Chapter 25

The History of Life on Earth

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: Lost Worlds

- Past organisms were very different from those now alive
- The fossil record shows **macroevolutionary** changes over large time scales including
  - The emergence of terrestrial vertebrates
  - The origin of photosynthesis
  - Long-term impacts of mass extinctions

Concept 25.1: Conditions on early Earth made the origin of life possible

- Chemical and physical processes on early Earth may have produced very simple cells through a sequence of stages:

  1. Abiotic synthesis of small organic molecules
  2. Joining of these small molecules into macromolecules
  3. Packaging of molecules into “protobionts”
  4. Origin of self-replicating molecules

Synthesis of Organic Compounds on Early Earth

- Earth formed about 4.6 billion years ago, along with the rest of the solar system
- Earth's early atmosphere likely contained water vapor and chemicals released by volcanic eruptions (nitrogen, nitrogen oxides, carbon dioxide, methane, ammonia, hydrogen, hydrogen sulfide)

- A. I. Oparin and J. B. S. Haldane hypothesized that the early atmosphere was a reducing environment
- Stanley Miller and Harold Urey conducted lab experiments that showed that the abiotic synthesis of organic molecules in a reducing atmosphere is possible

- However, the evidence is not yet convincing that the early atmosphere was in fact reducing
- Instead of forming in the atmosphere, the first organic compounds may have been synthesized near submerged volcanoes and deep-sea vents

PLAY Video: Tubeworms

PLAY Video: Hydrothermal Vent

- Amino acids have also been found in meteorites

Abiotic Synthesis of Macromolecules

- Small organic molecules polymerize when they are concentrated on hot sand, clay, or rock

Protobionts

- Replication and metabolism are key properties of life
- **Protobionts** are aggregates of abiotically produced molecules surrounded by a membrane or membrane-like structure
- Protobionts exhibit simple reproduction and metabolism and maintain an internal chemical environment

- Experiments demonstrate that protobionts could have formed spontaneously from abiotically produced organic compounds
- For example, small membrane-bounded droplets called liposomes can form when lipids or other organic molecules are added to water

Self-Replicating RNA and the Dawn of Natural Selection

- The first genetic material was probably RNA, not DNA
- RNA molecules called **ribozymes** have been found to catalyze many different reactions
  - For example, ribozymes can make complementary copies of short stretches of their own sequence or other short pieces of RNA

- Early protobionts with self-replicating, catalytic RNA would have been more effective at using resources and would have increased in number through natural selection
- The early genetic material might have formed an “RNA world”

Concept 25.2: The fossil record documents the history of life

- The fossil record reveals changes in the history of life on earth

The Fossil Record

- Sedimentary rocks are deposited into layers called *strata* and are the richest source of fossils

PLAY Video: Grand Canyon

- Few individuals have fossilized, and even fewer have been discovered
- The fossil record is biased in favor of species that
  - Existed for a long time
  - Were abundant and widespread
  - Had hard parts

PLAY Animation: The Geologic Record

How Rocks and Fossils Are Dated

- Sedimentary strata reveal the relative ages of fossils
- The absolute ages of fossils can be determined by **radiometric dating**
- A "parent" isotope decays to a "daughter" isotope at a constant rate
- Each isotope has a known **half-life**, the time required for half the parent isotope to decay

- Radiocarbon dating can be used to date fossils up to 75,000 years old
- For older fossils, some isotopes can be used to date sedimentary rock layers above and below the fossil

- The magnetism of rocks can provide dating information
- Reversals of the magnetic poles leave their record on rocks throughout the world

The Origin of New Groups of Organisms

- Mammals belong to the group of animals called *tetrapods*
- The evolution of unique mammalian features through gradual modifications can be traced from ancestral synapsids through the present

Concept 25.3: Key events in life's history include the origins of single-celled and multicelled organisms and the colonization of land

- The **geologic record** is divided into the Archaean, the Proterozoic, and the Phanerozoic eons

Table 25-1

Table 25.1 The Geologic Record

Relative Duration of Eons	Era	Period	Epoch	Age (Millions of Years Ago)	Some Important Events in the History of Life
Phanerozoic	Cenozoic	Neogene	Holocene		Historical time
				0.01	
			Pleistocene		Ice ages; humans appear
				1.8	
			Pliocene		Origin of genus *Homo*
				5.3	
			Miocene		Continued radiation of mammals and angiosperms; apelike ancestors of humans appear
				23	
		Paleogene	Oligocene		Origins of many primate groups, including apes
				33.9	
			Eocene		Angiosperm dominance increases; continued radiation of most present-day mammalian orders
				55.8	
			Paleocene		Major radiation of mammals, birds, and pollinating insects
				65.5	
	Mesozoic	Cretaceous			Flowering plants (angiosperms) appear and diversify; many groups of organisms, including most dinosaurs, become extinct at end of period
				145.5	
		Jurassic			Gymnosperms continue as dominant plants; dinosaurs abundant and diverse
				199.6	
		Triassic			Cone-bearing plants (gymnosperms) dominate landscape; dinosaurs evolve and radiate; origin of mammals
				251	
	Paleozoic	Permian			Radiation of reptiles; origin of most present-day groups of insects; extinction of many marine and terrestrial organisms at end of period
				299	
		Carboniferous			Extensive forests of vascular plants form; first seed plants appear; origin of reptiles; amphibians dominant
				359.2	
		Devonian			Diversification of bony fishes; first tetrapods and insects appear
				416	
		Silurian			Diversification of early vascular plants
				443.7	
		Ordovician			Marine algae abundant; colonization of land by diverse fungi, plants, and animals
				488.3	
		Cambrian			Sudden increase in diversity of many animal phyla (Cambrian explosion)
				542	
Proterozoic		Ediacaran			Diverse algae and soft-bodied invertebrate animals appear
				635	
				2,100	Oldest fossils of eukaryotic cells appear
				2,500	
Archaean				2,700	Concentration of atmospheric oxygen begins to increase
				3,500	Oldest fossils of cells (prokaryotes) appear
				3,800	Oldest known rocks on Earth's surface
				Approx. 4,600	Origin of Earth

- The Phanerozoic encompasses multicellular eukaryotic life
- The Phanerozoic is divided into three eras: the Paleozoic, Mesozoic, and Cenozoic
- Major boundaries between geological divisions correspond to extinction events in the fossil record

The First Single-Celled Organisms

- The oldest known fossils are **stromatolites**, rock-like structures composed of many layers of bacteria and sediment
- Stromatolites date back 3.5 billion years ago
- Prokaryotes were Earth's sole inhabitants from 3.5 to about 2.1 billion years ago

Photosynthesis and the Oxygen Revolution

- Most atmospheric oxygen (O_2) is of biological origin
- O_2 produced by oxygenic photosynthesis reacted with dissolved iron and precipitated out to form banded iron formations
- The source of O_2 was likely bacteria similar to modern cyanobacteria

- By about 2.7 billion years ago, O_2 began accumulating in the atmosphere and rusting iron-rich terrestrial rocks
- This “oxygen revolution” from 2.7 to 2.2 billion years ago
  - Posed a challenge for life
  - Provided opportunity to gain energy from light
  - Allowed organisms to exploit new ecosystems

The First Eukaryotes

- The oldest fossils of eukaryotic cells date back 2.1 billion years
- The hypothesis of **endosymbiosis** proposes that mitochondria and plastids (chloroplasts and related organelles) were formerly small prokaryotes living within larger host cells
- An *endosymbiont* is a cell that lives within a host cell

- The prokaryotic ancestors of mitochondria and plastids probably gained entry to the host cell as undigested prey or internal parasites
- In the process of becoming more interdependent, the host and endosymbionts would have become a single organism
- **Serial endosymbiosis** supposes that mitochondria evolved before plastids through a sequence of endosymbiotic events

- Key evidence supporting an endosymbiotic origin of mitochondria and plastids:
  - Similarities in inner membrane structures and functions
  - Division is similar in these organelles and some prokaryotes
  - These organelles transcribe and translate their own DNA
  - Their ribosomes are more similar to prokaryotic than eukaryotic ribosomes

The Origin of Multicellularity

- The evolution of eukaryotic cells allowed for a greater range of unicellular forms
- A second wave of diversification occurred when multicellularity evolved and gave rise to algae, plants, fungi, and animals

The Earliest Multicellular Eukaryotes

- Comparisons of DNA sequences date the common ancestor of multicellular eukaryotes to 1.5 billion years ago
- The oldest known fossils of multicellular eukaryotes are of small algae that lived about 1.2 billion years ago

- The “snowball Earth” hypothesis suggests that periods of extreme glaciation confined life to the equatorial region or deep-sea vents from 750 to 580 million years ago
- The Ediacaran biota were an assemblage of larger and more diverse soft-bodied organisms that lived from 565 to 535 million years ago

The Cambrian Explosion

- The **Cambrian explosion** refers to the sudden appearance of fossils resembling modern phyla in the Cambrian period (535 to 525 million years ago)
- The Cambrian explosion provides the first evidence of predator-prey interactions

- DNA analyses suggest that many animal phyla diverged before the Cambrian explosion, perhaps as early as 700 million to 1 billion years ago
- Fossils in China provide evidence of modern animal phyla tens of millions of years before the Cambrian explosion
- The Chinese fossils suggest that “the Cambrian explosion had a long fuse”

The Colonization of Land

- Fungi, plants, and animals began to colonize land about 500 million years ago
- Plants and fungi likely colonized land together by 420 million years ago
- Arthropods and tetrapods are the most widespread and diverse land animals
- Tetrapods evolved from lobe-finned fishes around 365 million years ago

Concept 25.4: The rise and fall of dominant groups reflect continental drift, mass extinctions, and adaptive radiations

- The history of life on Earth has seen the rise and fall of many groups of organisms

PLAY Video: Volcanic Eruption

PLAY Video: Lava Flow

Continental Drift

- At three points in time, the land masses of Earth have formed a supercontinent: 1.1 billion, 600 million, and 250 million years ago
- Earth's continents move slowly over the underlying hot mantle through the process of **continental drift**
- Oceanic and continental plates can collide, separate, or slide past each other
- Interactions between plates cause the formation of mountains and islands, and earthquakes

Consequences of Continental Drift

- Formation of the supercontinent **Pangaea** about 250 million years ago had many effects
  - A reduction in shallow water habitat
  - A colder and drier climate inland
  - Changes in climate as continents moved toward and away from the poles
  - Changes in ocean circulation patterns leading to global cooling

- The break-up of Pangaea lead to allopatric speciation
- The current distribution of fossils reflects the movement of continental drift
- For example, the similarity of fossils in parts of South America and Africa is consistent with the idea that these continents were formerly attached

Mass Extinctions

- The fossil record shows that most species that have ever lived are now extinct
- At times, the rate of extinction has increased dramatically and caused a **mass extinction**

The “Big Five” Mass Extinction Events

- In each of the five mass extinction events, more than 50% of Earth’s species became extinct

- The Permian extinction defines the boundary between the Paleozoic and Mesozoic eras
- This mass extinction occurred in less than 5 million years and caused the extinction of about 96% of marine animal species
- This event might have been caused by volcanism, which lead to global warming, and a decrease in oceanic oxygen

- The Cretaceous mass extinction 65.5 million years ago separates the Mesozoic from the Cenozoic
- Organisms that went extinct include about half of all marine species and many terrestrial plants and animals, including most dinosaurs

- The presence of iridium in sedimentary rocks suggests a meteorite impact about 65 million years ago
- The Chicxulub crater off the coast of Mexico is evidence of a meteorite that dates to the same time

Is a Sixth Mass Extinction Under Way?

- Scientists estimate that the current rate of extinction is 100 to 1,000 times the typical background rate
- Data suggest that a sixth human-caused mass extinction is likely to occur unless dramatic action is taken

Consequences of Mass Extinctions

- Mass extinction can alter ecological communities and the niches available to organisms
- It can take from 5 to 100 million years for diversity to recover following a mass extinction
- Mass extinction can pave the way for adaptive radiations

Adaptive Radiations

- **Adaptive radiation** is the evolution of diversely adapted species from a common ancestor upon introduction to new environmental opportunities

Worldwide Adaptive Radiations

- Mammals underwent an adaptive radiation after the extinction of terrestrial dinosaurs
- The disappearance of dinosaurs (except birds) allowed for the expansion of mammals in diversity and size
- Other notable radiations include photosynthetic prokaryotes, large predators in the Cambrian, land plants, insects, and tetrapods

Regional Adaptive Radiations

- Adaptive radiations can occur when organisms colonize new environments with little competition
- The Hawaiian Islands are one of the world's great showcases of adaptive radiation

Concept 25.5: Major changes in body form can result from changes in the sequences and regulation of developmental genes

- Studying genetic mechanisms of change can provide insight into large-scale evolutionary change

Evolutionary Effects of Development Genes

- Genes that program development control the rate, timing, and spatial pattern of changes in an organism's form as it develops into an adult

Changes in Rate and Timing

- **Heterochrony** is an evolutionary change in the rate or timing of developmental events
- It can have a significant impact on body shape
- The contrasting shapes of human and chimpanzee skulls are the result of small changes in relative growth rates

PLAY Animation: Allometric Growth

- Heterochrony can alter the timing of reproductive development relative to the development of nonreproductive organs
- In **paedomorphosis**, the rate of reproductive development accelerates compared with somatic development
- The sexually mature species may retain body features that were juvenile structures in an ancestral species

Changes in Spatial Pattern

- Substantial evolutionary change can also result from alterations in genes that control the placement and organization of body parts
- **Homeotic genes** determine such basic features as where wings and legs will develop on a bird or how a flower's parts are arranged

- *Hox* genes are a class of homeotic genes that provide positional information during development
- If *Hox* genes are expressed in the wrong location, body parts can be produced in the wrong location
- For example, in crustaceans, a swimming appendage can be produced instead of a feeding appendage

- Evolution of vertebrates from invertebrate animals was associated with alterations in *Hox* genes
- Two duplications of *Hox* genes have occurred in the vertebrate lineage
- These duplications may have been important in the evolution of new vertebrate characteristics

The Evolution of Development

- The tremendous increase in diversity during the Cambrian explosion is a puzzle
- Developmental genes may play an especially important role
- Changes in developmental genes can result in new morphological forms

Changes in Genes

- New morphological forms likely come from gene duplication events that produce new developmental genes
- A possible mechanism for the evolution of six-legged insects from a many-legged crustacean ancestor has been demonstrated in lab experiments
- Specific changes in the *Ubx* gene have been identified that can "turn off" leg development

Changes in Gene Regulation

- Changes in the form of organisms may be caused more often by changes in the regulation of developmental genes instead of changes in their sequence
- For example three-spine sticklebacks in lakes have fewer spines than their marine relatives
- The gene sequence remains the same, but the regulation of gene expression is different in the two groups of fish

Concept 25.6: Evolution is not goal oriented

- Evolution is like tinkering—it is a process in which new forms arise by the slight modification of existing forms

Evolutionary Novelties

- Most novel biological structures evolve in many stages from previously existing structures
- Complex eyes have evolved from simple photosensitive cells independently many times
- Exaptations are structures that evolve in one context but become co-opted for a different function
- Natural selection can only improve a structure in the context of its current utility

Evolutionary Trends

- Extracting a single evolutionary progression from the fossil record can be misleading
- Apparent trends should be examined in a broader context

- According to the species selection model, trends may result when species with certain characteristics endure longer and speciate more often than those with other characteristics
- The appearance of an evolutionary trend does not imply that there is some intrinsic drive toward a particular phenotype

You should now be able to:

1. Define radiometric dating, serial endosymbiosis, Pangaea, snowball Earth, exaptation, heterochrony, and paedomorphosis
2. Describe the contributions made by Oparin, Haldane, Miller, and Urey toward understanding the origin of organic molecules
3. Explain why RNA, not DNA, was likely the first genetic material

4. Describe and suggest evidence for the major events in the history of life on Earth from Earth’s origin to 2 billion years ago
5. Briefly describe the Cambrian explosion
6. Explain how continental drift led to Australia’s unique flora and fauna
7. Describe the mass extinctions that ended the Permian and Cretaceous periods
8. Explain the function of *Hox* genes