History of life on Earth & Classification of living organisms
Conditions on early Earth made the origin of life possible

A recipe for life
Raw materials +
Suitable environment +
Energy sources
Stages that led to life forms

- **Chemical conditions**
  - Stage 1: Abiotic synthesis of monomers
  - Stage 2: Formation of polymers
  - Stage 3: Packaging of polymers into protobionts
  - Stage 4: Self-replication

- **Physical conditions**

Last 0.5 billion years
- Phanerozoic eon
- Cenozoic
- Mesozoic
- Paleozoic

Origin of solar system and Earth
- Colonization of land
- Animals

Proterozoic eon
- Billions of years ago
- Multicellular eukaryotes

Archaean eon
- Prokaryotes

Atmospheric oxygen
- Single-celled eukaryotes
- Multicellular eukaryotes

Humans

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Stage 1: The abiotic synthesis of monomers
Stanley Miller’s experiments produced abundant amino acids and other organic molecules

H₂O vapor and compounds released from volcanic eruptions, including N₂ and its oxides, CO₂, CH₄, NH₃, H₂, and H₂S
Stage 2: The formation of polymers

- Monomers could have combined to form organic polymers
- Clay as substratum for polymerization?
Stage 3: Packaging of polymers into protobionts

– Polymers could have aggregated into complex, organized, cell-like structures
What characteristics do cells and protobionts share?

- Structural organization
- Simple reproduction
- Simple metabolism
- Simple homeostasis
Stage 4: Self-replication

- RNA: first genetic material *and* as the first enzymes
- The first genes made of RNA that replicated without protein support
- RNA catalysts or *ribozymes* may have assisted in this process.

RNA world!
Prokaryotes lived alone on Earth for 1.5 billion years
- Transformed Earth’s biosphere

- Metabolic pathways evolved within prokaryotes
  - Cellular respiration arose in prokaryotes, using oxygen to harvest energy from organic molecules
Key events in life’s history:
- The origins of single-celled and multi-celled organisms
- The colonization of land
• **Origin of the eukaryotic cells:**
  A community of prokaryotes, when small prokaryotes capable of aerobic respiration or photosynthesis began living in larger cells
  – Oldest fossils of eukaryotes are 2.1 billion years old

• **Multi-cellular forms** arose about 1.5 billion years ago
  – The descendents of these forms include a variety of algae, plants, fungi, animals
  – The oldest known fossils were small algae, living 1.2 billion years ago
• The diversity of animal forms increased suddenly and dramatically about 535–525 million years ago in the Cambrian explosion
  - Tetrapods & Arthropods are the most widespread and diverse land animals
  - Human lineage diverged from apes 7–6 million years ago

• Fungi and plants colonized land together 500 million years ago
  - Roots of most plants have fungal associates that exchange water and minerals for nutrients
Forces shaping Macroevolution and Earth’s History

The **fossil record** documents the main events in the history of life

- Continental drift
- Mass extinctions were followed by diversification of life-forms
Continental drift is the slow, continuous movement of Earth’s crustal plates on the hot mantle
– Crustal plates carrying continents and seafloors float on a liquid mantle

Figure 15.3A

Edge of one plate being pushed over edge of neighboring plate (zones of violent geologic events)
• Important geologic processes occur at plate boundaries
  – Sliding plates are earthquake zones
  – Colliding plates form mountains
The formation of Pangaea

Continental drift changes the land masses on earth and impact all forms of life:
altering habitats and triggered extinctions

Figure 15.3B
Mass extinctions destroy large numbers of species

– Extinction is the fate of all species and most lineages
– The history of life on Earth reflects a steady background extinction rate with episodes of mass extinction
– Over the last 600 million years, five mass extinctions have occurred in which 50% or more of the Earth’s species went extinct
<table>
<thead>
<tr>
<th>Relative Duration of Eons</th>
<th>Era</th>
<th>Period</th>
<th>Epoch</th>
<th>Age (Millions of Years Ago)</th>
<th>Some Important Events in the History of Life</th>
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<tbody>
<tr>
<td>Proterozoic</td>
<td>Cenozoic</td>
<td>Neogene</td>
<td>Holocene</td>
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<td>Historical time</td>
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<td>Pleistocene</td>
<td>1.8</td>
<td>Ice ages; humans appear</td>
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<td>Pliocene</td>
<td>5.3</td>
<td>Origin of genus Homo</td>
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<td>Miocene</td>
<td>23</td>
<td>Continued radiation of mammals and angiosperms; apelike ancestors of humans appear</td>
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<td>Oligocene</td>
<td>33.9</td>
<td>Origins of many primate groups, including apes</td>
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<td>Paleogene</td>
<td>Eocene</td>
<td>Angiosperm dominance increases; continued radiation of most present-day mammalian orders</td>
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<td></td>
<td></td>
<td>55.6</td>
<td>Major radiation of mammals, birds, and pollinating insects</td>
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<td>65.5</td>
<td>Flowering plants appear; many groups of organisms, including most dinosaurs, become extinct at end of period</td>
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<td>Mesozoic</td>
<td>Cretaceous</td>
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<td>145.5</td>
<td>Gymnosperms continue as dominant plants; dinosaurs abundant and diverse</td>
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<td>Jurassic</td>
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<td>199.6</td>
<td>Cone-bearing plants dominate landscape; origin and radiation of dinosaurs; origin of mammals</td>
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<td>Triassic</td>
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<td>Relative Duration of Eons</td>
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<tr>
<td>Archaean</td>
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<td></td>
<td>2,100</td>
<td>Oldest fossils of eukaryotic cells</td>
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<td>2,500</td>
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<td></td>
<td></td>
<td>2,700</td>
<td>Concentration of atmospheric oxygen increases</td>
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<td>3,500</td>
<td>Oldest fossils of cells (prokaryotes)</td>
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<td>3,800</td>
<td>Oldest known rocks on Earth’s surface</td>
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<td>Approx. 4,600</td>
<td>Origin of Earth</td>
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<td>Paleozoic</td>
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<td></td>
<td>635</td>
<td>Diverse algae and soft-bodied invertebrate animals</td>
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<td></td>
<td></td>
<td>542</td>
<td>Sudden increase in diversity of many animal phyla</td>
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<td>488.3</td>
<td>Marine algae abundant; colonization of land by fungi, plants, and animals</td>
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<td>443.7</td>
<td>Diversification of early vascular plants</td>
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<td>359.2</td>
<td>Diversification of bony fishes; first tetrapods and insects</td>
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<td>299</td>
<td>Forests of vascular plants; first seed plants; origin of reptiles; amphibians dominant</td>
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<td>251</td>
<td>Radiation of reptiles; origin of most present-day groups of insects; extinction of many marine and terrestrial organisms at end of period</td>
</tr>
</tbody>
</table>
Permian extinction
- 96% of shallow water marine species died in the Permian extinction
- Possible cause?
  - Extreme vulcanism in Siberia released CO$_2$, warmed global climate, slowed mixing of ocean water, and reduced O$_2$ availability in the ocean
Cretaceous extinction

- 50% of marine species and many terrestrial lineages went extinct 65 million years ago
  - All dinosaurs (except birds) went extinct
- Likely cause was a large asteroid that struck the Earth, blocking light and disrupting the global climate

![Map of North America with Yucatán Peninsula and Chicxulub crater](image)
Biodiversity and Classification

• **Taxonomy** is the field of study of biodiversity and its classification
  – Taxonomists assign a binomial consisting of a genus and species name, to each species

• **Phylogeny** is the study of the evolutionary history of a species or group of species- based on structural homologies in fossils and living organisms

• **Systematics** connects classification with evolutionary history
A phylogenetic Tree

A hypothesis of evolutionary relationships within a group constructed on the basis of shared characters.

Phylogenetic Tree

- Iguana
- Duck-billed platypus
- Kangaroo
- Beaver

Hair, mammary glands

Gestation

Long gestation
Molecular Systematics

– Compares nucleic acids or other molecules to infer relatedness of groups of organisms

– The more recently two species have branched from a common ancestor, the more similar their DNA sequences should be
Constructing the tree of life is a work in progress

- The three **domain system** was developed using the divergence of rRNA genes
1. Most recent common ancestor of all living things
2. Gene transfer between mitochondrial ancestor and ancestor of eukaryotes
3. Gene transfer between chloroplast ancestor and ancestor of green plants
## Major evolutionary steps

**Eukaryotic cells (aquatic)**

**Protists** - Diverse plant-like and animal-like
- un-icellular & Multicellular

### Multi-cellular

- **Animals**
  - Invertebrates
  - Vertebrates

- **Plants**
  - Mosses
  - Ferns
  - Cone-bearing
  - Flowering