Life on Earth: The Fossil Record and Present Life forms
Visual Overview

The Six Kingdoms

Relationship among taxa that constitute the Archaea, Eukarya, Bacteria, Plants, Fungi, and Animals.

BACTERIA

Many Bacteria break-down cells and tissues of dead organisms; others cause illnesses.

EUKARYA

Fungi absorb food from dead organisms.

ARCHAEA

Many Archaea tolerate extreme environmental conditions.

Fungi produce spores that lack tissue.

Bacteria are animal-like protists.

Plants are multicellular algae.

Animals are simple animals with tissues.

NUCLEAR LIKE PROKARYOTIC

Fungi absorb food from dead organisms.

Plants produce spores that lack tissue.

Sponges are animals that lack tissue.

Prymnesia enhance food.

Many Bacteria break-down cells and tissues of dead organisms; others cause illnesses.

Bacteria are animal-like protists.

Plants are multicellular algae.

Animals are simple animals with tissues.

Most animal groups with tissues belong to the protostome group, which includes mollusks and arthropods, or the deuterostome group, which includes vertebrate animals.
What is life?
1. Metabolism
Uptake of chemicals from the environment, their transformation within the cell, and elimination of wastes into the environment. The cell is thus an *open* system.

2. Reproduction (growth)
Chemicals from the environment are turned into new cells under the direction of preexisting cells.
3. Differentiation
Formation of a new cell structure such as a spore, usually as part of a cellular life cycle.

4. Communication
Cells communicate or interact primarily by means of chemicals that are released or taken up.
5. Movement
Living organisms are often capable of self-propulsion.

6. Evolution
Cells evolve to display new biological properties. Phylogenetic trees show the evolutionary relationships between cells.
What is Life?

- Composed of organic compounds
- Resistance to entropy (disorder)
  - Requires energy (must be able to gather and process (metabolize) energy)
- Ability to maintain a controlled environment
  - Requires ability to be isolated from environment
- Information storage
- Self replication
  - Including ability to pass on information
- Ability to adapt to its environment
  - Undergoes biological evolution
Life on Earth: Organic Compounds

<table>
<thead>
<tr>
<th>Important Elements</th>
<th>Human</th>
<th>Alfalfa</th>
<th>Bacteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen (O)</td>
<td>62.8%</td>
<td>77.9%</td>
<td>73.7%</td>
</tr>
<tr>
<td>Carbon (C)</td>
<td>19.4%</td>
<td>11.3%</td>
<td>12.1%</td>
</tr>
<tr>
<td>Hydrogen (H)</td>
<td>9.3%</td>
<td>8.7%</td>
<td>9.9%</td>
</tr>
<tr>
<td>Nitrogen (N)</td>
<td>5.1%</td>
<td>0.8%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Phosphorous (P)</td>
<td>0.6%</td>
<td>0.7%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Sulfur (S)</td>
<td>0.6%</td>
<td>0.1%</td>
<td>0.3%</td>
</tr>
</tbody>
</table>

Carbon provides a framework for all organic compounds.
Why Carbon?

- Small and Abundant
  - 4th most abundant element in the Solar System
- Bonds with a lot of different atoms
  - Forms lots of different organic compounds
- Forms long chains (polymers)
- Forms very strong bonds
  - Hard to destroy (Stable)
- Bonds “store” a lot of energy
- Forms compounds that are water soluble
Life on Earth: 
Organic Compounds

Types of Organic Compounds

1. Lipids - (H,C (hydrocarbons))
   → Fats and Oils
   → cell membranes & energy storage

2. Carbohydrates - (C, H, O)
   → Sugars, Starches and Cellulose
   → energy storage & structure
Life on Earth: Organic Compounds

Types of Organic Compounds

3. Amino Acids $\rightarrow$ Proteins - (C, H, O, N, S)
   $\rightarrow$ Enzymes - catalysts for chemical reactions
   $\rightarrow$ also Hair, silk, fingernails, etc.

   $\rightarrow$ DNA (Deoxyribonucleic Acid)
   $\rightarrow$ RNA (Ribonucleic Acid)
   $\rightarrow$ store & transfer genetic information
Organic Compounds

Cells

Organisms

Not Alive

Alive
Life on Earth: Controlled Environment

Cell
How are life forms distinguished from one another?
Taxonomic Groups

• Taxonomy
  – Study of composition and relationship of the taxonomic groups

• Taxonomic groups
  – The six kingdoms and their subordinate groups
  – Taxa (Taxon)
Taxonomic Groups

Domains

Bacteria
- Green nonsulfur bacteria
- Mitochondrion
- Proteobacteria
- Chloroplast
- Flavobacteria
- Cyanobacteria
- Thermotoga
- Thermodesulfobacterium
- Aquifex

Archaea
- Crenarchaeota
  - Thermoproteus
  - Pyrodictium
  - Marine Crenarchaeota
  - "Korarchaeota"

Eukarya
- Euryarchaeota
  - Methanosarcina

- Extremophiles
  - Methanobacterium
  - Methanococcus

- Thermoarchaeota
  - Thermococcus
  - Pyrolobus

- Methanopyrus

Eukaryota
- Entamoebae
- Slime molds
- Animals
- Fungi
- Plants
- Ciliates
- Flagellates
- Trichomonads
- Diplomonads (Giardia)
- Microsporidia
Six kingdoms

- Prokaryotes
  - Archaeobacteria
  - Eubacteria
- Eukaryotes
  - Plantae
    - Producer
  - Fungi
    - Consumer
  - Animalia
    - Consumer
  - Protista
Prokaryotes

• Archaeobacteria
  – Can tolerate extreme conditions
    • Very high temperatures
      – Hot springs
    • Low or no oxygen
    • Acidic conditions
Archaea: two groups

- Env-marine
- Halobacterium
- Natronobacterium
- Halophilic methanogens
- Methanobacterium
- Methanococcus
- Pyrococcus
- Methanopyrus
- Thermoproteus
- Pyrolobus
- Desulfurococcus
- Thermogrobins

- Methanogens, halophiles, acidophiles
- hyperthermophiles
Prokaryotes

• Eubacteria
  – Divided by structure of cell walls
  – Cyanobacteria
    • Photosynthetic
      – Spherical
      – Filamentous
    • Can form mats or scum
Eukarya

- Flagellates
- Slime molds
- Diplomonads
- Trichomonads
- Ciliates
- Animals
  - Green algae
  - Plants
  - Red algae
  - Fungi
  - Diatoms
  - Brown algae

Early-branching, lack mitochondria
**Taxonomic Groups**

- Taxa range from broad (phylum) to narrow (species)
  - Phylum
  - Species
    - Group of individuals that can interbreed
    - Name includes genus
    - Italicized
- Class: Mammalia
  - Order: Primates
Relationships Between Living Things - Phylogeny
Phylogeny is Related to Classification

- Family
- Genus
- Species
Phylogeny = Evolutionary History
Taxonomic Groups

- **Phylogeny**
  - Tree of life
  - Structure formed by branches of species

- **Cluster into groups with similar traits, equivalent to taxa**
  - **Genera**
    - Small clusters
Taxonomic Groups

- Primitive traits
  - Appear early in evolutionary history
  - Hagfish group traits

- Derived traits
  - Evolved later
  - Present only in some subgroups
  - Jaws, lungs, claws or nails, feather, fur, and mammary glands
Taxonomic Groups

• **Clade**
  – Cluster of species that share a common ancestry
  – All species within each clade must be traceable to a common ancestor

• **Cladistics**

• **Homologous**
Taxonomic Groups

- Horse ancestry
  - Detailed phylogeny due to abundant fossil record
- Three clades
  - Subfamilies
- All members of the modern horse family belong to *Equus* and originated in North America
Figure 7-20
Earth System History, Second Edition
© 2005 W.H. Freeman and Company
“Unrooted” Phylogeny of the Domains of Life
Protista

• Many single-celled organisms
• Some simple multicellular organisms
• Includes algae
  – Seaweed
Protista

• Protozoans
  – Animal-like protista
    • Amoebas
      – Change shape
    • Flagellates
      – Flagellum for locomotion
  • Ciliate
    – Cilia for locomotion
Protista

- Unicellular algae
  - Plant-like protista
    - Dinoflagellates
    - Diatoms
    - Calcareous nanoplanckton

- Originated in the Mesozoic Era
  - Important marine producers
Protista

- Dinoflagellates
  - Two flagella for locomotion
  - Drift
  - Dormancy
    - Armor in a cyst
    - Often fossilized as cysts
Protista

- Diatoms
  - Two-part skeleton of opal (SiO$_2$)
    - Halves fit together
  - Freshwater and marine
    - Most planktonic
    - Some benthic
  - Accumulations can produce chert
Protista

- Calcareous Nannoplankton
  - Small spherical cells
  - Armored
    - Overlapping plates of calcium carbonate
  - Mostly marine plankton
- Accumulations can produce chalk
Protista

- Multicellular algae
  - Most kinds attach to seafloor
  - Some drift
- Some red and green algae secrete calcium carbonate skeletons
  - Limestone
Prostista

• Protozoans with skeletons
  – Foraminifera
    • Chambered skeleton of calcium carbonate
    • Very abundant
    • Useful for dating rocks and sediments
Protista

- Protozoa with skeletons
- Radiolarians
  - Skeleton made of silica
  - Size of a grain of sand
Chalk
(Coccolithophores)
Coccolithophores: calcareous phytoplankton (photosynthetic/autotrophs)
Foramifera: calcareous (CaCO$_3$) heterotrophs

http://www.ucl.ac.uk/GeolSci/micropal/calcnanno.html
Diatoms: siliceous (SiO$_2$) phytoplankton (photosynthetic/autotrophs)

http://www.ucl.ac.uk/GeolSci/micropal/calcnanno.html
Radiolarians: siliceous (SiO$_2$) heterotrophs

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Diagram showing the classification of life into three domains: Archaea, Bacteria, and Eukarya. The domains are further divided into kingdoms: Plantae, Fungi, Protista, and Animalia. The kingdoms are divided into multicellular and unicellular organisms, with the eukaryotes and prokaryotes represented separately.
Fungi

- Decomposers
  - Obtain nutrients from dead organisms
- Diverse
  - Yeast
  - Mushroom
- Poor fossil record
- Chitinous membranes (shellfish?)
Plants

- Differ from multi-cellular green algae
  - Internal fertilization of egg
  - Tissue (lower H/C ratios)

- Vascular
  - Vessels for transport of water, dissolved nutrients, food >> lignin and cellulose

- Non-vascular
  - Transportation of materials by diffusion
    - Moss
Plants

- Seedless vascular plants
  - Evolved first
  - *Psilotum*
    - Simplest vascular plant
    - No leaves or roots
    - Similar to earliest fossil forms
Plants

- Ferns
  - Roots and leaves
  - Alternation of generations
    - Spore-producing then sperm-producing generation
  - Spores
    - One set of chromosomes
    - Fertilized by sperm
    - Requires moisture
  - Vast Late Paleozoic swamps led to coal formation
Plants

- **Gymnosperms**
  - “Naked seed” plants
  - **Conifers**
    - Cone-bearing plants
    - Eggs are fertilized in cone by pollen
      - Pollen bears sperm; carried by wind
    - Dominant in the Mesozoic

- **Angiosperms**
  - Flowering plants
    - Pollen carried by pollenators (animals)
Animals

- Two groups
  - Vertebrates
    - Possess a backbone
  - Invertebrates
- Coelom
  - Body cavity housing internal organs
- Protostomes
  - First opening becomes the mouth
- Deuterostomes
  - First opening becomes the anus
Animals

- **Sponges**
  - Simple invertebrates
  - Suspension feeds
    - Strain particles from water
    - Mostly eat bacteria
    - Flagella pump water through internal canals
  - Calcium carbonate or silica spicules support structure
- Cambrian - modern
Cnidarians

- Jellyfish and corals
- Radial symmetry
- Inner and outer body layer
  - Jelly-like layer in between
- Use tentacles to catch prey
  - Stinging cells
- Sexual and asexual reproduction
Mollusks

- Clams, snails, octopuses
  - Shell of aragonite, calcite, or both
- Mantle
  - Fleshy, sheetlike organ
  - Secretes shell
- Radula
  - File-like structure for food
- Base of Cambrian

- Monoplacophorans
  - Primitive mollusks
Mollusks

- **Gastropods**
  - Snails
  - Marine and freshwater
  - Terrestrial
  - Lung

- Most are grazers
  - Some suspension feeders
- Beginning of Paleozoic
Mollusks

- **Cephalopods**
  - Squids, octopuses, chambered nautiluses
  - Swim in the sea
    - Jet propulsion
    - Eyes
  - Carnivores
    - Catch with tentacles
    - Eat with strong beak
- Chambered nautilus
  - Buoyancy due to gas in shell
- Common in Phanerozoic
Mollusks

• **Bivalves**
  – Clams, mussels, oysters, scallops
    • Shell divided into two valves
    • No head or radula
    • Muscles pull shell together
    • Suspension feeders mostly
Protostome Invertebrate

- Segmented worms
  - Fluid-filled coelom
    - Primitive skeleton
    - Each segment has own coelomic cavity
  - Expand, contract for movement
Lophophores

- Brachiopods
  - Shell divided into two valves
  - Lampshells
  - Lophophores
    - Pump water
    - Strain food
  - Inarticular brachiopods
    - Lack hinge teeth
    - Lingula
  - Articulate brachiopods
Bryozoans

- Moss animals
- Colonial
- Closely related to brachiopods
  - Lophophore extended from skeleton to feed
  - Calcified skeleton
- Ordovician
Arthropods

- Insects, crabs, spiders, lobsters, trilobites

- Trilobite
  - Three-lobed body
    - Central, left- and right- lobed
  - External skeleton
  - Gill-like structure for respiration
  - Legs
  - Primitive eyes

- Common in Cambrian
Arthropods

• **Crustaceans**
  – Head of five fused segments
  – Thorax and abdomen
  – Weakly calcified exoskeleton

• **Insects**
  – Head, thorax, abdomen
  – Two pairs of wings
  – Poor fossil record
  – Precede angiosperms
Arthropods

- **Onychophorans**
  - Intermediate between segmented worms and arthropods
  - Early forms
    - Marine
    - Nearly to base of Paleozoic
  - Modern forms
    - Terrestrial
Echinoderms

- Spiny-skinned form
- Five-fold symmetry
  - Starfishes
    - Predators
    - Lower Paleozoic
  - Sea urchins
    - Regular sea urchins
      - Radially symmetrical bodies
    - Irregular sea urchins
      - Bilaterally symmetric
      - Burrowers
Echinoderms

• Crinoids
  – Sea lilies
  – Sieve food using arms
    • Pass food to mouth with tube feet
  – May swim
  – May be attached by flexible stalk
  – Disk-shaped plates from stalk
Chordates

- **Notochord**
  - Flexible, rodlike structure
    - Runs length of body
    - Supports body
      - For some part of lifecycle
  - Spinal cord
    - Runs next to notochord

- **Primitive Chordate**
  - **Lancet**
    - Notochord is skeleton
    - Can swim
    - Usually rests
Vertebrates

• Notochord develops into vertebral column
  – Usually bony
  – Cartilage in sharks
Conodonts

- “Cone-teeth”
  - Originally thought to be teeth of a marine animal
- Later determined to be eel-like fish and a vertebrate
Vertebrates

- **Fishes**
  - Ray-finned fishes
    - Fins supported by thin bones radiating from body
  - Lobe-finned fishes
    - Evolved into amphibians
    - Coelacanth
      - Discovered in 1939

- **Amphibians**
  - First to live on land as adults
  - Metamorphosis
Vertebrates

- Reptiles
  - Eggs with protective shells
  - Ectothermic
    - Environment controls internal body temperature
- Dinosaurs
- Birds
  - Endothermic
Vertebrates

- Mammals
  - Endothermic, with hair
  - Bear live young
  - Monotreme mammals
    - Lay eggs
  - Marsupial mammals
    - Offspring develop in pouch
  - Placental (majority)

- Therapsids
  - Ancestral mammals
  - Arose in Mesozoic
Fossils

• Tangible remains or signs of ancient organisms
• Found in sedimentary rocks or sediments, especially marine sediments
• Thousands to millions of years old
How to become a fossil

- Permineralization
- Replacement
- Molds
- Casts
- Impressions
- Carbonization
- Trace Fossils
- Biomarkers
Unaltered Remains
(Usually “younger” fossils)

Amber

Subfossil Wood

Mammoth Hair

2,400yr old Bog Man, Denmark
Fossils

- Most fossils are hard parts of organism
  - Teeth, skeleton
  - Crinoid
Fossils

• Hard parts may be completely replaced by minerals
Fossils

• Fossilization of soft parts is rare
  – Requires oxygen-poor environment
  – Burial in fine-grained sediment

• Permineralization
  – Infilling of woody tissue by inorganic materials
  – Petrified wood
Fossils

- Fossil need not be skeletal
- Mold
  - 3-D negative imprint
Molds and Casts

Mold - Pennsylvanian Shark’s Jaw

Cast - Paleozoic Crinoid
Fossils

• Impressions
  – 2-D preservation of outlines and surface features

• Carbonization
  – Concentrated residue of remaining carbon
Fossils

• Fossils provide biased view of biota
  – Not all organisms are preserved
    • Rare
    • Lack hard parts
  – Not all skeletal material is preserved
    • Scavengers
    • Transport and abrasion
    • Post-burial alteration of rock
  – Not all fossils are exposed at the surface
  – Some form fossil fuels
Fossils
“Fossilized” Remains

Permineralization

Replacement

Carbonization

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“Trace Fossils”

**Track**: an impression made by a single foot.
**Trackway**: a number of tracks made during a single trip.
**Trail**: an impression made by a tail or other “non-foot”.

**Burrows**: a hole or holes an animal dug into loose sediment (like mud).

**Eggs and Nests**: shells that at one time would have contained babies and the nests that the babies would have been kept in.

**Coprolites**: poop that has become fossilized.
Fossils

- Trace fossils
  - Tracks/trackways
  - Trails
  - Burrows

- Provides behavioral information about extinct animals
Trackways and Trails

Fish Fin Marks (Nova Scotia)

Dino Tracks (Connecticut)

Trilobite Trails, New York
505 million years old (Cambrian)
Trace Fossils

Worm trails

Arthropod tracks

Trilobite tracks
Worm Burrows

Middle Silurian, Grimsby Formation, Hamilton, Ontario
Dino Nests

*Upper Cretaceous close to KT boundary, Henan province, China*
Miocene Mammal (WA)

Coprolites

Cretaceous Hadrosaur (MT)
How do Fossils Form?

- Remains of organisms are called **body fossils**
  - mostly durable skeletal elements such as bones, teeth and shells

- rarely we might find entire animals preserved by freezing or mummification
Unaltered Remains

• 40,000-year-old frozen baby mammoth found in Siberia in 1971
  - hair around the feet is still visible
Altered Remains

- Petrified tree stump in Florissant Fossil Beds National Monument, Colorado
Altered Remains

Carbon film of a palm frond

Carbon film of an insect