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
  - $\text{H}_2\text{O} + \text{CO}_2 \rightarrow \text{H}_2\text{CO}_3$
  - Weak carbonic acid reacts w/ rock and soil
Chemical Reactions

- Another example
  - Chemical reaction for photosynthesis
  - $6\text{CO}_2 + 6\text{H}_2\text{O} \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2$

- The two reactions start with same compounds but end up with very different products.
Energy from sun

CO₂

H₂O

O₂

At the cell level: chlorophyll (green plant absorbs sunlight)

General Photosynthesis: chemical reaction

\[ 6\text{CO}_2 + 6\text{H}_2\text{O} \xrightarrow{\text{sunlight}} \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]

Carbon + water \xrightarrow{\text{sunlight}} Sugar (glucose) + oxygen
Biogeochemical cycles

- Atmosphere
  - Biological uptake
  - Biological release
- Organic material
  - Mineralization
  - Biological uptake
- Soil (available)
  - Mineral formation
  - Weathering
- Soil and rock minerals (slow turnover)
  - Water flow
- Dust and inorganic gases
- Rain and dust
  - From the biosphere
  - To the biosphere
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
The periodic table of elements with a focus on calcium. The table includes:

- Atomic number
- Element symbol
- Name
- Environmentally important trace elements
- Naturally occurring elements
- Elements relatively abundant in the Earth’s crust

Additional symbols and notes:

- Green squares indicate elements required for all life.
- Yellow squares indicate elements required for some life-forms.
- A slash through an element indicates it is moderately toxic, either slightly toxic to all life or highly toxic to a few forms.
- A cross through an element indicates it is 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
The Tectonic Cycle

- Involves creation and destruction of the lithosphere (outer layer of Earth)
  - ~100 km thick and broken into several plates
  - The movement of plates called plate tectonics

- Plate tectonics has large scale effects
  - Alterations in climate
  - Ecological islands
  - Areas of volcanic activity and earthquakes
The Rock Cycle

Life puts carbon in sediments, in part regulating the carbon cycle on land and in the atmosphere.
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
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
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