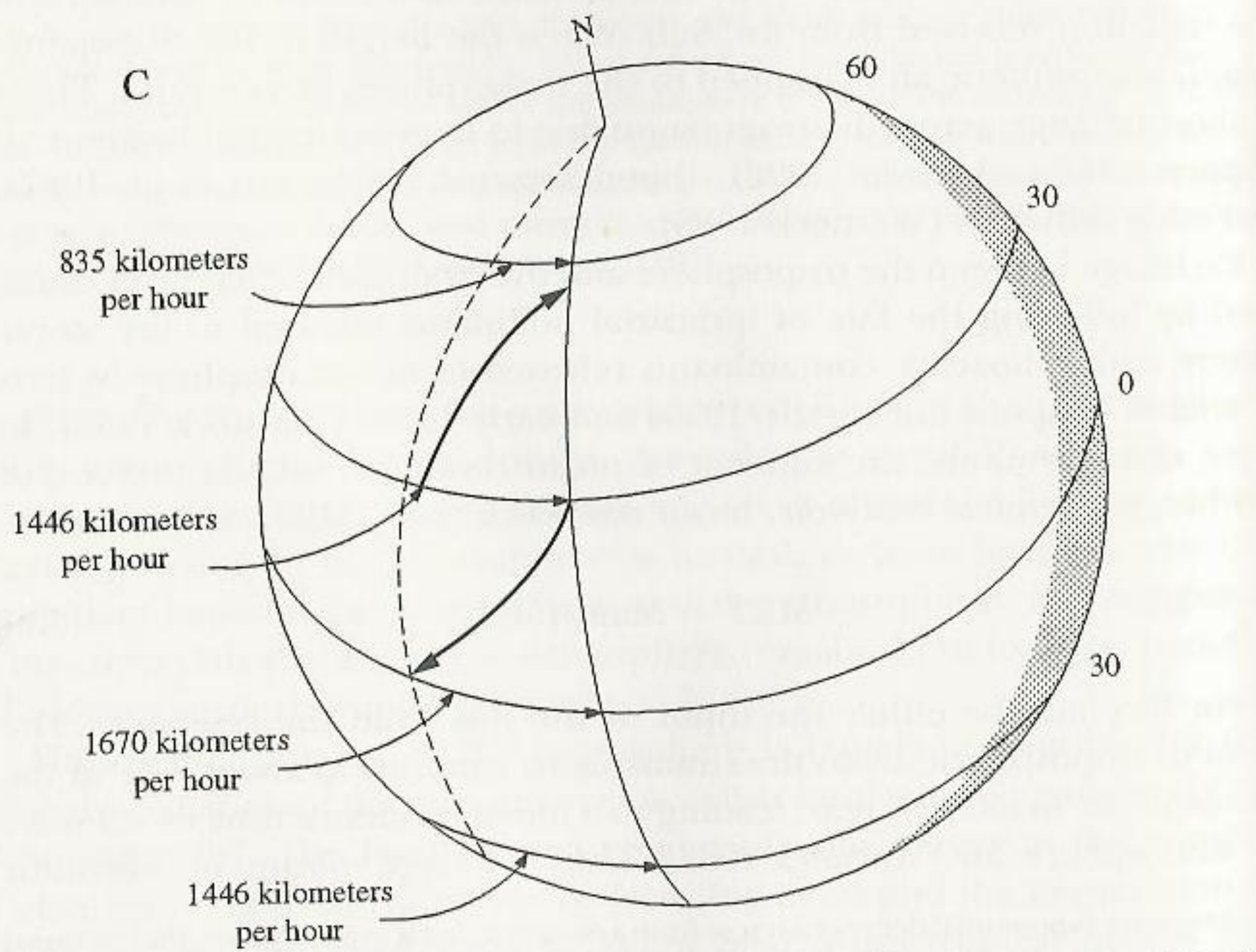
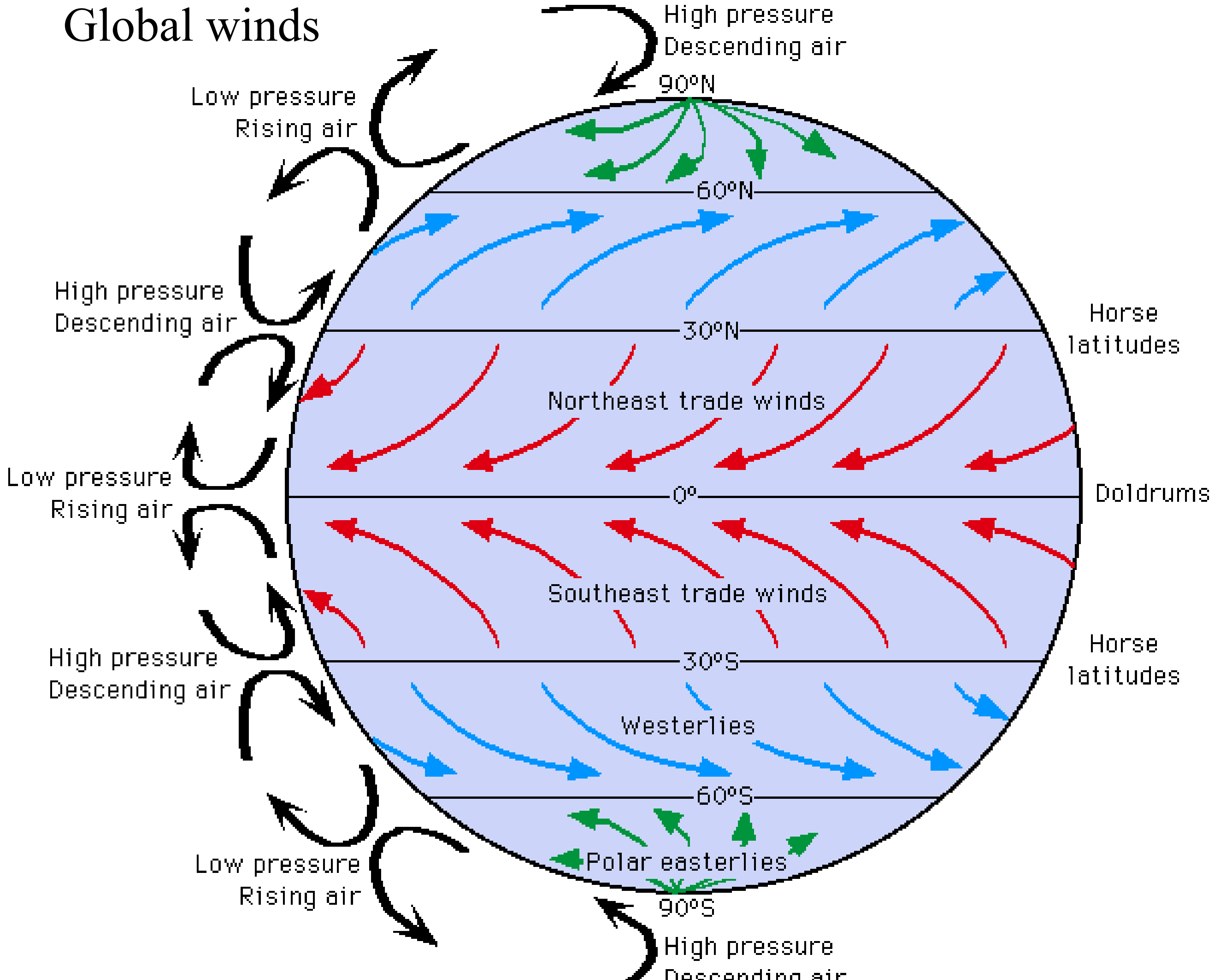
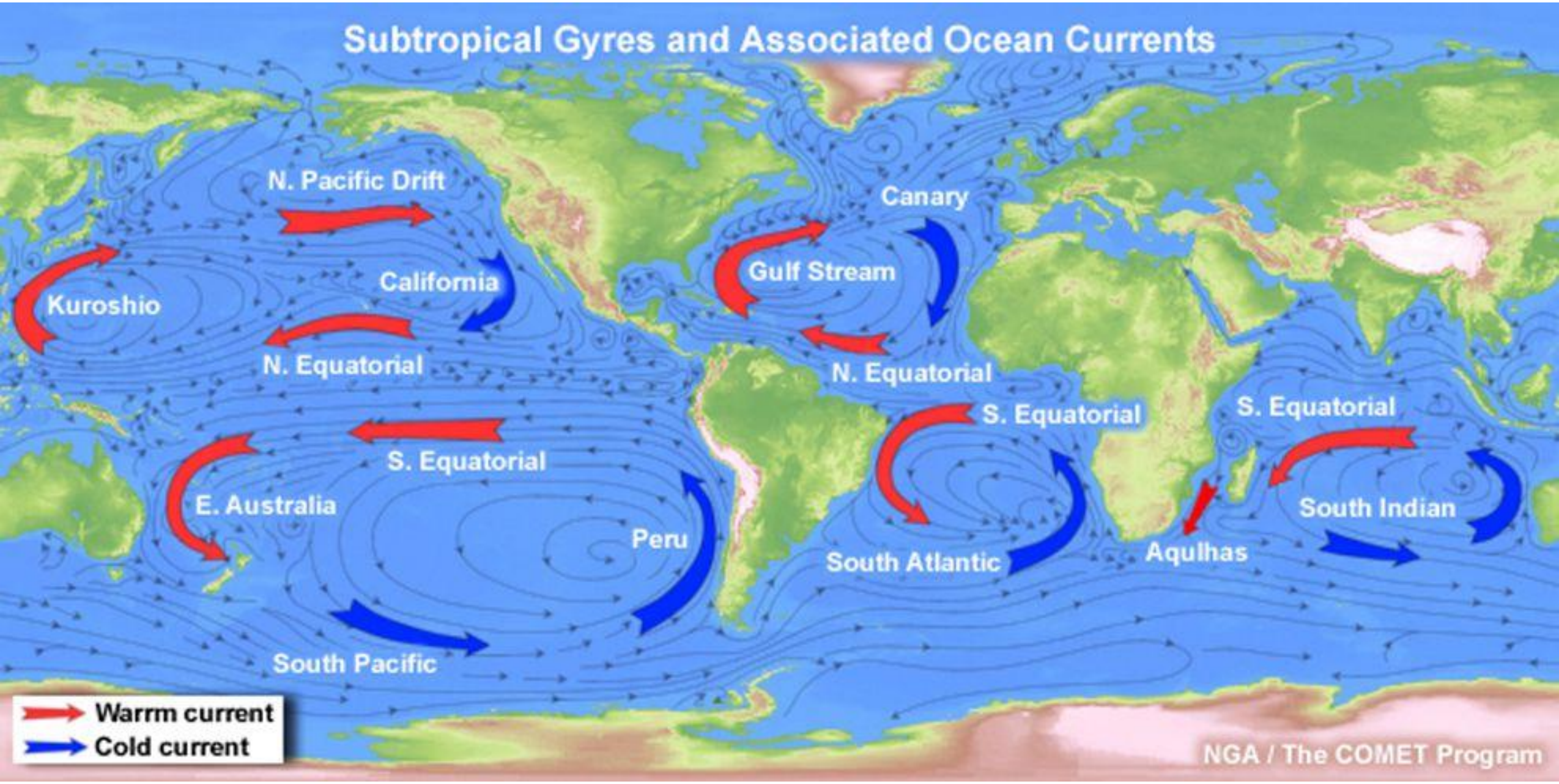


Figure 3.3 Generalized pattern of global circulation showing (a) surface patterns, (b) vertic[al] patterns, and (c) origin of the Coriolis force. As air masses move across different latitude[s] they are deflected by the Coriolis force, which arises because of the different speeds of th[e] Earth's rotation at different latitudes. For instance, if you were riding on an air mass movin[g]

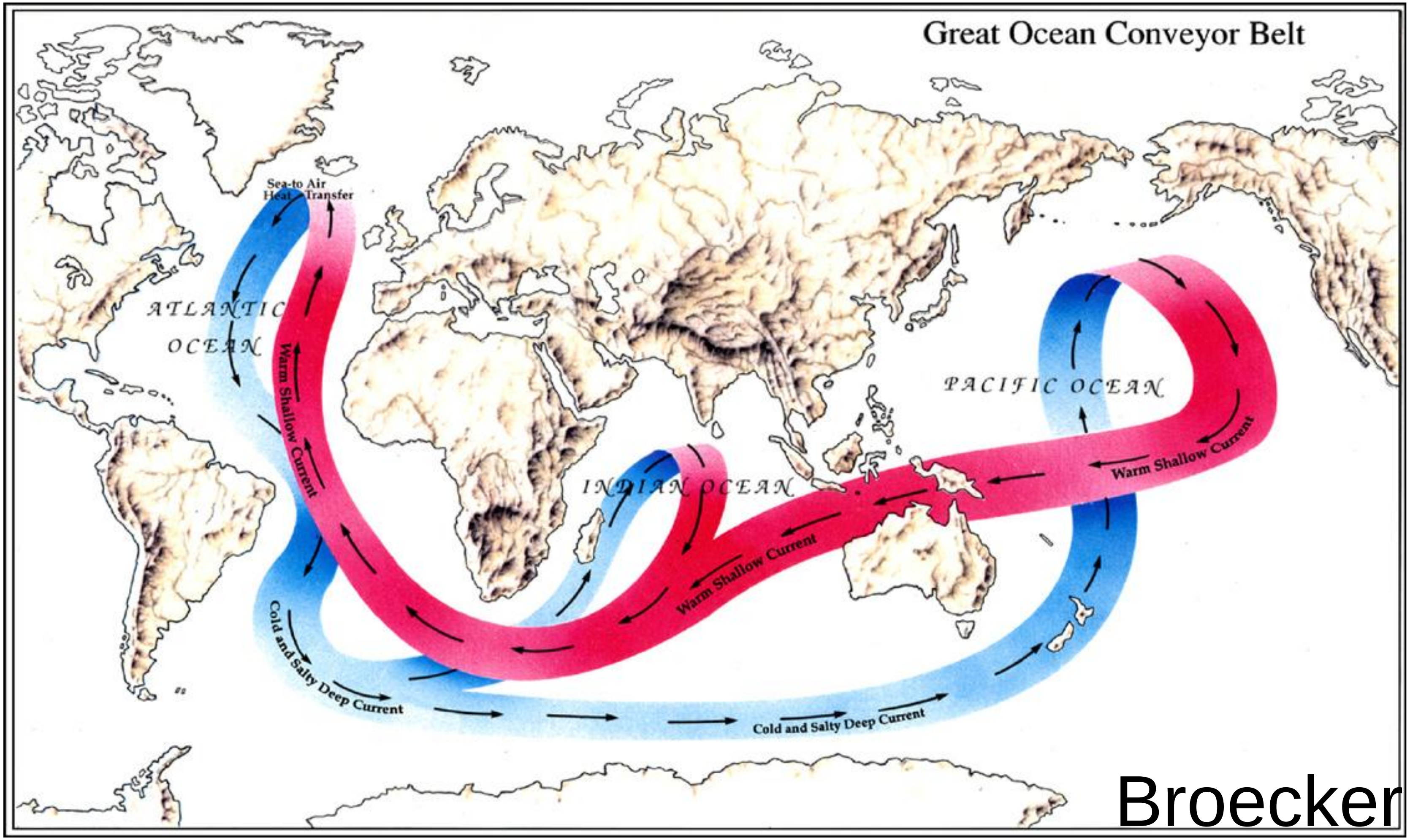
Global winds



Surface ocean currents

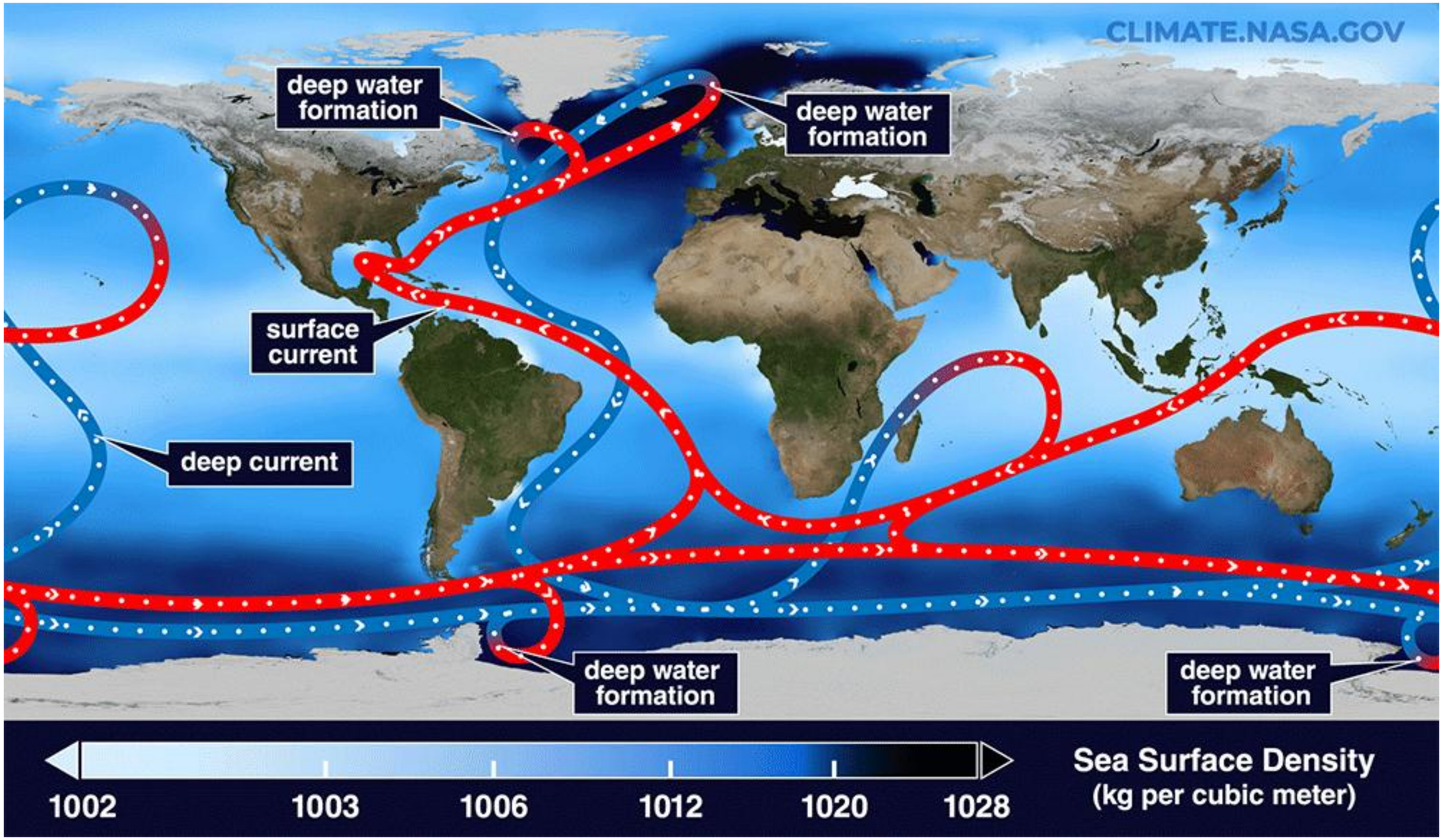


The general circulation of the ocean

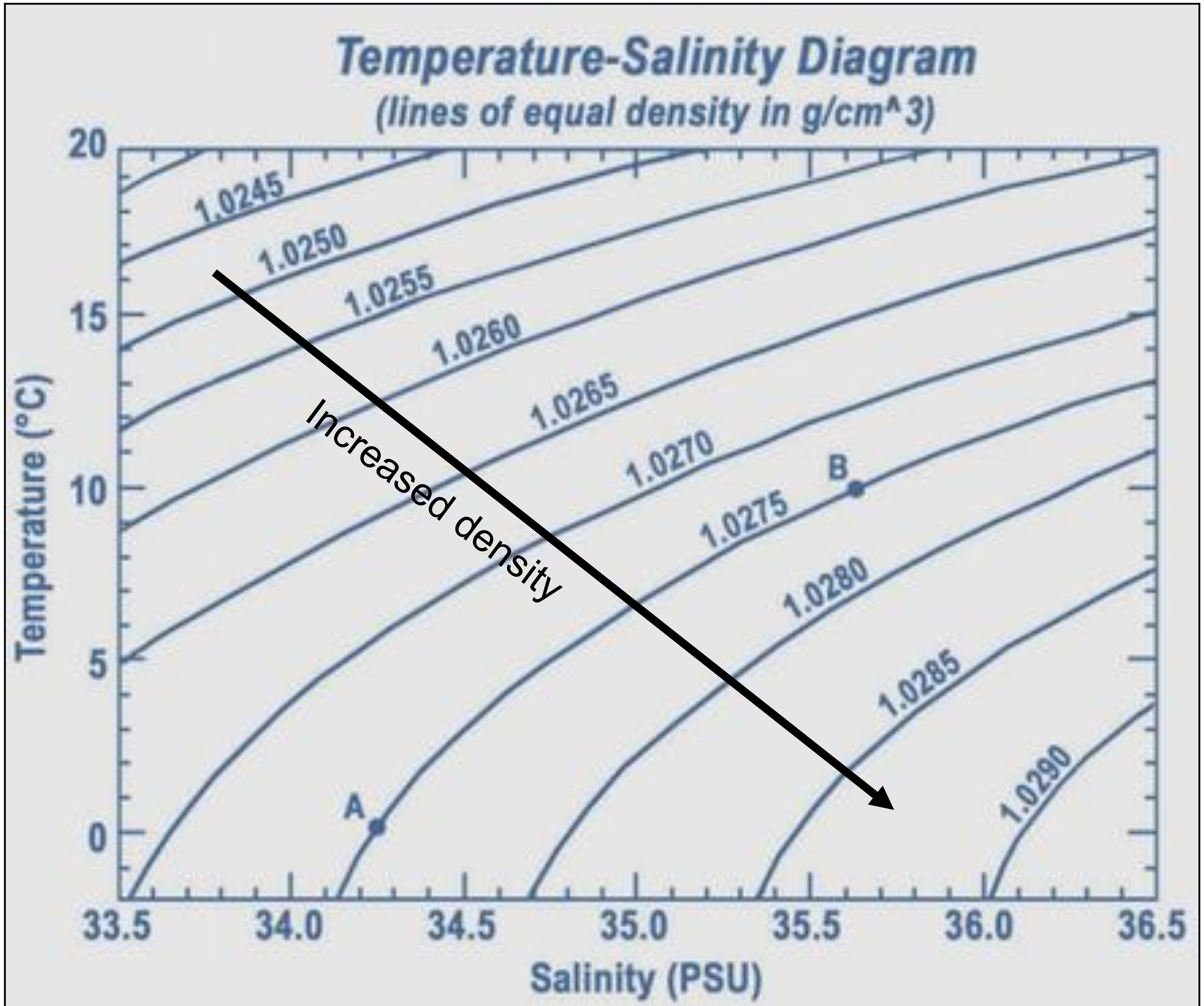


Broecker 198

The general circulation of the oceans



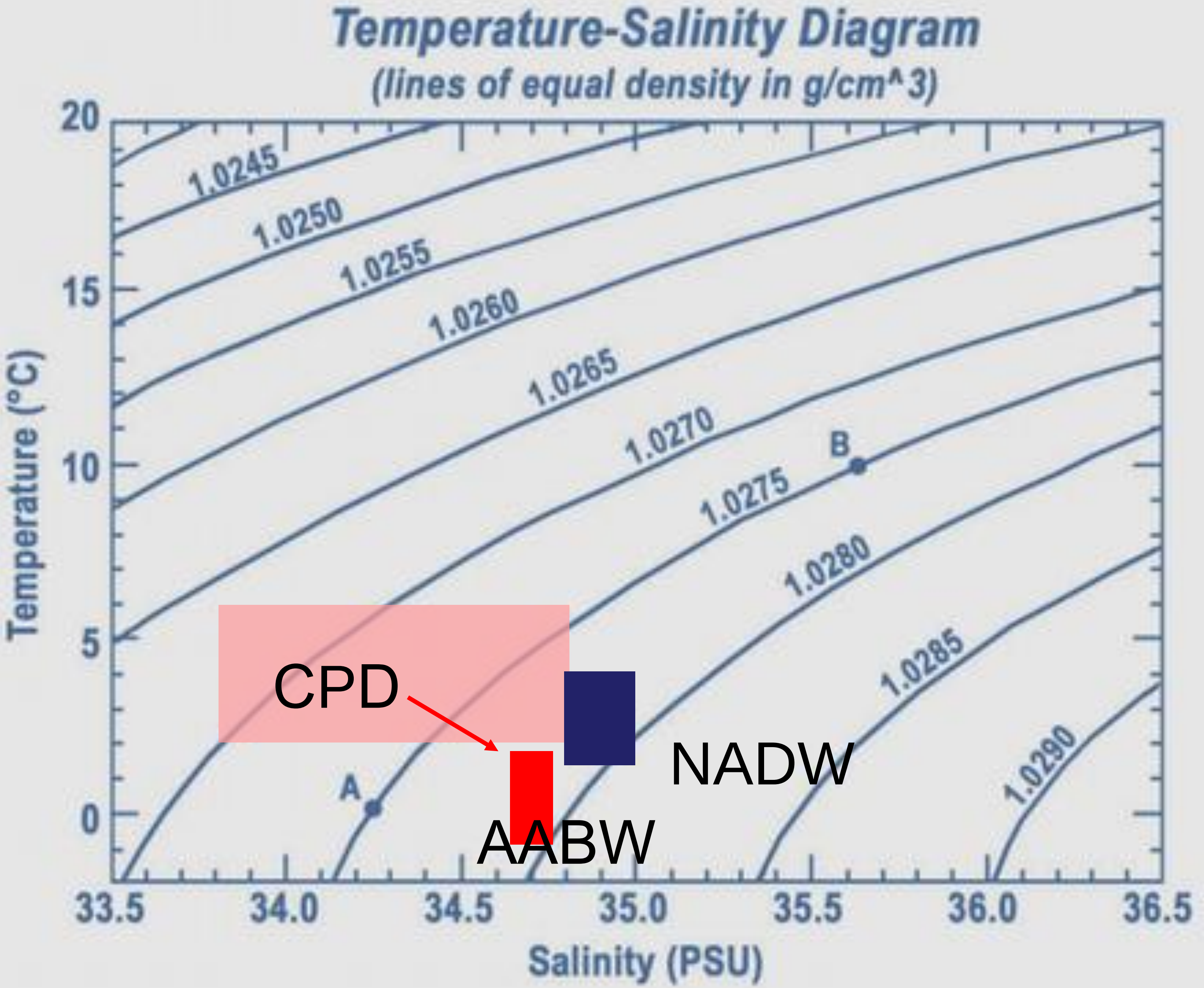
TS diagram for seawater: the thermal and salinity gradients dictate the thermohaline circulation



SW density
Isopycnal lines
Points A and B
have the density

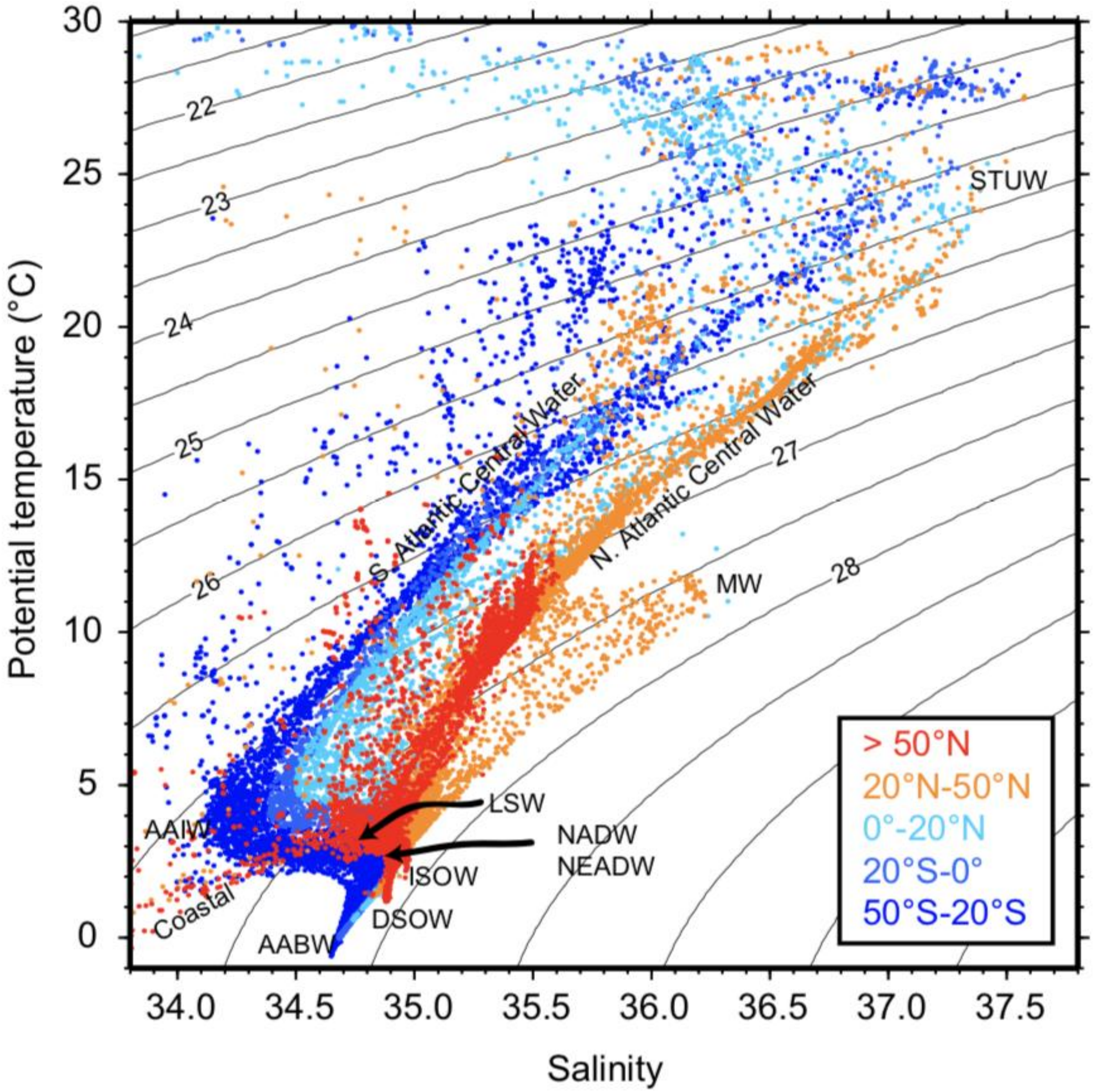
Less saline

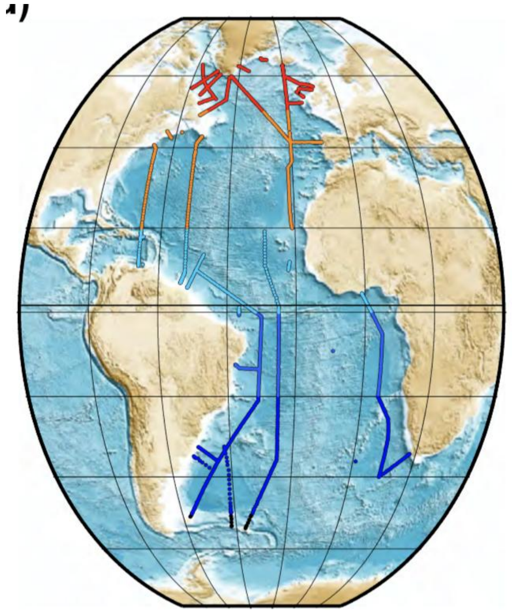
saline



Temperature-Salinity Diagram
(lines of equal density in g/cm^3)
Temperature (°C)
Salinity (PSU)
20
15
10
5
0
33.5
34.0
34.5
35.0
35.5
36.0
36.5
1.0245
1.0250
1.0255
1.0260
1.0265
1.0270
1.0275
1.0280
1.0285
1.0290
A
B
CPD
NADW
AABW

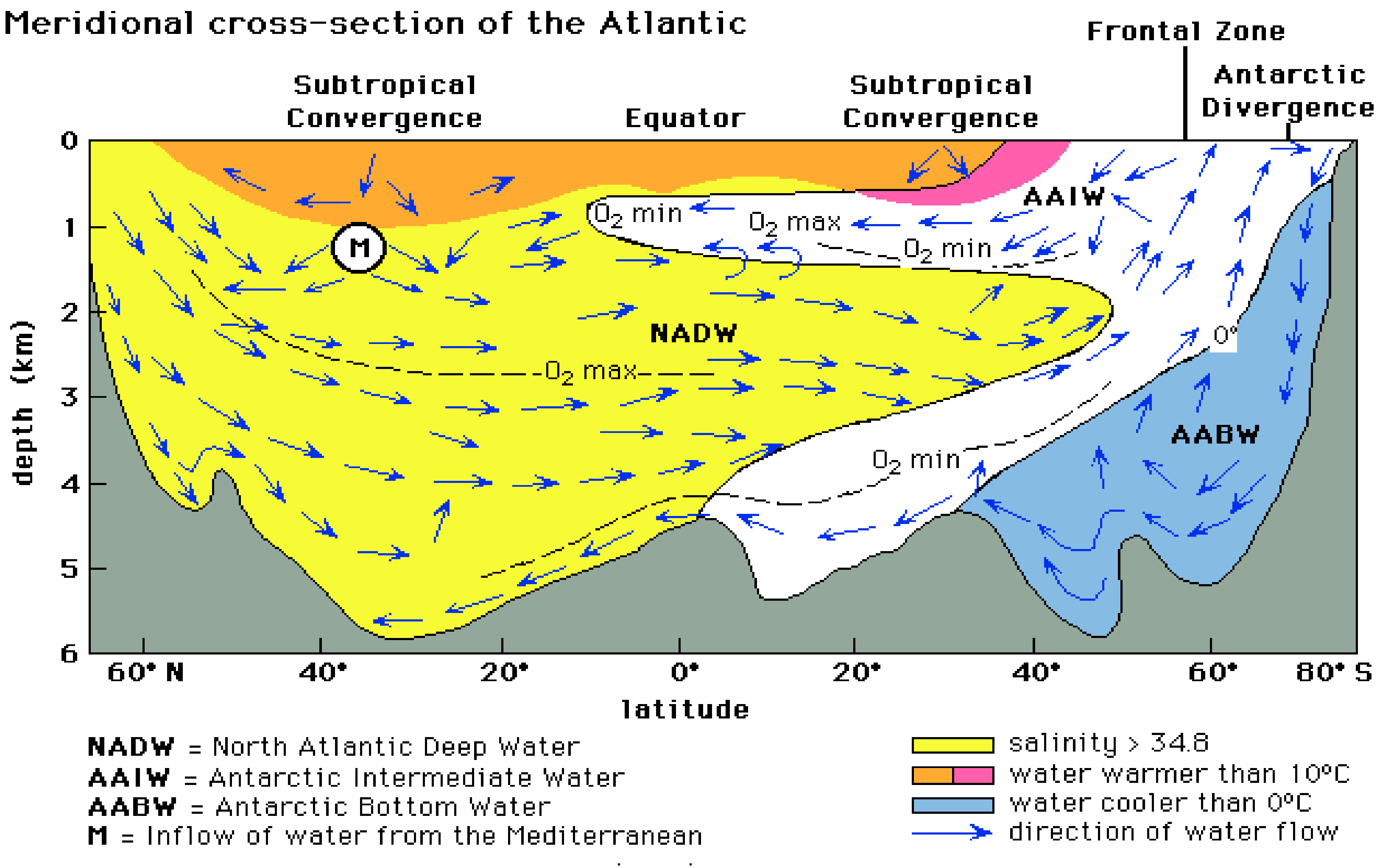
Atlantic ocean real data





Talley 2011

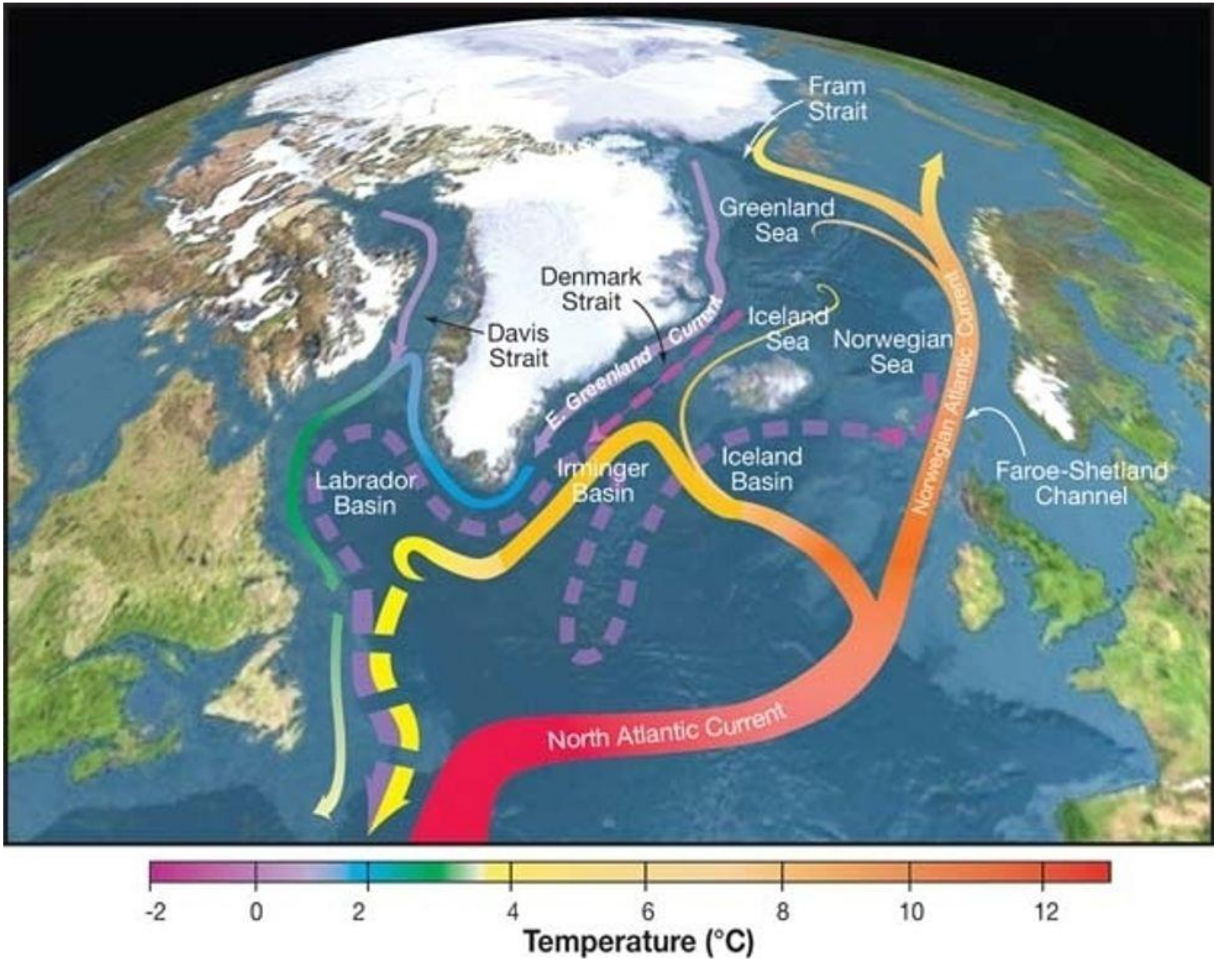
Atlantic ocean general circulation



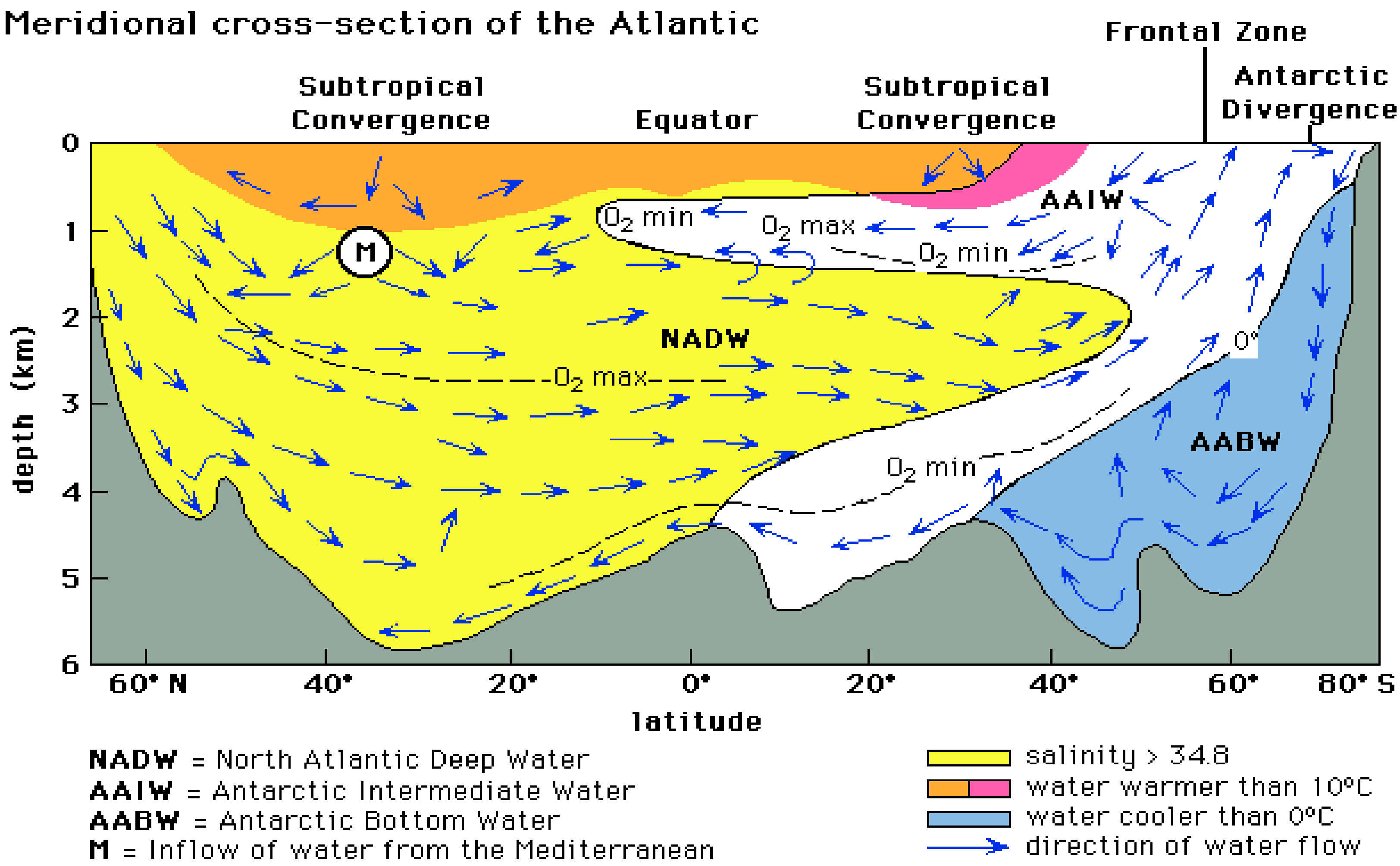
Ocean currents surface, deep and back

The Gulf Stream bring equatorial warm water northwards. Evaporation and cooling increases the density of the water that together with very cold water from the Labrador current Greenland Iceland and the Norwegian seas make together **the North Atlantic Deep Water**

North Atlantic Deep water formation (GIN) Greenland, Iceland, Norwegian



Atlantic ocean general circulation

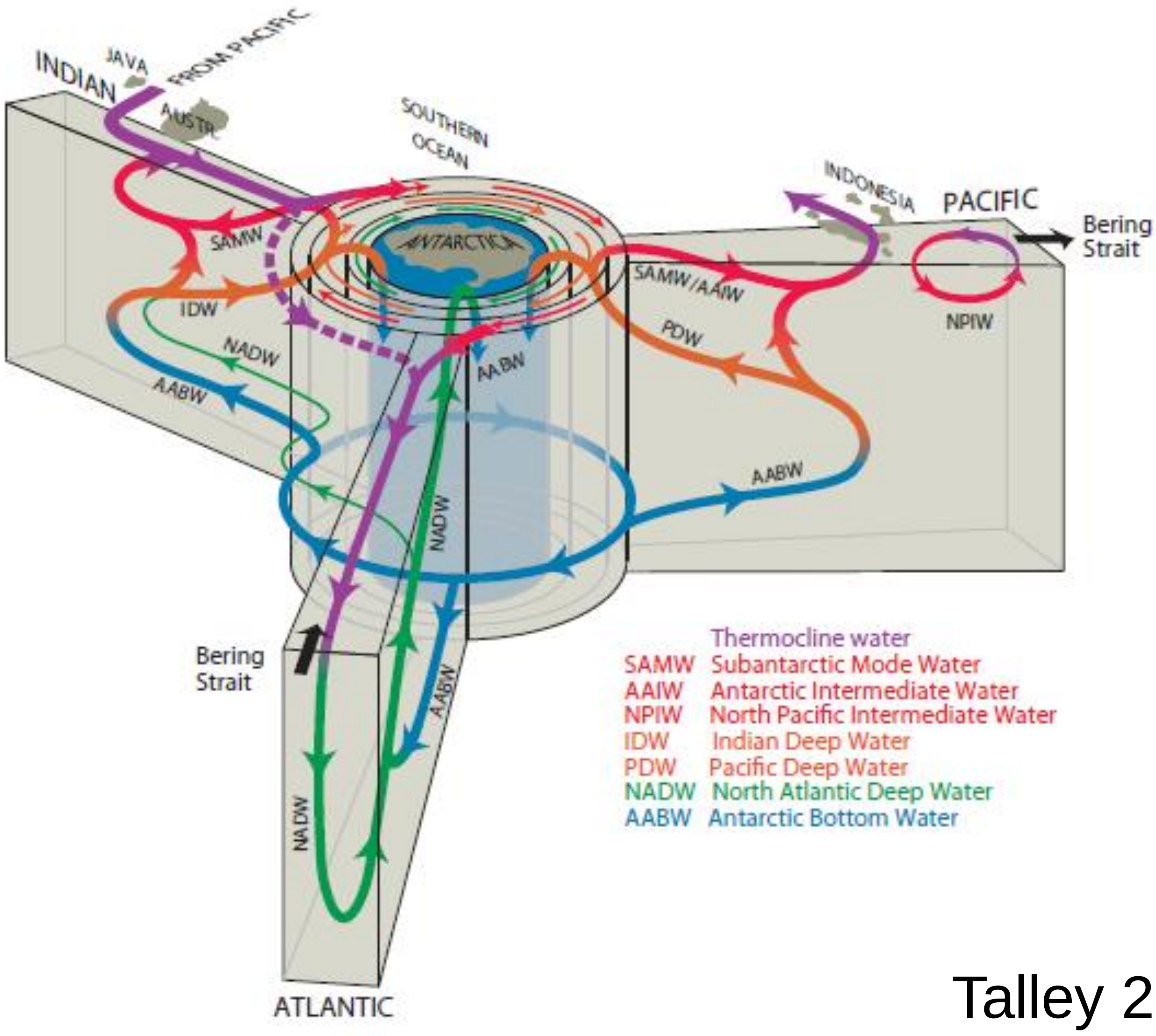


Estimates from hydrography

The volume transport of the overturning circulation at 24 N has been estimated as **17 Sv (1 Sv = 10^6 m^3/s)**

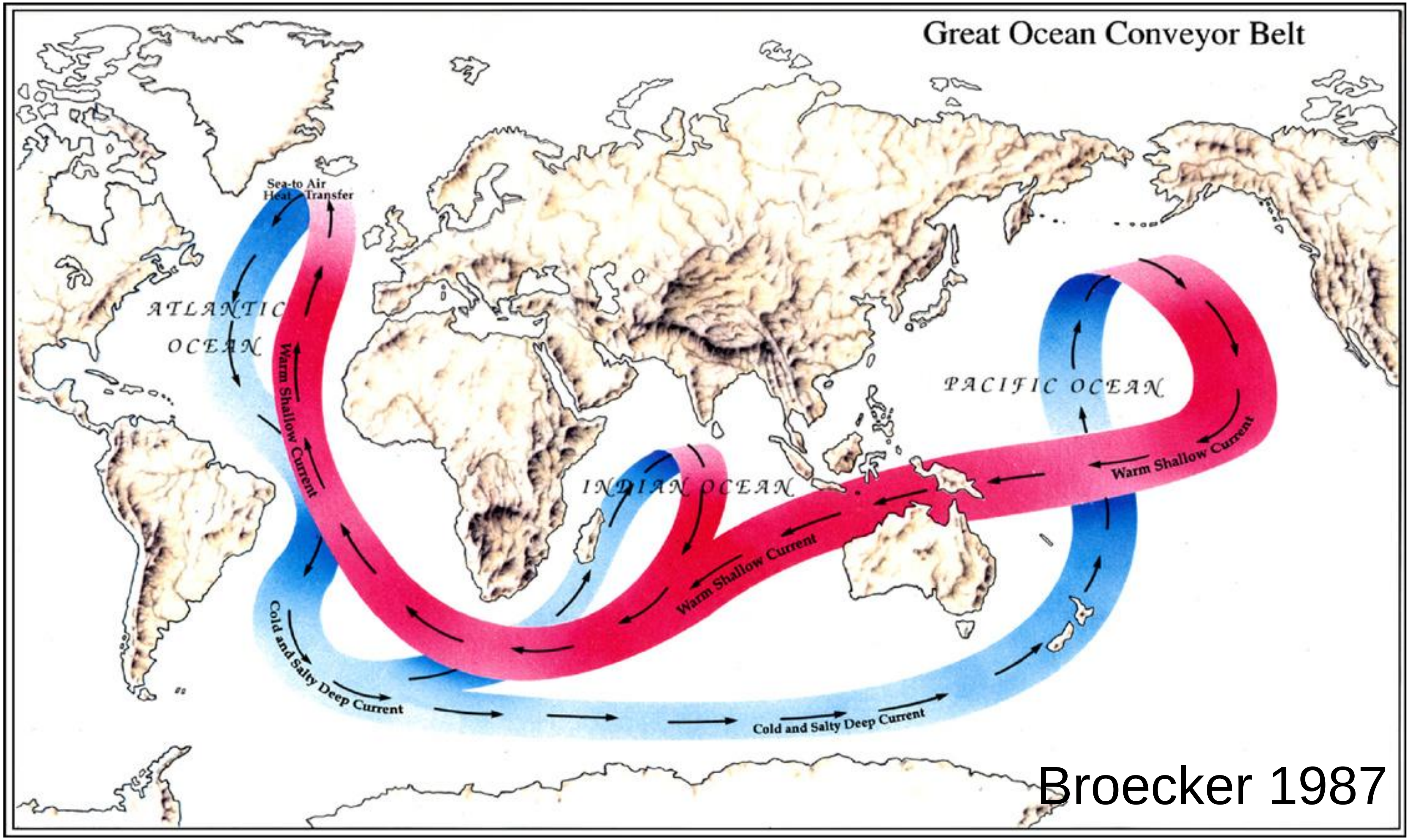
Its heat transport is 1.2 PW (1 PW = 10^{15} W).

The general circulation of the oceans



Talley 2015

The general circulation of the ocean



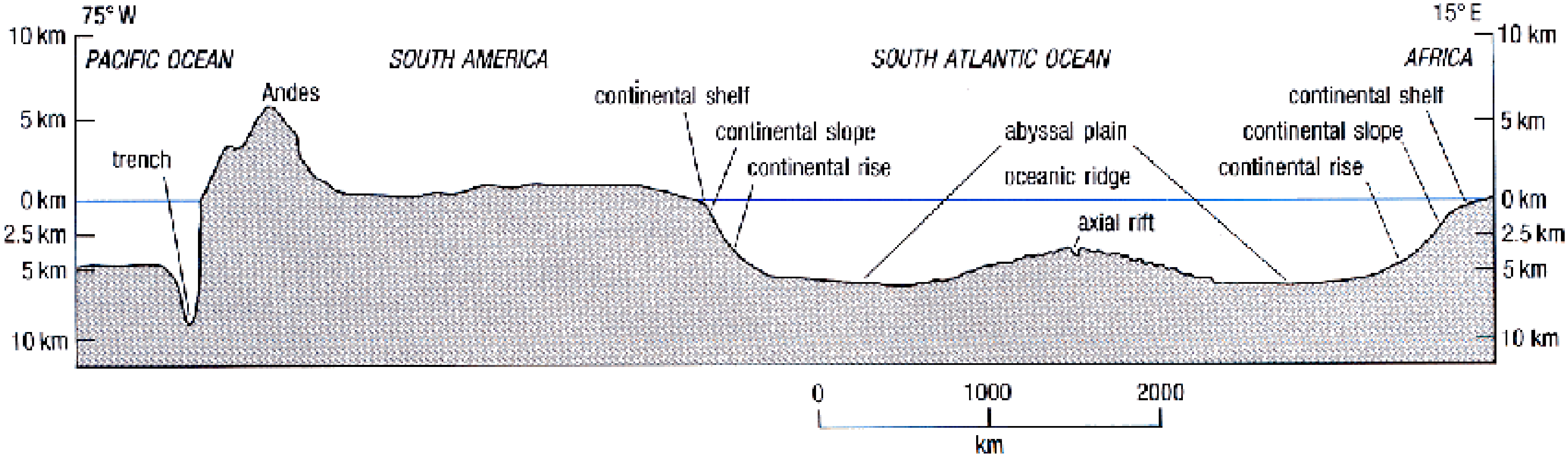
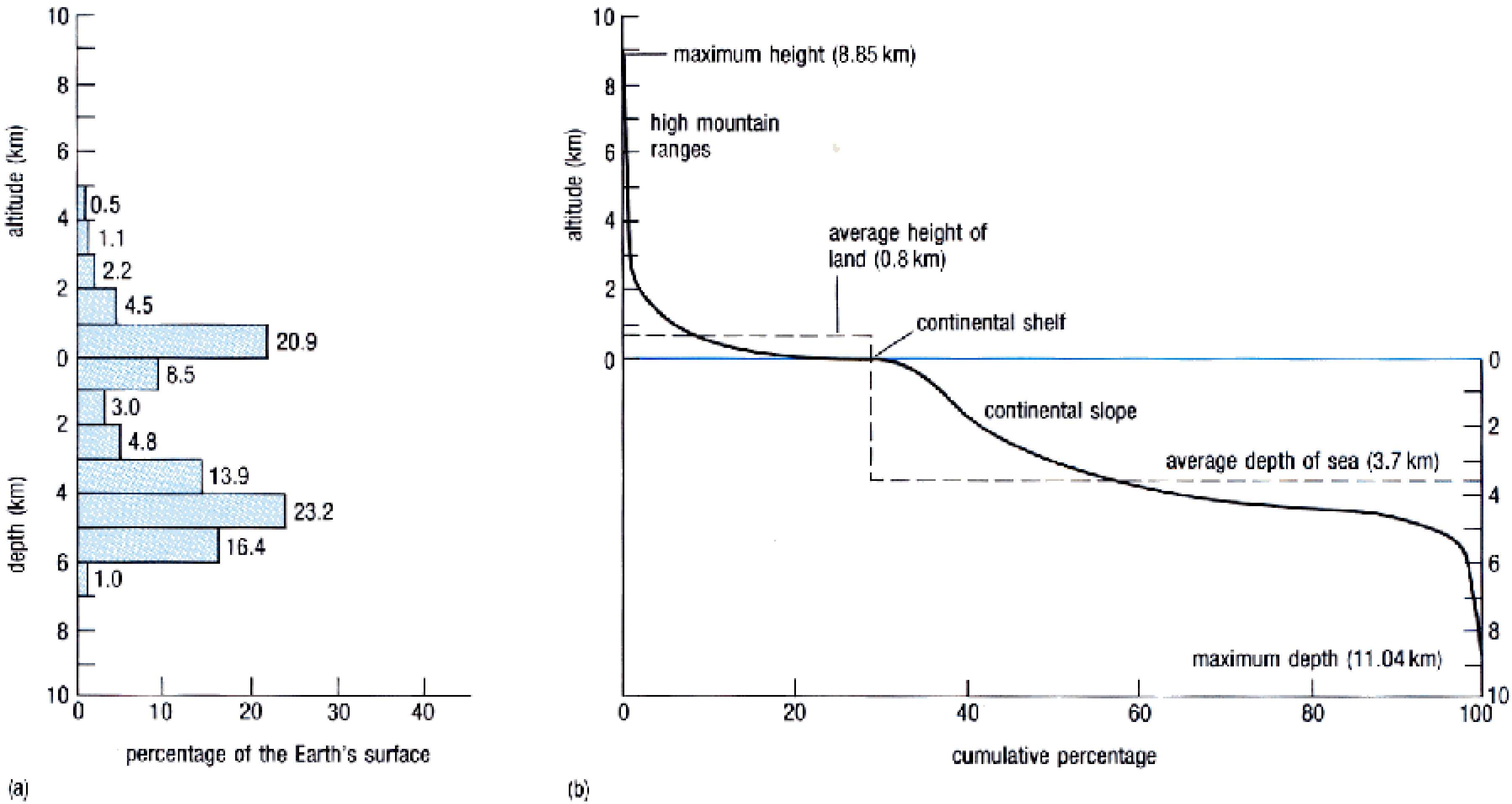
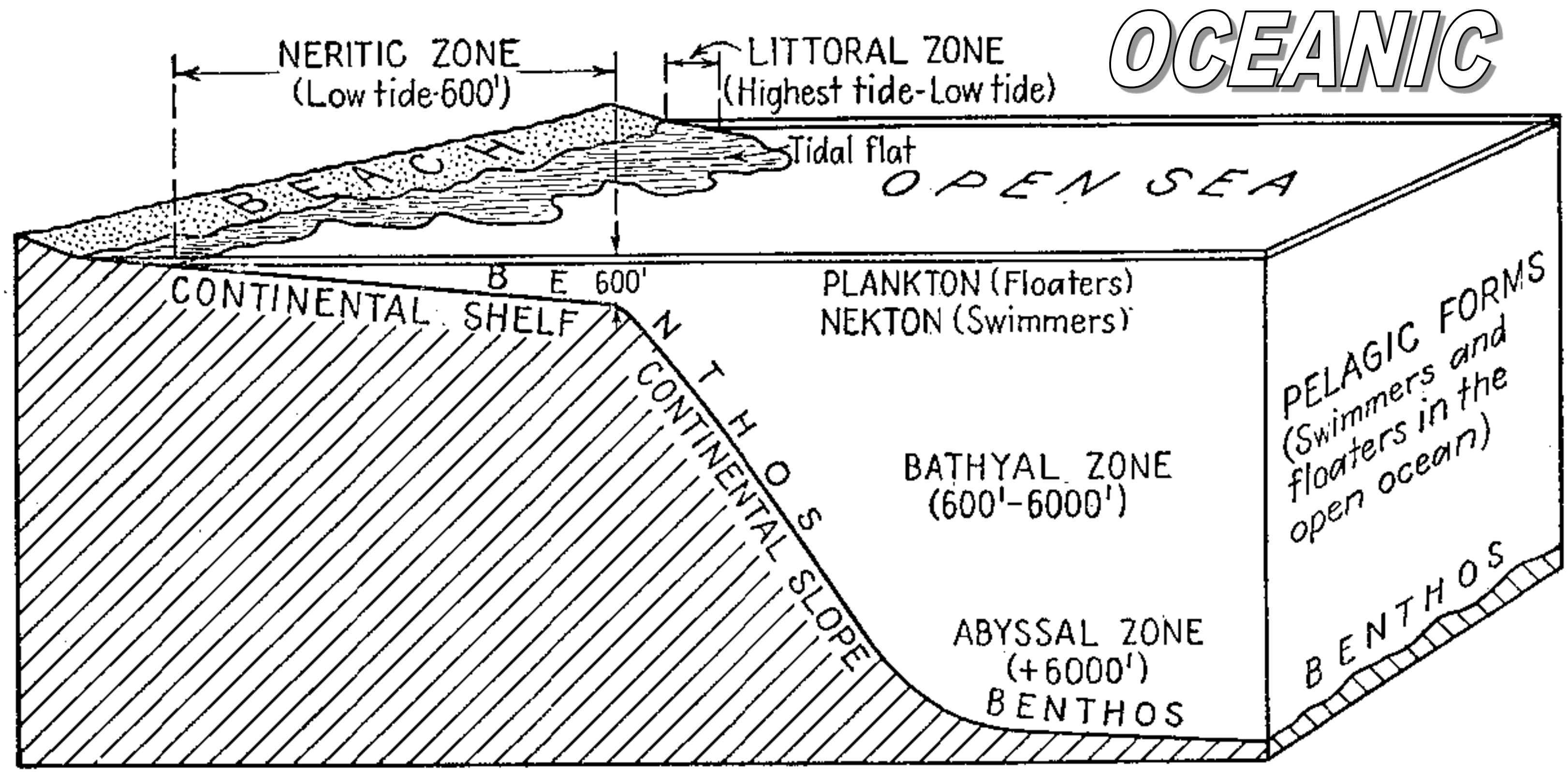


Fig. 7 An example cross-section to show the surface of the Earth between South America and Africe. Vertical exaggeration x 100.



<u>Fig. 8</u> The distribution of levels on the Earth's surface. (a) A histogram showing the actual frequency distribution. (b) A cumulative-frequency (hypsographic) curve based on (a). This is not a profile of the Earth's surface but a curve of percentages of the Earth's surface that lie above, below or within any given level.

Marine environments of life



End of lecture 1

- 10-15 min break