ENVIRONMENT

THE SCIENCE BEHIND THE STORIES

Jay Withgott • Scott Brennan

Third Edition

Ch 7

Environmental Systems and Ecosystem Ecology

Part 1: Foundations of Environmental Science

PowerPoint® Slides prepared by
Jay Withgott and Heidi Marcum

This lecture will help you understand:

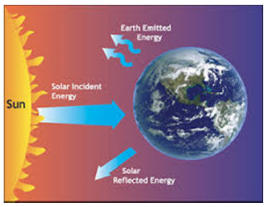
- The nature of environmental systems
- Ecosystems and how living and nonliving entities interact
- The carbon, phosphorus, nitrogen, and water cycles
- How plate tectonics and the rock cycle shape the Earth

Central Case: The Gulf of Mexico's "Dead Zone"

- Gulf of Mexico brings in 600 million kg/year shrimp, fish, and shellfish
- Gulf "dead zone" = a region of water so depleted of oxygen that kills or drives away marine organisms
- **Hypoxia** = low concentrations of dissolved oxygen water
- Caused by fertilizer, runoff, sewage

The Earth's systems

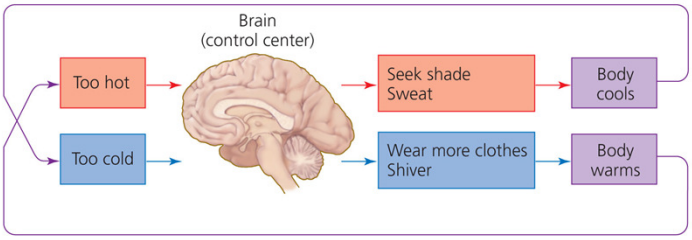
- **System** = a network of relationships among parts elements or components that interact with and influence one another
  - Exchange of energy, matter, or information
  - Receives inputs of energy, matter, or information; processes these inputs; and produces outputs
- Systems often show behavior that is hard to understand and predict
- **Feedback loop** = a system's output serves as input to that same system
  - A circular process



Earth is a closed system

Negative feedback loop

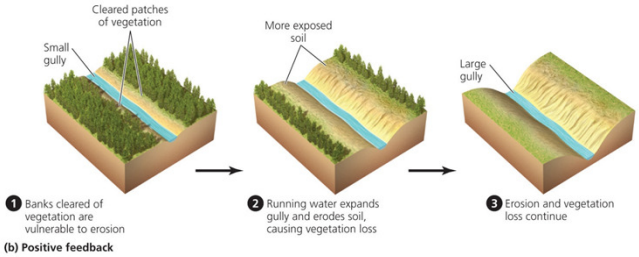
- **Negative feedback loop** = output that results from a system moving in one direction acts as input that moves the system in the other direction.
  - Input and output essentially neutralize one another
  - Stabilizes the system
  - Example: body temperature
  - Most systems in nature



(a) Negative feedback

Positive feedback loop

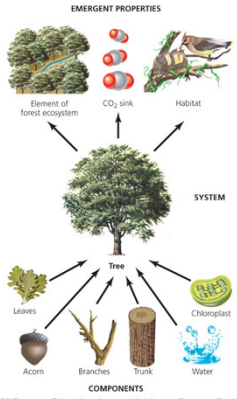
- **Positive feedback loop** = instead of stabilizing a system, it drives it further toward one extreme or another
- Examples: exponential growth in human population, spread of cancer, erosion
- Rare in nature
  - But are common in natural systems altered by human impact



(b) Positive feedback

Systems are active

- **Dynamic equilibrium** = system processes move in opposing directions at equivalent rates, balancing their effects
- **Homeostasis** = a system maintains constant or stable internal conditions
- **Emergent properties** = system characteristics not evident in the components alone
  - "The whole is more than the sum of the parts"



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It is hard to fully understand systems; they connect to other systems and do not have sharp boundaries

Understanding requires system considerations

- Environmental entities are complex systems that interact with each other
  - For example, river systems consist of hundreds of smaller tributary subsystems
- To solve environmental problems, all appropriate systems must be considered

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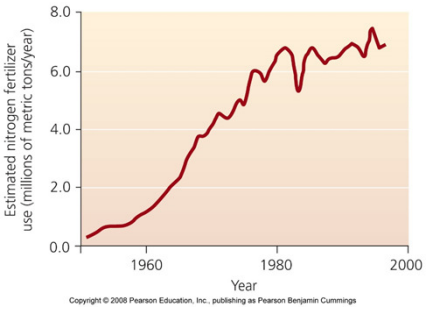
Systems are perceived in various ways

- Categorizing environmental systems helps make Earth's dazzling complexity comprehensible
- For example, the earth consists of structural spheres
  - **Lithosphere** = rock and sediment
  - **Atmosphere** = the air
  - **Hydrosphere** = liquid, solid or vapor water
  - **Biosphere** = all the planet's living organisms and the abiotic portions of the environment
- Boundaries overlap, so the systems interact

The Gulf of Mexico from a systems perspective

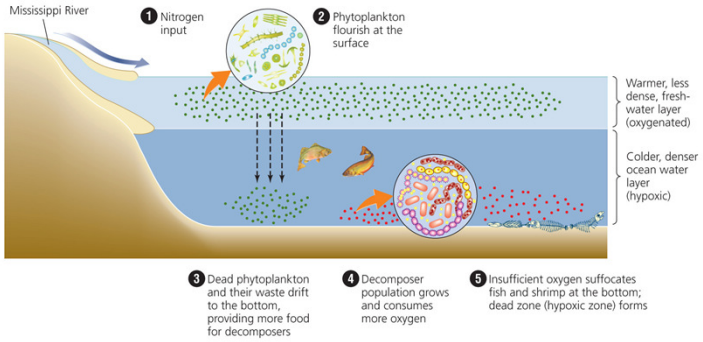
- Nutrients from fertilizer enter the Mississippi River from Midwestern farms
- Fertilizer use has increased, which causes….
- Phytoplankton to grow, then…
- Bacteria eat dead phytoplankton and wastes and deplete oxygen, causing…
- Fish and other aquatic organisms to suffocate



Eutrophication

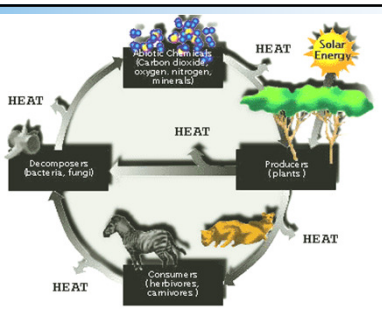
- The process of nutrient overenrichment, blooms of algae, increased production of organic matter, and ecosystem degradation

Ex: Lake Erie



Lake Erie

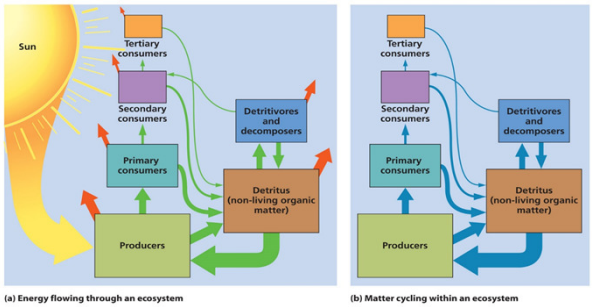
Ecosystems



- **Ecosystem** = all organisms and nonliving entities that occur and interact in a particular area at the same time
  - Includes abiotic and biotic components
  - Energy flows and matter cycles among these components
- Biological entities are highly intertwined with chemical and physical entities
  - Interactions and feedback loops

Systems of interacting entities in ecosystems

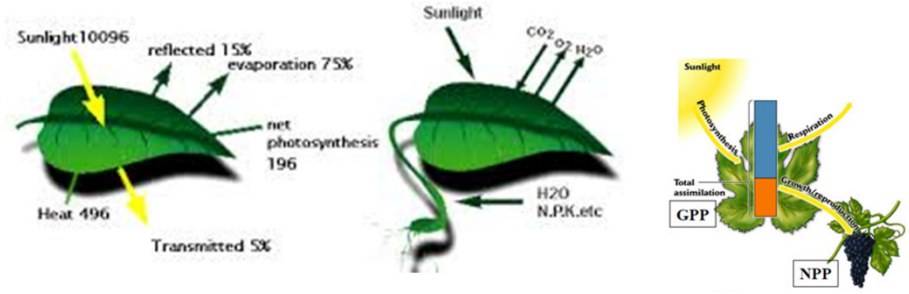
- Energy from the sun flows in one direction
  - Energy entering the system is processed and transformed
- Matter is recycled within ecosystem, resulting in outputs such as heat, water flow, and waste products



(a) Energy flowing through an ecosystem (b) Matter cycling within an ecosystem

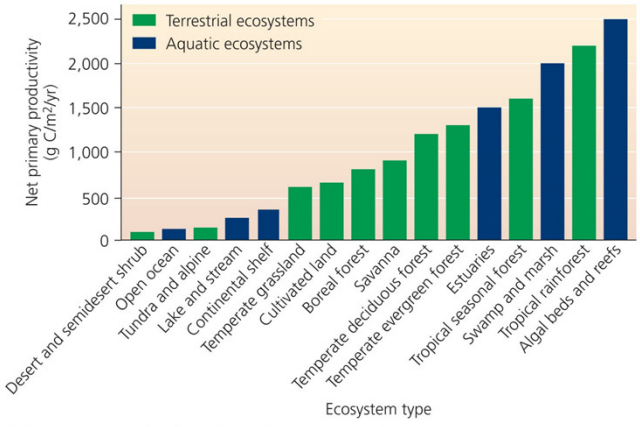
Energy is converted to biomass

- **Primary production =** conversion of solar energy to chemical energy by autotrophs
- **Gross primary production (GPP)** = assimilation of energy by autotrophs
- **Net primary production (NPP)** = energy remaining after respiration, and is used to generate biomass
  - Available for heterotrophs
- **Secondary production** = biomass generated by heterotrophs
- **Productivity** = rate at which ecosystems generate biomass



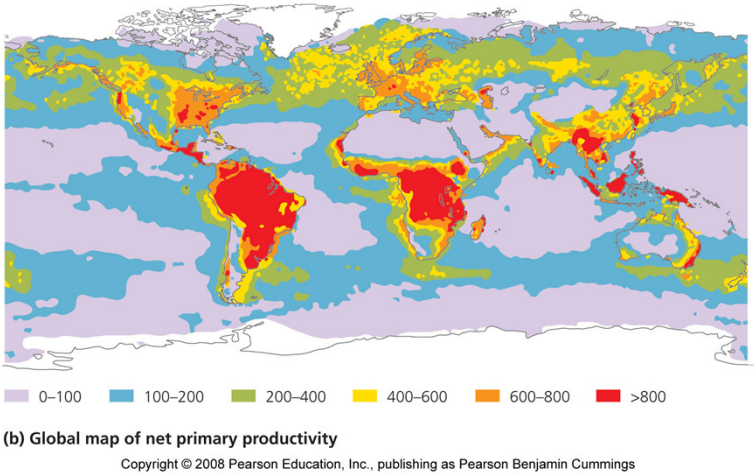
Net primary productivity of various ecosystems

High net primary productivity = ecosystems whose plants rapidly convert solar energy to biomass



(a) Net primary productivity for major ecosystem types

NPP variation causes global geographic patterns



(b) Global map of net primary productivity

NPP increases with temperature and precipitation on land, and with light and nutrients in aquatic ecosystems

Nutrients can limit productivity

- **Nutrients** = elements and compounds required for survival that are consume by organisms
- **Macronutrients** = nutrients required in relative large amounts
  - Nitrogen, carbon, phosphorus
- **Micronutrients** = nutrients needed in smaller amounts
- Stimulate plant production
- Nitrogen and phosphorus are important for plant and algal growth

Dramatic growth of algae in water treated with phosphate

Nutrient runoff is devastating aquatic systems

- Dead zones of water result from nutrient pollution from farms, cities, and industry
- Pollution and human impact have devastated fisheries and altered aquatic ecosystems
- Scientists are investigating innovative and economical ways to reduce nutrient runoff

Phytoplankton blooms off the Louisiana coast

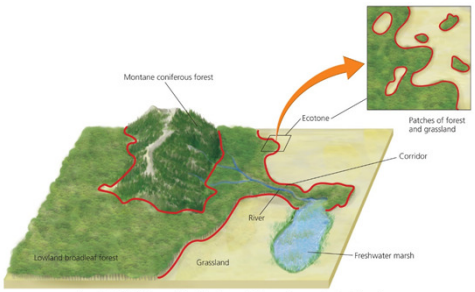
Ecosystems integrate spatially

- Ecosystems vary greatly in size
- The term "ecosystem" is most often applied to self-contained systems of moderate geographic extent
- Adjacent ecosystems may share components and interact
- **Ecotones** = transitional zones between two ecosystems in which elements of different ecosystems mix

Marshes: Salt and freshwater mix

Landscape ecology

- **Landscape ecology** = the study of landscape structure and how it affects the abundance, distribution, and interaction of organisms
  - Helpful for sustainable regional development
- **Patches** = form the landscape, and are distributed spatially in complex patterns (a **mosaic**)
- **Landscape** = larger than an ecosystem and smaller than a biome

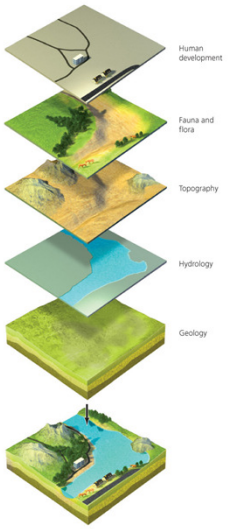


Metapopulations and conservation biology

- **Metapopulation** = a network of subpopulations
  - Most members stay within patches but may move among patches or mate with those of other patches
  - Individuals in small patches risk extinction
- **Conservation biologists** = study the loss, protection, and restoration of biodiversity
- **Habitat fragmentation** = breaking habitat into small, isolated patches due to human impact
  - Corridors of habitat can link patches

Remote sensing applies landscape ecology

- Remote sensing technologies allow scientists to create a complete picture of the landscape
- **Geographic information system (GIS)** = computer software used in landscape ecology research
- Can analyze how elements within the landscape are arranged to help make planning and land-use decisions



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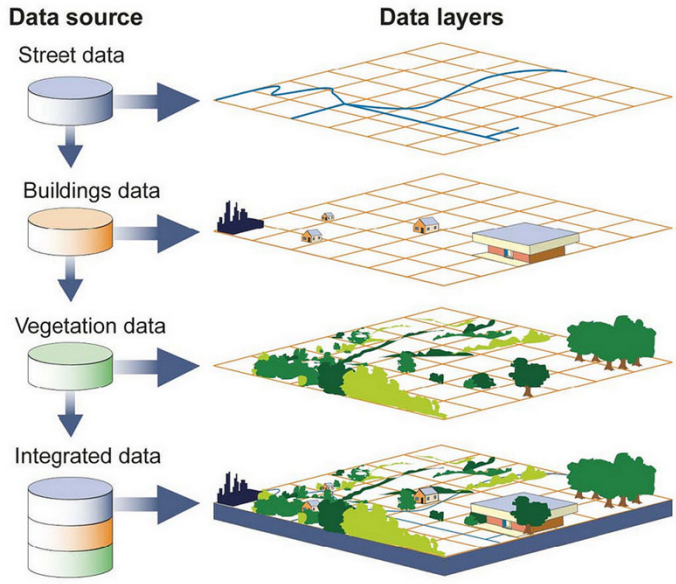

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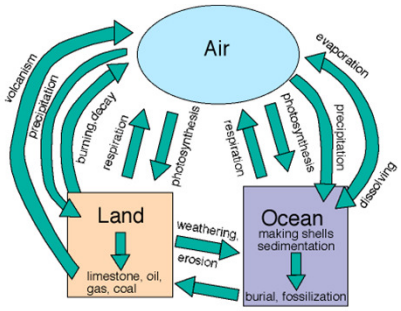
Nutrients circulate through ecosystems

- Physical matter is circulated continually in an ecosystem
- **Nutrient (biogeochemical) cycle** = the movement of nutrients through ecosystems
  - Atmosphere, hydrosphere, lithosphere, and biosphere
- **Pools (reservoirs)** = where nutrients reside for varying amounts of time
- **Flux** = movement of nutrients among pools, which change over time and are influenced by human activities

- **Sources** = pools that release more nutrients than they accept
- **Sinks** = accept more nutrients than they release

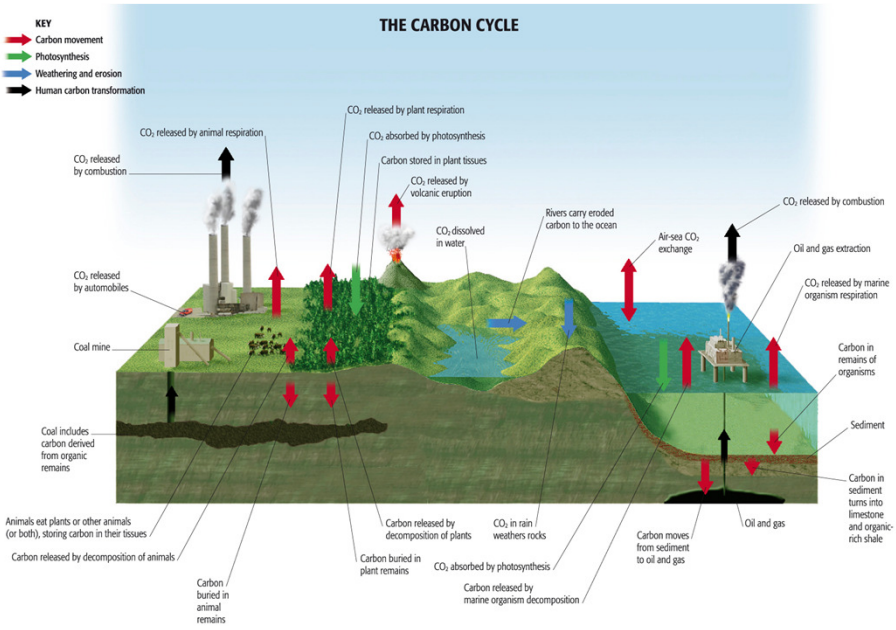


The carbon cycle on Earth

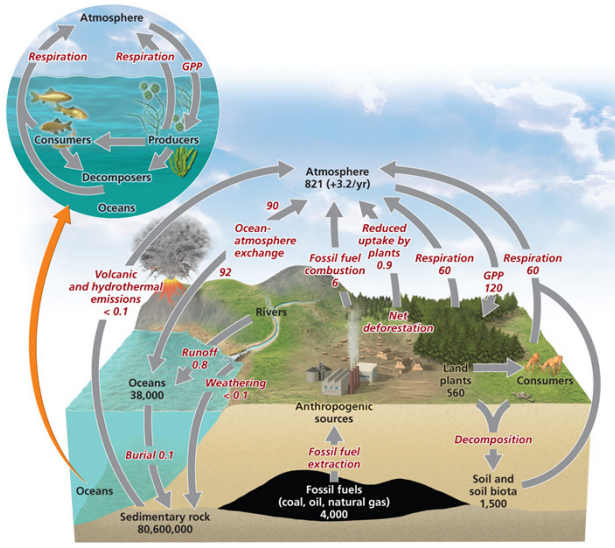
The carbon cycle

- Carbon is found in carbohydrates, fats, proteins, bones
- **Carbon cycle** = describes the routes that carbon atoms take through the environment
- Photosynthesis moves carbon from the air to organisms
- Respiration returns carbon to the air and oceans
- Decomposition returns carbon to the sediment, the largest reservoir of carbon
  - Ultimately, it may be converted into fossil fuels
- The world's oceans are the second largest reservoir of carbon

Clip



The carbon cycle



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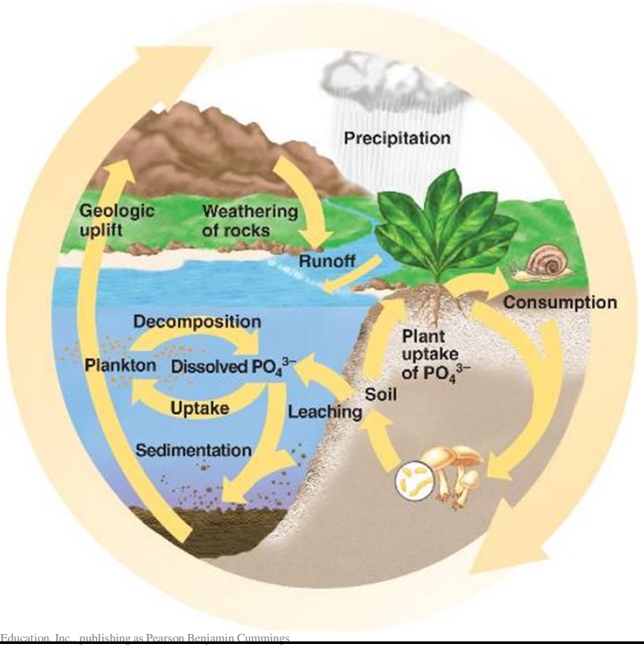
Humans affect the carbon cycle

- Burning fossil fuels moves carbon from the ground to the air
- Cutting forests and burning fields moves carbon from organisms to the air
- Today's atmospheric carbon dioxide reservoir is the largest in the past 650,000 years
  - The driving force behind climate change
- The missing carbon sink: 1-2 billion metric tons of carbon are unaccounted for
  - It may be the plants or soils of northern temperate and boreal forests

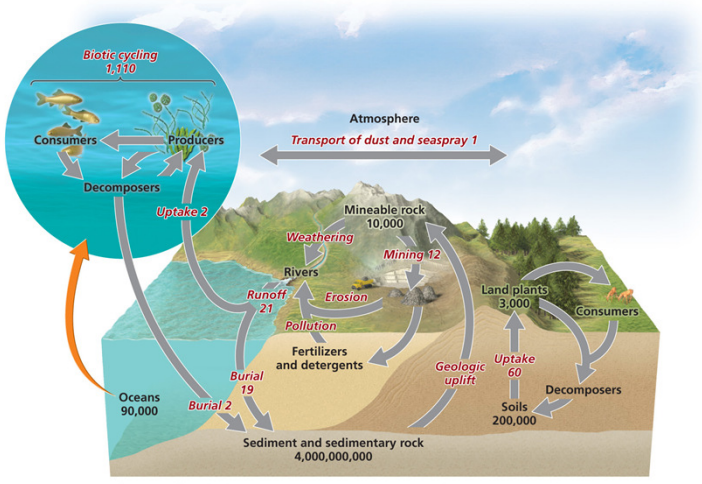
The phosphorus cycle

- Phosphorus is a key component of cell membranes, DNA, RNA, ATP and ADP
- **Phosphorus cycle** = describes the routes that phosphorus atoms take through the environment
  - No significant atmospheric component
  - Most phosphorus is within rocks and is released by weathering
- With naturally low environmental concentrations, phosphorus is a limiting factor for plant growth

Phosphorus Cycle

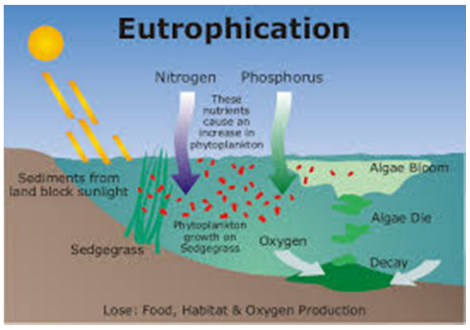


The phosphorus cycle



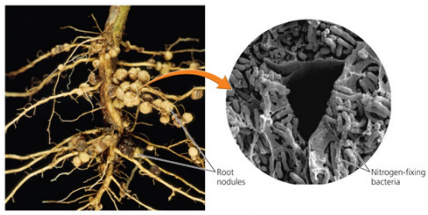
Humans affect the phosphorus cycle

- Mining rocks for fertilizer moves phosphorus from the soil to water systems
  - Wastewater discharge also releases phosphorus
- Runoff containing phosphorus causes eutrophication of aquatic systems



The nitrogen cycle

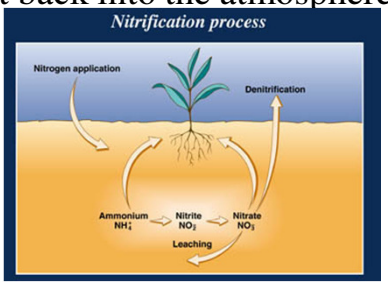
- Nitrogen comprises 78% of our atmosphere, and is contained in proteins, DNA and RNA
- **Nitrogen cycle** = describes the routes that nitrogen atoms take through the environment
  - Nitrogen gas is inert and cannot be used by organisms
- **Nitrogen fixation** = Nitrogen gas is combined (fixed) with hydrogen by nitrogen-fixing bacteria to become ammonium
  - Which can be used by plants



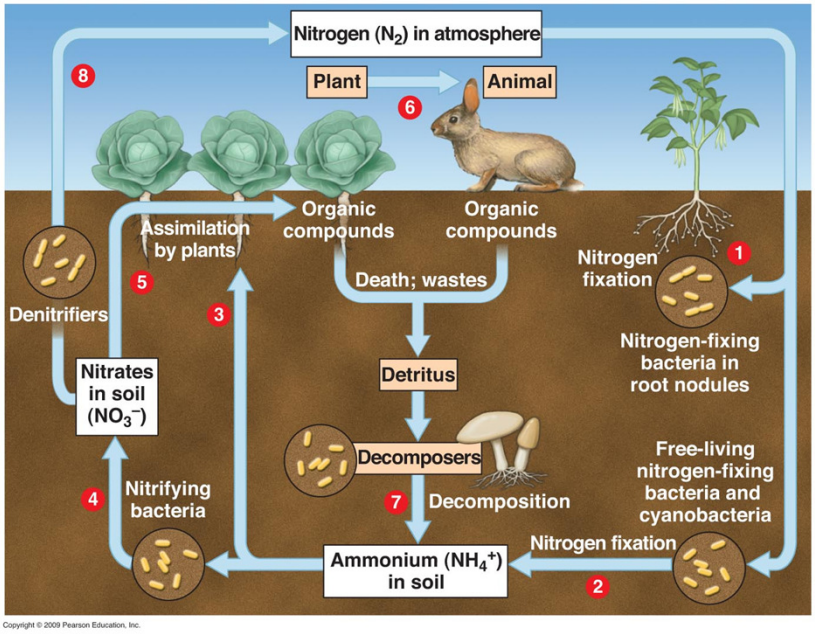
Nitrification and denitrification

- **Nitrification** = bacteria that convert ammonium ions first into nitrite ions then into nitrate ions
  - Plants can take up these ions
- Animals obtain nitrogen by eating plants or other animals
- **Denitrifying bacteria** = convert nitrates in soil or water to gaseous nitrogen, releasing it back into the atmosphere

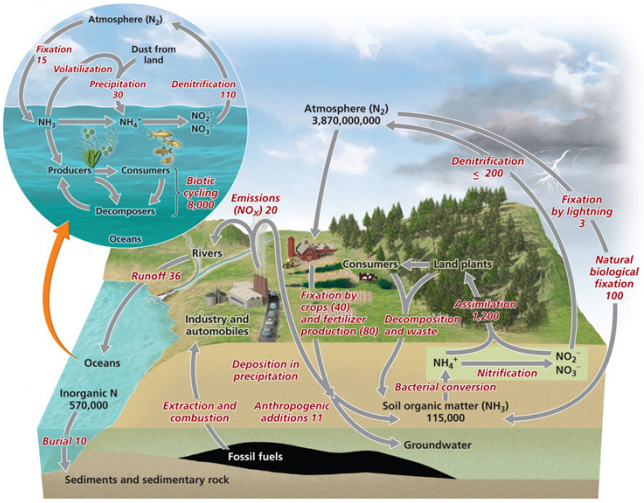
- **Assimilation** is the process by which plants and animals incorporate the NO3- and ammonia formed through nitrogen fixation and nitrification. Plants take up these forms of nitrogen through their roots, and incorporate them into plant proteins and nucleic acids.



Nitrogen Cycle



The nitrogen cycle



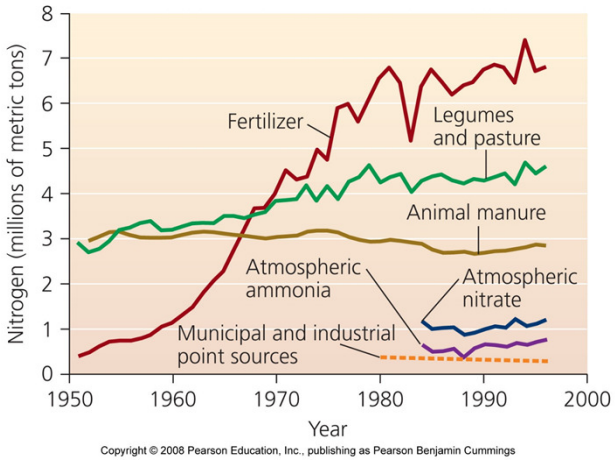
Nitrogen and Phosphorus Cycle Clip

Humans affect the nitrogen cycle

- **Haber-Bosch process** = synthetic production of fertilizers by combining nitrogen and hydrogen to synthesize ammonia
  - Dramatically changed the nitrogen cycle
  - Humans are fixing as much nitrogen as nature does
- Increased emissions of nitrogen-containing greenhouse gases
- Calcium and potassium in soil washed out by fertilizers
- Acidified water and soils
- Moved more nitrogen into plants and terrestrial systems
- Reduced biodiversity of plants adapted to low-nitrogen soils
- Changed estuaries and coastal ecosystems and fisheries

Human inputs of nitrogen into the environment

Fully half of nitrogen entering the environment is of human origin



A law addressing hypoxia in the Gulf

- The Harmful Algal Bloom and Hypoxia Research and Control Act (1998) called for an assessment of hypoxia in the Gulf
- Solutions outlined included:
  - Reduce nitrogen fertilizer use in Midwestern farms
  - Change timing of fertilizer applications to minimize runoff
  - Use alternative crops
  - Restore wetlands and create artificial ones
  - Improve sewage = treatment technologies
  - Evaluate these approaches

Sulfur Cycle

- In ground: most found in rocks, or salt in earth, or as sediment at bottom of ocean
  - Found as S, H_2S, SO_4^{-2}, $(NH_4)_2SO_4$
  - Enter ground: Plants absorb, or left by acid deposition (fog or precipitation)
  - As SO_4^{-2}, $(NH_4)_2SO_4$, and then turn H_2S (Hydrogen Sulfide) by bacteria, decay, and plant use
  - Stored: Ground, rock, ocean, somewhat in air
  - Oxidized in atmosphere to SO_2 (Sulfur Dioxide), and then to H_2SO_4 (Sulfuric acid) with water contact
  - Mined ores released to atmosphere in factories as H_2S and SO_2
  - Volcanoes and hot springs
  - 90-95% SO_2 from power plants and factories

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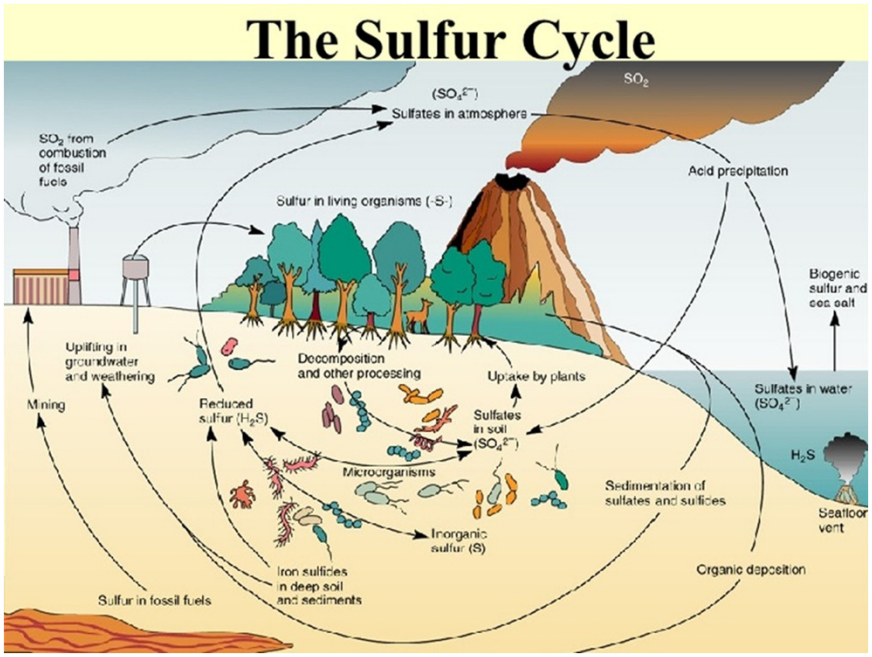
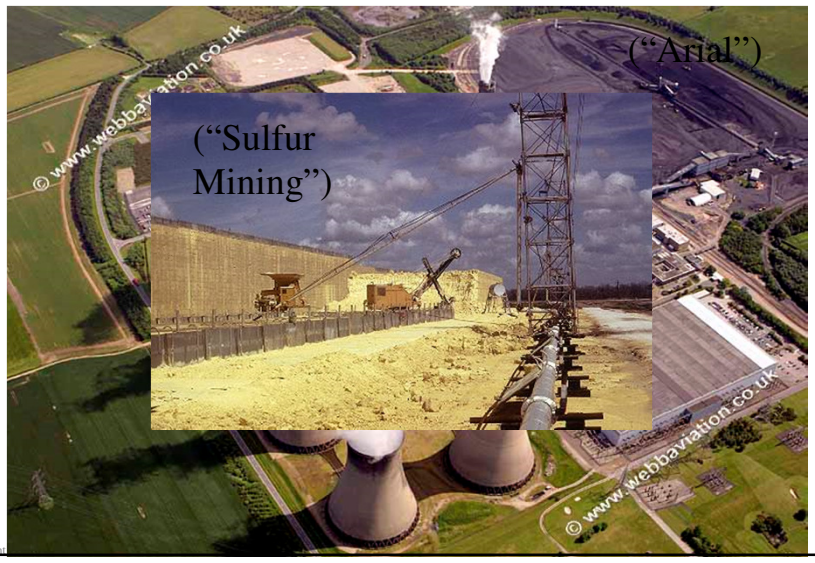
Sulfur Cycle

- When mine ores, sulfur/sulfides released into soil
- Combustion of fossil fuels
  - Release of SO_2, causes acid rain, increases amount already present
  - 28% of sulfur in rivers from pollution, mining, erosion, etc.
  - Help move cycle but also upset balance- too much S means acid rain



Human Effect

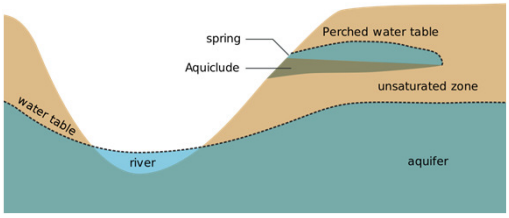


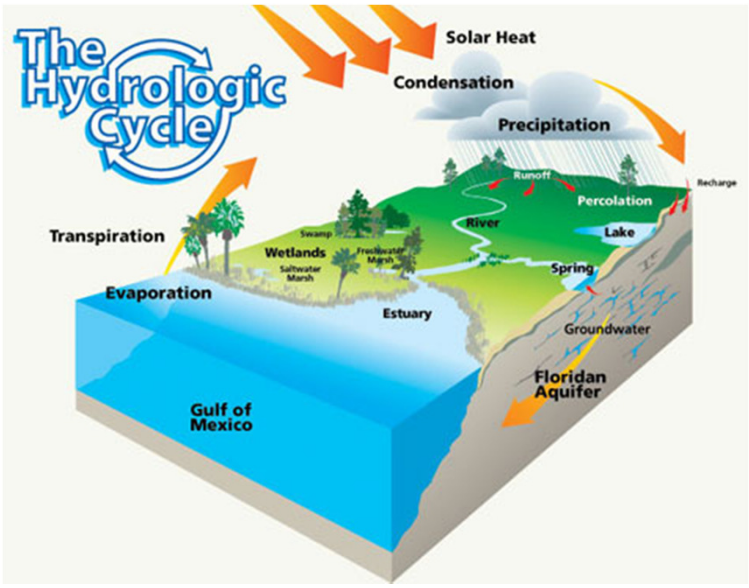
The hydrologic cycle

- Water is essential for biochemical reactions and is involved in nearly every environmental system
- **Hydrologic cycle** = summarizes how liquid, gaseous and solid water flows through the environment
  - Oceans are the main reservoir
- **Evaporation** = water moves from aquatic and land systems to air
- **Transpiration** = release of water vapor by plants
- **Precipitation** = condensation of water vapor as rain or snow

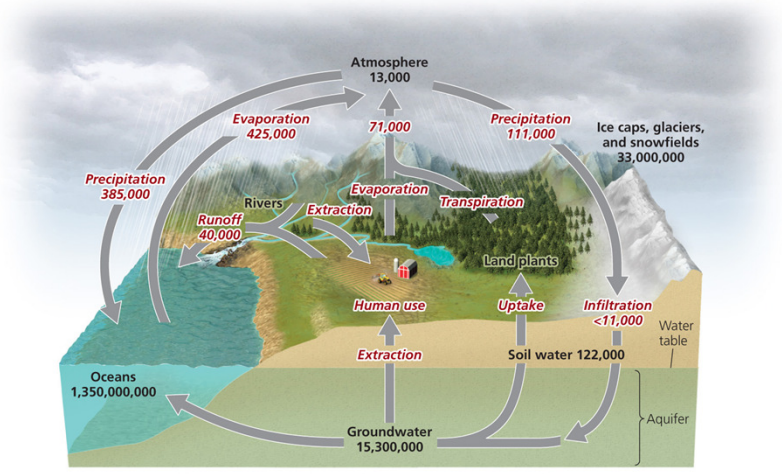
Groundwater

- **Aquifers** = underground reservoirs of sponge-like regions of rock and soil that hold …
  - **Groundwater** = water found underground beneath layers of soil
  - **Water table** = the upper limit of groundwater held in an aquifer
  - Water may be ancient (thousands of years old)
- Groundwater becomes exposed to the air where the water table reaches the surface





The hydrologic cycle

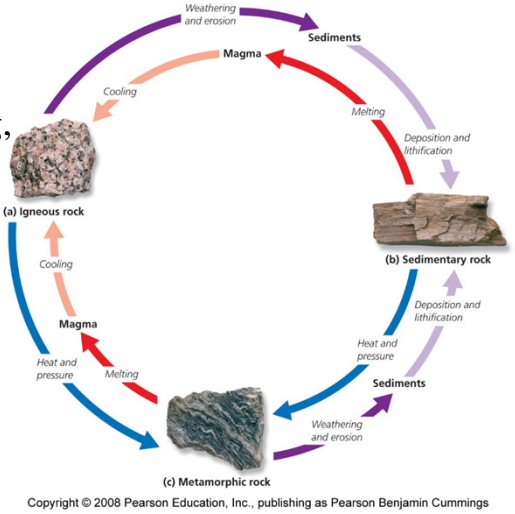


Human impacts on hydrologic cycle

- Damming rivers increases evaporation and infiltration
- Altering the surface and vegetation increases runoff and erosion
- Spreading water on agricultural fields depletes rivers, lakes and streams
- Removing forests and vegetation reduces transpiration and lowers water tables
- Emitting pollutants changes the nature of precipitation
- The most threatening impact is overdrawing groundwater for drinking, irrigation, and industrial use

The rock cycle

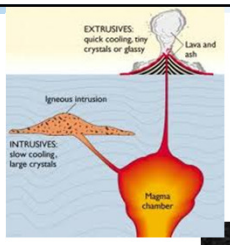
- **Rock cycle** = The heating, melting, cooling, breaking and reassembling of rocks and minerals
- Rocks help determine soil chemistry, which influences ecosystems
- Helps us appreciate the formation and conservation of soils, mineral resources, fossil fuels, and other natural resources



Rock Cycle Clip (Jelly Beans)

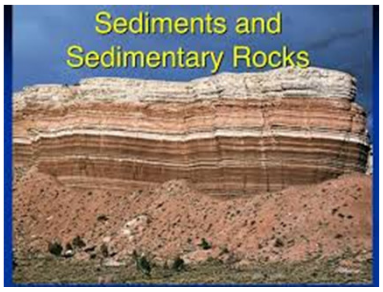
Igneous rock

- **Magma** = the molten, liquid state of rock
- **Lava** = magma released from the lithosphere
- **Igneous rock** = forms when magma cools
- **Intrusive rock** = magma that cools slowly well below Earth's surface (i.e., granite)
- **Extrusive rock** = magma ejected from a volcano (i.e., basalt)



Sedimentary rock

- **Sediments** = particles of rock are blown by wind or washed away by water
- **Sedimentary rock** = dissolved minerals seep through sediment layers and crystallize and bind sediment particles together
- **Lithification** = formation of rock through the processes of compaction, binding, and crystallization



Formation of sedimentary rock

- Some rock is formed by chemical means when rocks dissolve and their components crystallize to form new rock
  - Limestone and rock salt

- Other rocks are formed when layers of sediment compress and physically bond to one another
  - Conglomerate, sandstone, shale

Metamorphic rock

- **Metamorphic rock** = great heat or pressure on a rock changes its form
- Temperatures is high enough to reshape crystals and change its appearance and physical properties
- **Marble** = heated and pressurized limestone
- **Slate** = heated and metamorphosed shale

Rock Cycle Clip

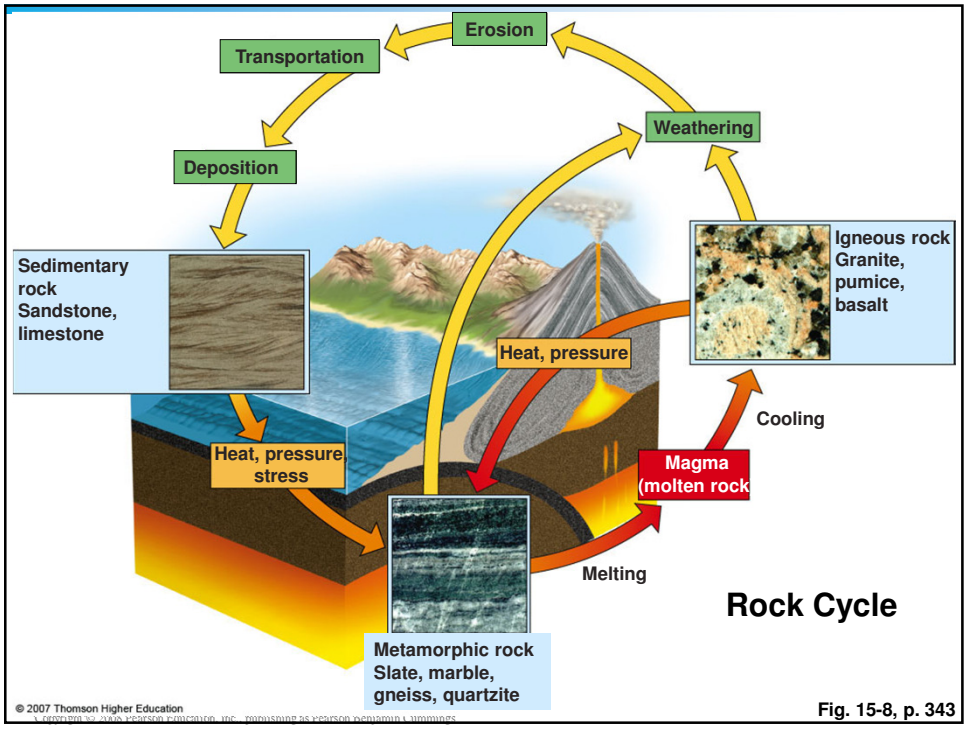
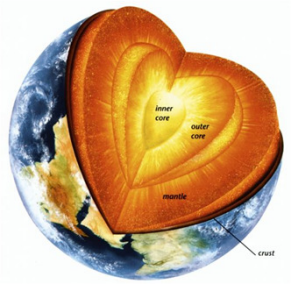


Fig. 15-8, p. 343

Plate tectonics shapes the Earth

- **Plate tectonics** = process that underlies earthquakes and volcanoes and that determines the geography of the Earth's surface
- **Crust** = lightweight thin component of Earth's surface
- **Mantle** = malleable layer on which the crust floats
- **Core** = molten heavy center of Earth made mostly of iron



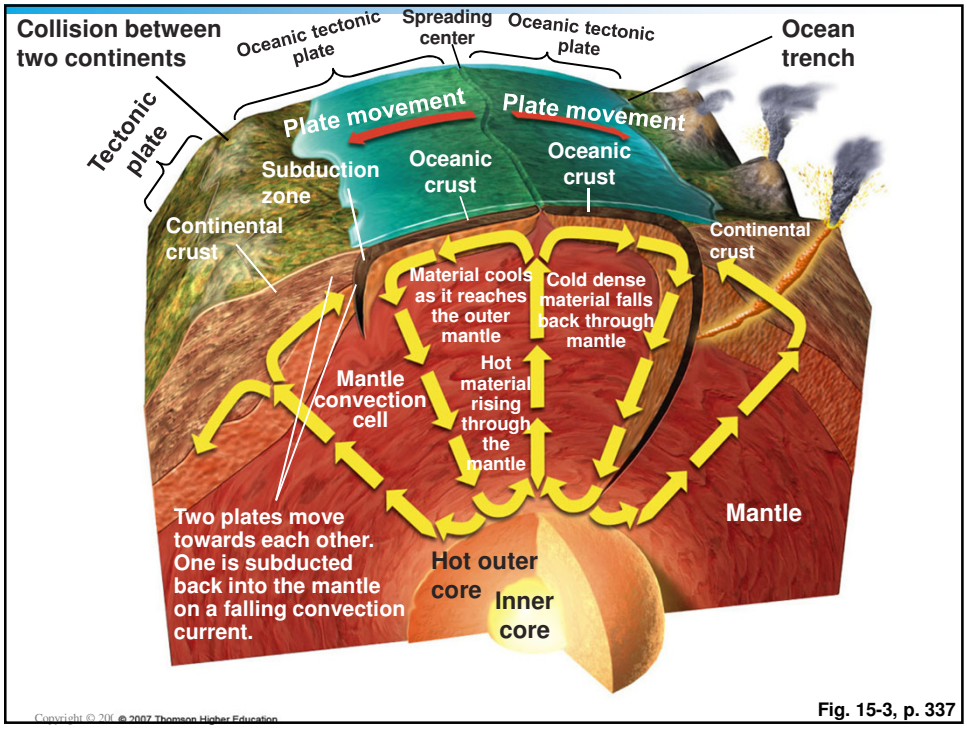
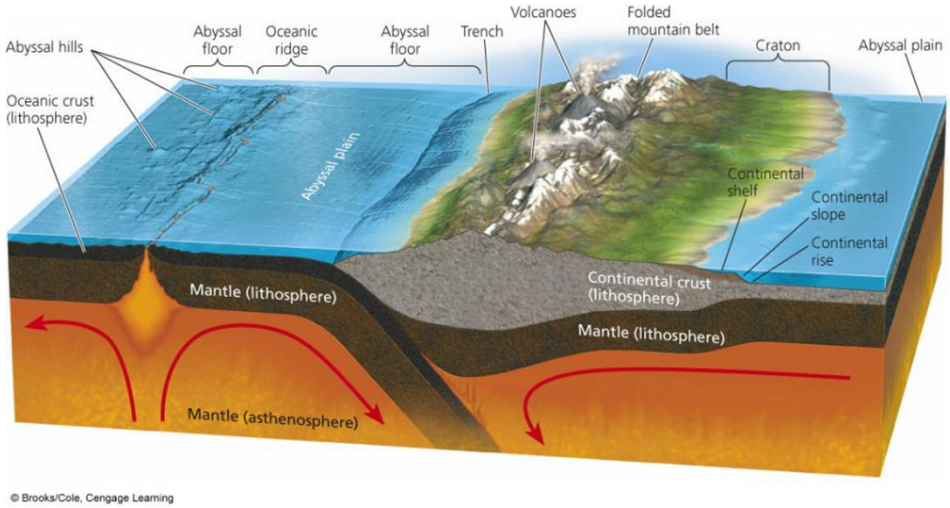


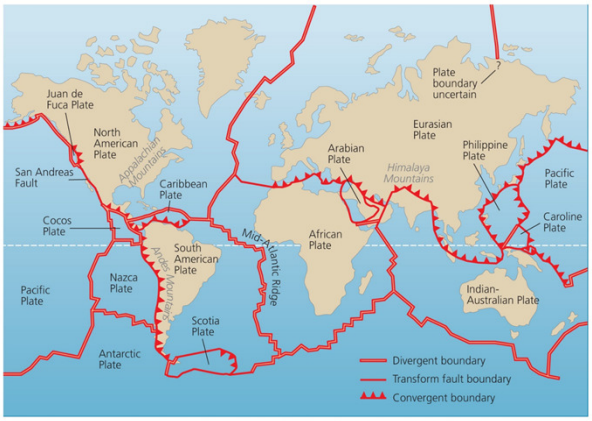
Fig. 15-3, p. 337

Major Features of the Earth's Crust and Upper Mantle



The Earth has 15 major tectonic plates

Movement of these plates influences climate and evolution



(a) World map of tectonic plates

Pangaea: the supercontinent

Pangaea = at least twice in Earth's history, all landmasses were joined in one supercontinent

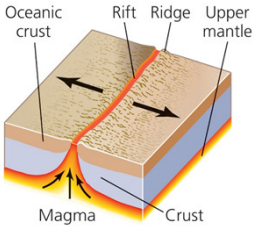
(b) Pangaea, the "supercontinent," 225 million years ago

The Earth Beneath Your Feet Is Moving (2)

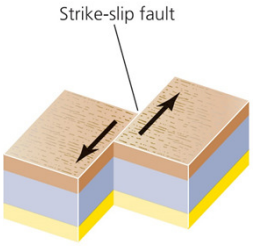
- Three types of boundaries between plates
  - **Divergent plates**
    - **Magma**
    - **Oceanic ridge**
  - **Convergent plates**
    - **Subduction**
    - **Subduction zone**
    - **Trench**
  - **Transform fault; e.g., San Andreas fault**

Earth's crust is constantly created and destroyed

- **Divergent plate boundaries** = magma surging upward to the surface divides plates and pushes them apart, creating new crust as it cools and spreads
- **Transform plate boundary** = two plates meet, slipping and grinding alongside one another
  - Friction spawns earthquakes along slip-strike faults

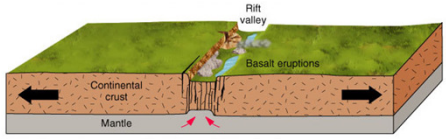


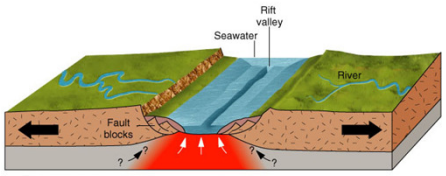
(a) Divergent plate boundary

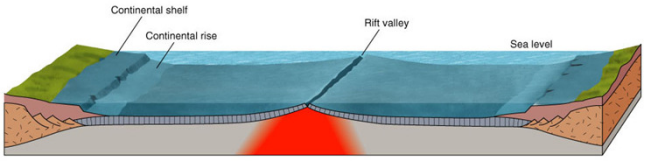


(b) Transform plate boundary

Divergent Example







GEOLOGIC PROCESSES

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- The San Andreas Fault is an example of a transform fault.

Tectonic plates can collide

- **Convergent plate boundaries** = where plates collide
- **Subduction** = one plate of crust may slide beneath another

  One plate is heavier than the other
  - Magma erupts through the surface in volcanoes
- Two colliding plates of continental crust may lift material from both plates (Same density)
  - Resulted in the Himalaya and Appalachian mountains

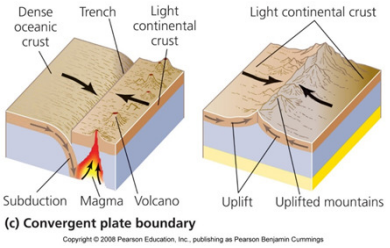
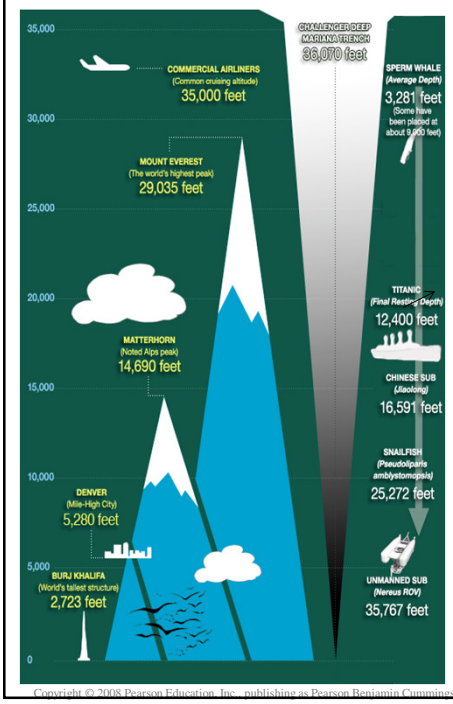
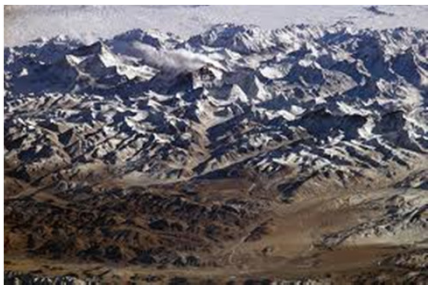
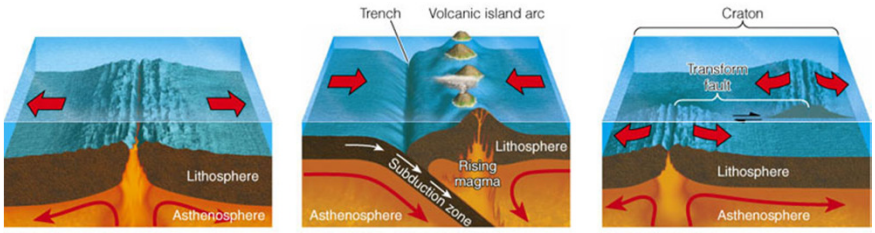


Plate tectonic Clip





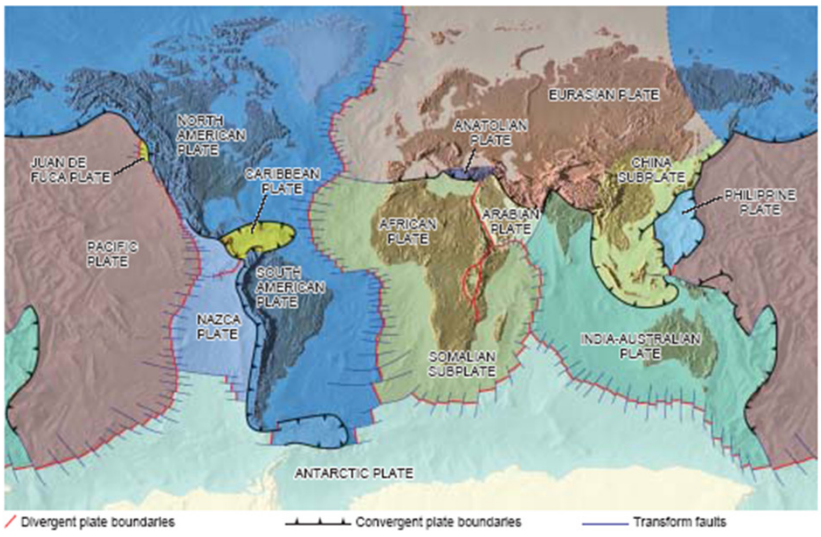


Divergent plate boundaries

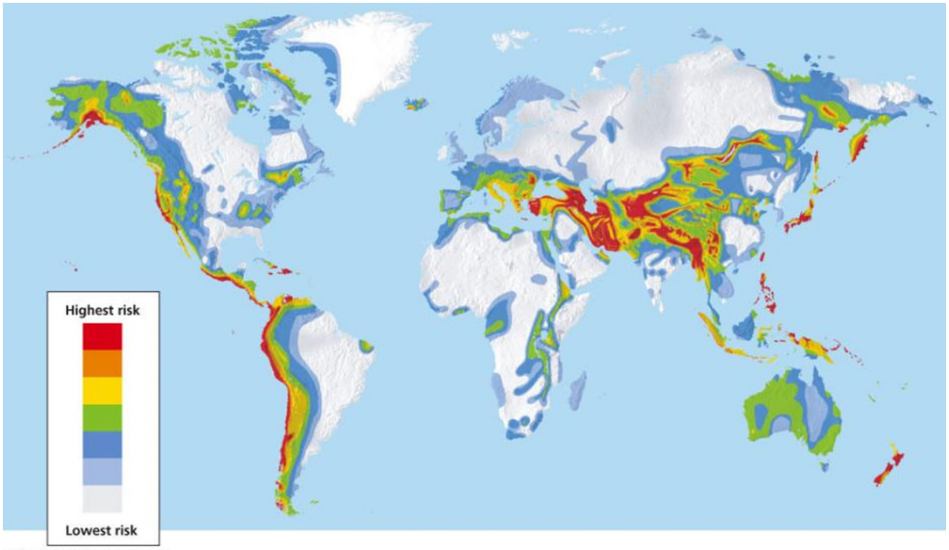
Convergent plate boundaries

Transform faults

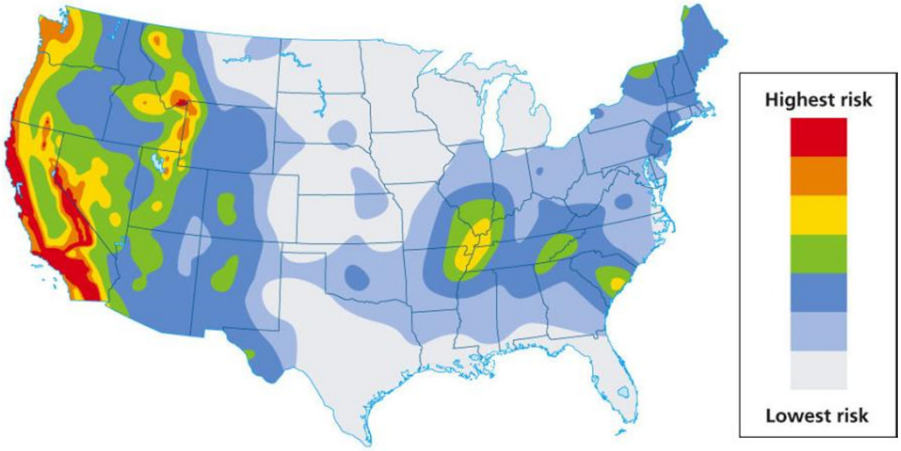
The Earth's Major Tectonic Plates



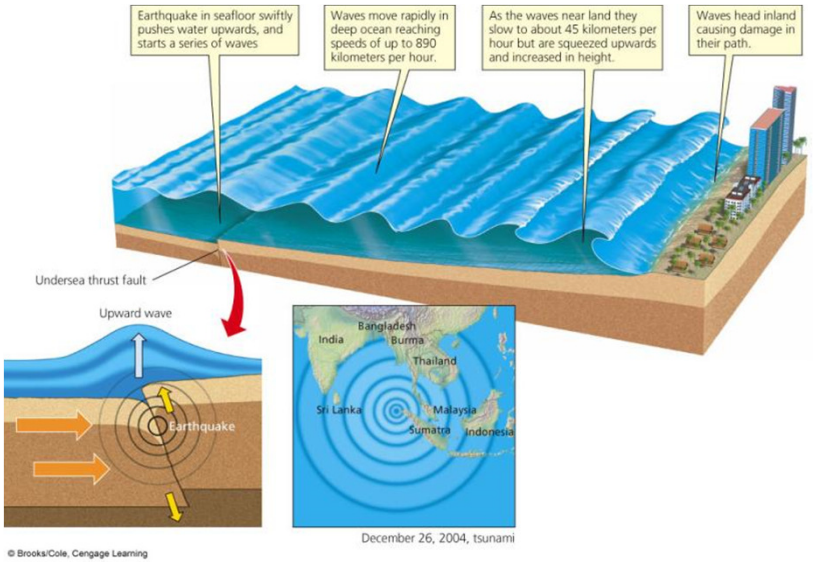
Areas of Greatest Earthquake Risk in the World



Areas of Greatest Earthquake Risk in the United States



Formation of a Tsunami and Map of Affected Area of Dec 2004 Tsunami



Conclusion

- The biogeochemical cycles, the rock cycle, and plate tectonics lay the groundwork for spreading life across Earth
- Understanding biogeochemical cycles is crucial
  - Humans are causing significant changes in the ways those cycles function
- Thinking in terms of systems can teach us how to avoid disrupting Earth's processes and how to mitigate any disruptions we cause