Chapter 5: The Chemistry of Life

Biogeochemical Cycles

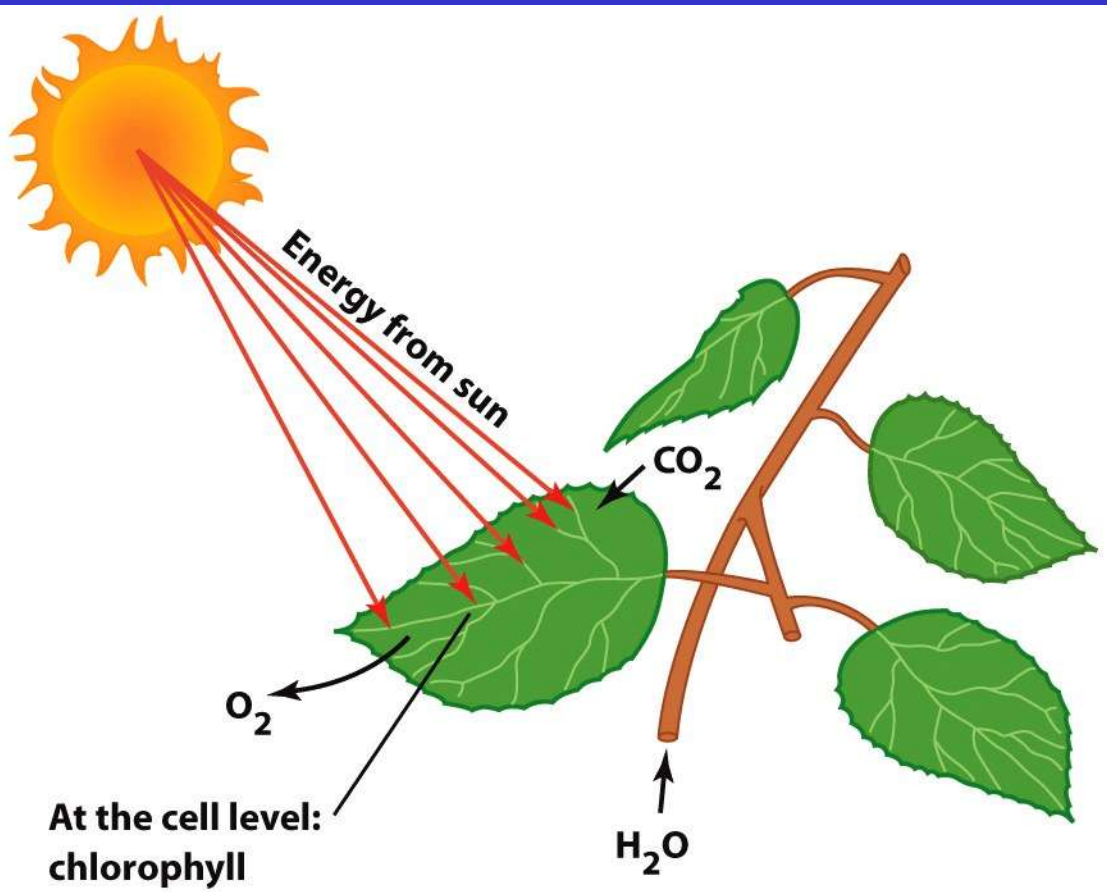
- A biogeochemical cycle is the complete path a chemical takes through the four major components of Earth's system.
  - Atmosphere
  - Hydrosphere
  - Lithosphere
  - Biosphere

Chemical Reactions

- A process in which new chemicals are formed from elements and compounds that undergo a chemical change.
  - E.g. rain water and carbon dioxide
  - $H_2O + CO_2 \rightarrow H_2CO_3$
  - Weak carbonic acid reacts w/ rock and soil

Chemical Reactions

- Another example
  - Chemical reaction for photosynthesis
  - $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
- The two reactions start with same compounds but end up with very different products.

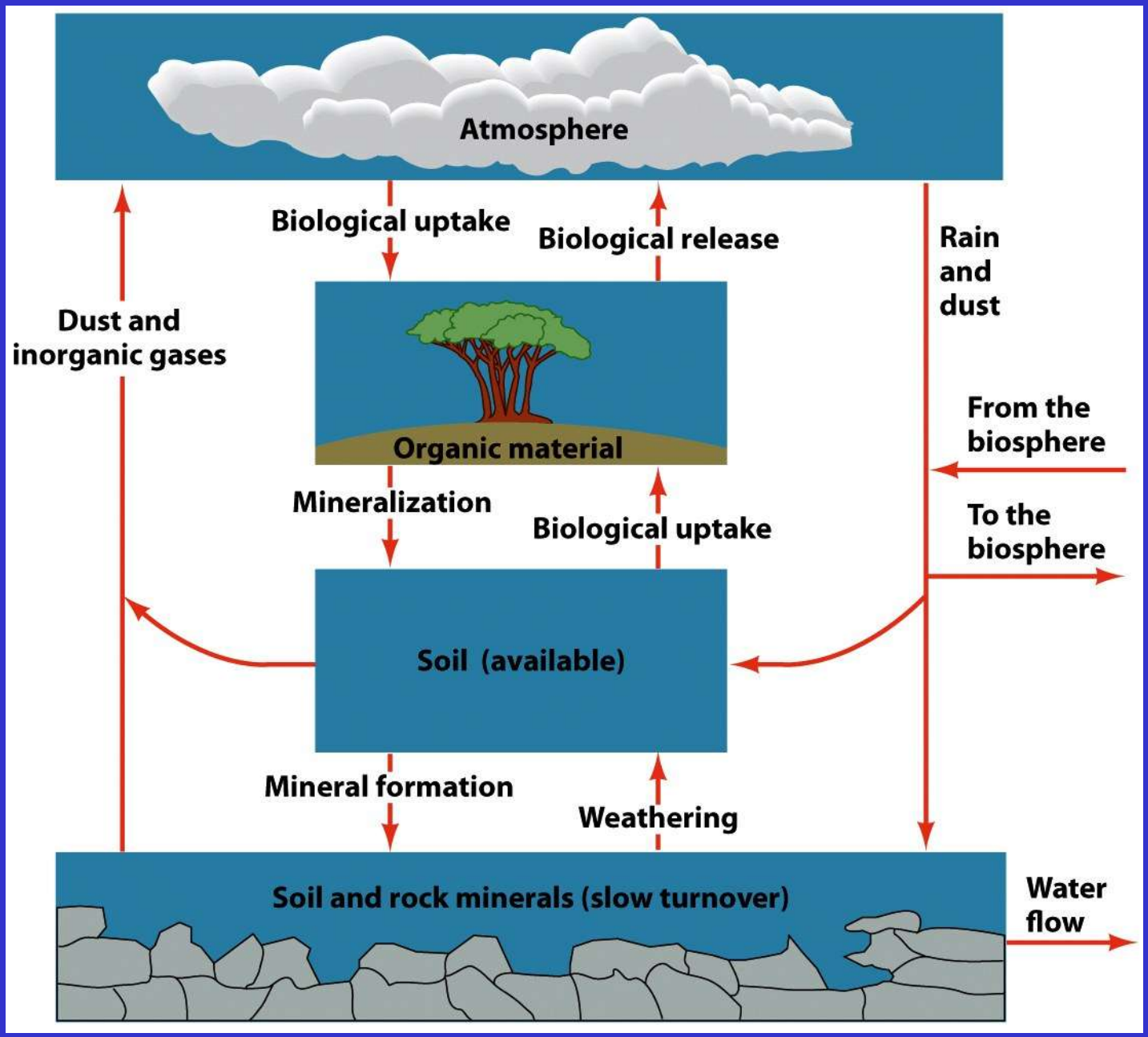


General Photosynthesis: chemical reaction

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

carbon + water $\xrightarrow{\text{sunlight}}$ sugar (glucose) + oxygen

Biogeochemical cycles



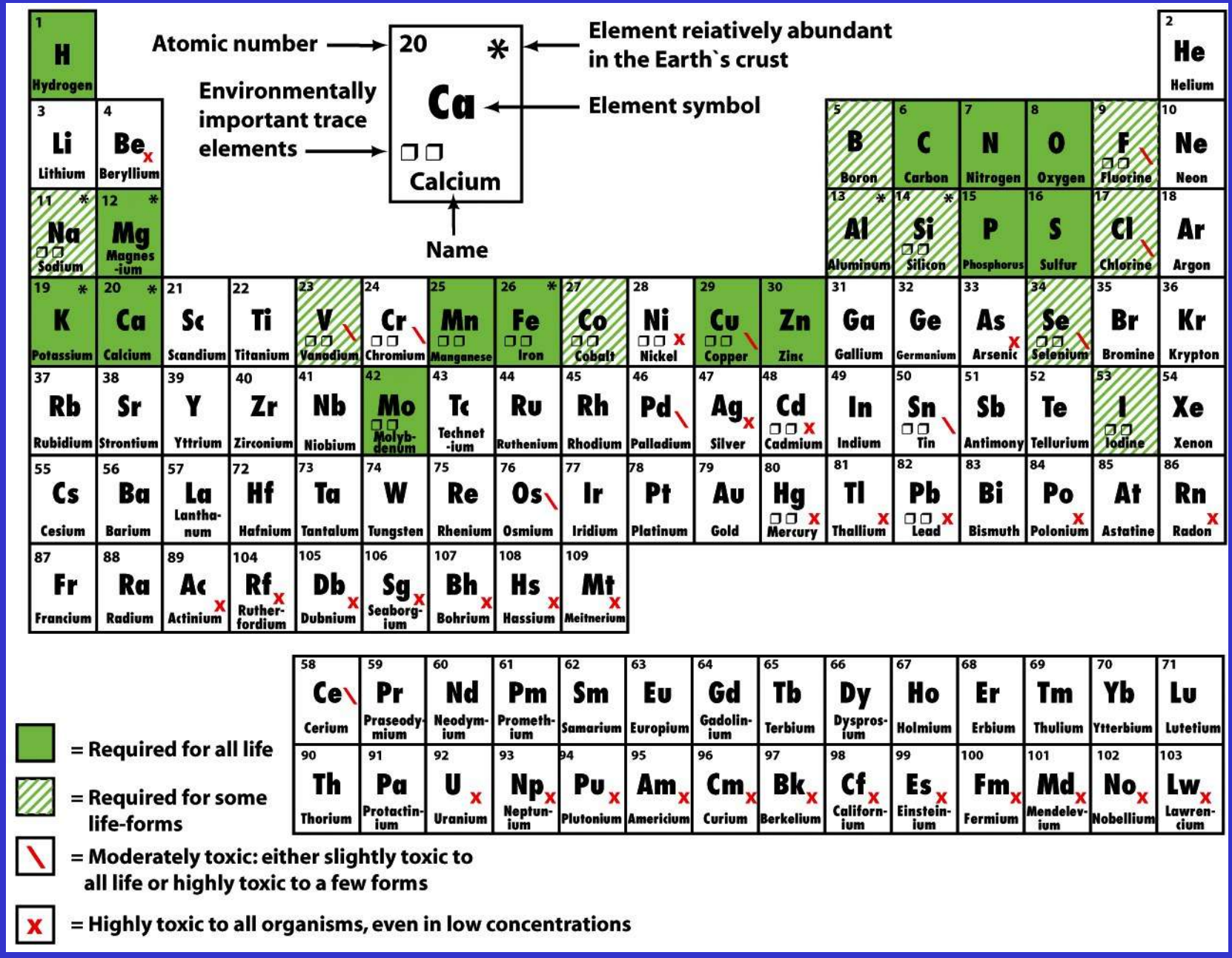
Chemical Reactions

- Chemicals in the four major components have different average storage time
  - Long in rocks
  - Short in the atmosphere
  - Intermediate in the hydrosphere and biosphere

Biogeochemical Cycles and Life

- Of the 103 known elements only 24 required for life.
  - Macronutrients- required in large amounts
    - Big six = C, H, N, O, P, S
  - Micronutrients- required either in small/ moderate amounts
- For life to persist elements must be available at right time, right amount, and right concentrations relative to one another.

When this does not happen chemical can become a **limiting factor**

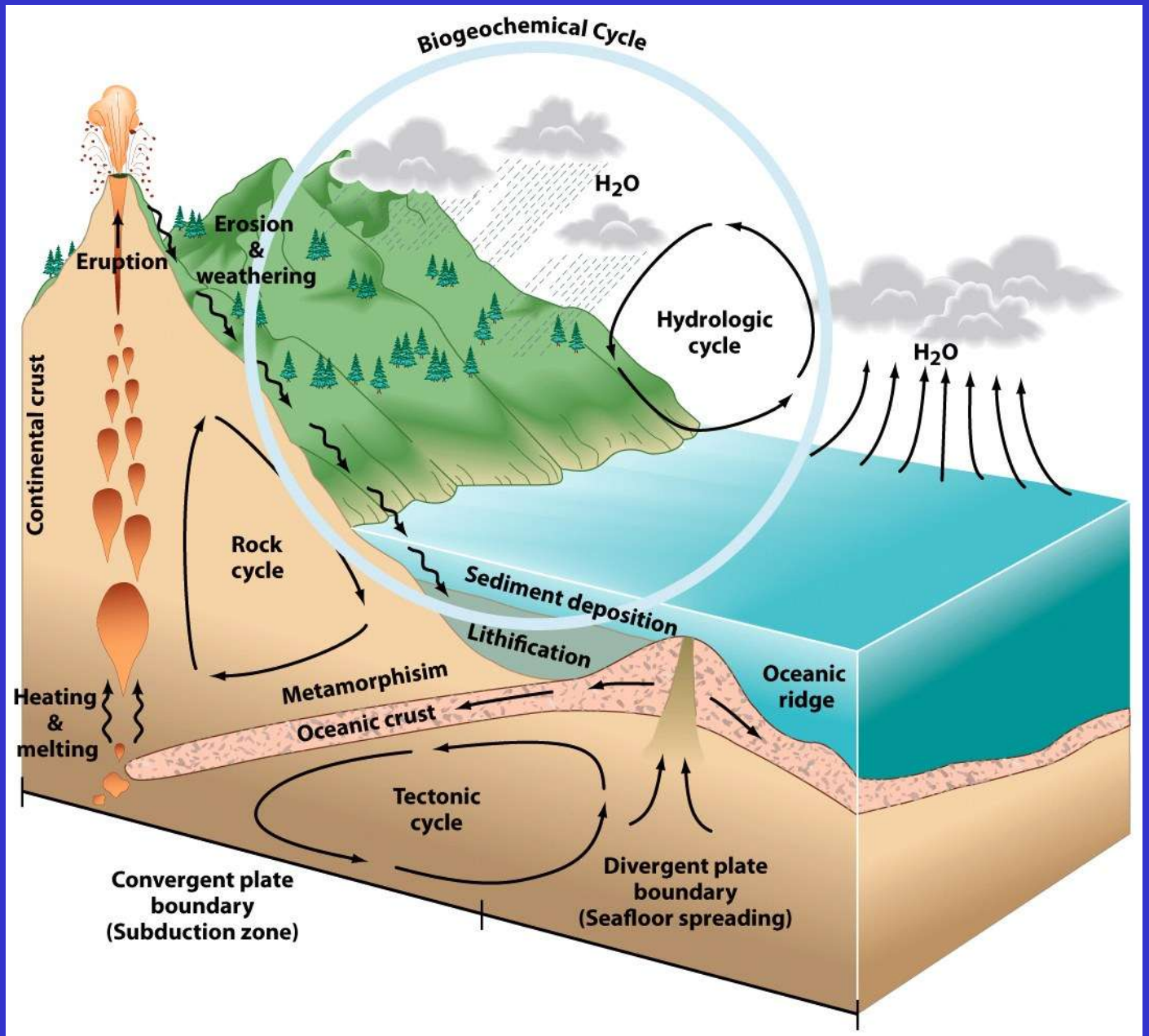

Atomic number
20
Ca
Calcium
Name
Element reiatively abundant in the Earth`s crust
Element symbol
Environmentally important trace elements
1 H Hydrogen
2 He Helium
3 Li Lithium
4 Be Beryllium
5 B Boron
6 C Carbon
7 N Nitrogen
8 O Oxygen
9 F Fluorine
10 Ne Neon
11 Na Sodium
12 Mg Magnes-ium
13 Al Aluminum
14 Si Silicon
15 P Phosphorus
16 S Sulfur
17 Cl Chlorine
18 Ar Argon
19 K Potassium
20 Ca Calcium
21 Sc Scandium
22 Ti Titanium
23 V Vanadium
24 Cr Chromium
25 Mn Manganese
26 Fe Iron
27 Co Cobalt
28 Ni Nickel
29 Cu Copper
30 Zn Zinc
31 Ga Gallium
32 Ge Germanium
33 As Arsenic
34 Se Selenium
35 Br Bromine
36 Kr Krypton
37 Rb Rubidium
38 Sr Strontium
39 Y Yttrium
40 Zr Zirconium
41 Nb Niobium
42 Mo Molyb-denum
43 Tc Technet-ium
44 Ru Ruthenium
45 Rh Rhodium
46 Pd Palladium
47 Ag Silver
48 Cd Cadmium
49 In Indium
50 Sn Tin
51 Sb Antimony
52 Te Tellurium
53 I Iodine
54 Xe Xenon
55 Cs Cesium
56 Ba Barium
57 La Lantha-num
72 Hf Hafnium
73 Ta Tantalum
74 W Tungsten
75 Re Rhenium
76 Os Osmium
77 Ir Iridium
78 Pt Platinum
79 Au Gold
80 Hg Mercury
81 Tl Thallium
82 Pb Lead
83 Bi Bismuth
84 Po Polonium
85 At Astatine
86 Rn Radon
87 Fr Francium
88 Ra Radium
89 Ac Actinium
104 Rf Ruther-fordium
105 Db Dubnium
106 Sg Seaborg-ium
107 Bh Bohrium
108 Hs Hassium
109 Mt Meitnerium
58 Ce Cerium
59 Pr Praseody-mium
60 Nd Neodym-ium
61 Pm Prometh-ium
62 Sm Samarium
63 Eu Europium
64 Gd Gadolin-ium
65 Tb Terbium
66 Dy Dyspros-ium
67 Ho Holmium
68 Er Erbium
69 Tm Thulium
70 Yb Ytterbium
71 Lu Lutetium
90 Th Thorium
91 Pa Protactin-ium
92 U Uranium
93 Np Neptun-ium
94 Pu Plutonium
95 Am Americium
96 Cm Curium
97 Bk Berkelium
98 Cf Californ-ium
99 Es Einstein-ium
100 Fm Fermium
101 Md Mendelev-ium
102 No Nobellium
103 Lw Lawren-cium
= Required for all life
= Required for some life-forms
= Moderately toxic: either slightly toxic to all life or highly toxic to a few forms
= Highly toxic to all organisms, even in low concentrations

General Concepts Central to Biogeochemical Cycles

- Some chemicals cycle quickly and are readily regenerated for biological activity.
  - They typically have a gas phase, are soluble and carried by the hydrologic cycle.
- Other chemical elements are relatively immobile and returned by geological processes.
  - Typically lack a gas phase and insoluble

The Geologic Cycle

- Over the last 4.6 billion years rocks and soils has been continually
  - Created, maintained, changed, and destroyed
  - By physical, chemical, and biological processes
- Geologic cycle- group of cycles that is responsible for formation and change
  - Tectonic, hydrologic, rock, and biogeochemical


Biogeochemical Cycle
H_2O
Erosion & weathering
Eruption
Hydrologic cycle
H_2O
Continental crust
Rock cycle
Sediment deposition
Lithification
Metamorphisim
Oceanic ridge
Heating & melting
Oceanic crust
Tectonic cycle
Convergent plate boundary (Subduction zone)
Divergent plate boundary (Seafloor spreading)

The Tectonic Cycle

- Involves creation and destruction of the lithosphere (outer layer of Earth)
  - ~100 km thick and broken in to several plates
  - The movement of plates called plate tectonics
- Plate tectonics has large scales effects
  - Alterations in climate
  - Ecological islands
  - Areas of volcanic activity and earthquakes

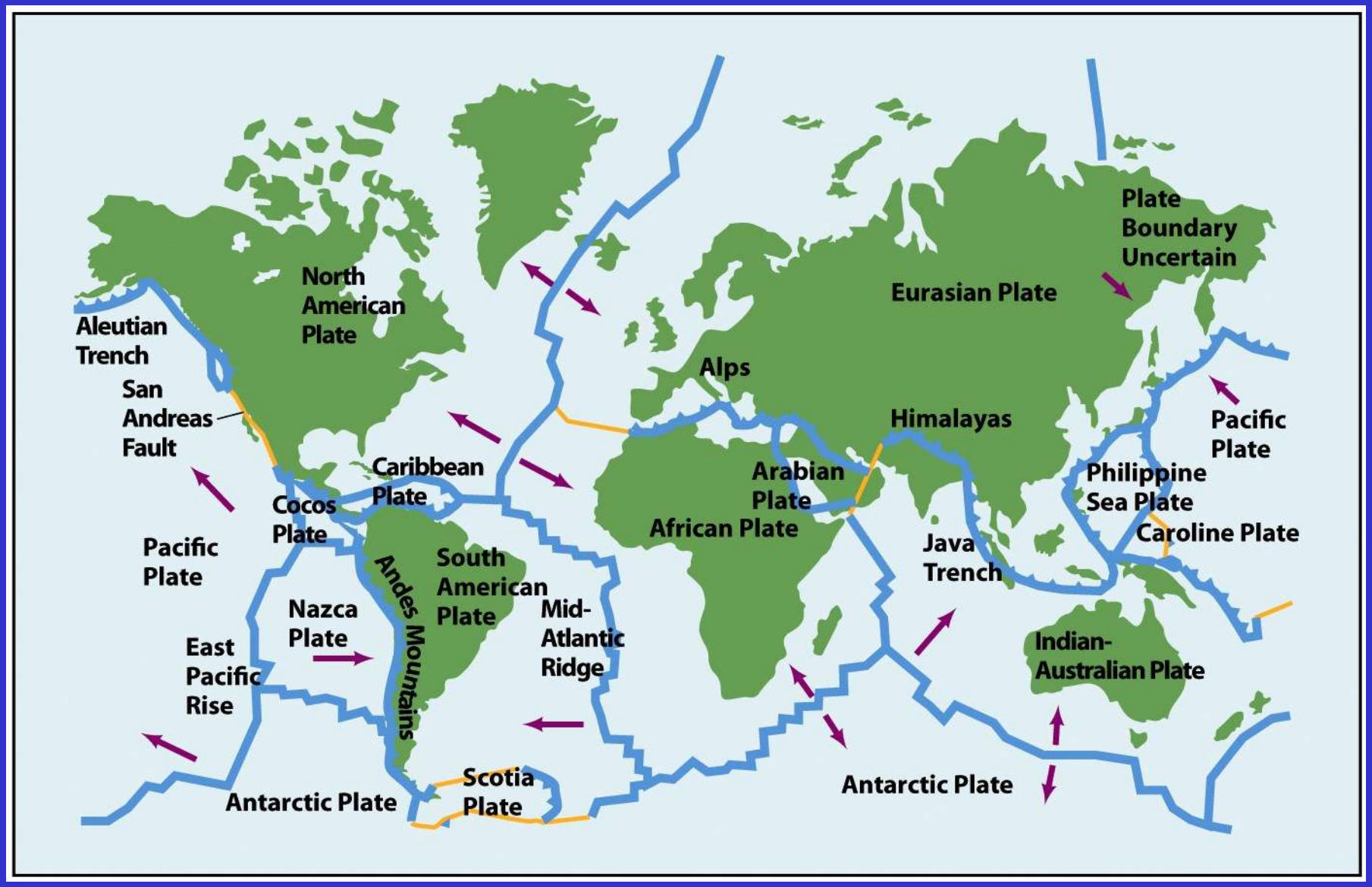
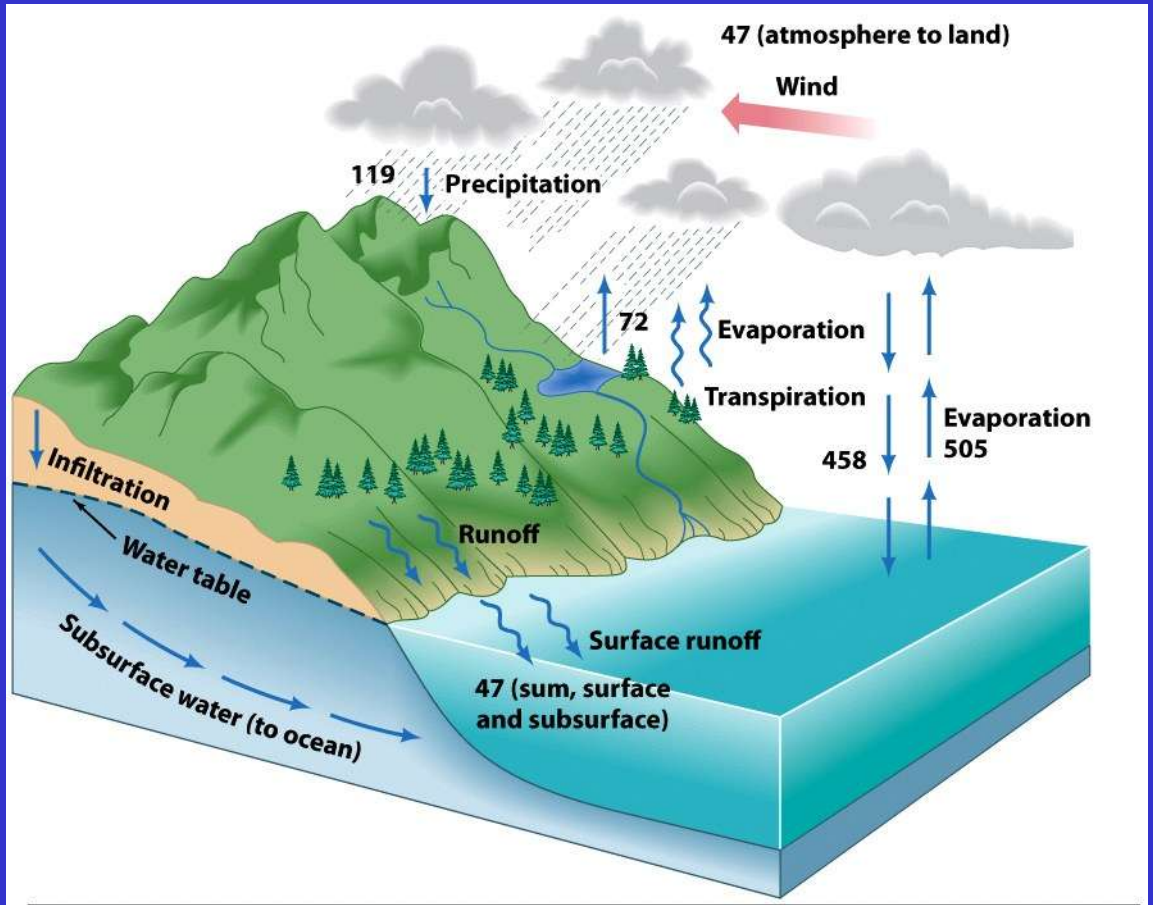


Plate Boundary Uncertain
North American Plate
Eurasian Plate
Aleutian Trench
San Andreas Fault
Alps
Himalayas
Pacific Plate
Caribbean Plate
Arabian Plate
Philippine Sea Plate
Cocos Plate
African Plate
Caroline Plate
Pacific Plate
Java Trench
South American Plate
Andes Mountains
Nazca Plate
Mid-Atlantic Ridge
Indian-Australian Plate
East Pacific Rise
Scotia Plate
Antarctic Plate
Antarctic Plate

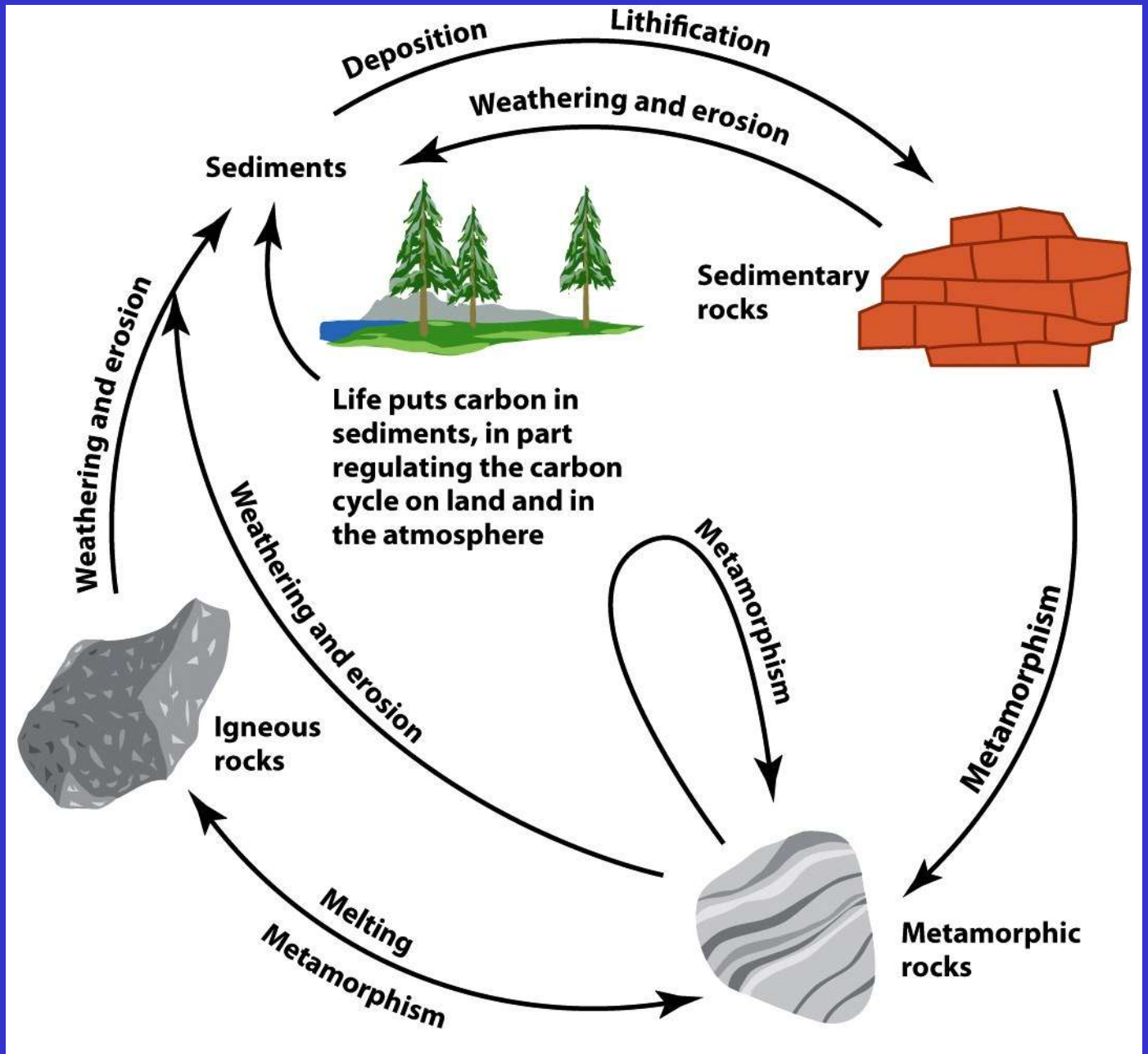
The Hydrologic Cycle



Storage Compartments of Water

Compartment	Vol. (thousands of km^3)	Percentage of Total Water
Ocean	1,338,000	96.5
Glaciers and ice caps	24,064	1.74
Shallow groundwater	10,530	0.76
Lakes	176.4	0.013
Soil moisture	16.5	0.001
Atmosphere	12.9	0.001
Rivers	2.12	0.0002

The Rock Cycle



The Carbon Cycle

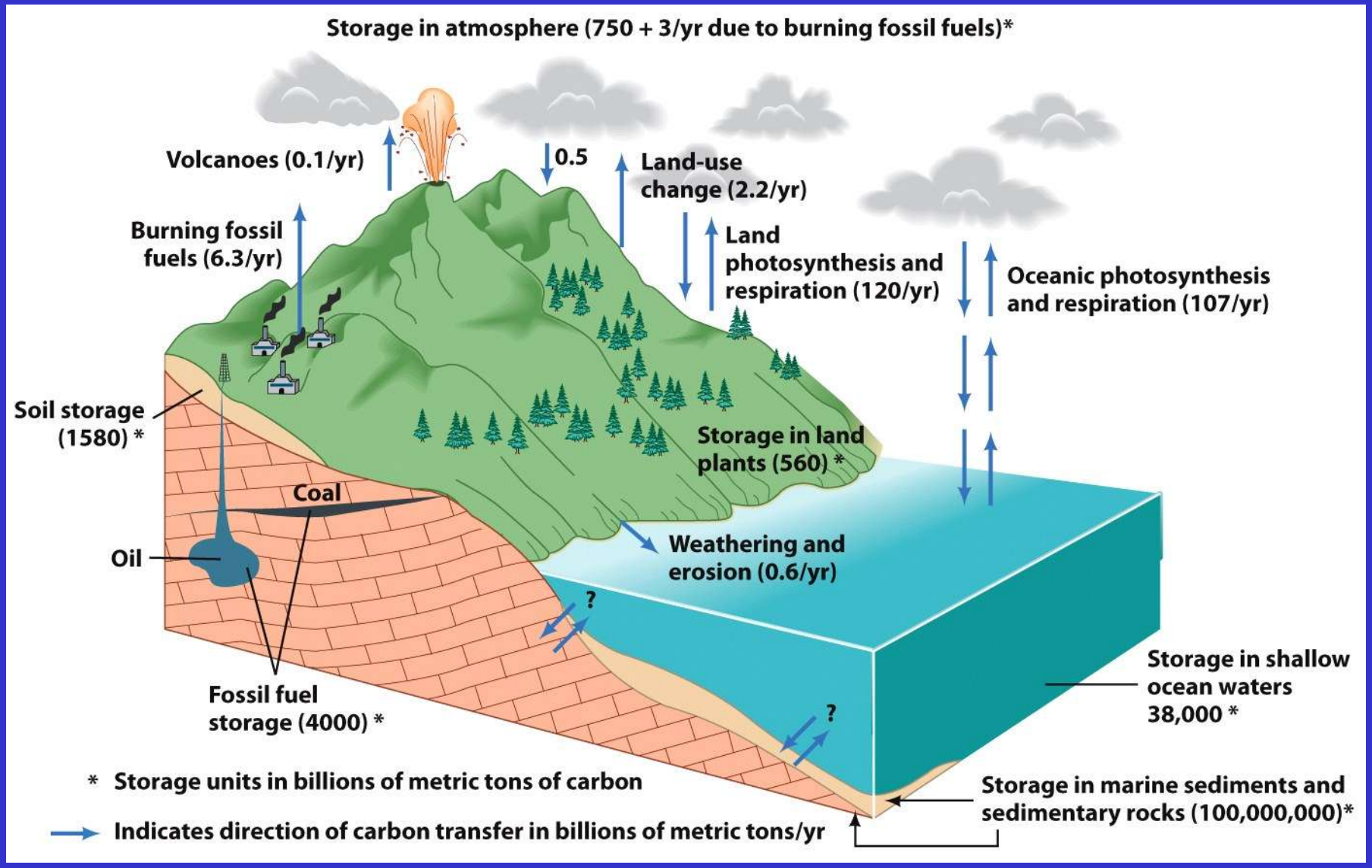
- Carbon is the element that anchors all organic substances.
- Carbon has a gaseous phrase
  - Enters atmosphere (CO_2 and CH_4) through respiration, fires and diffusion.
  - Removed from the atmosphere by photosynthesis

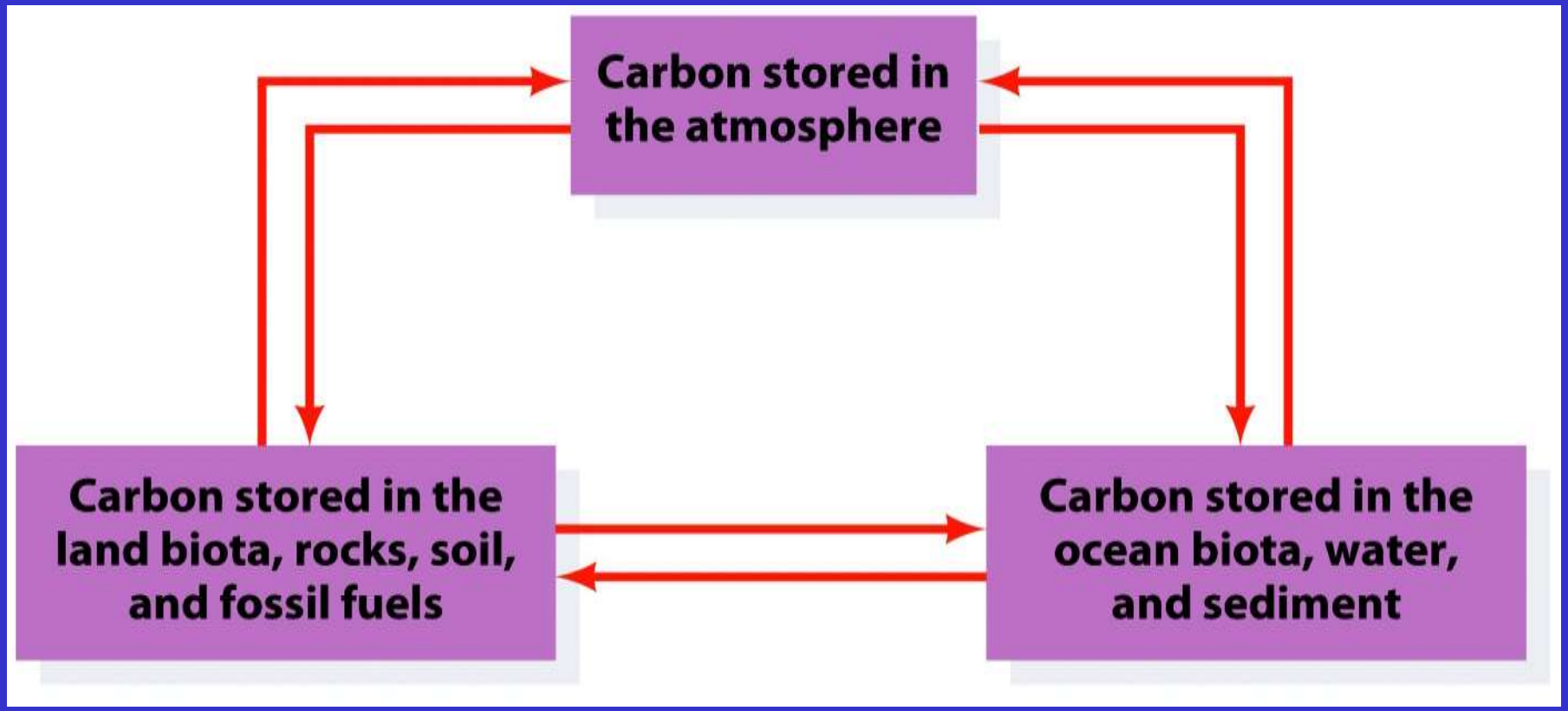
The Carbon Cycle

- Carbon occurs in the ocean in several forms
  - Dissolved CO_2, carbonate and bicarbonate
  - Marine organisms and their products, $CaCO_3$
- Enters the ocean by
  - Simple diffusion then dissolves
  - Transfer from land in rivers as dissolved carbon
  - Wind

The Carbon Cycle

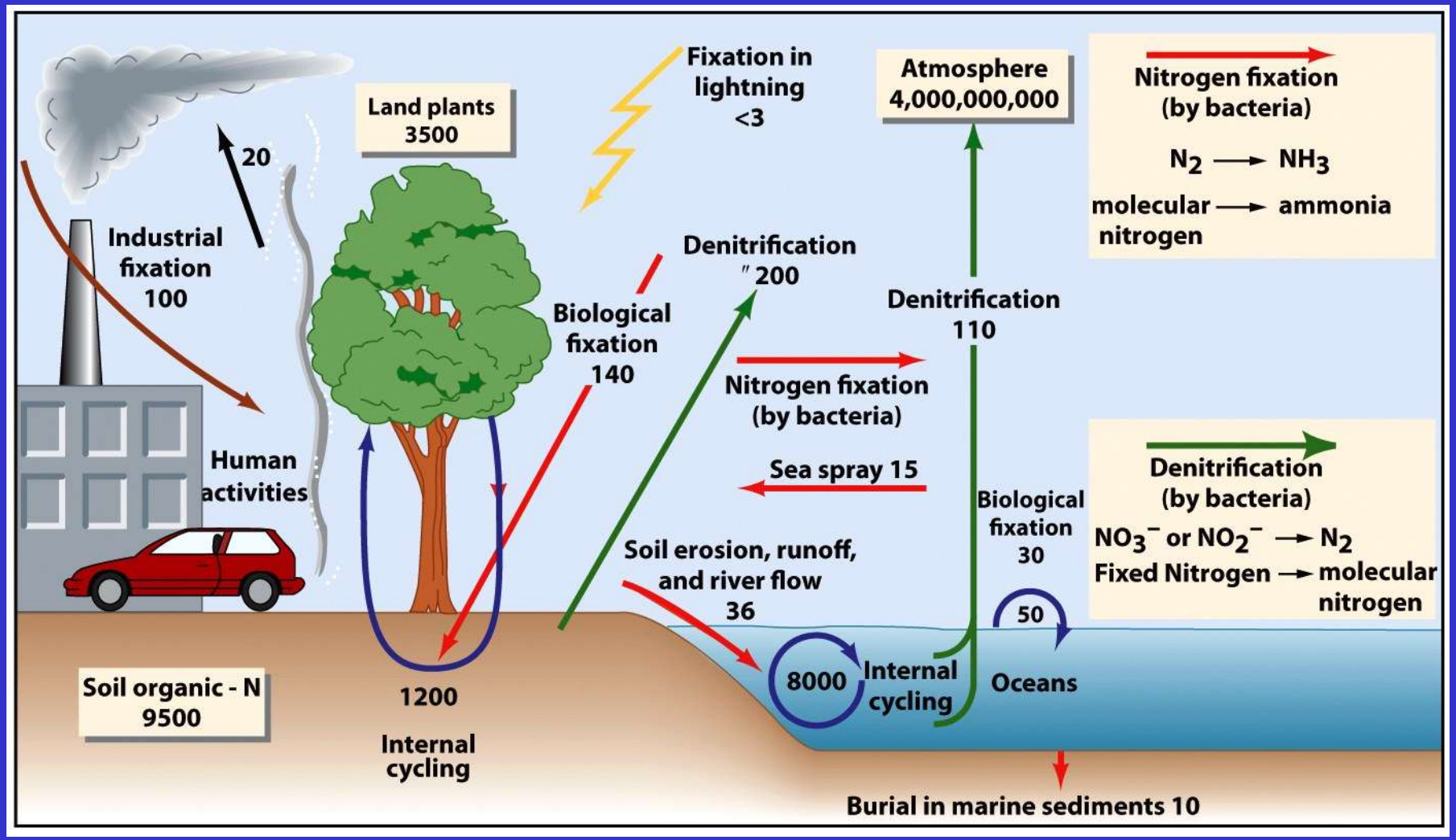
- Carbon enters the biota through photosynthesis and then returned by respiration or fire.
  - When organism dies decomposition releases carbon.
  - If buried under certain conditions carbon is not be released
    - Transformed into fossil fuels


Storage in atmosphere (750 + 3/yr due to burning fossil fuels)*
Volcanoes (0.1/yr)
0.5
Land-use change (2.2/yr)
Burning fossil fuels (6.3/yr)
Land photosynthesis and respiration (120/yr)
Oceanic photosynthesis and respiration (107/yr)
Soil storage (1580) *
Storage in land plants (560) *
Coal
Oil
Weathering and erosion (0.6/yr)
?
?
Fossil fuel storage (4000) *
Storage in shallow ocean waters 38,000 *
* Storage units in billions of metric tons of carbon
Storage in marine sediments and sedimentary rocks (100,000,000)*
Indicates direction of carbon transfer in billions of metric tons/yr


Carbon stored in the atmosphere
Carbon stored in the land biota, rocks, soil, and fossil fuels
Carbon stored in the ocean biota, water, and sediment

The Nitrogen Cycle

- N essential to life because it is necessary for the production of proteins and DNA.
- Free N_2 makes up 80% of atmosphere
  - But most organisms can't use it directly
  - Relatively unreactive element must be converted to NO_3^- or NH_4^+
  - Done by bacteria

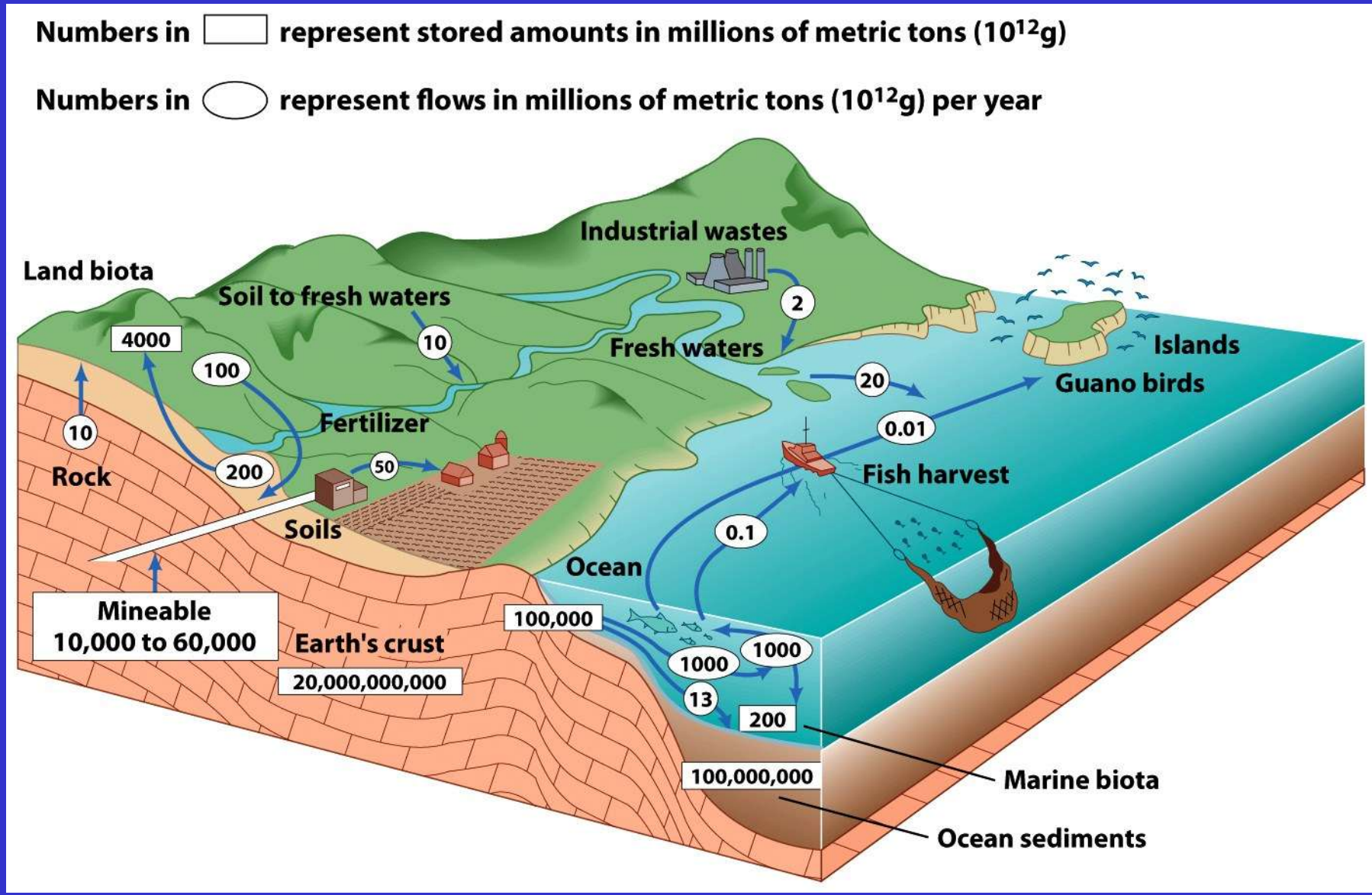

Land plants
3500
Fixation in
lightning
<3
Atmosphere
4,000,000,000
Nitrogen fixation
(by bacteria)
N_2 → NH_3
molecular nitrogen → ammonia
20
Industrial
fixation
100
Denitrification
200
Biological
fixation
140
Denitrification
110
Nitrogen fixation
(by bacteria)
Sea spray 15
Human
activities
Denitrification
(by bacteria)
NO_3^- or NO_2^- → N_2
Fixed Nitrogen → molecular nitrogen
Biological
fixation
30
Soil erosion, runoff,
and river flow
36
50
8000
Internal
cycling
Oceans
Soil organic - N
9500
1200
Internal
cycling
Burial in marine sediments 10

The Phosphorus Cycle

- P one of the “big six” required for life
  - Often a limiting factor for plant and algal growth
- Does not have a gaseous phase
  - Rate of transfer slow

The Phosphorus Cycle

- Enters biota through uptake as phosphate by plants, algae and some bacteria.
  - Returns to soil when plants die or is lost to oceans via runoff
  - Returned to land via ocean feeding birds (guano)
- Guano deposits major source of P for fertilizers


Numbers in ▭ represent stored amounts in millions of metric tons (10^{12}g)
Numbers in ⬭ represent flows in millions of metric tons (10^{12}g) per year
Industrial wastes
Land biota
Soil to fresh waters
4000
10
100
Fresh waters
2
Islands
20
Guano birds
Fertilizer
0.01
10
Rock
200
50
Fish harvest
Soils
0.1
Ocean
Mineable
10,000 to 60,000
Earth's crust
20,000,000,000
100,000
1000
1000
13
200
100,000,000
Marine biota
Ocean sediments