CAMPBELL
BIOLOGY TENTH EDITION
Reece • Urry • Cain • Wasserman • Minorsky • Jackson

25

The History of Life on Earth

Lecture Presentation by Nicole Tunbridge and Kathleen Fitzpatrick

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Lost Worlds

- Past organisms were very different from those now alive
- The fossil record shows **macroevolutionary** changes over large time scales, for example
  - The emergence of terrestrial vertebrates
  - The impact of mass extinctions
  - The origin of flight in birds

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Figure 25.1

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Figure 25.1a

***Cryolophosaurus* skull**

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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 **protocells**
  4. Origin of self-replicating molecules

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Synthesis of Organic Compounds on Early Earth

- Earth formed about 4.6 billion years ago, along with the rest of the solar system
- Bombardment of Earth by rocks and ice likely vaporized water and prevented seas from forming before about 4 billion years ago
- Earth's early atmosphere likely contained water vapor and chemicals released by volcanic eruptions (nitrogen, nitrogen oxides, carbon dioxide, methane, ammonia, hydrogen)

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- In the 1920s, A. I. Oparin and J. B. S. Haldane hypothesized that the early atmosphere was a reducing environment
- In 1953, Stanley Miller and Harold Urey conducted lab experiments that showed that the abiotic synthesis of organic molecules in a reducing atmosphere is possible

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- 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 volcanoes or deep-sea vents
- Miller-Urey-type experiments demonstrate that organic molecules could have formed with various possible atmospheres

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Figure 25.2

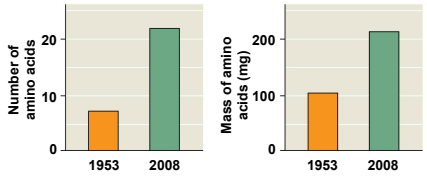

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Figure 25.3

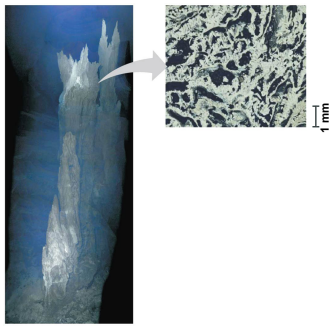

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Figure 25.3a

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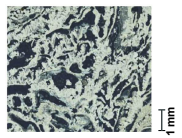
Figure 25.3b



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Video: Tube Worms

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- Amino acids have also been found in meteorites

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Abiotic Synthesis of Macromolecules

- RNA monomers have been produced spontaneously from simple molecules
- Small organic molecules polymerize when they are concentrated on hot sand, clay, or rock

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Protocells

- Replication and metabolism are key properties of life and may have appeared together in protocells
- Protocells may have formed from fluid-filled vesicles with a membrane-like structure
- In water, lipids and other organic molecules can spontaneously form vesicles with a lipid bilayer

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- Adding clay can increase the rate of vesicle formation
- Vesicles exhibit simple reproduction and metabolism and maintain an internal chemical environment

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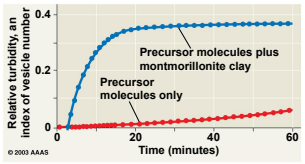
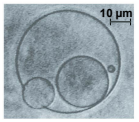


(a) Self-assembly



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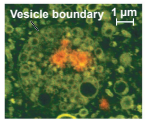

(c) Absorption of RNA

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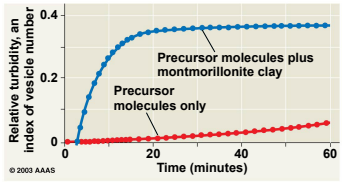
Figure 25.4a



(a) Self-assembly

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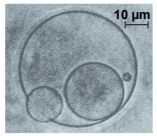
Figure 25.4b



(b) Reproduction

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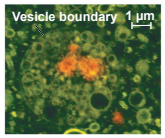

(c) Absorption of RNA

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Self-Replicating RNA

- 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 RNA

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- Natural selection has produced self-replicating RNA molecules
- RNA molecules that were more stable or replicated more quickly would have left the most descendant RNA molecules
- The early genetic material might have formed an "RNA world"

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- Vesicles containing RNA capable of replication would have been protocells
- RNA could have provided the template for DNA, a more stable genetic material

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Concept 25.2: The fossil record documents the history of life

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

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The Fossil Record

- Sedimentary rocks are deposited into layers called strata and are the richest source of fossils
- The fossil record shows changes in kinds of organisms on Earth over time

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Figure 25.5

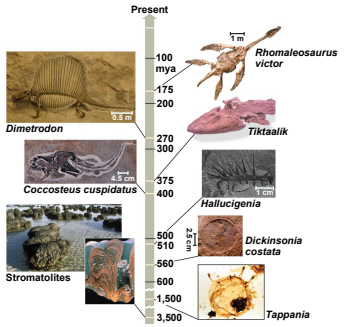

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Figure 25.5a

Stromatolite cross section

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Figure 25.5b

Stromatolites

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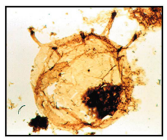

Tappania

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Figure 25.5d

Dickinsonia costata

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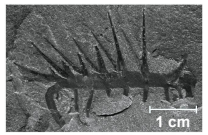
Figure 25.5e



Hallucigenia

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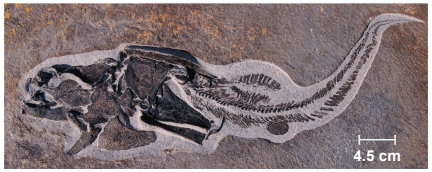
Figure 25.5f



Coccosteus cuspidatus

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Figure 25.5g

Tiktaalik

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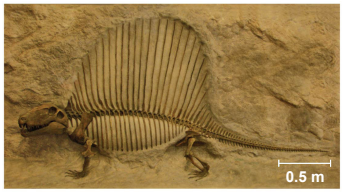
Figure 25.5h



Dimetrodon

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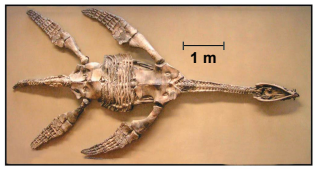
Figure 25.5i



Rhomaleosaurus victor

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Video: Grand Canyon

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- 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

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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 radioactive "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

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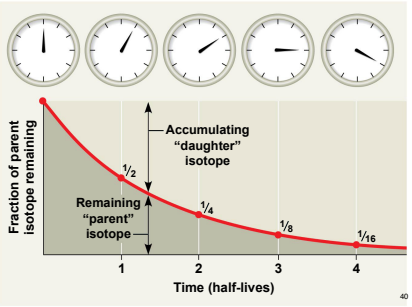
Figure 25.6



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

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The Origin of New Groups of Organisms

- Mammals belong to the group of animals called tetrapods
- The evolution of unique mammalian features can be traced through gradual changes over time

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Figure 25.7

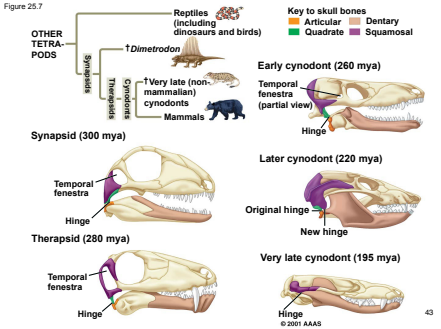

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Figure 25.7a

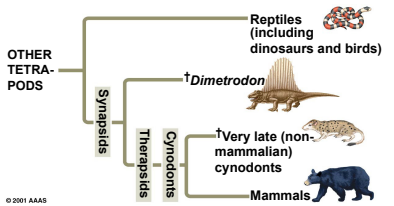

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Figure 25.7b

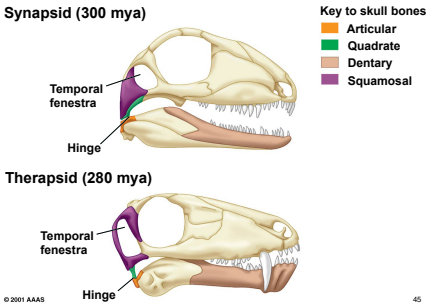

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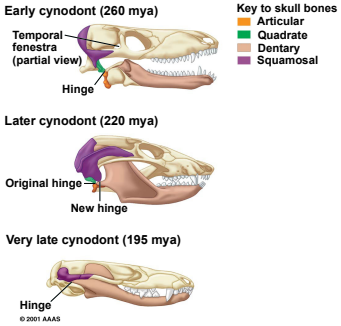
Figure 25.7c



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Concept 25.3: Key events in life's history include the origins of unicellular and multicellular organisms and the colonization of land

- The **geologic record** is divided into the Hadean, Archaean, Proterozoic, and Phanerozoic eons
- The Phanerozoic eon includes the last half billion years
- The Phanerozoic is divided into three eras: the Paleozoic, Mesozoic, and Cenozoic

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Table 25.1

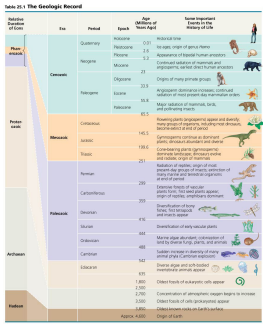

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Table 25.1a

		251mya	
Paleozoic	Permian		Radiation of reptiles; origin of most present-day groups of insects; extinction of many marine and terrestrial organisms at end of period
	Carboniferous	299	Extensive forests of vascular plants form; first seed plants appear; origin of reptiles; amphibians dominant
	Devonian	359	Diversification of bony fishes; first tetrapods and insects appear
	Silurian	416	Diversification of early vascular plants
	Ordovician	444	Marine algae abundant; colonization of land by diverse fungi, plants, and animals
	Cambrian	488	Sudden increase in diversity of many animal phyla (Cambrian explosion)
	Ediacaran	542	Diverse algae and soft-bodied invertebrate animals appear
		635	
		1,800	Oldest fossils of eukaryotic cells appear
		2,500	
		2,700	Concentration of atmospheric oxygen begins to increase
		3,500	Oldest fossils of cells (prokaryotes) appear
		3,850	Oldest known rocks on Earth's surface
		Approx. 4,600	Origin of Earth

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Table 25.1b

Cenozoic	Quaternary	Holocene	Historical time
		0.01	
		Pleistocene	Ice ages; origin of genus *Homo*
		2.6	
	Neogene	Pliocene	Appearance of bipedal human ancestors
		5.3	
		Miocene	Continued radiation of mammals and angiosperms; earliest direct human ancestors
		23	
	Paleogene	Oligocene	Origins of many primate groups
		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
		251mya	

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- Major boundaries between eras correspond to major extinction events in the fossil record

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Figure 25.8-1

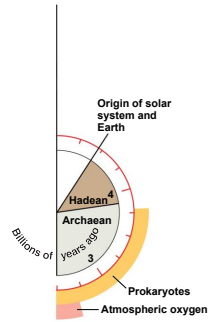

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Figure 25.8-2

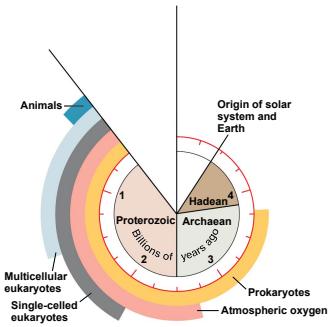

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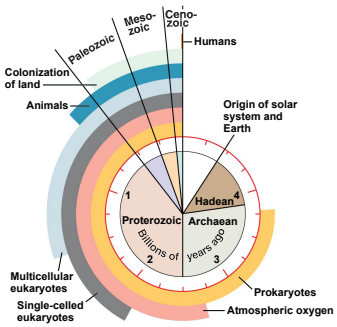
Figure 25.8-3



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The First Single-Celled Organisms

- The oldest known fossils are **stromatolites**, rocks formed by the accumulation of sedimentary layers on bacterial mats
- Stromatolites date back 3.5 billion years ago
- Prokaryotes were Earth's sole inhabitants for more than 1.5 billion years

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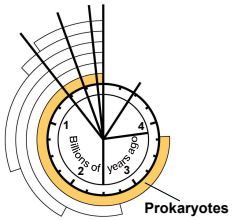
Figure 25.UN01



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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

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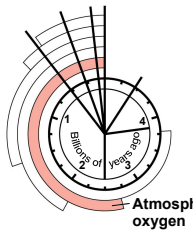
Figure 25.UN02



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- 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 2.3 billion years ago caused the extinction of many prokaryotic groups
- Some groups survived and adapted using cellular respiration to harvest energy

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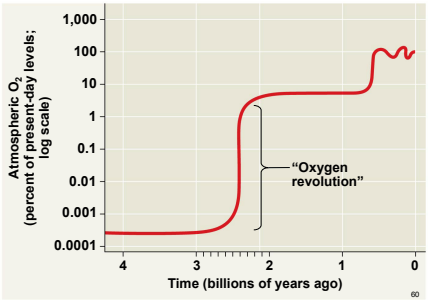
Figure 25.9



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The First Eukaryotes

- The oldest fossils of eukaryotic cells date back 1.8 billion years
- Eukaryotic cells have a nuclear envelope, mitochondria, endoplasmic reticulum, and a cytoskeleton
- The **endosymbiont theory** 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

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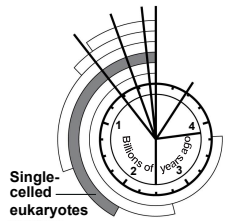
Figure 25.UN03



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- 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

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Figure 25.10-1

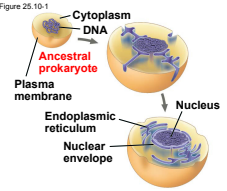

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Figure 25.10-2

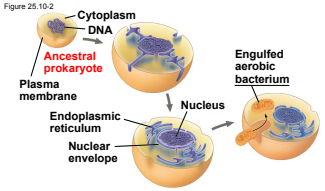

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Figure 25.10-3

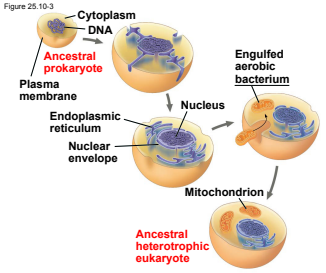

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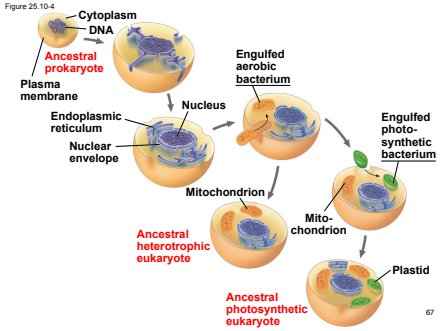
Figure 25.10-4



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- Key evidence supporting an endosymbiotic origin of mitochondria and plastids
  - Inner membranes are similar to plasma membranes of prokaryotes
  - Division and DNA structure 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

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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

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Early Multicellular Eukaryotes

- The oldest known fossils of multicellular eukaryotes that can be resolved taxonomically are of small algae that lived about 1.2 billion years ago
- Older fossils, dating to 1.8 billion years ago, may also be small, multicellular eukaryotes
- The Ediacaran biota were an assemblage of larger and more diverse soft-bodied organisms that lived from 600 to 535 million years ago

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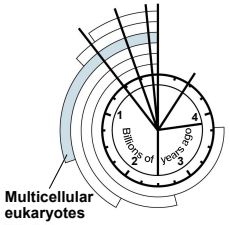
Figure 25.UN04



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The Cambrian Explosion

- The **Cambrian explosion** refers to the sudden appearance of fossils resembling modern animal phyla in the Cambrian period (535 to 525 million years ago)
- A few animal phyla appear even earlier: sponges, cnidarians, and molluscs
- The Cambrian explosion provides the first evidence of predator-prey interactions

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Figure 25.UN05

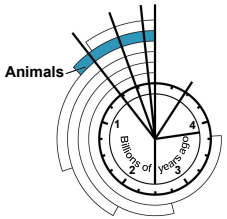

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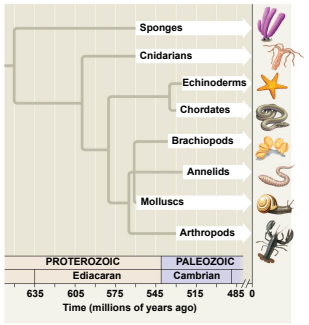
Figure 25.11



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- DNA analyses suggest that sponges and the common ancestor to several other animal phyla evolved 700 to 670 million years ago
- Fossil evidence of early animals dates back to 710 to 560 million years ago
- Molecular and fossil data suggest that "the Cambrian explosion had a long fuse"

75

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The Colonization of Land

- Fungi, plants, and animals began to colonize land about 500 million years ago
- Vascular tissue in plants transports materials internally and appeared by about 420 million years ago

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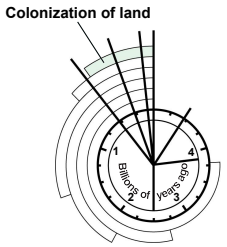
Figure 25.UN06



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- Plants and fungi likely colonized land together
- Fossilized plants show evidence of mutually beneficial associations with fungi (mycorrhizae) that are still seen today

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Figure 25.12

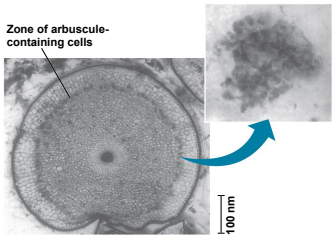

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Figure 25.12a

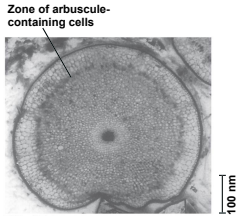

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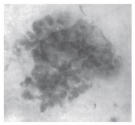
Figure 25.12b



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- Arthropods and tetrapods are the most widespread and diverse land animals
- Tetrapods evolved from lobe-finned fishes around 365 million years ago
- The human lineage of tetrapods evolved around 6–7 million years ago, and modern humans originated only 195,000 years ago

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Concept 25.4: The rise and fall of groups of organisms reflect differences in speciation and extinction rates

- The history of life on Earth has seen the rise and fall of many groups of organisms
- The rise and fall of groups depends on speciation and extinction rates within the group

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Figure 25.13

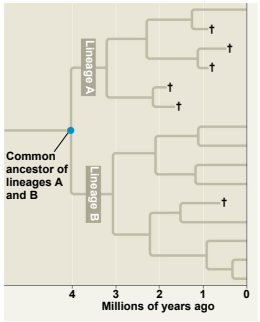

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Plate Tectonics

- The land masses of Earth have formed a supercontinent three times over the past 1.5 billion years: 1.1 billion, 600 million, and 250 million years ago
- According to the theory of **plate tectonics**, Earth's crust is composed of plates floating on Earth's mantle

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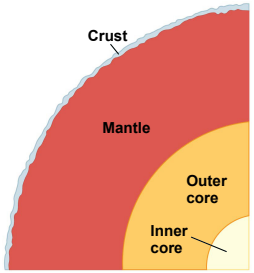
Figure 25.14



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- Tectonic plates move slowly 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

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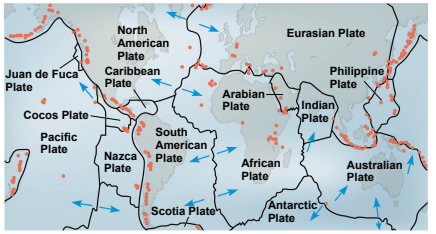
Figure 25.15



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Video: Lava Flow

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Video: Volcanic Eruption

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Consequences of Continental Drift

- Formation of the supercontinent **Pangaea** about 250 million years ago had many effects
  - A deepening of ocean basins
  - A reduction in shallow water habitat
  - A colder and drier climate inland

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Figure 25.16

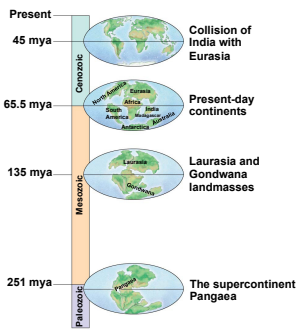

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Figure 25.16a

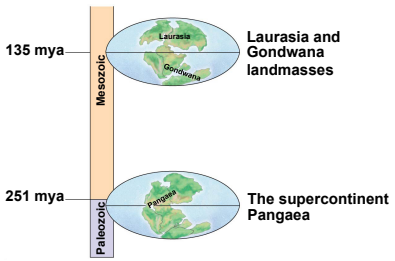

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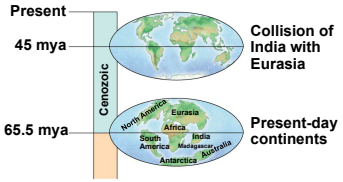
Figure 25.16b



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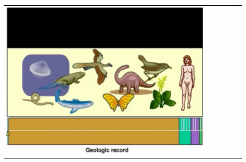
Animation: The Geologic Record



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- Continental drift has many effects on living organisms
  - A continent's climate can change as it moves north or south
  - Separation of land masses can lead to allopatric speciation

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- The distribution of fossils and living groups reflects the historic movement of continents
  - For example, the similarity of fossils in parts of South America and Africa is consistent with the idea that these continents were formerly attached

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Mass Extinctions

- The fossil record shows that most species that have ever lived are now extinct
- Extinction can be caused by changes to a species' environment
- At times, the rate of extinction has increased dramatically and caused a **mass extinction**
- Mass extinction is the result of disruptive global environmental changes

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The "Big Five" Mass Extinction Events

- In each of the five mass extinction events, 50% or more of marine species became extinct

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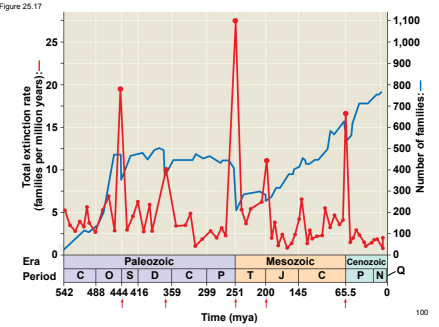

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- The Permian extinction defines the boundary between the Paleozoic and Mesozoic eras 251 million years ago
- This mass extinction occurred in less than 500,000 years and caused the extinction of about 96% of marine animal species

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- A number of factors might have contributed to these extinctions
  - Intense volcanism in what is now Siberia
  - Global warming and ocean acidification resulting from the emission of large amounts of CO_2 from the volcanoes
  - Anoxic conditions resulting from nutrient enrichment of ecosystems

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

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- The presence of iridium in sedimentary rocks suggests a meteorite impact about 65 million years ago
- Dust clouds caused by the impact would have blocked sunlight and disturbed global climate
- The Chicxulub crater off the coast of Mexico is evidence of a meteorite that dates to the same time

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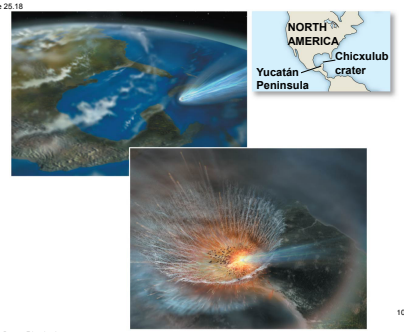
Figure 25.18



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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
- Extinction rates tend to increase when global temperatures increase
- Data suggest that a sixth, human-caused mass extinction is likely to occur unless dramatic action is taken

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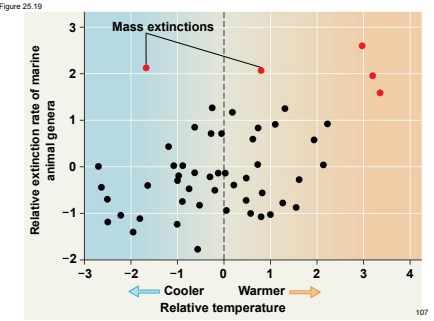
Figure 25.19



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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 extinctions can change the types of organisms found in ecological communities
  - For example, the percentage of marine organisms that were predators increased after the Permian and Cretaceous mass extinctions

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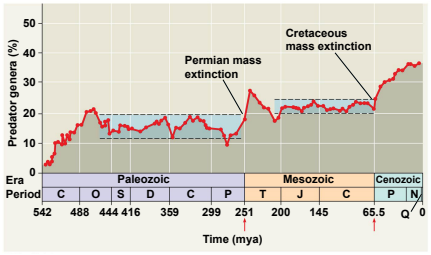
Figure 25.20



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- Lineages with novel and advantageous features can be lost during mass extinctions
- By eliminating so many species, mass extinctions can pave the way for adaptive radiations

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Adaptive Radiations

- **Adaptive radiation** is the rapid evolution of diversely adapted species from a common ancestor
- Adaptive radiations may follow
  - Mass extinctions
  - The evolution of novel characteristics
  - The colonization of new regions

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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

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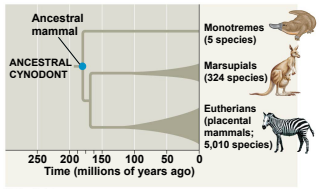
Figure 25.21



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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

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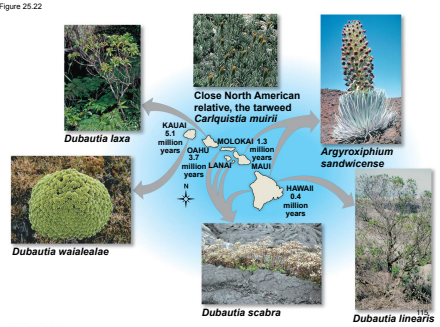

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Figure 25.22a

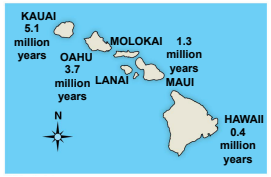

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Figure 25.22b

Close North American relative, the tarweed *Carlquistia muirii*

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Figure 25.22c

Dubautia waialealae

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Figure 25.22d

Dubautia laxa

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Figure 25.22e

Dubautia scabra

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Figure 25.22f

Argyroxiphium sandwicense

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Figure 25.22g

Dubautia linearis

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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

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Effects of Developmental 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

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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

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Figure 25.23

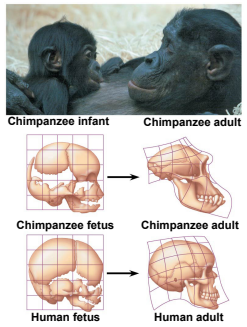

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Figure 25.23a

Chimpanzee infant **Chimpanzee adult**

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Animation: Allometric Growth

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- 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

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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

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- *Hox* genes are a class of homeotic genes that provide positional information during animal embryonic 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

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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

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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

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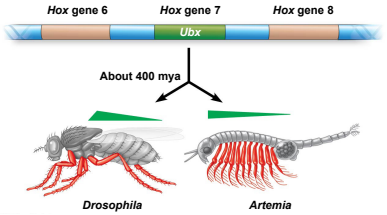
Figure 25.25



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Changes in Gene Regulation

- Changes in morphology likely result from changes in the regulation of developmental genes rather than changes in the sequence of developmental genes
  - For example, threespine 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

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Figure 25.26

Results

Hypothesis A: Differences in sequence

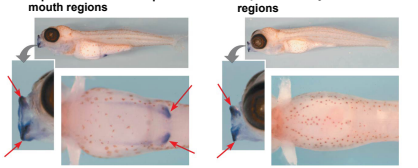
Result: No
The 283 amino acids of the *Pitx1* protein are identical.

Hypothesis B: Differences in expression

Result: Yes

Marine stickleback embryo: expression in ventral spine and mouth regions

Lake stickleback embryo: expression only in mouth regions



Red arrows indicate regions of *Pitx1* expression.

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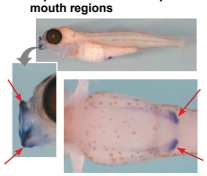
Figure 25.26a

Marine stickleback embryo: expression in ventral spine and mouth regions



Red arrows indicate regions of *Pitx1* expression.

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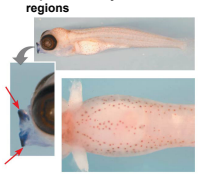
Figure 25.26b

Lake stickleback embryo: expression only in mouth regions



Red arrows indicate regions of *Pitx1* expression.

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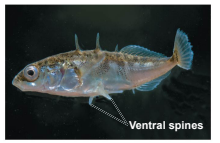
Figure 25.26c



Threespine stickleback (*Gasterosteus aculeatus*)

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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

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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

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Figure 25.28

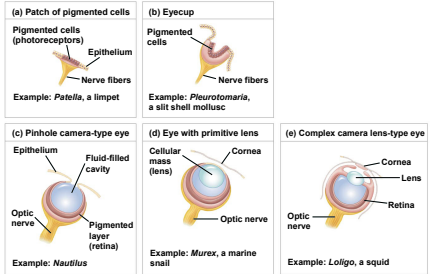

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Figure 25.28a

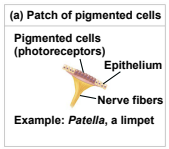

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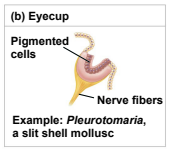
Figure 25.28b



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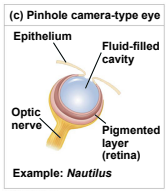

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Figure 25.28d

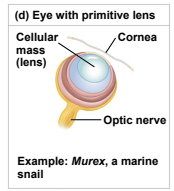

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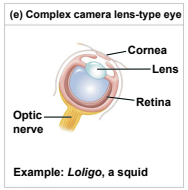
Figure 25.28e



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Evolutionary Trends

- Extracting a single evolutionary progression from the fossil record can be misleading
- Apparent trends should be examined in a broader context
- The species selection model suggests that differential speciation success may determine evolutionary trends
- Evolutionary trends do not imply an intrinsic drive toward a particular phenotype

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Figure 25.29

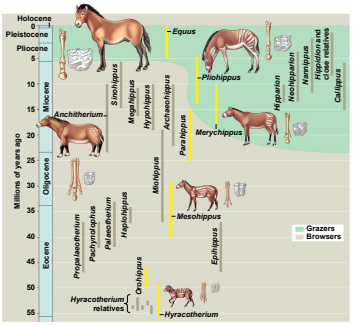

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Figure 25.29a

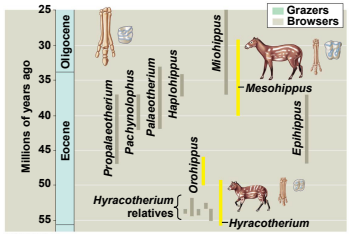

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Figure 25.29b

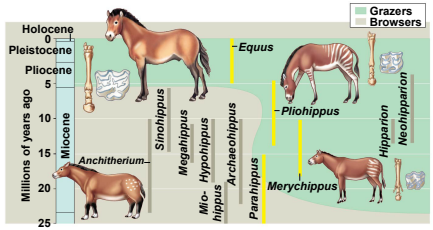

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Figure 25.UN07a

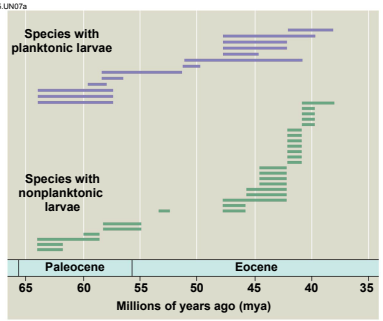

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Figure 25.UN07b

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Figure 25.UN08

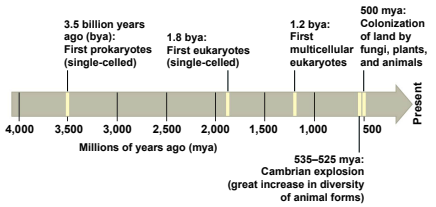

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Figure 25.UN09

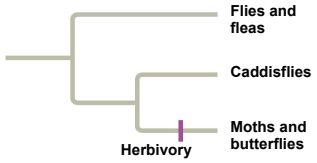

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Figure 25.UN10

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