Chapter 15 Tracing Evolutionary History

PowerPoint Lectures for

Campbell Biology: Concepts & Connections, ***Seventh Edition***

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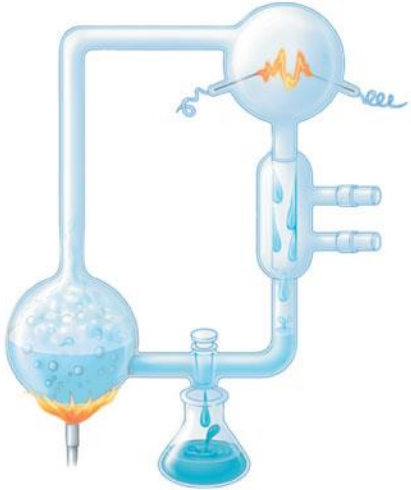
Lecture by Edward J. Zalisko

Introduction

- Different types of wings evolved from the same ancestral tetrapod limb.
  - Pterosaur wings consist of a membrane primarily supported by one greatly elongated finger.
  - Bird wings consist of feathers supported by an elongated forearm and modified wrist and hand bones.
  - Bat wings consist of a membrane supported by arm bones and four very elongated fingers.

Figure 15.0_1

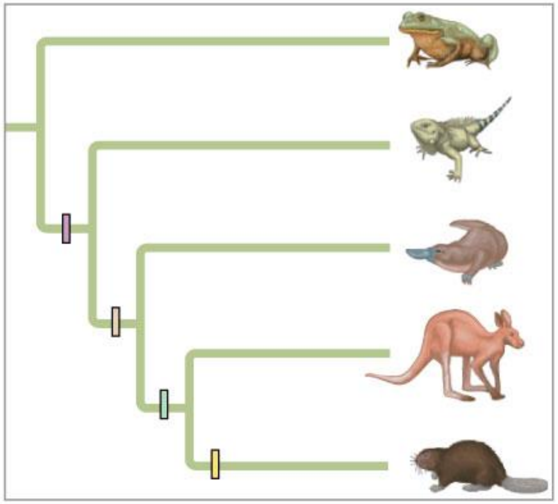
Chapter 15: Big Ideas



Early Earth and the Origin of Life

Major Events in the History of Life

Mechanisms of Macroevolution



Phylogeny and the Tree of Life

Figure 15.0_2

EARLY EARTH AND THE ORIGIN OF LIFE

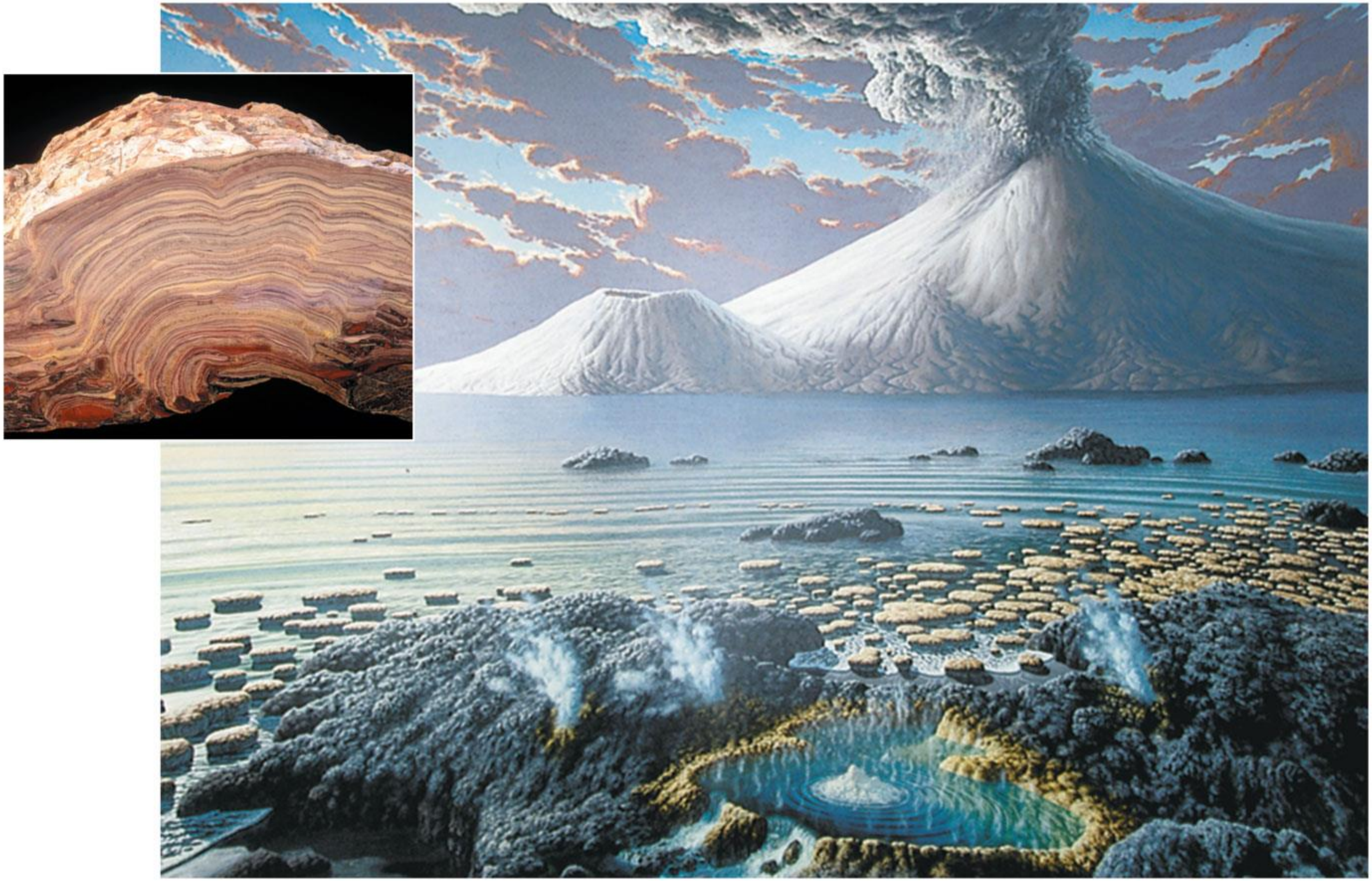
15.1 Conditions on early Earth made the origin of life possible

- The Earth formed about 4.6 billion years ago.
- As the Earth cooled and the bombardment slowed about 3.9 billion years ago, the conditions on the planet were extremely different from those today.
  - The first atmosphere was probably thick with
    - water vapor and
    - various compounds released by volcanic eruptions, including nitrogen and its oxides, carbon dioxide, methane, ammonia, hydrogen, and hydrogen sulfide.
  - Lightning, volcanic activity, and ultraviolet radiation were much more intense than today.

15.1 Conditions on early Earth made the origin of life possible

- The earliest evidence for life on Earth
  - comes from 3.5-billion-year-old fossils of **stromatolites**,
  - built by ancient photosynthetic prokaryotes still alive today.
- Because these 3.5-billion-year-old prokaryotes used photosynthesis, it suggests that life first evolved earlier, perhaps as much as 3.9 billion years ago.

Figure 15.1



15.1 Conditions on early Earth made the origin of life possible

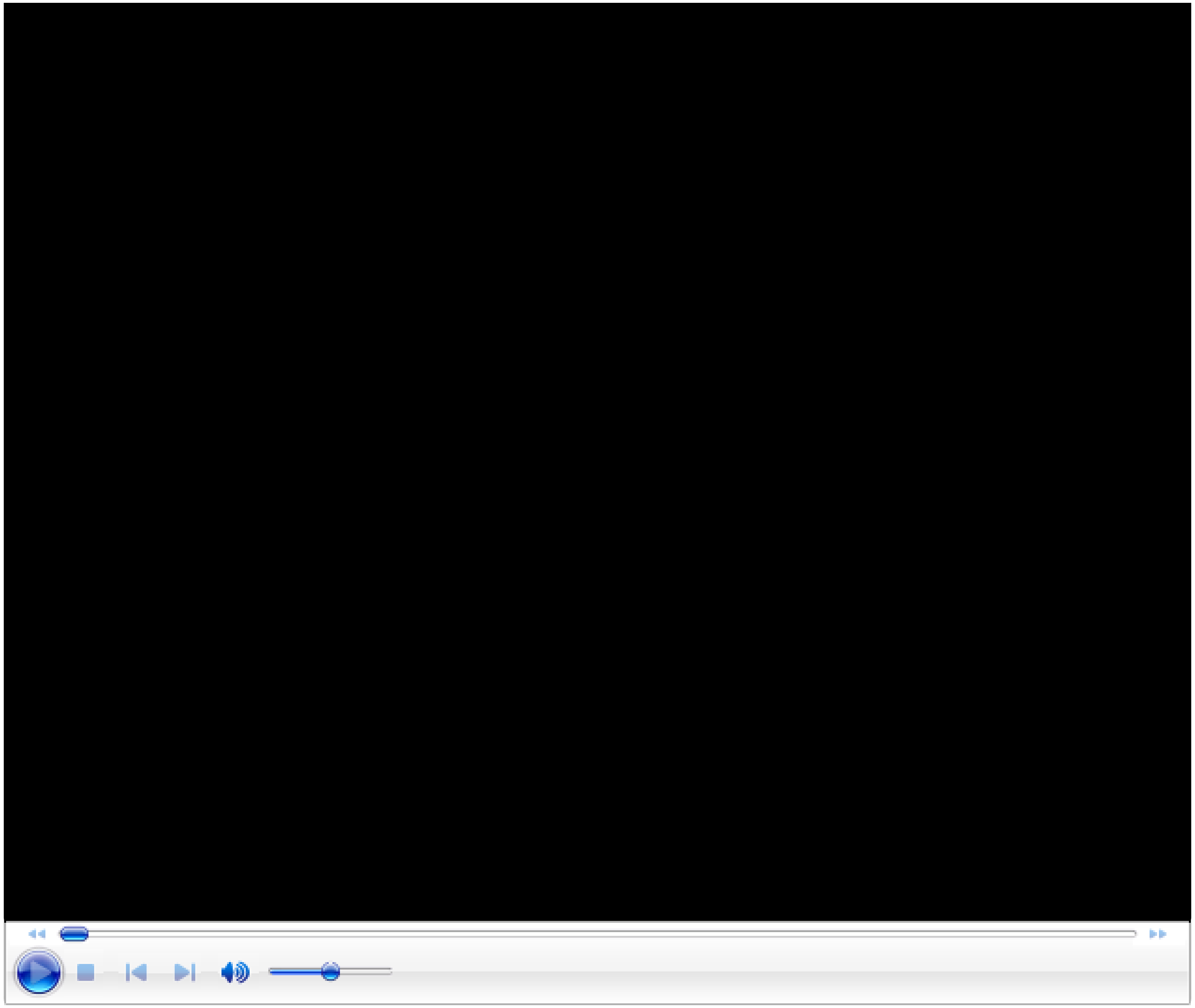
- The first life may have evolved through four stages.
  1. The abiotic (nonliving) synthesis of small organic molecules, such as amino acids and nitrogenous bases.
  2. The joining of these small molecules into polymers, such as proteins and nucleic acids.
  3. The packaging of these molecules into “protocells,” droplets with membranes that maintained an internal chemistry different from that of their surroundings.
  4. The origin of self-replicating molecules that eventually made inheritance possible.

15.2 SCIENTIFIC DISCOVERY: Experiments show that the abiotic synthesis of organic molecules is possible

- In the 1920s, two scientists, the Russian A. I. Oparin and the British J. B. S. Haldane, independently proposed that organic molecules could have formed on the early Earth.
- Our modern atmosphere is rich in O_2, which oxidizes and disrupts chemical bonds.
- The early Earth likely had a reducing atmosphere.

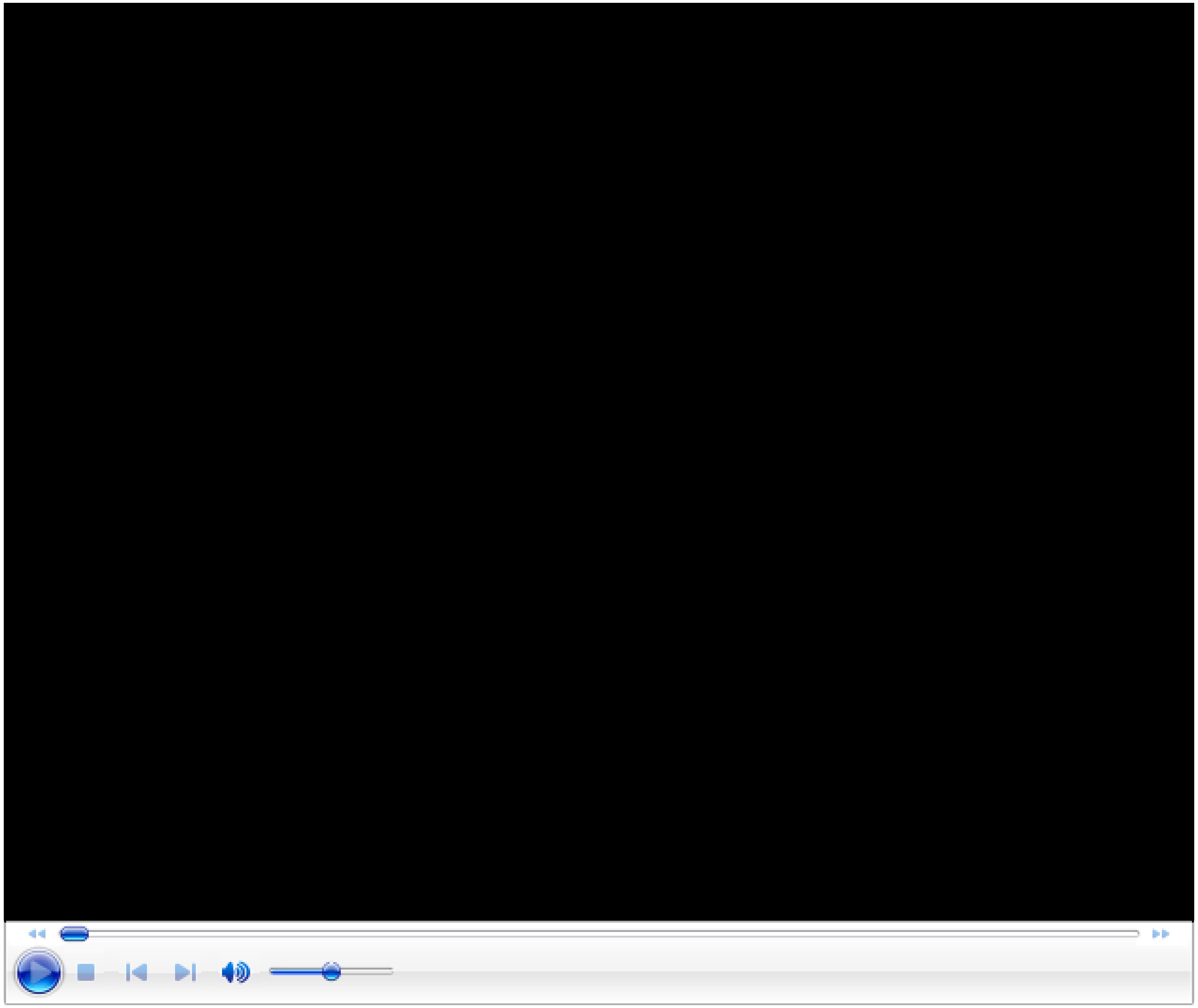
15.2 SCIENTIFIC DISCOVERY: Experiments show that the abiotic synthesis of organic molecules is possible

- In 1953, graduate student Stanley Miller, working under Harold Urey, tested the Oparin-Haldane hypothesis.
  - Miller set up an airtight apparatus with gases circulating past an electrical discharge, to simulate conditions on the early Earth.
  - He also set up a control with no electrical discharge.



Video: Hydrothermal Vent

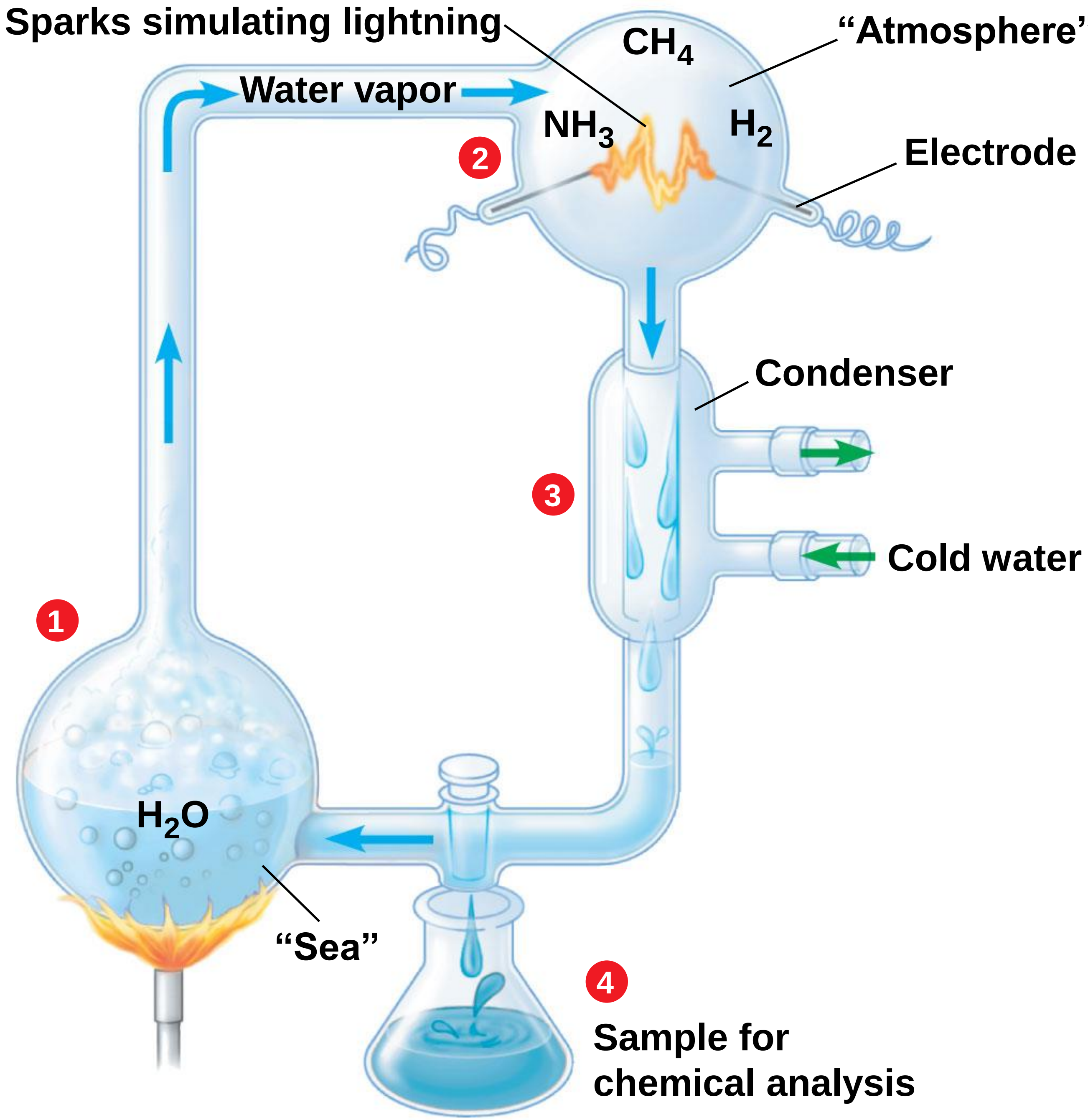
Use windows controls to play



Video: Tubeworms

Use windows controls to play

Figure 15.2A

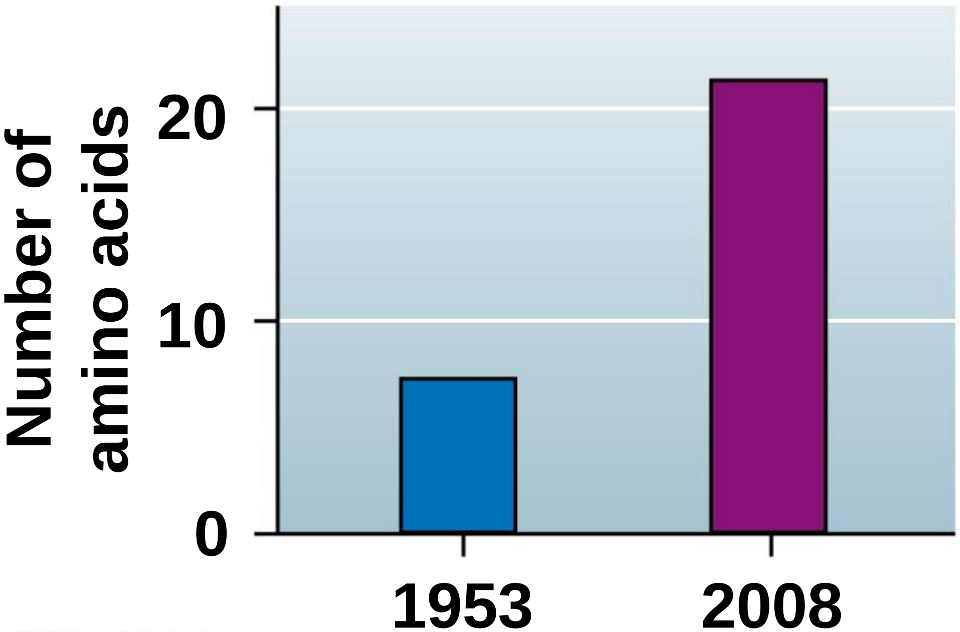


Sparks simulating lightning
Water vapor
CH_4
"Atmosphere"
NH_3
H_2
2
Electrode
Condenser
3
Cold water
1
H_2O
"Sea"
4
Sample for chemical analysis

15.2 SCIENTIFIC DISCOVERY: Experiments show that the abiotic synthesis of organic molecules is possible

- After a week, Miller's setup produced abundant amino acids and other organic molecules.
  - Similar experiments used other atmospheres and other energy sources, with similar results.
  - **Stage 1, abiotic synthesis of organic molecules**, was demonstrated to be possible by the Miller-Urey experiments.

Figure 15.2B



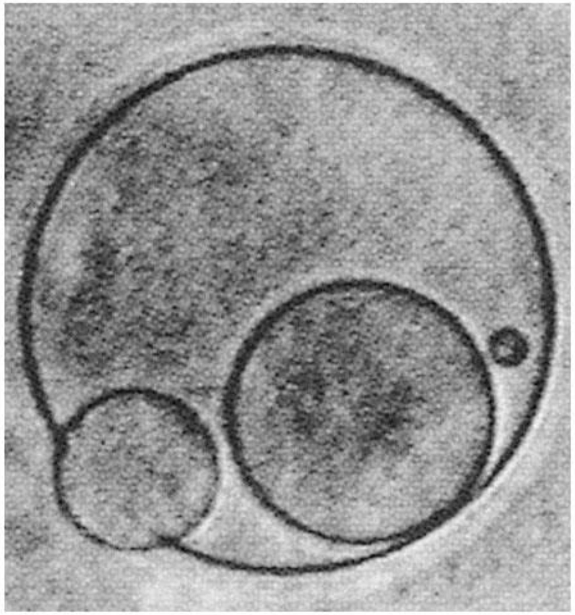
15.2 SCIENTIFIC DISCOVERY: Experiments show that the abiotic synthesis of organic molecules is possible

- Other hypotheses about the origins of life include
  - deep sea environments near submerged volcanoes or hydrothermal vents or
  - meteorites as sources of amino acids and other key organic molecules.

15.3 Stages in the origin of the first cells probably included the formation of polymers, protocells, and self-replicating RNA

- **Stage 2: The joining of monomers into polymers**
  - Hot sand, clay, or rock may have helped monomers combine to form polymers.
  - Waves may have splashed organic molecules onto fresh lava or other hot rocks and then rinsed polypeptides and other polymers back into the sea.

Figure 15.3A



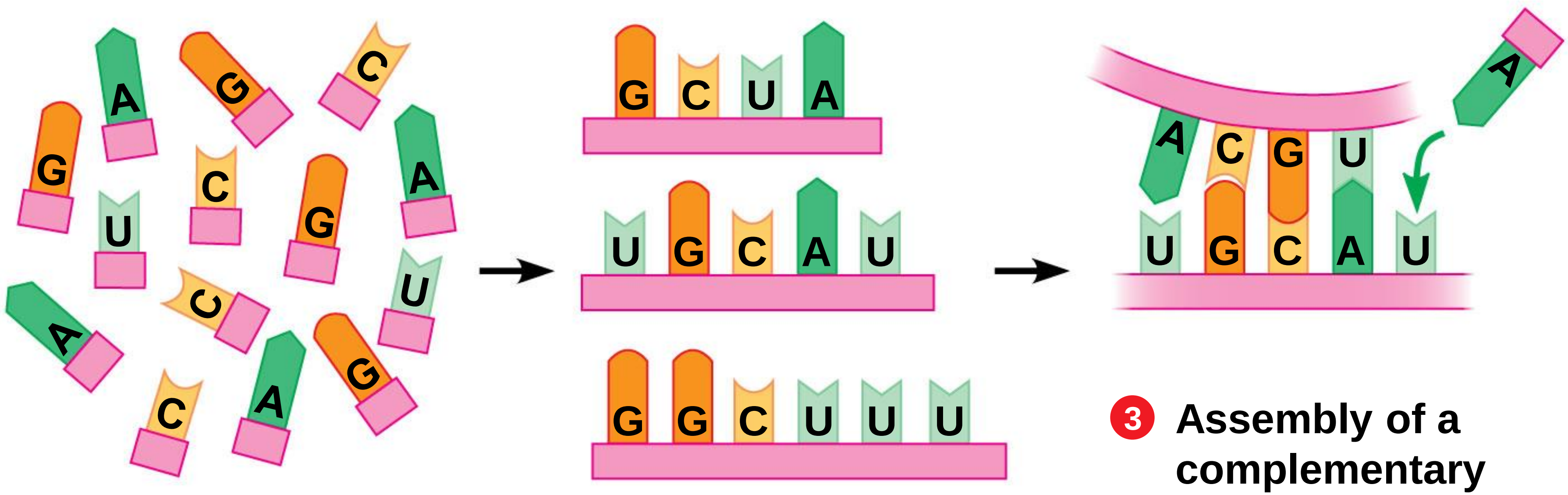
15.3 Stages in the origin of the first cells probably included the formation of polymers, protocells, and self-replicating RNA

- **Stage 3: Packaging of polymers into protocells**
  - Small membrane-bounded sacs or vesicles form when lipids are mixed with water.
  - These abiotically created vesicles are able to grow and divide (reproduce).

15.3 Stages in the origin of the first cells probably included the formation of polymers, protocells, and self-replicating RNA

- **Stage 4: The origin of self-replicating molecules**
  - Today's cells transfer genetic information from DNA to RNA to protein assembly. However, RNA molecules can assemble spontaneously from RNA monomers.
  - RNA monomers in the presence of RNA molecules form new RNA molecules complementary to parts of the starting RNA.
  - Some RNA molecules, called **ribozymes**, can carry out enzyme-like functions.

Figure 15.3B_s3



1 **Collection of monomers**

2 **Formation of short RNA polymers: simple "genes"**

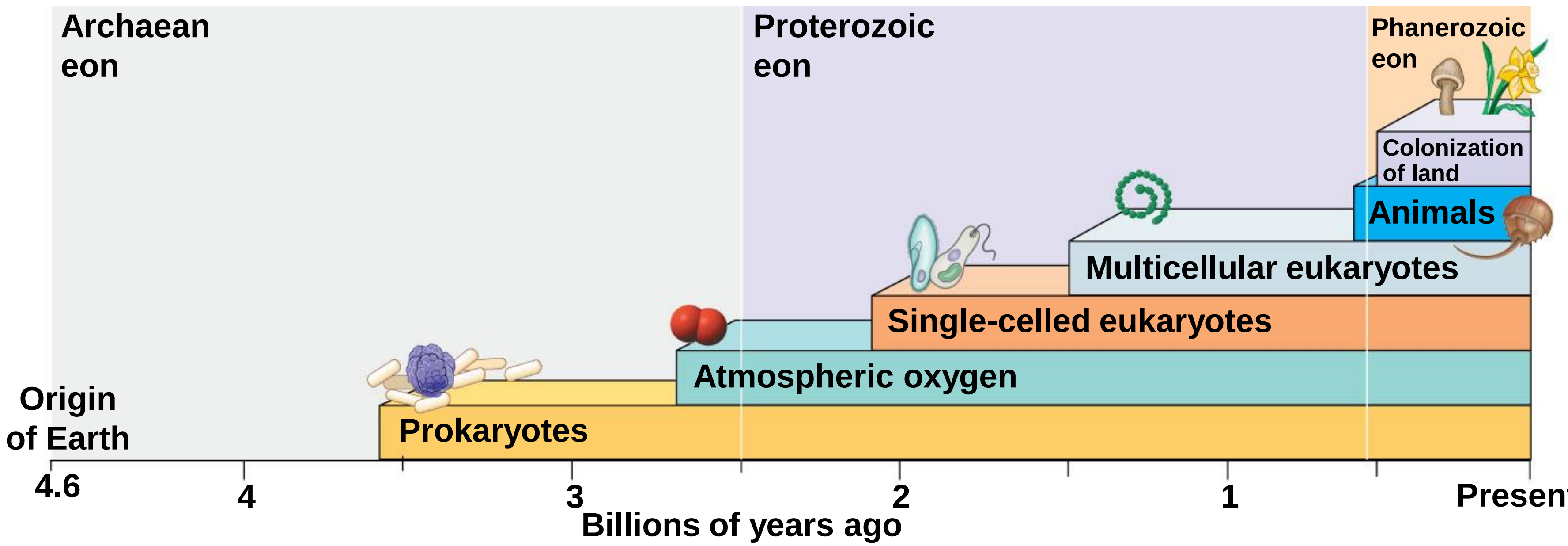
3 **Assembly of a complementary RNA chain, the first step in the replication of the original "gene"**

MAJOR EVENTS IN THE HISTORY OF LIFE

15.4 The origins of single-celled and multicelled organisms and the colonization of land were key events in life's history

- **Macroevolution** is the broad pattern of changes in life on Earth.
- The entire 4.6 billion years of Earth's history can be broken into three eons of geologic time.
  - The Archaean and Proterozoic eons lasted about 4 billion years.
  - The Phanerozoic eon includes the last half billion years.

Figure 15.4



Archaean eon
Proterozoic eon
Phanerozoic eon
Colonization of land
Animals
Multicellular eukaryotes
Single-celled eukaryotes
Atmospheric oxygen
Prokaryotes
Origin of Earth
4.6
4
3
2
1
Present
Billions of years ago

Figure 15.4_1

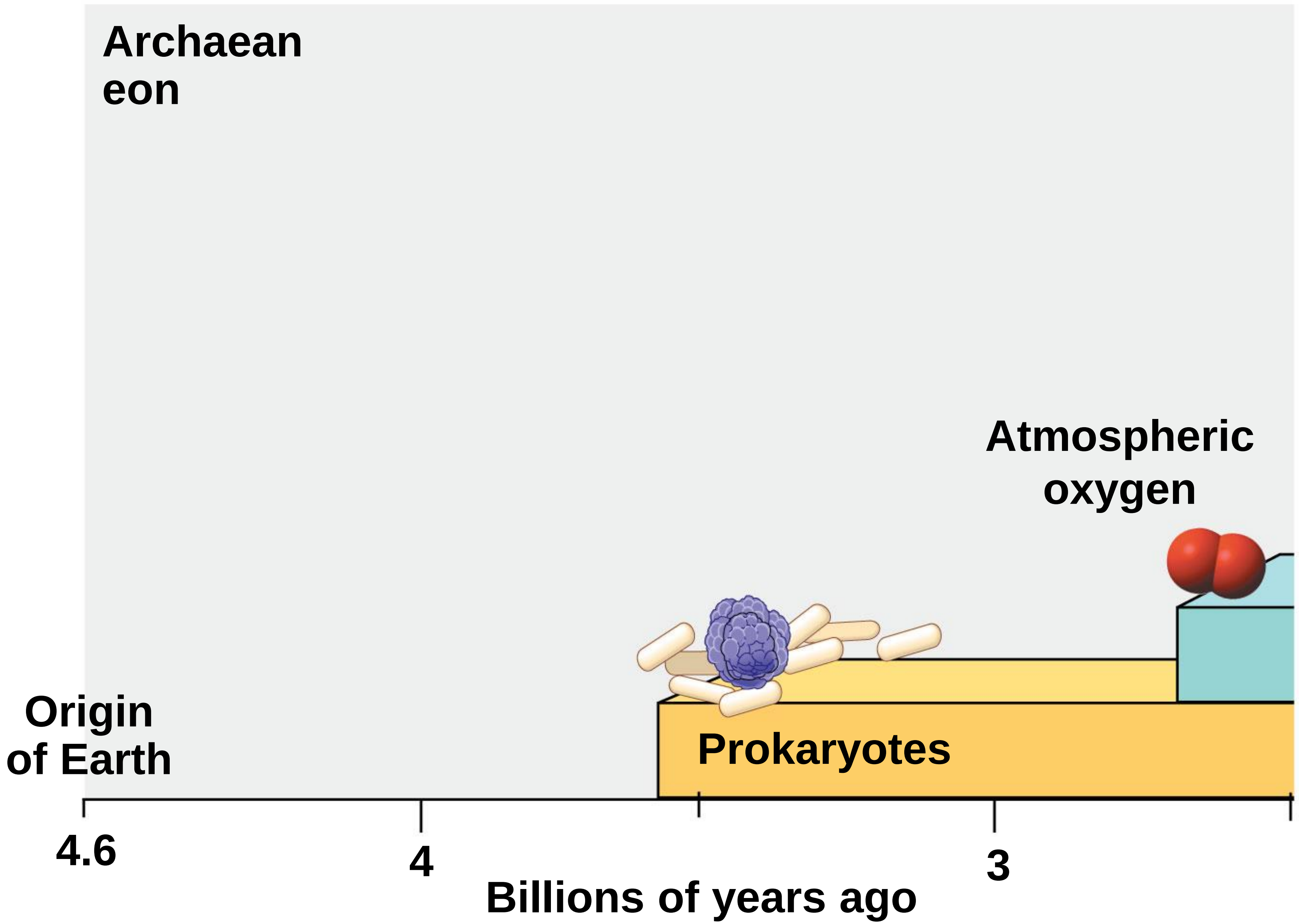
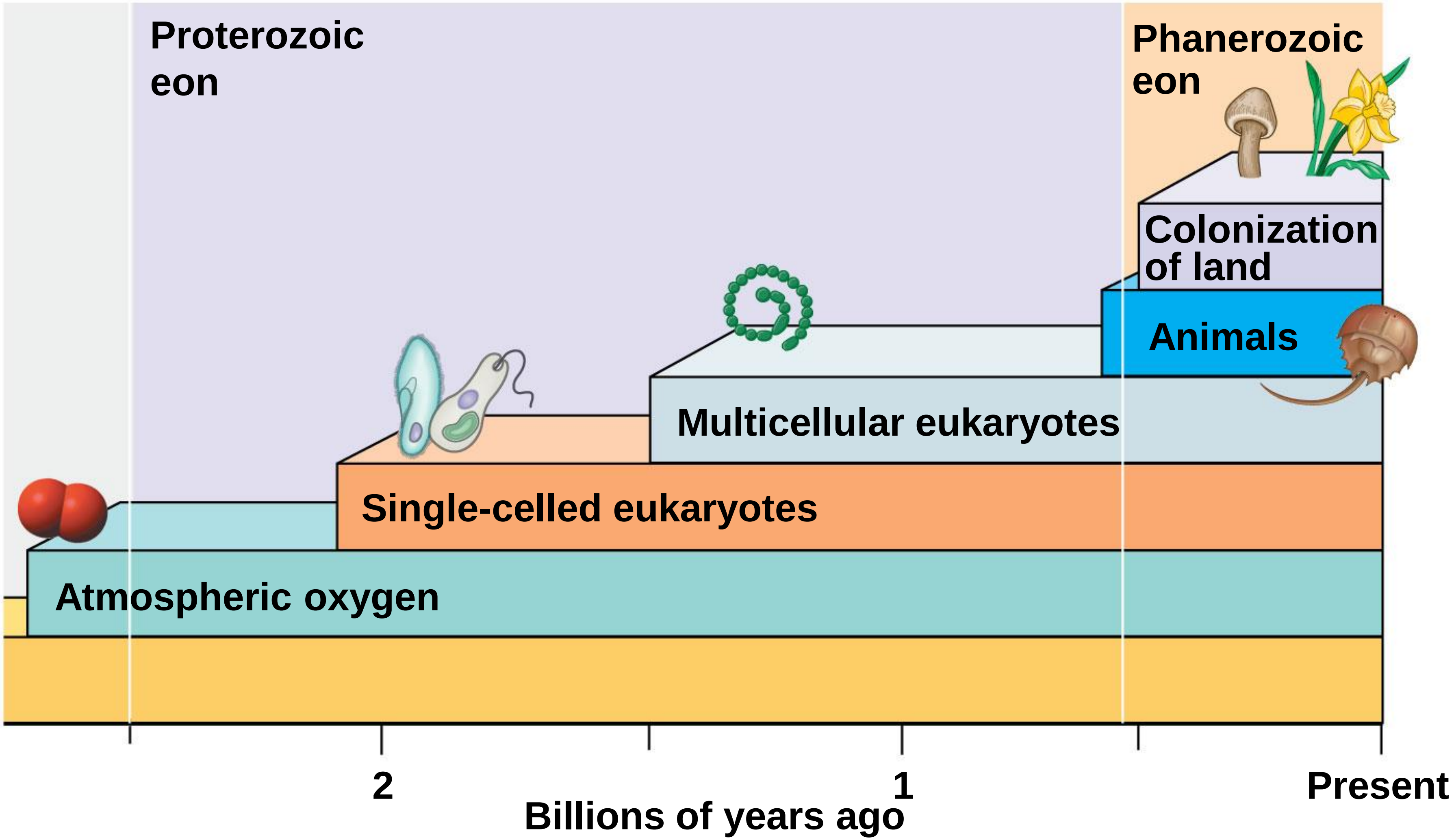

Archaean
eon
Atmospheric
oxygen
Origin
of Earth
Prokaryotes
4.6
4
3
Billions of years ago

Figure 15.4_2



Proterozoic eon
Phanerozoic eon
Colonization of land
Animals
Multicellular eukaryotes
Single-celled eukaryotes
Atmospheric oxygen
2
1
Present
Billions of years ago

15.4 The origins of single-celled and multicelled organisms and the colonization of land were key events in life's history

- Prokaryotes lived alone on Earth for 1.5 billion years, from 3.5 to 2 billion years ago.
  - During this time, prokaryotes transformed the atmosphere.
  - Prokaryotic photosynthesis produced oxygen that enriched the water and atmosphere of Earth.
  - Anaerobic and aerobic cellular respiration allowed prokaryotes to flourish.

15.4 The origins of single-celled and multicelled organisms and the colonization of land were key events in life's history

- The oldest fossils of eukaryotes are about 2.1 billion years old.
- The common ancestor of all multicellular eukaryotes lived about 1.5 billion years ago.
- The oldest fossils of multicellular eukaryotes are about 1.2 billion years old.
- The first multicellular plants and fungi began to colonize land about 500 million years ago.

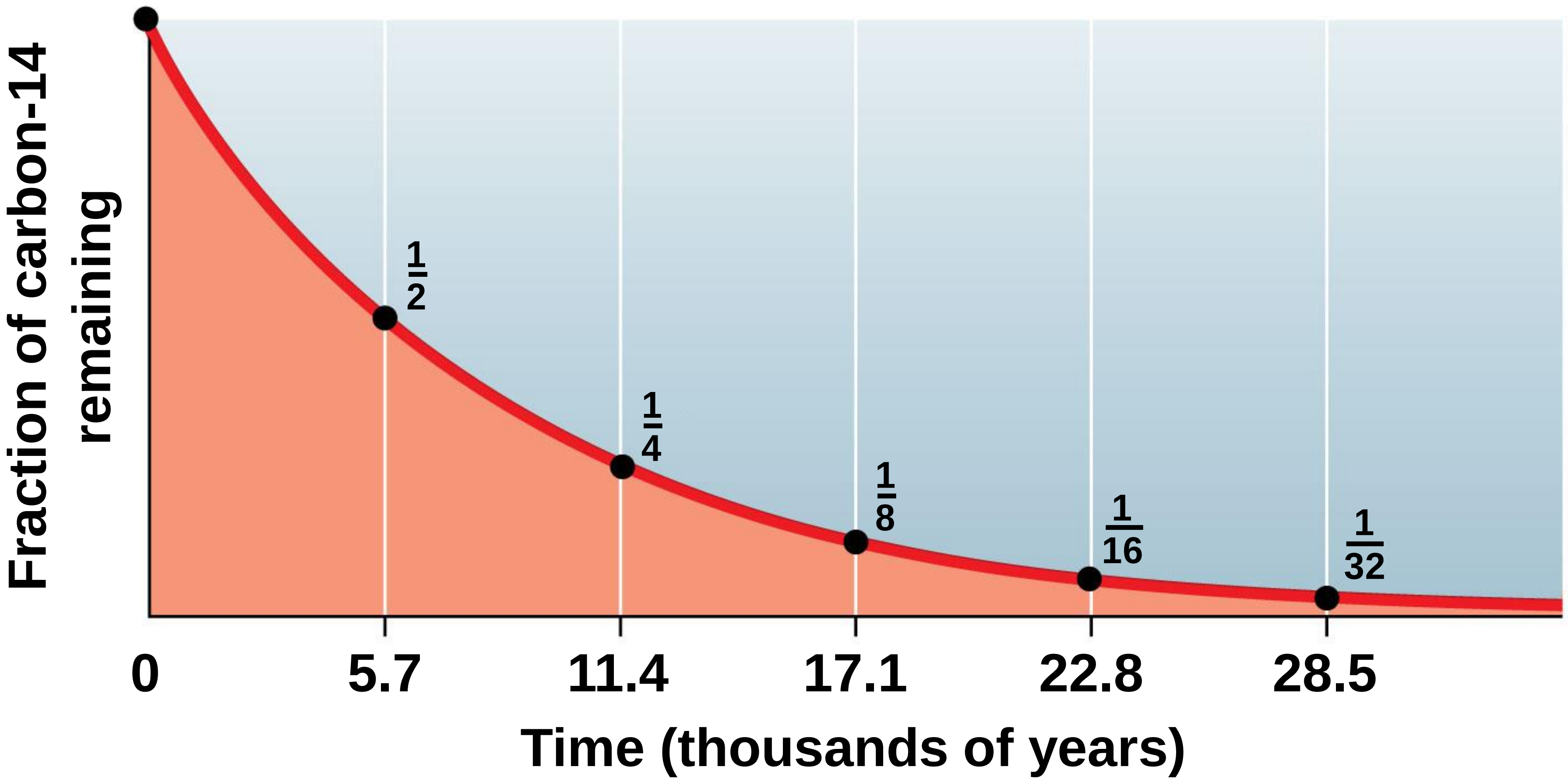
15.4 The origins of single-celled and multicelled organisms and the colonization of land were key events in life's history

- Humans diverged from other primates about 6 to 7 million years ago.
- Our species, *Homo sapiens*, originated about 195,000 years ago.
- If the Earth's history were compressed into an hour, humans appeared less than 0.2 seconds ago!

15.5 The actual ages of rocks and fossils mark geologic time

- **Radiometric dating** measures the decay of radioactive isotopes.
- The rate of decay is expressed as a half-life, the time required for 50% of an isotope in a sample to decay.
- There are many different isotopes that can be used to date fossils. These isotopes have different half-lives, ranging from thousands to hundreds of millions of years.

Figure 15.5



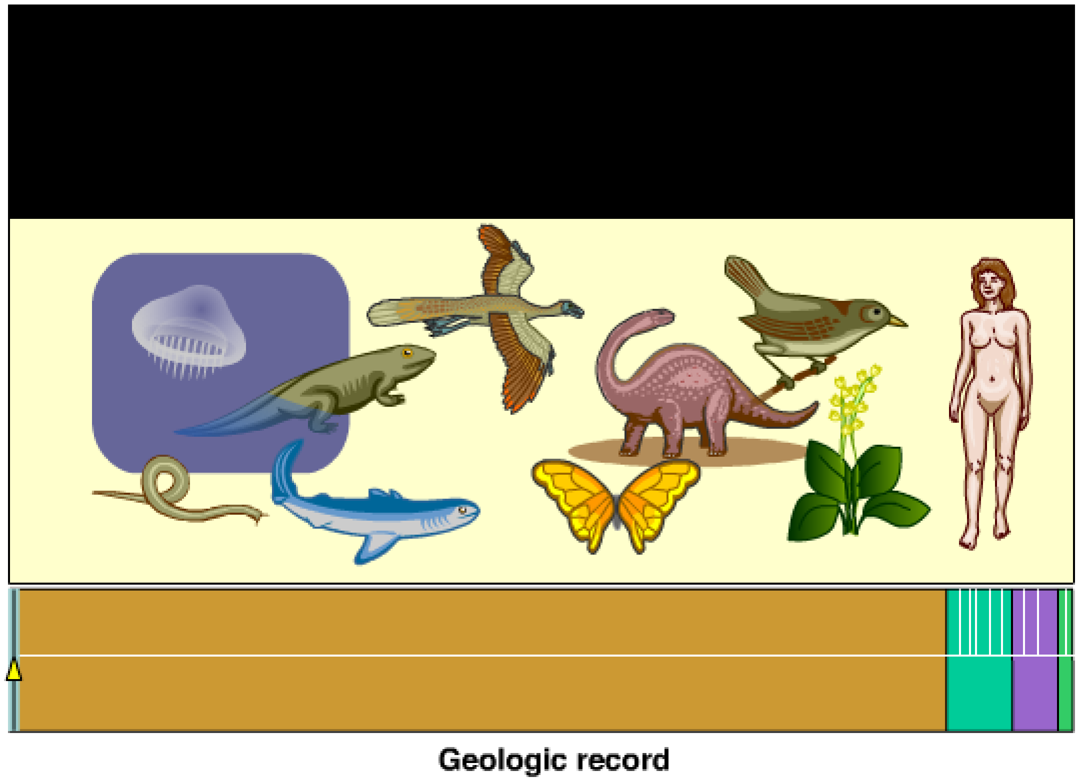
Fraction of carbon-14 remaining
1/2
1/4
1/8
1/16
1/32
0
5.7
11.4
17.1
22.8
28.5
Time (thousands of years)

15.5 The actual ages of rocks and fossils mark geologic time

- The age of a fossil can also be inferred from the ages of rock layers above and below the strata in which a fossil is found.

15.6 The fossil record documents the history of life

- The **geologic record** is based on the sequence and age of fossils in the rock strata.
- The most recent Phanerozoic eon
  - includes the past 542 million years and
  - is divided into three eras
    - Paleozoic,
    - Mesozoic, and
    - Cenozoic.
- The boundaries between eras are marked by mass extinctions.



Animation: The Geologic Record
Right click on animation / Click play

Table 15.6

TABLE 15.6 THE GEOLOGIC RECORD

Relative Duration of Eons	Era	Period	Epoch	Age (millions of years ago)	Important Events in the History of Life
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01	Historical time
			Pleistocene	2.6	Ice ages; origin of genus *Homo*
		Tertiary	Pliocene	5.3	Appearance of bipedal human ancestors
			Miocene	23	Continued radiation of mammals and angiosperms; earliest direct human ancestors
			Oligocene	33.9	Origins of many primate groups
			Eocene	55.8	Angiosperm dominance increases; continued radiation of most present-day mammalian orders
			Paleocene	65.5	Major radiation of mammals, birds, and pollinating insects
	Mesozoic	Cretaceous		145.5	Flowering plants (angiosperms) appear and diversify; many groups of organisms, including most dinosaurs, become extinct at end of period
		Jurassic		199.6	Gymnosperms continue as dominant plants; dinosaurs abundant and diverse
		Triassic		251	Cone-bearing plants (gymnosperms) dominate landscape; dinosaurs evolve and radiate; origin of mammals
	Paleozoic	Permian		299	Radiation of reptiles; origin of most present-day groups of insects; extinction of many marine and terrestrial organisms at end of period
		Carboniferous		359	Extensive forests of vascular plants form; first seed plants appear; origin of reptiles; amphibians dominant
		Devonian		416	Diversification of bony fishes; first tetrapods and insects appear
		Silurian		444	Diversification of early vascular plants
		Ordovician		488	Marine algae abundant; colonization of land by diverse fungi, plants, and animals
		Cambrian		542	Sudden increase in diversity of many animal phyla (Cambrian explosion)
Proterozoic		Ediacaran		635	Diverse algae and soft-bodied invertebrate animals appear
				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

Table 15.6_1

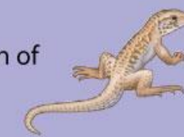
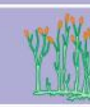
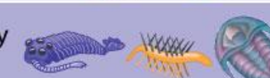
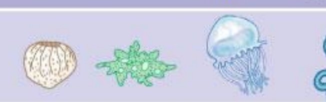
TABLE 15.6 THE GEOLOGIC RECORD

Order

Relative Duration of Eons	Era	Period	Epoch	Age (millions of years ago)	Important Events in the History of Life
Phan-erozoic	Cenozoic	Quaternary	Holocene		Historical time
				0.01	
			Pleistocene		Ice ages; origin of genus *Homo*
				2.6	
		Tertiary	Pliocene		Appearance of bipedal human ancestors
				5.3	
			Miocene		Continued radiation of mammals and angiosperms; earliest direct human ancestors
				23	
			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
Proter-ozoic				251	

Table 15.6_2

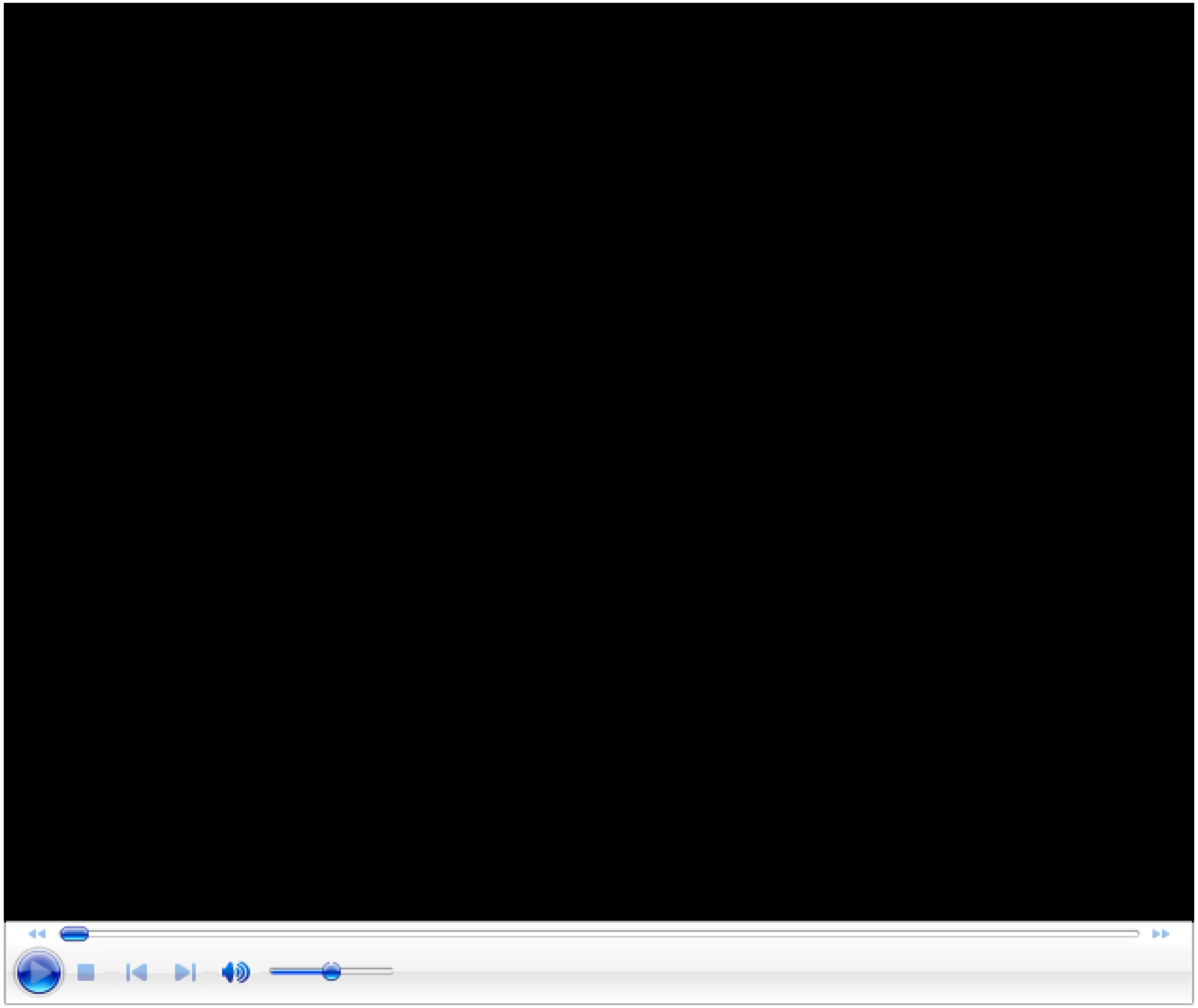
TABLE 15.6 THE GEOLOGIC RECORD

Relative Duration of Eons	Order Era	Period	Epoch	Age (millions of years ago)	Important Events in the History of Life
	Paleozoic	Permian		251	Radiation of reptiles; origin of most present-day groups of insects; extinction of many marine and terrestrial organisms at end of period 
		Carboniferous			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 
Archaean		Cambrian		488	Sudden increase in diversity of many animal phyla (Cambrian explosion) 
		Ediacaran		542	Diverse algae and soft-bodied invertebrate animals appear 
				635	
				2,100	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
				3,800	Oldest known rocks on Earth's surface
				Approx. 4,600	Origin of Earth

MECHANISMS OF MACROEVOLUTION

15.7 Continental drift has played a major role in macroevolution

- According to the theory of **plate tectonics**,
  - the Earth's crust is divided into giant, irregularly shaped plates that
  - essentially float on the underlying mantle.
- In a process called continental drift, movements in the mantle cause the plates to move.
- Since the origin of multicellular life roughly 1.5 billion years ago, there have been three occasions in which the landmasses of Earth came together to form a supercontinent.



Video: Lava Flow

Use window controls to play

Figure 15.7A

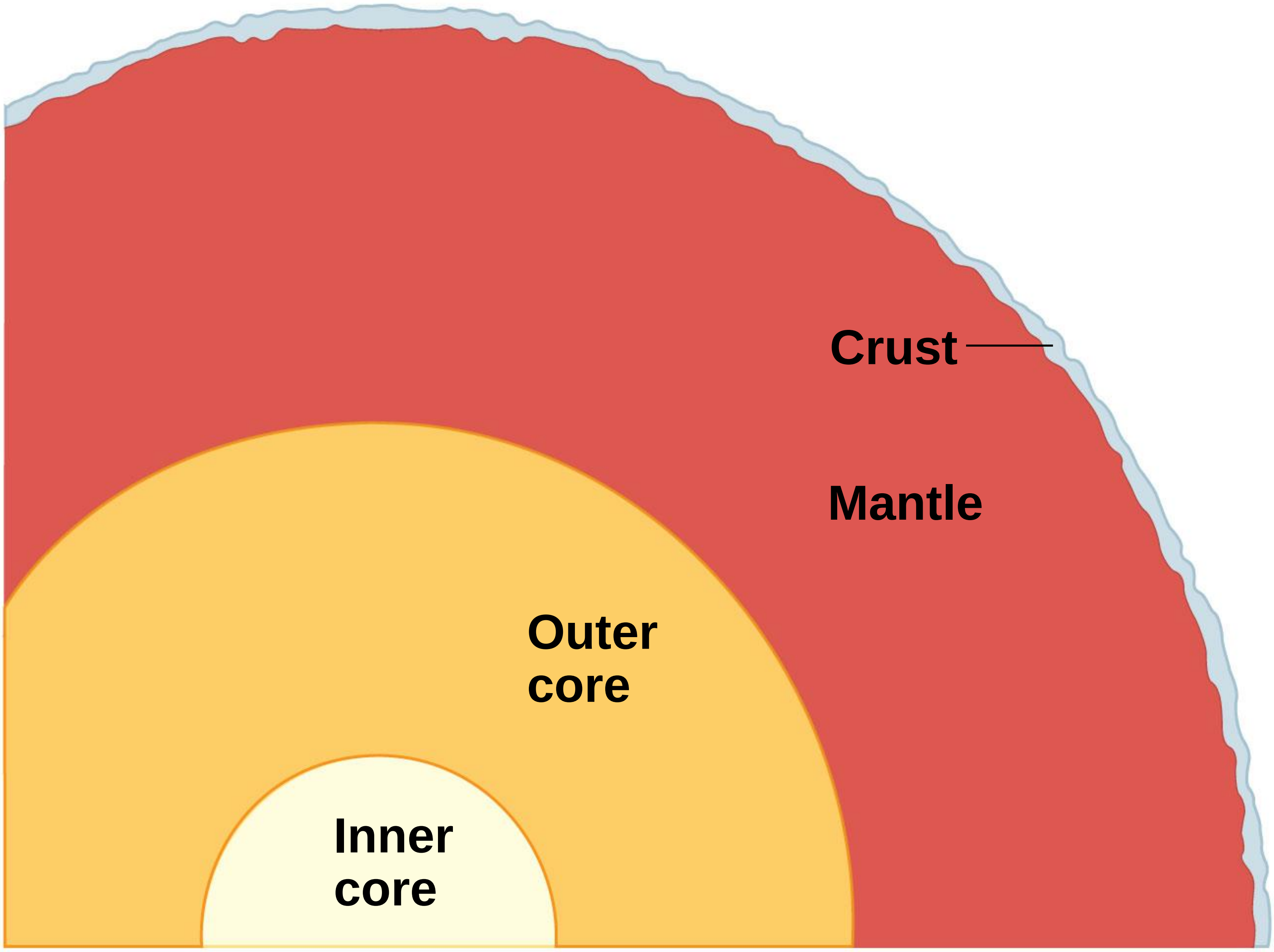
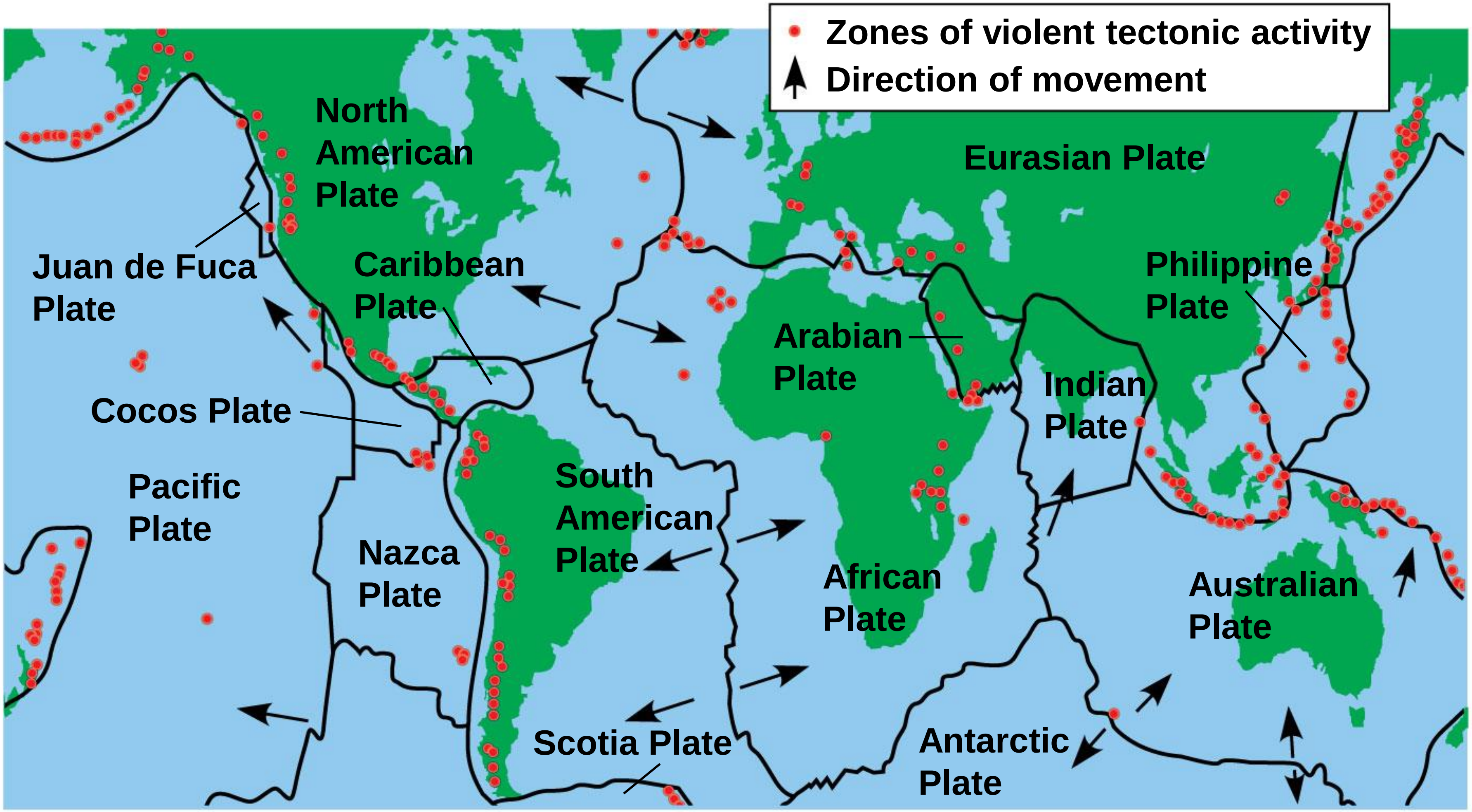


Figure 15.7B

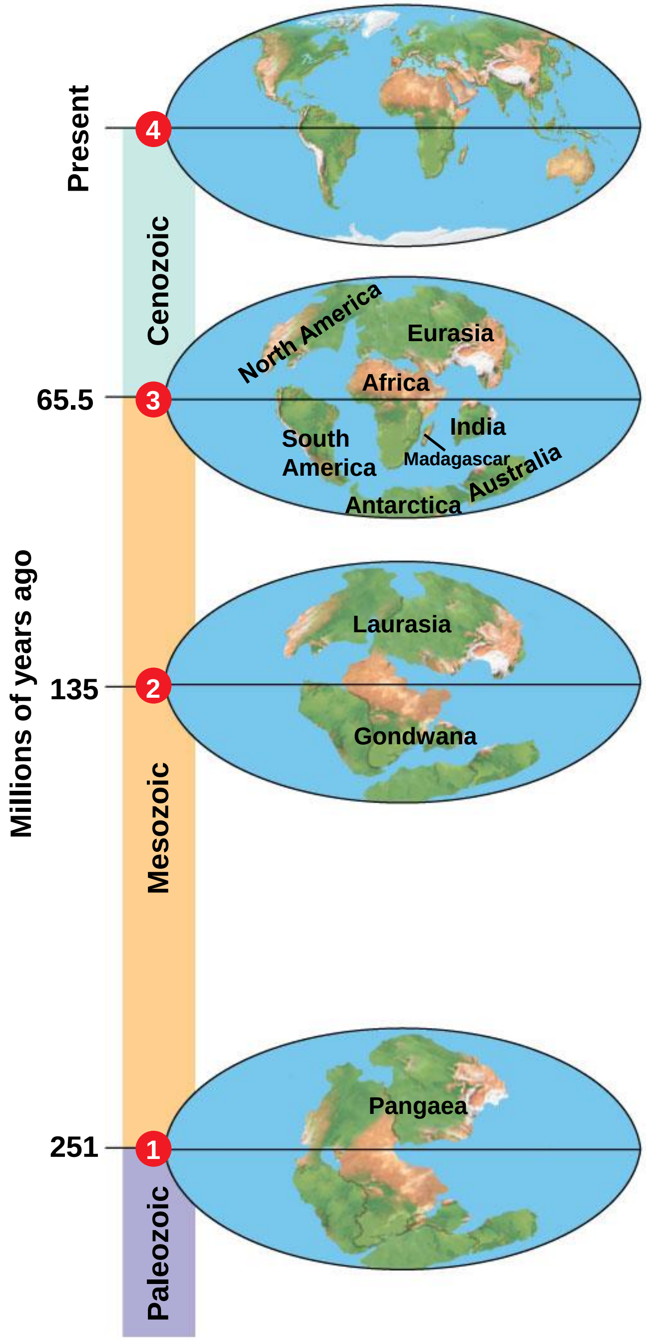


Zones of violent tectonic activity
Direction of movement
North American Plate
Eurasian Plate
Juan de Fuca Plate
Caribbean Plate
Philippine Plate
Arabian Plate
Indian Plate
Cocos Plate
Pacific Plate
South American Plate
Nazca Plate
African Plate
Australian Plate
Scotia Plate
Antarctic Plate

15.7 Continental drift has played a major role in macroevolution

- About 250 million years ago
  - plate movements brought all the landmasses together and
  - the supercontinent of **Pangaea** was formed.
- During the Mesozoic era,
  - Pangaea started to break apart,
  - the physical environment and climate changed dramatically,
  - Australia became isolated, and
  - biological diversity was reshaped.

Figure 15.7C



Present
4
Cenozoic
65.5
3
North America
Eurasia
Africa
South America
India
Madagascar
Australia
Antarctica
Millions of years ago
Laurasia
135
2
Gondwana
Mesozoic
Pangaea
251
1
Paleozoic

Figure 15.7C_1

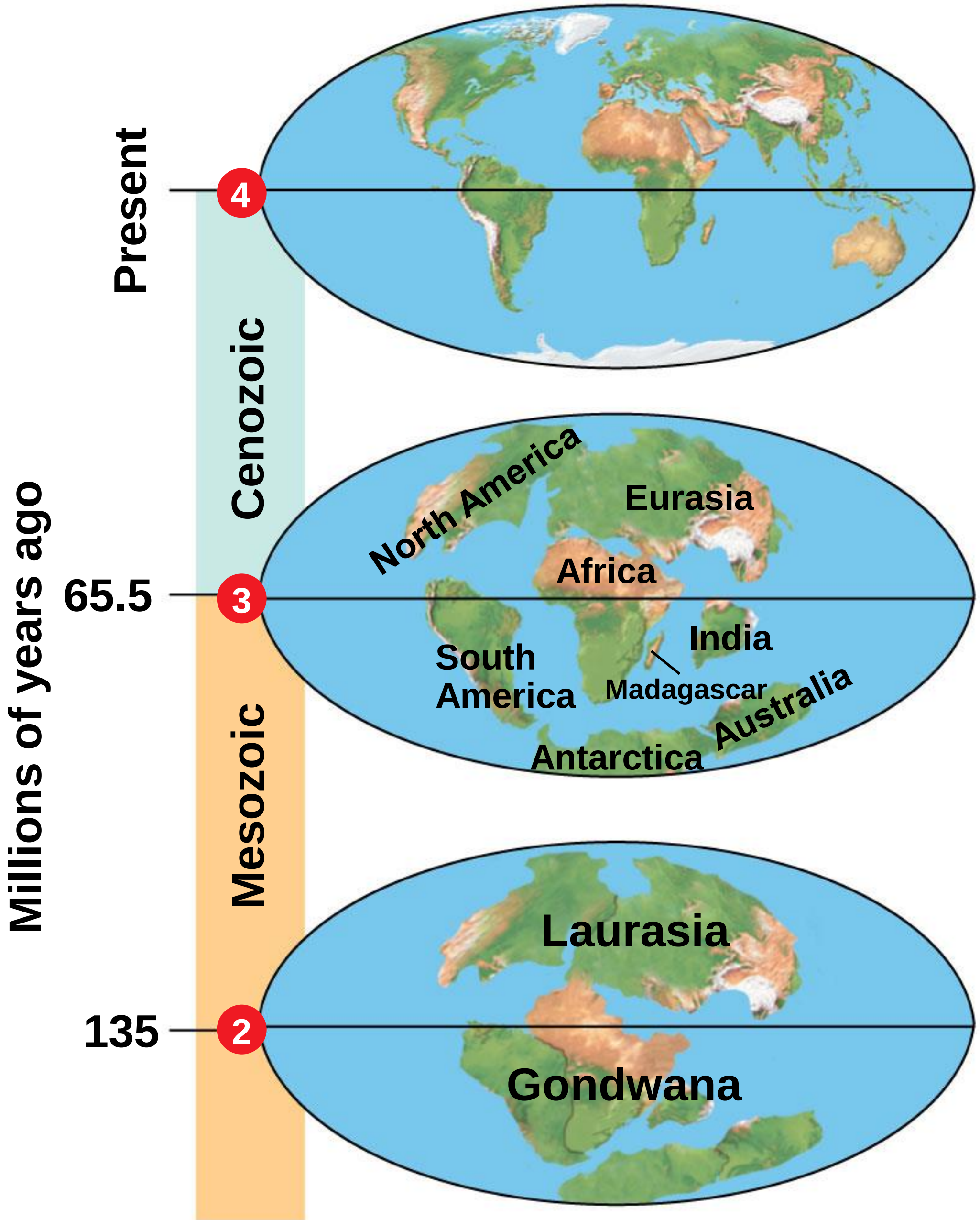
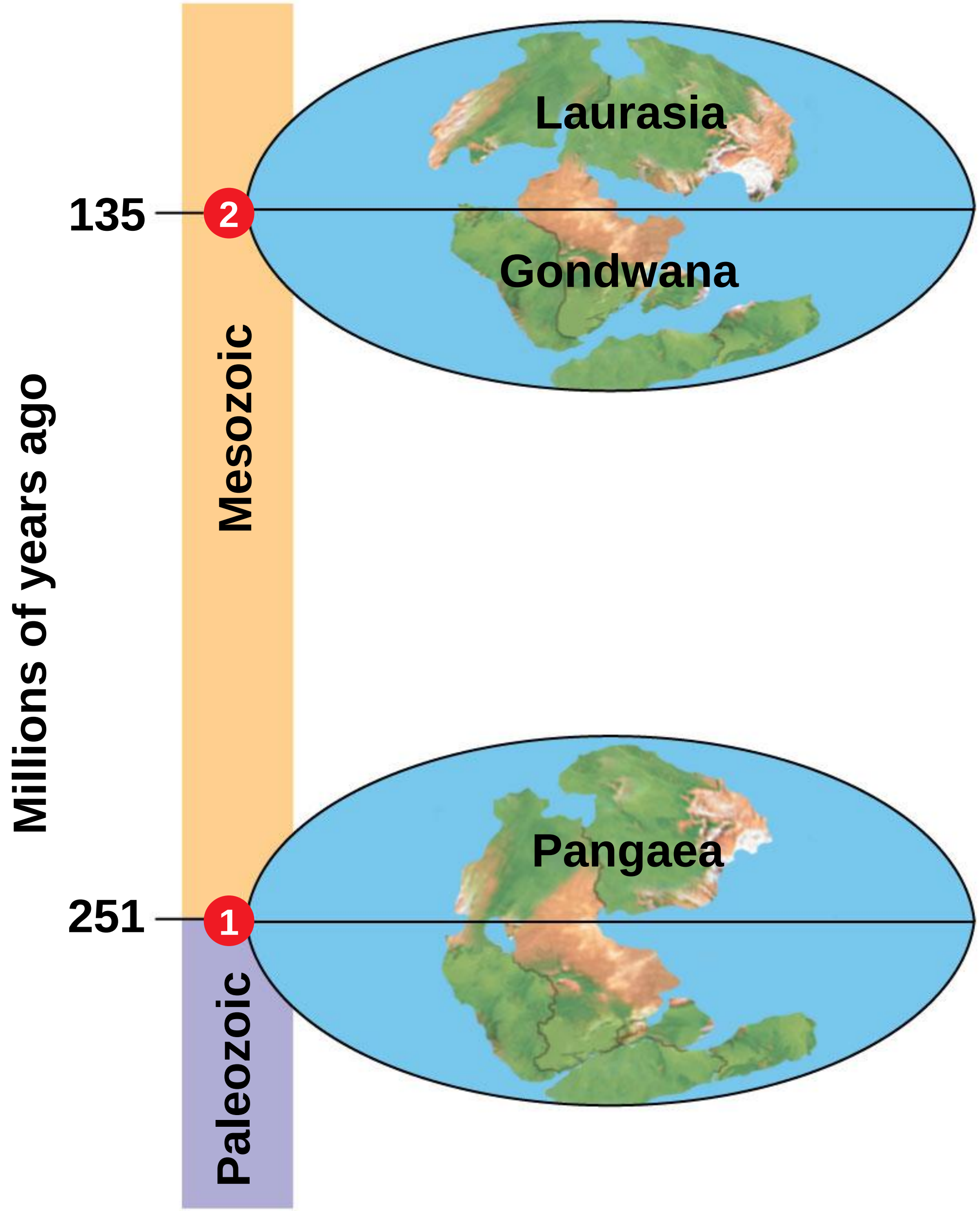


Figure 15.7C_2



15.7 Continental drift has played a major role in macroevolution

- Continental drift explains the distribution of lungfishes.
  - Fossils of lungfishes are found on every continent except Antarctica.
  - Today, living lungfishes are found in
    - South America,
    - Africa, and
    - Australia.
  - This evidence suggests that lungfishes evolved when Pangaea was still intact.

Figure 15.7D

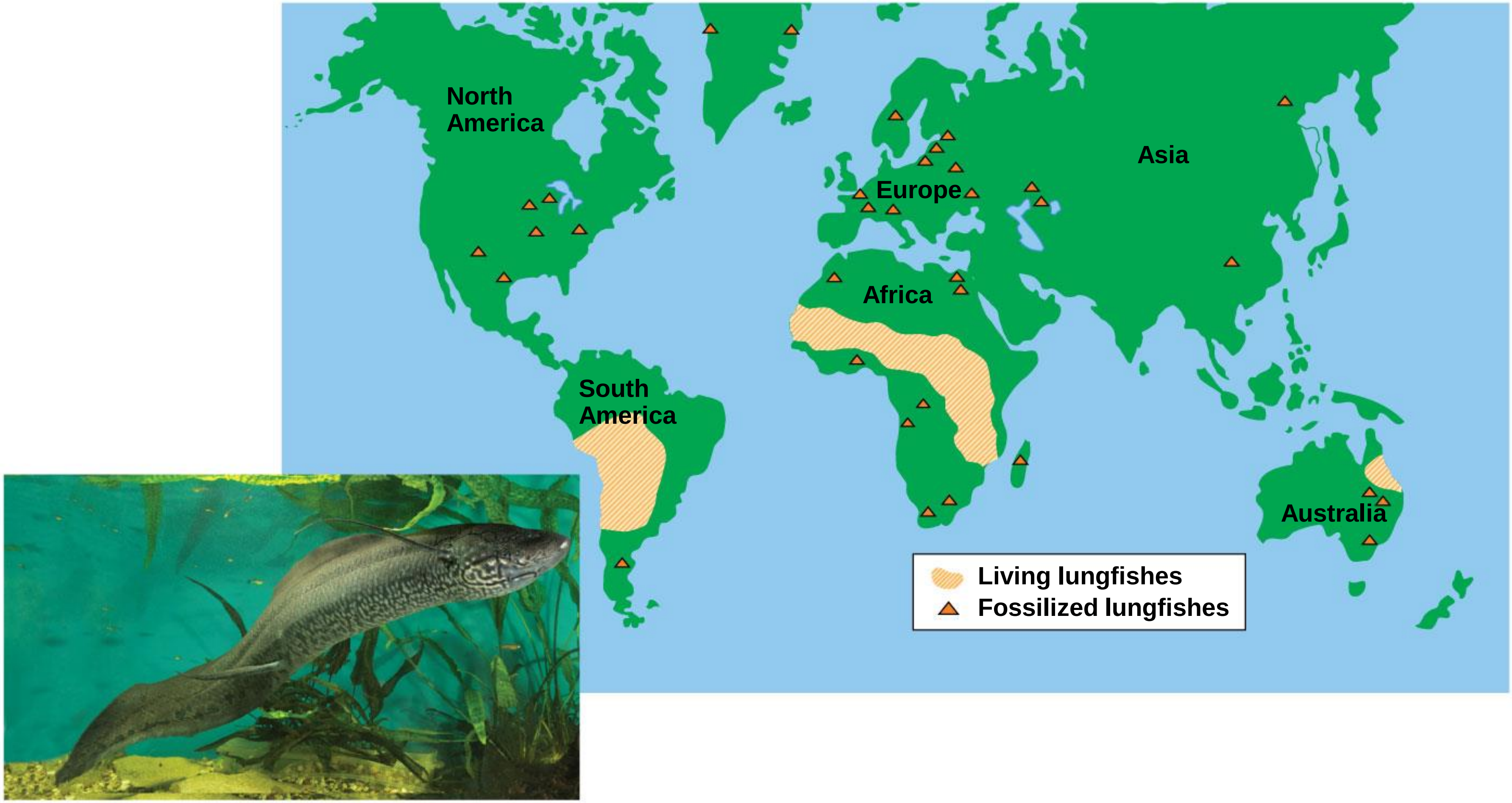

North America
South America
Europe
Africa
Asia
Australia
Living lungfishes
Fossilized lungfishes

Figure 15.7D_1

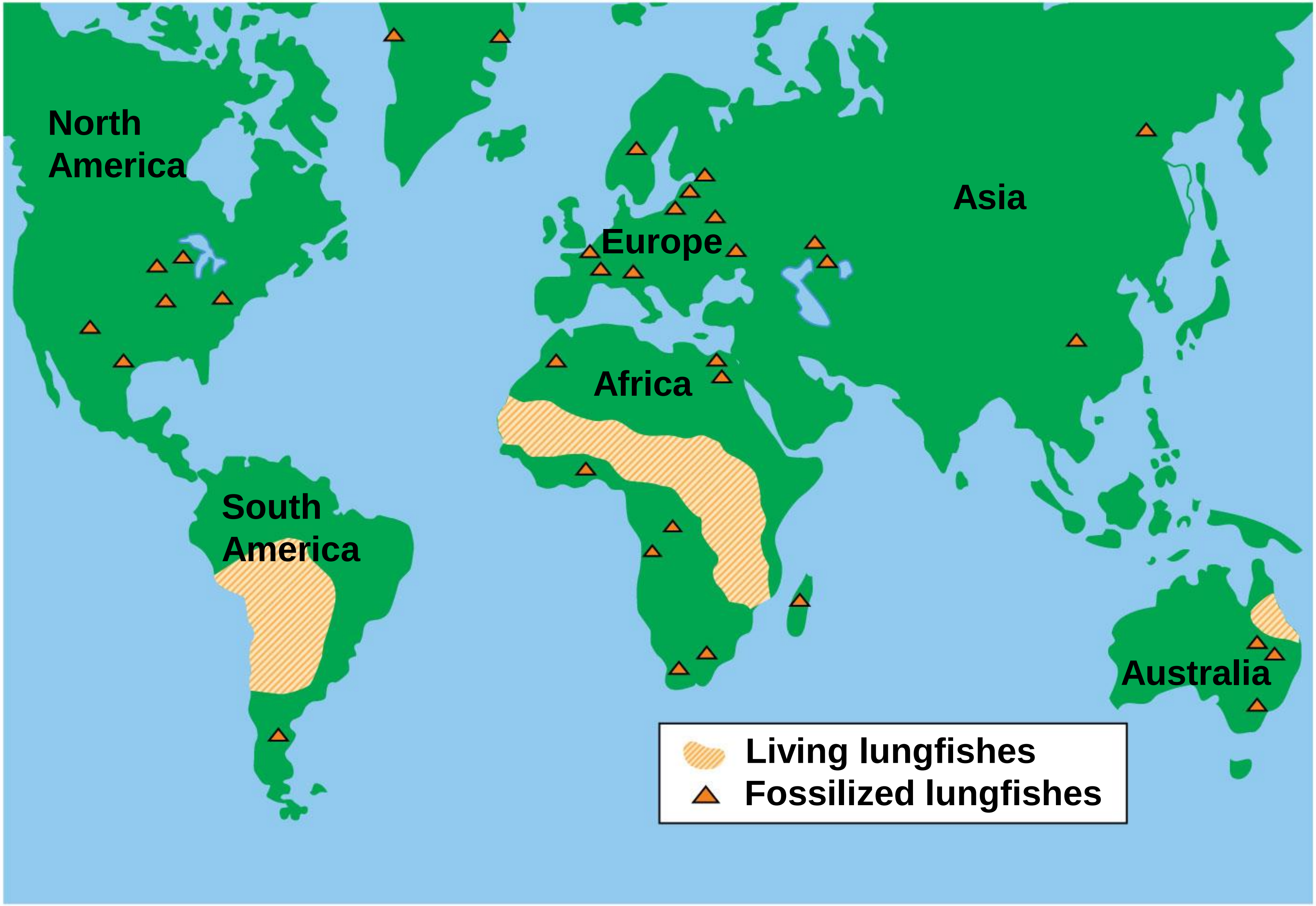
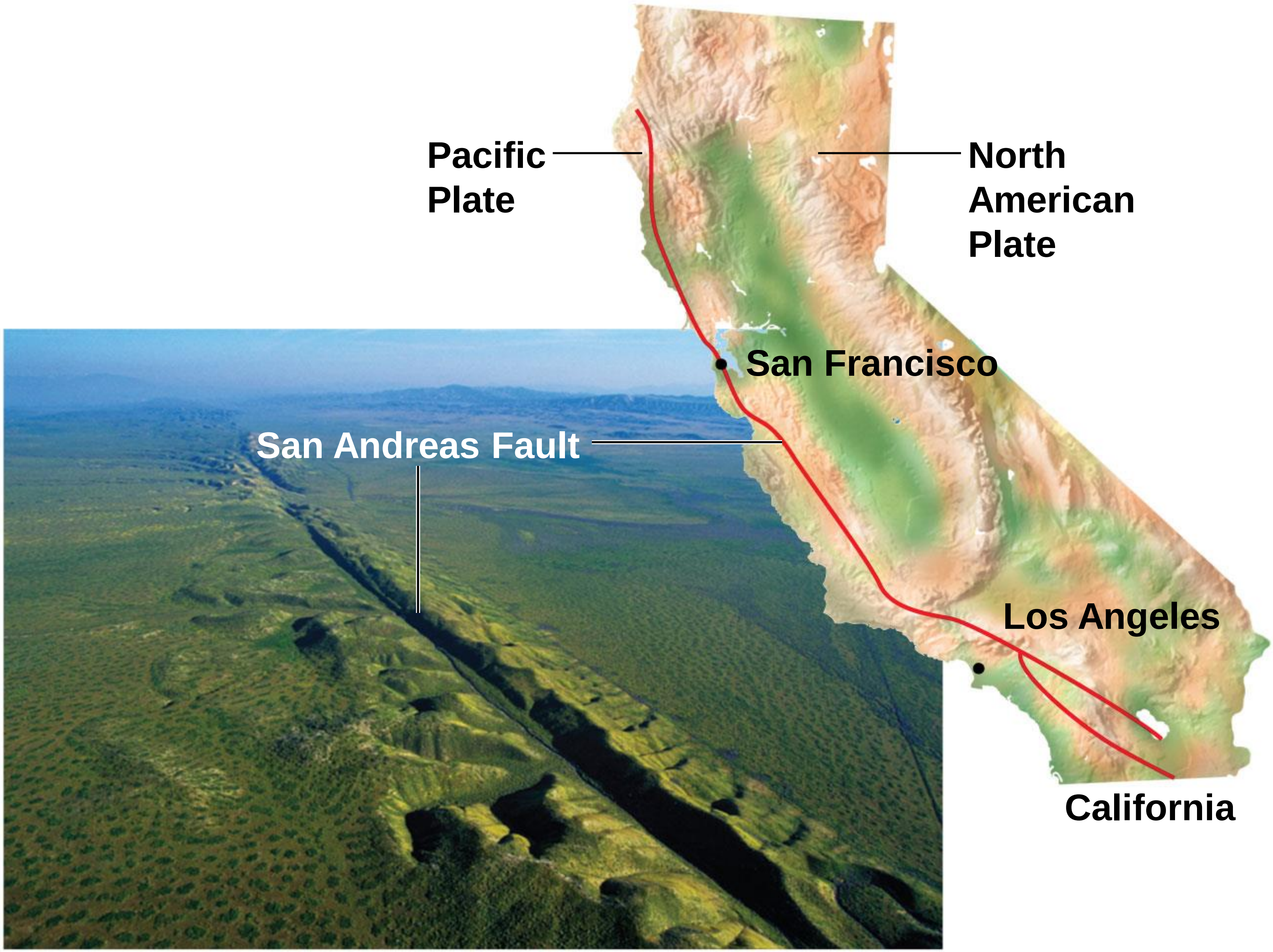


Figure 15.7D_2

15.8 CONNECTION: Plate tectonics may imperil human life

- Volcanoes and earthquakes result from the movements of crustal plates.
  - The boundaries of plates are hotspots of volcanic and earthquake activity.
  - An undersea earthquake caused the 2004 tsunami, when a fault in the Indian Ocean ruptured.

Figure 15.8


Pacific
Plate
North
American
Plate
San Francisco
San Andreas Fault
Los Angeles
California

15.9 During mass extinctions, large numbers of species are lost

- Extinction is inevitable in a changing world.
- The fossil record shows that the vast majority of species that have ever lived are now extinct.
- Over the last 500 million years,
  - five mass extinctions have occurred, and
  - in each event, more than 50% of the Earth's species went extinct.

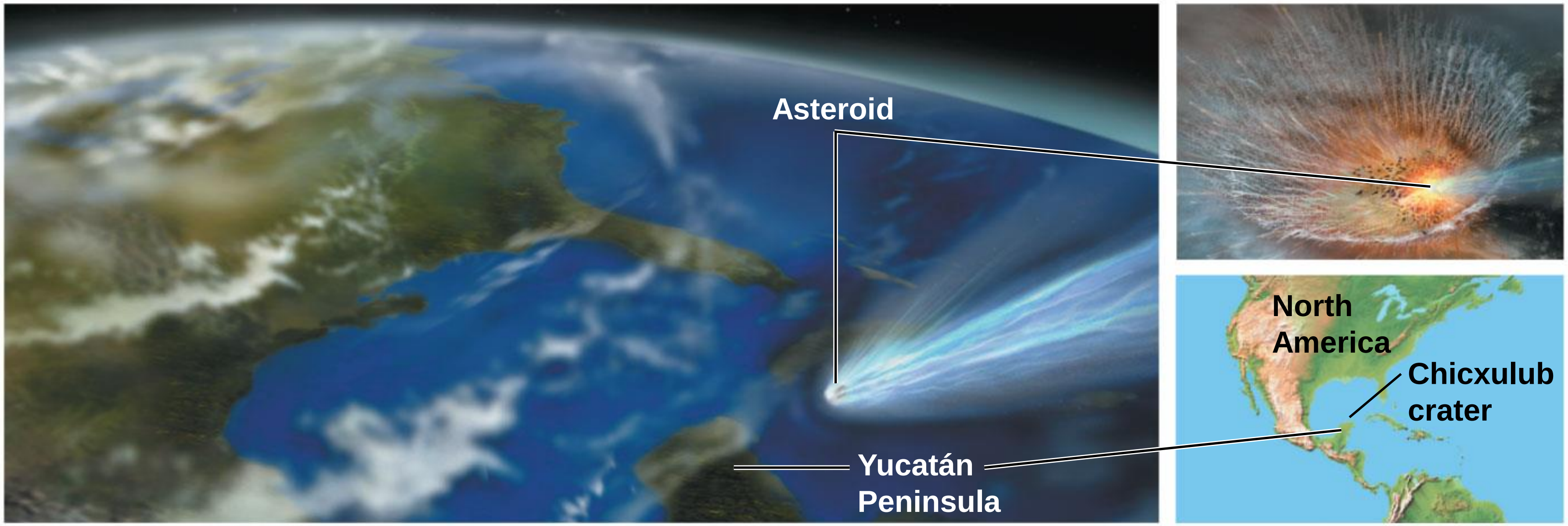
15.9 During mass extinctions, large numbers of species are lost

- The Permian mass extinction
  - occurred about 251 million years ago,
  - defines the boundary between the Paleozoic and Mesozoic eras,
  - claimed 96% of marine animal species,
  - took a tremendous toll on terrestrial life, and
  - was likely caused by enormous volcanic eruptions.

15.9 During mass extinctions, large numbers of species are lost

- The Cretaceous mass extinction
  - caused the extinction of all the dinosaurs except birds and
  - was likely caused by a large asteroid that struck the Earth, blocking light and disrupting the global climate.

Figure 15.9


Asteroid
Yucatán Peninsula
North America
Chicxulub crater

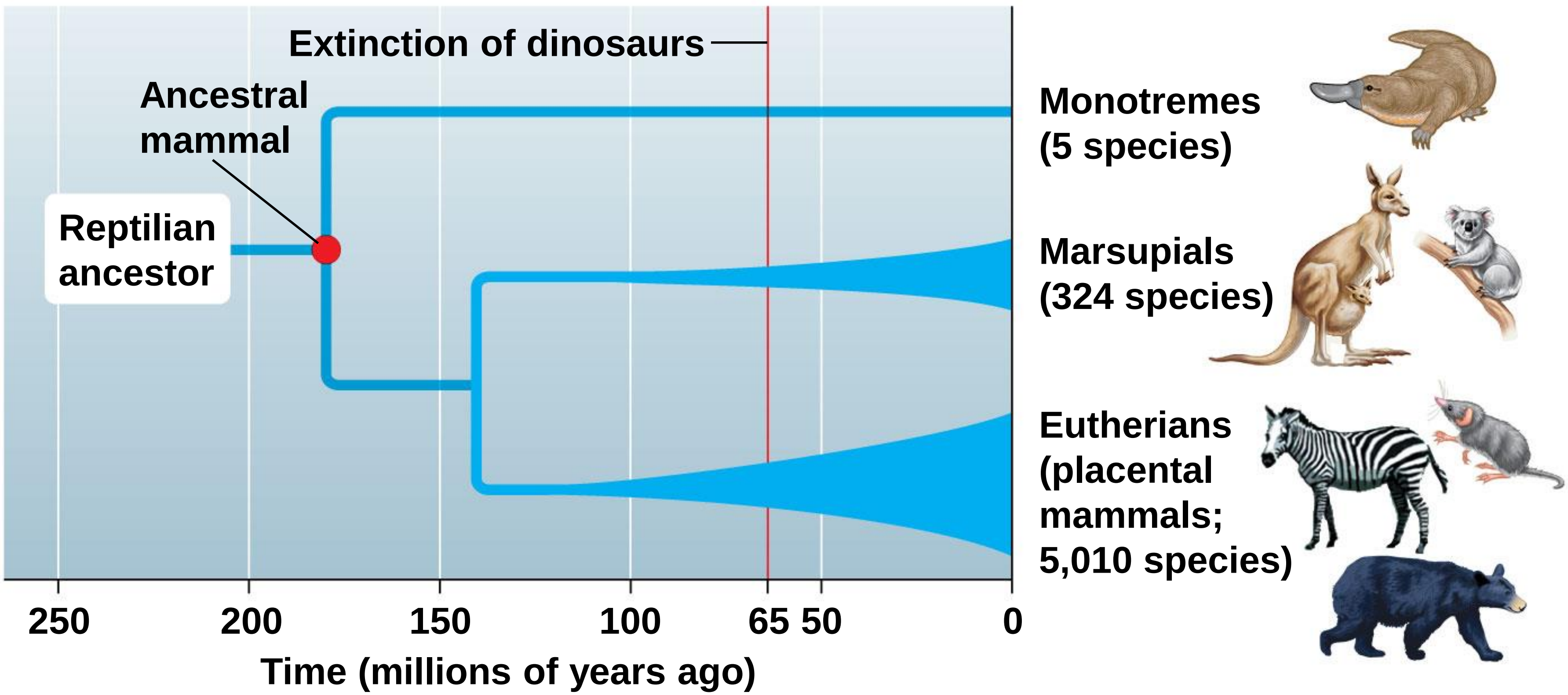
15.9 During mass extinctions, large numbers of species are lost

- Mass extinctions affect biological diversity profoundly.
- It took 100 million years for the number of marine families to recover after Permian mass extinction.
- Is a sixth extinction under way?
  - The current extinction rate is 100–1,000 times the normal background rate.
  - It may take life on Earth millions of years to recover.

15.10 Adaptive radiations have increased the diversity of life

- Adaptive radiations are periods of evolutionary change that
  - occur when many new species evolve from a common ancestor that colonizes a new, unexploited area and
  - often follow extinction events.
- Radiations may result from the evolution of new adaptations such as
  - wings in pterosaurs, birds, bats, and insects and
  - adaptations for life on land in plants, insects, and tetrapods.

Figure 15.10



Extinction of dinosaurs
Ancestral mammal
Reptilian ancestor
Monotremes (5 species)
Marsupials (324 species)
Eutherians (placental mammals; 5,010 species)
250
200
150
100
65 50
0
Time (millions of years ago)

15.11 Genes that control development play a major role in evolution

- The fossil record can tell us
  - *what* the great events in the history of life have been and
  - *when* they occurred.
- Continental drift, mass extinctions, and adaptive radiation provide a big-picture view of *how* those changes came about.
- We are now increasingly able to understand the basic biological mechanisms that underlie the changes seen in the fossil record.

15.11 Genes that control development play a major role in evolution

- The field of **evo-devo**
  - addresses the interface of evolutionary biology and developmental biology and
  - examines how slight genetic changes can produce major morphological differences.
- Genes that program development control the
  - rate,
  - timing, and
  - spatial pattern of change in an organism's form as it develops.

Animation: Allometric Growth

Right click on animation / Click play

15.11 Genes that control development play a major role in evolution

- Many dramatic evolutionary transformations are the result of a change in the rate or timing of developmental events.
- **Paedomorphosis**
  - is the retention in the adult of body structures that were juvenile features in an ancestral species and
  - occurs in the axolotl salamander in which sexually mature adults retain gills and other larval features.

Figure 15.11A

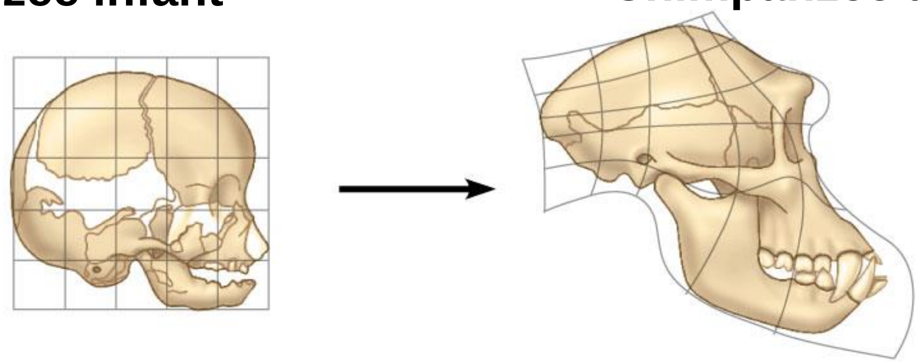
15.11 Genes that control development play a major role in evolution

- Slight changes in the relative growth of different body parts can change an adult form substantially.
- Skulls of humans and chimpanzees are
  - more similar as fetuses but
  - quite different as adults due to different rates of growth.

Figure 15.11B

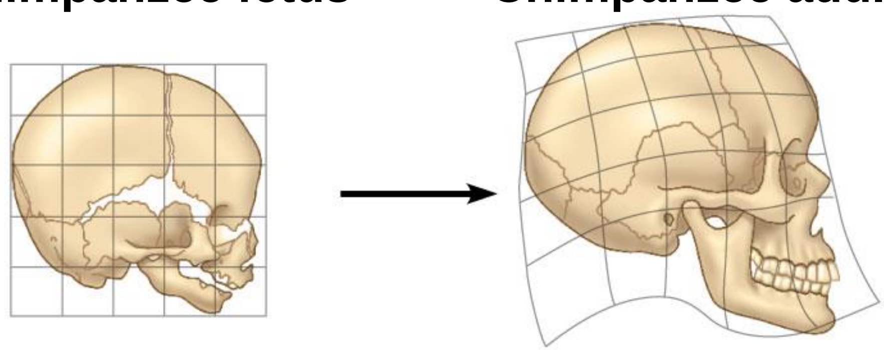
Chimpanzee infant

Chimpanzee adult



Chimpanzee fetus

Chimpanzee adult



Human fetus

Human adult

15.11 Genes that control development play a major role in evolution

- **Homeotic genes**
  - are called master control genes and
  - determine basic features, such as where pairs of wings or legs develop on a fruit fly.
- Profound alterations in body form can result from
  - changes in homeotic genes or
  - how or where homeotic genes are expressed.

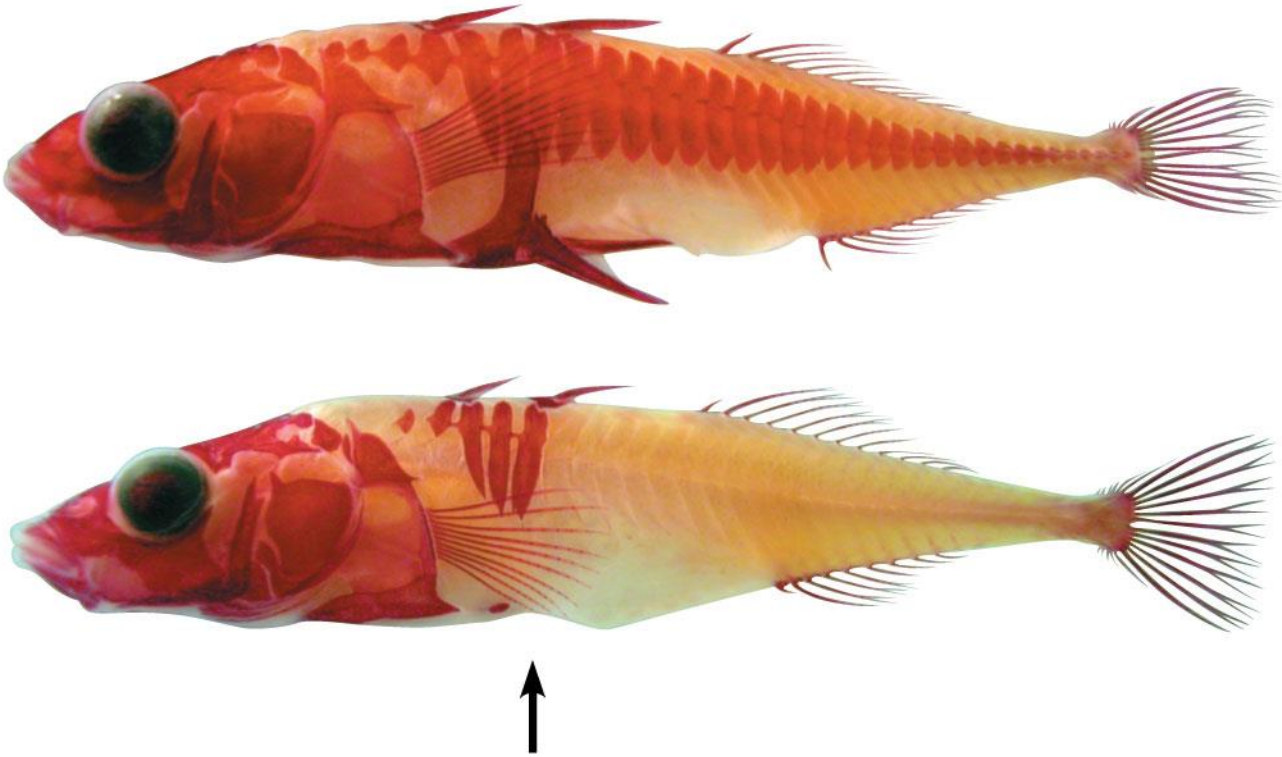
15.11 Genes that control development play a major role in evolution

- Duplication of developmental genes can also be important in the formation of new morphological features.
  - A fruit fly has a single cluster of homeotic genes.
  - A mouse has four clusters of homeotic genes.
  - Two duplications of these gene clusters occurred in the evolution of vertebrates from invertebrates.

15.11 Genes that control development play a major role in evolution

- In the threespine stickleback fish, those fish that that live
  - in the ocean have bony plates and a large set of pelvic spines but
  - in lakes have reduced or absent bony plates and pelvic spines, resulting from a change in the expression of a developmental gene in the pelvic region.

Figure 15.11C



15.12 Evolutionary novelties may arise in several ways

- In most cases, complex structures evolve by increments from simpler versions with the same basic functions.
- In the evolution of an eye or any other complex structure, behavior, or biochemical pathway, each step must
  - bring a selective advantage to the organism possessing it and
  - increase the organism's fitness.

15.12 Evolutionary novelties may arise in several ways

- Mollusc eyes evolved from an ancestral patch of photoreceptor cells through a series of incremental modifications that were adaptive at each stage.
- A range of complexity can be seen in the eyes of living molluscs.
- Cephalopod eyes are as complex as vertebrate eyes, but arose separately.

Figure 15.12

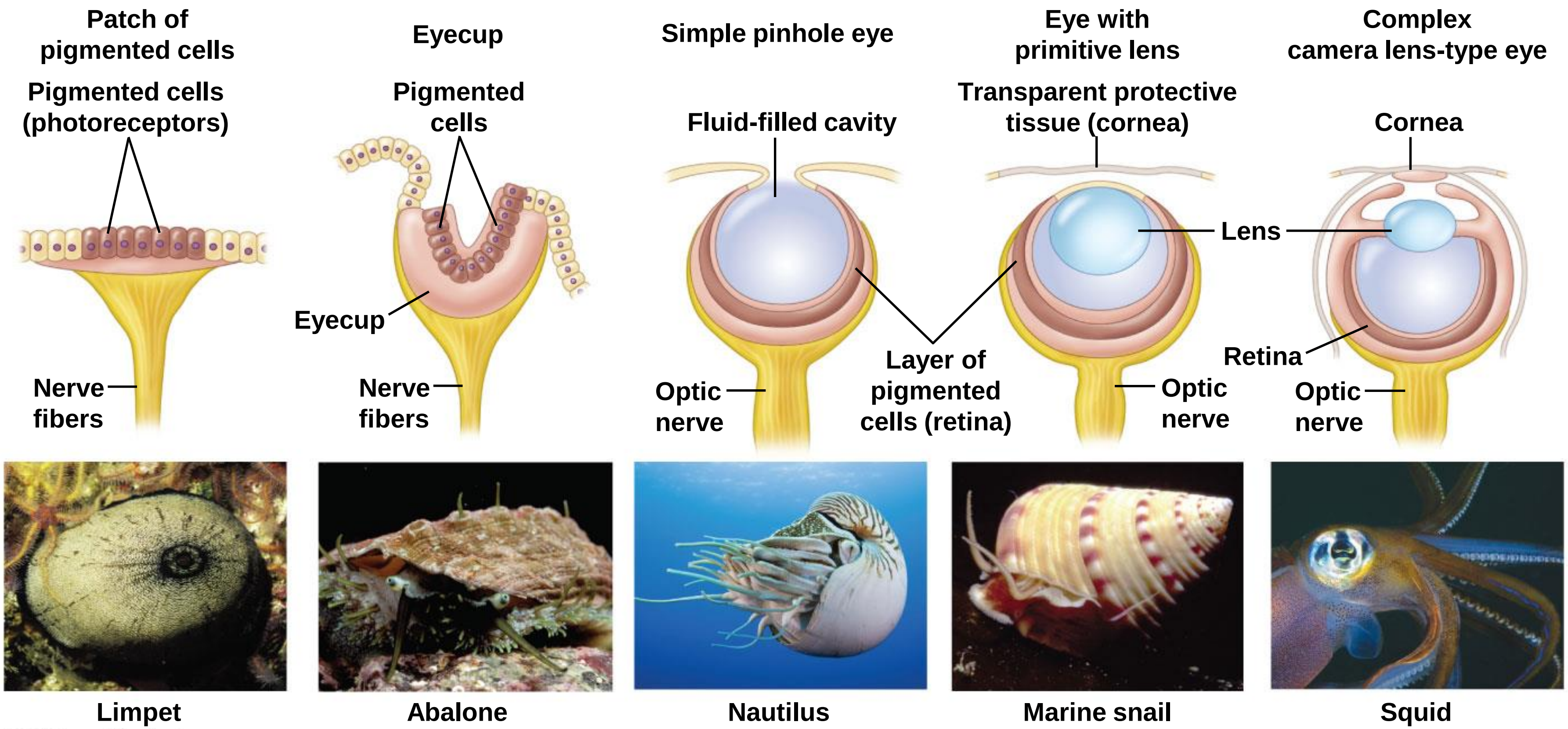
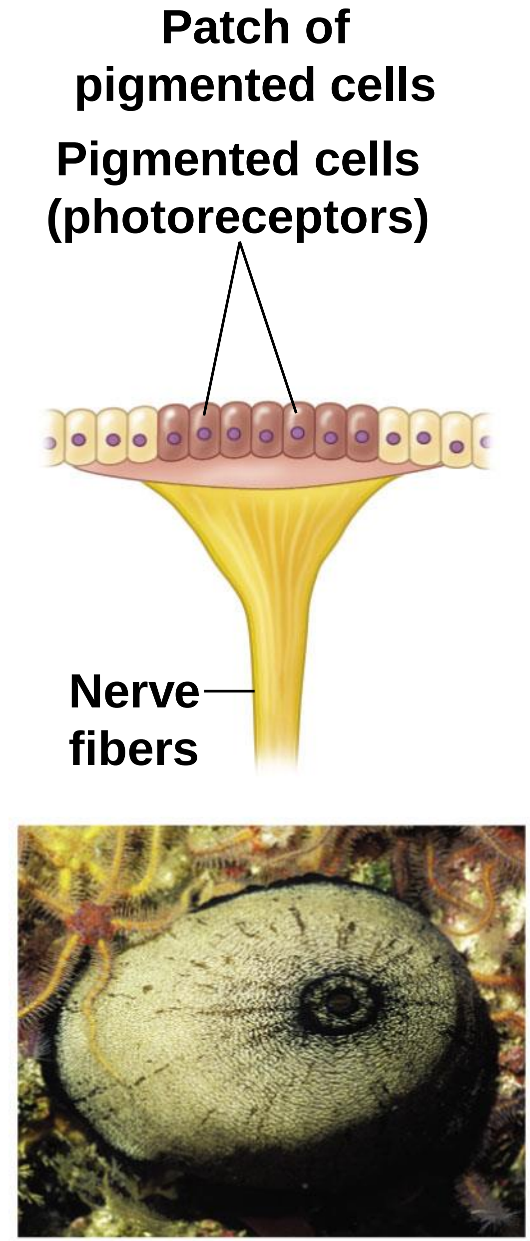
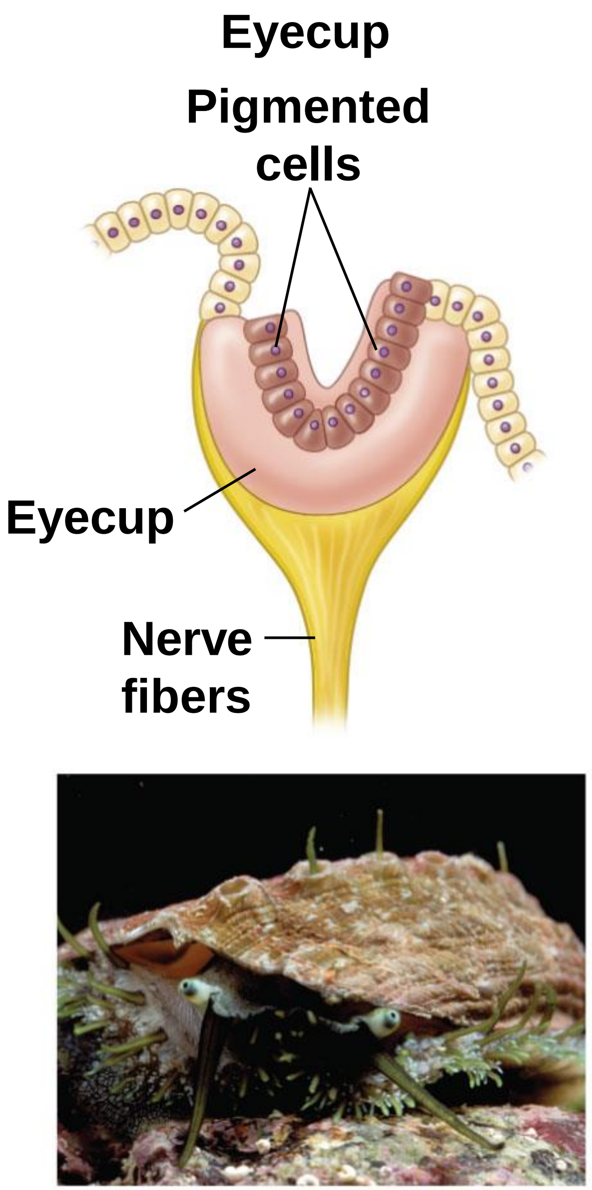

Patch of pigmented cells
Pigmented cells (photoreceptors)
Nerve fibers
Eyecup
Pigmented cells
Eyecup
Nerve fibers
Simple pinhole eye
Fluid-filled cavity
Optic nerve
Layer of pigmented cells (retina)
Eye with primitive lens
Transparent protective tissue (cornea)
Lens
Optic nerve
Complex camera lens-type eye
Cornea
Retina
Optic nerve
Limpet
Abalone
Nautilus
Marine snail
Squid

Figure 15.12_1



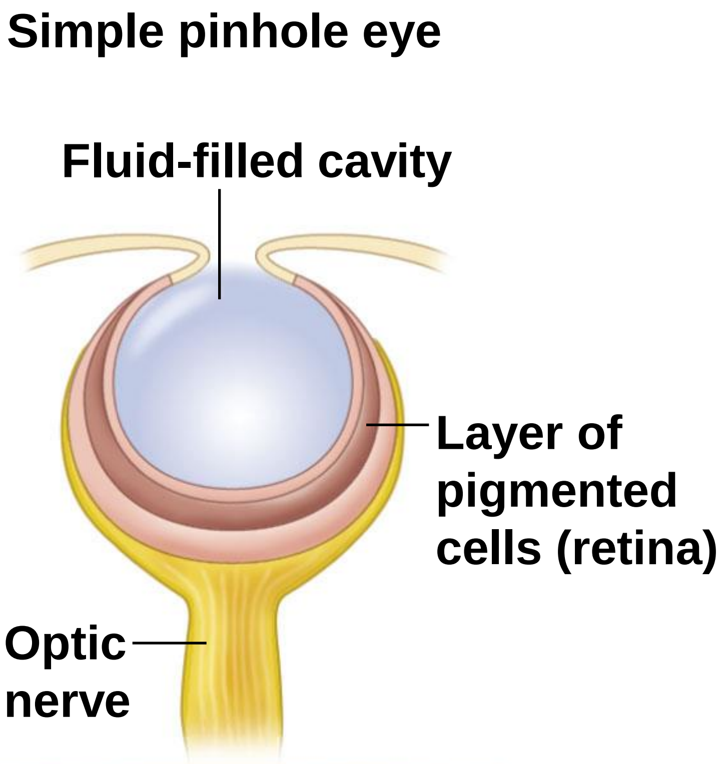
Limpet

Figure 15.12_2



Abalone

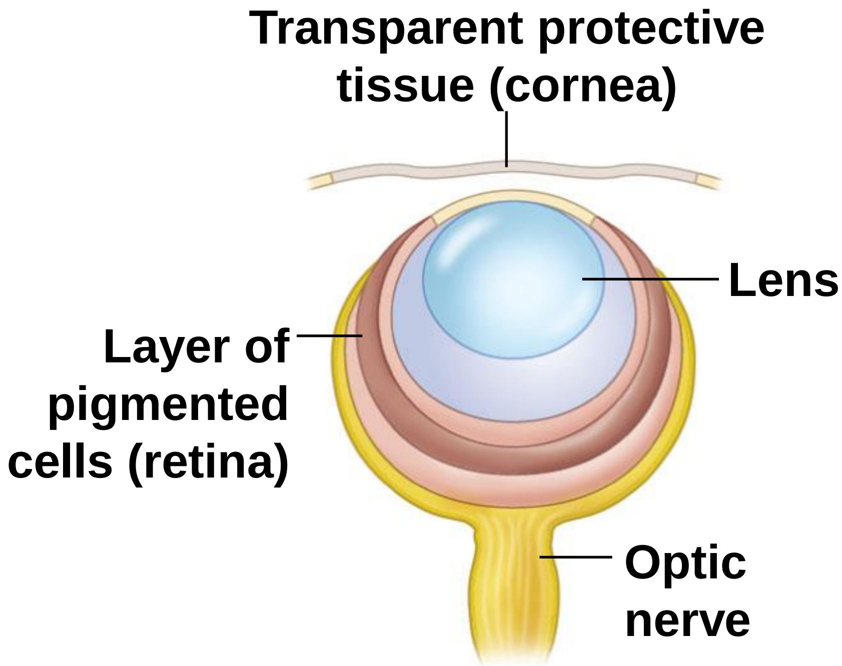
Figure 15.12_3



Nautilus

Figure 15.12_4

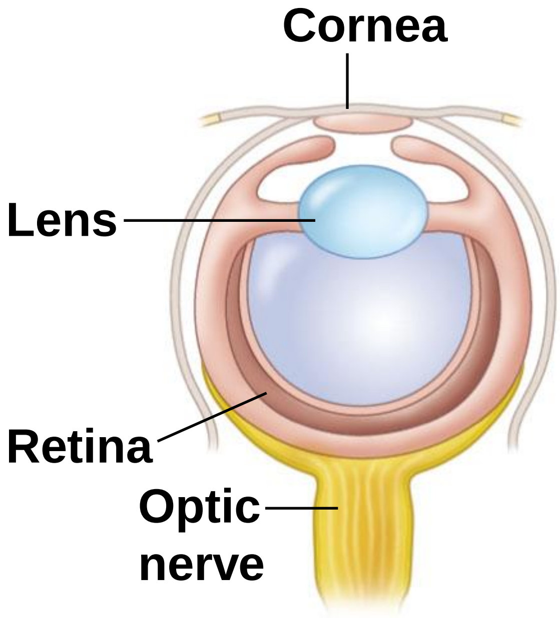
Eye with primitive lens



Marine snail

Figure 15.12_5

Complex camera lens-type eye



Squid

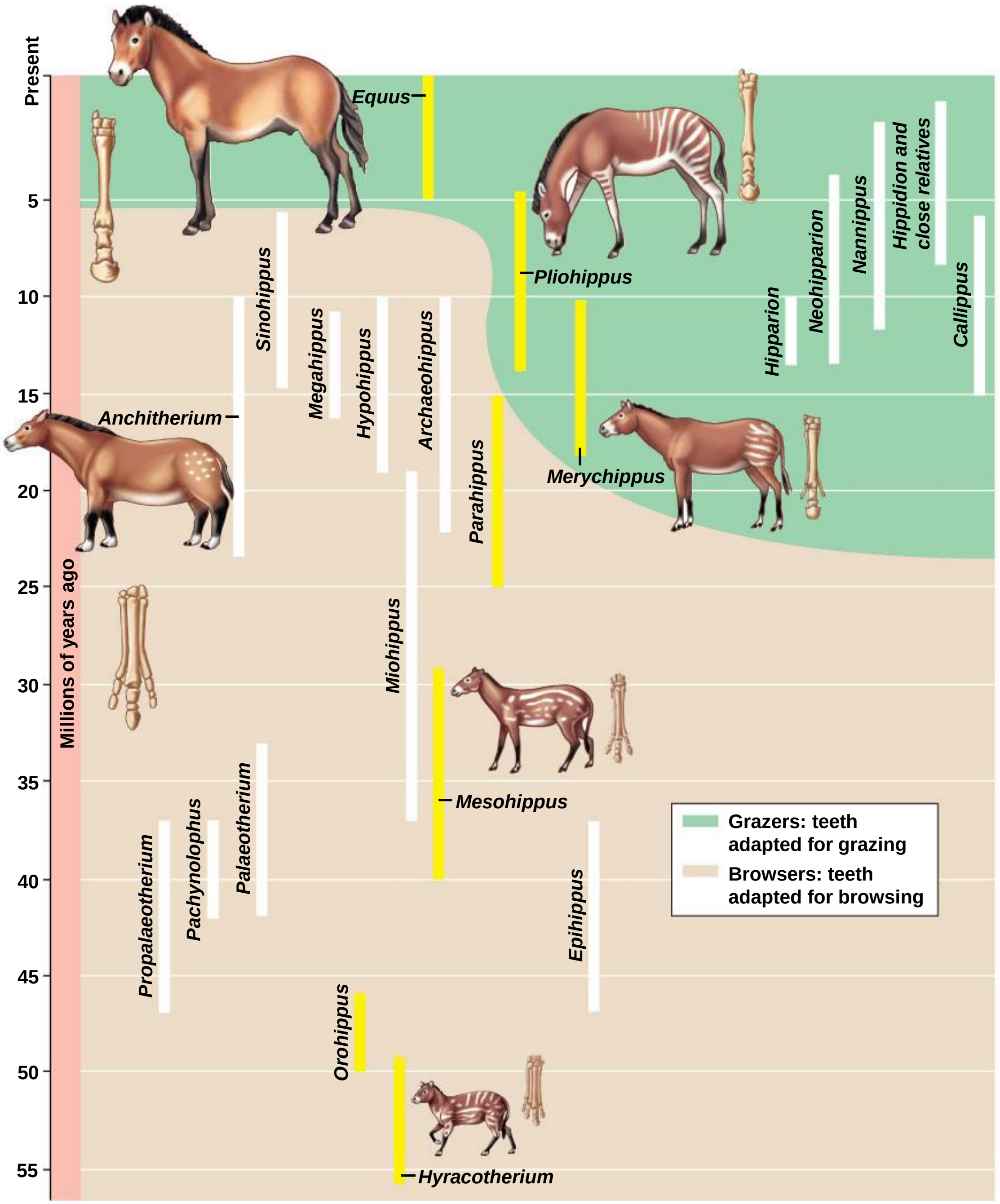
15.12 Evolutionary novelties may arise in several ways

- In other cases, evolutionary novelties result from the gradual adaptation of existing structures to new functions.
- Such structures that evolve in one context but become co-opted for another function are often called *exaptations*.
- Examples of exaptations include
  - feathers that may have first functioned for insulation and later were co-opted for flight and
  - flippers of penguins that first functioned for flight and were co-opted for underwater swimming.

15.13 EVOLUTION CONNECTION: Evolutionary trends do not mean that evolution is goal directed

- The fossil record seems to reveal trends in the evolution of many species, but identifying trends can be problematic.
- The evolution of horses reveals a potential misunderstanding.
  - If we select only certain species in this family tree, it appears that there was a general trend toward the reduction in the number of toes, larger size, and teeth modified for grazing.
  - However, if we consider all of the known members of this family tree, this apparent trend vanishes.

Figure 15.13



Present
5
10
15
20
25
30
35
40
45
50
55
Millions of years ago
Equus
Pliohippus
Hippidion and close relatives
Nannippus
Neohipparion
Hipparion
Callippus
Sinohippus
Megahippus
Hypohippus
Archaeohippus
Anchitherium
Parahippus
Merychippus
Miohippus
Mesohippus
Propalaeotherium
Pachynolophus
Palaeotherium
Epihippus
Orohippus
Hyracotherium
Grazers: teeth adapted for grazing
Browsers: teeth adapted for browsing

Figure 15.13_1

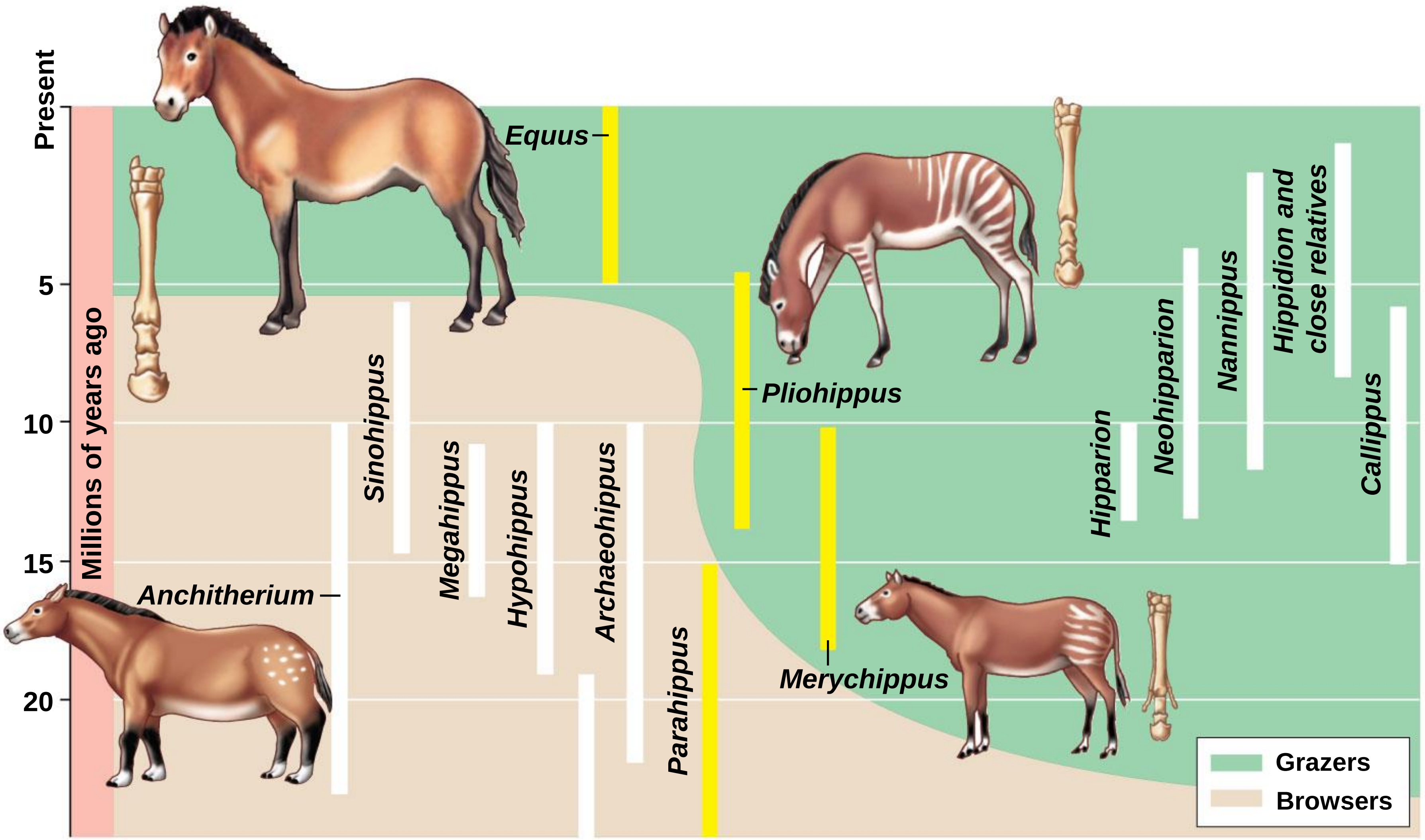
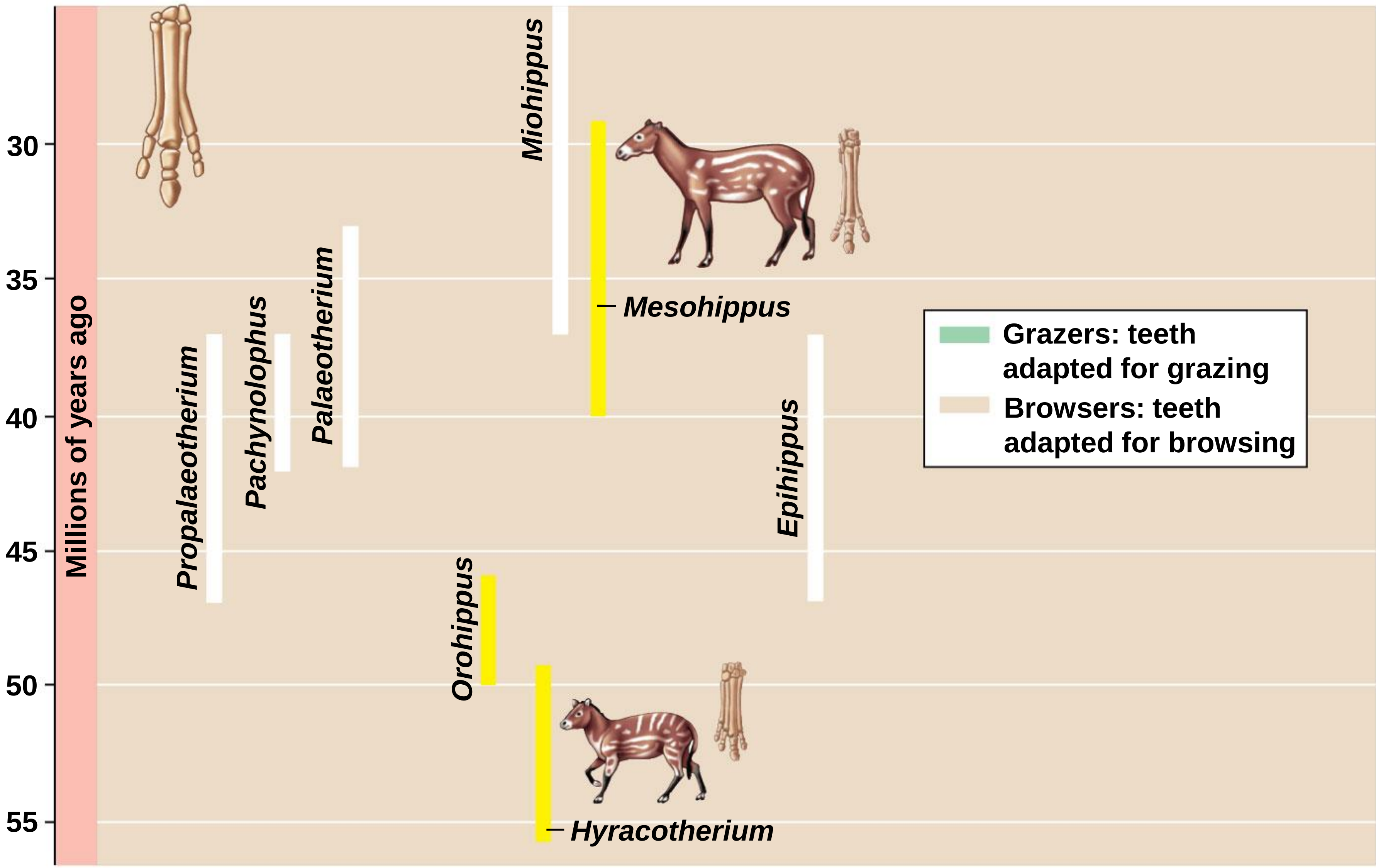


Figure 15.13_2



15.13 EVOLUTION CONNECTION: Evolutionary trends do not mean that evolution is goal directed

- Branching evolution can lead to genuine trends.
- The species selection model of long-term trends compares species to individuals.
  - Speciation is their birth,
  - extinction their death, and
  - new species that diversify from them are their offspring.
  - Unequal survival of species and unequal generation of new species play a role in macroevolution similar to the role of unequal reproduction in microevolution.

15.13 EVOLUTION CONNECTION: Evolutionary trends do not mean that evolution is goal directed

- Evolutionary trends can also result directly from natural selection. For example,
  - when horse ancestors invaded the grasslands that spread during the mid-Cenozoic,
  - there was strong selection for grazers that could escape predators by running fast.
- Whatever its cause, it is important to recognize that an evolutionary trend does not imply that evolution is goal directed.
- Evolution is the result of interactions between organisms and the current environment.

PHYLOGENY AND THE TREE OF LIFE

15.14 Phylogenies based on homologies reflect evolutionary history

- **Phylogeny** is the evolutionary history of a species or group of species.
- Phylogeny can be inferred from
  - the fossil record,
  - morphological homologies, and
  - molecular homologies.

15.14 Phylogenies based on homologies reflect evolutionary history

- Homologies are similarities due to shared ancestry, evolving from the same structure in a common ancestor.
- Generally, organisms that share similar morphologies are closely related.
  - However, some similarities are due to similar adaptations favored by a common environment, a process called **convergent evolution**.
  - A similarity due to convergent evolution is called **analogy**.

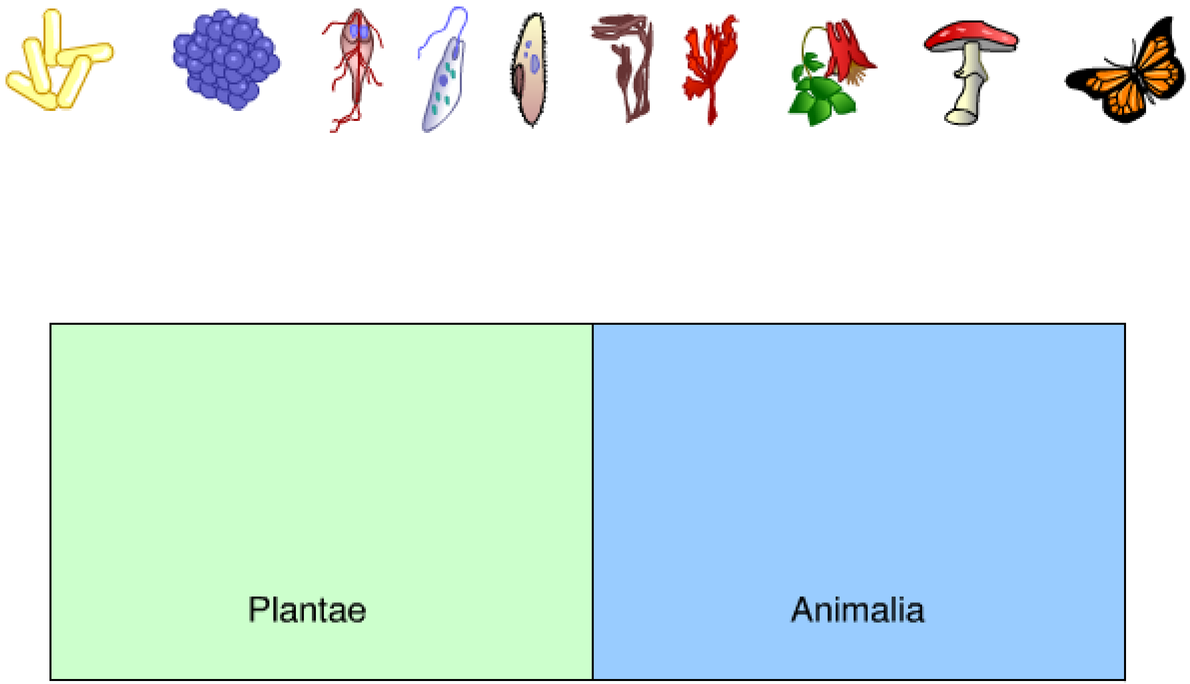
Figure 15.14

15.15 Systematics connects classification with evolutionary history

- **Systematics** is a discipline of biology that focuses on
  - classifying organisms and
  - determining their evolutionary relationships.
- Carolus Linnaeus introduced **taxonomy**, a system of naming and classifying species.

15.15 Systematics connects classification with evolutionary history

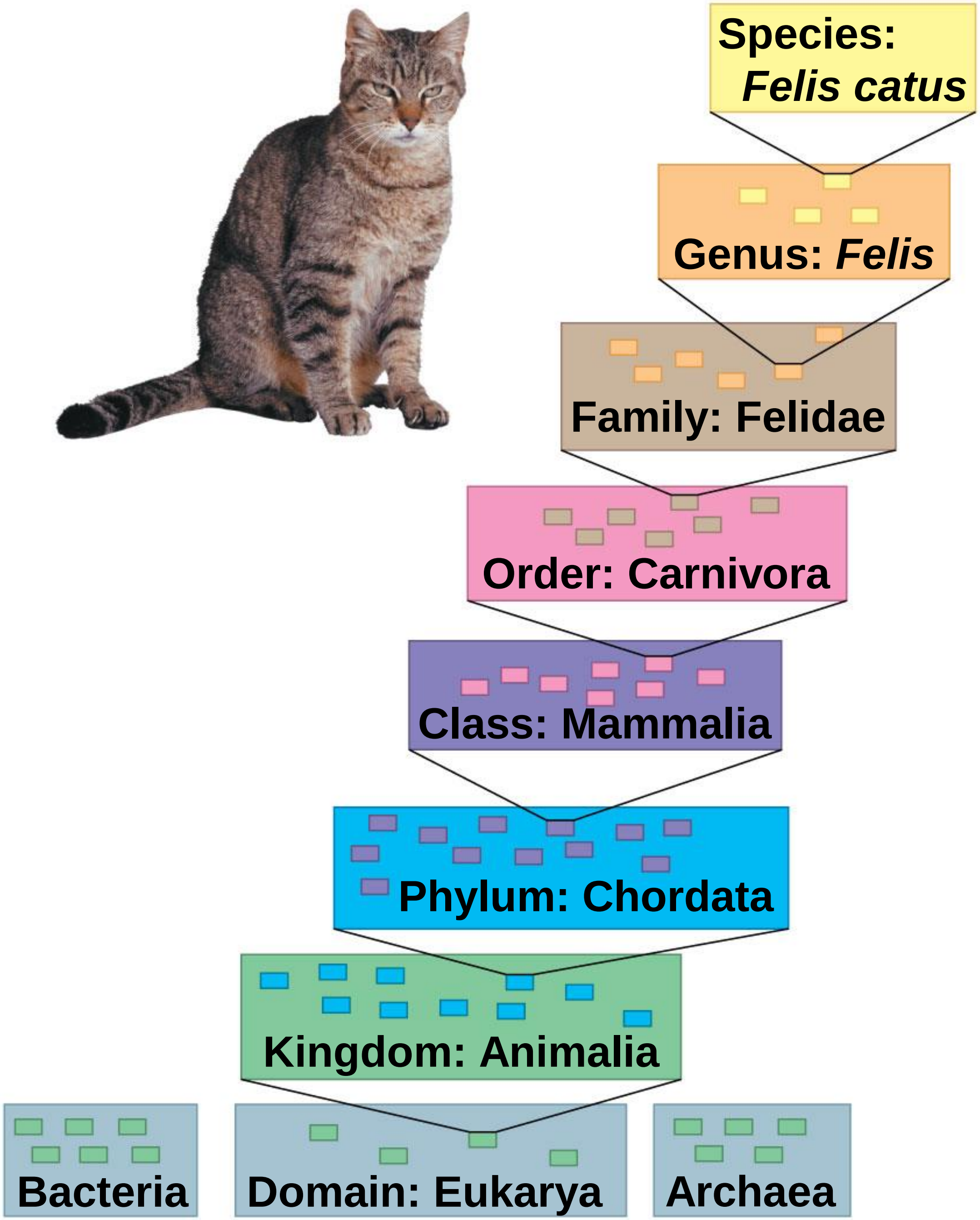
- Biologists assign each species a two-part scientific name, or **binomial**, consisting of
  - a **genus** and
  - a unique part for each species within the genus.
- Genera are grouped into progressively larger categories.
- Each taxonomic unit is a **taxon**.



Animation: Classification Schemes

Right click on animation / Click play

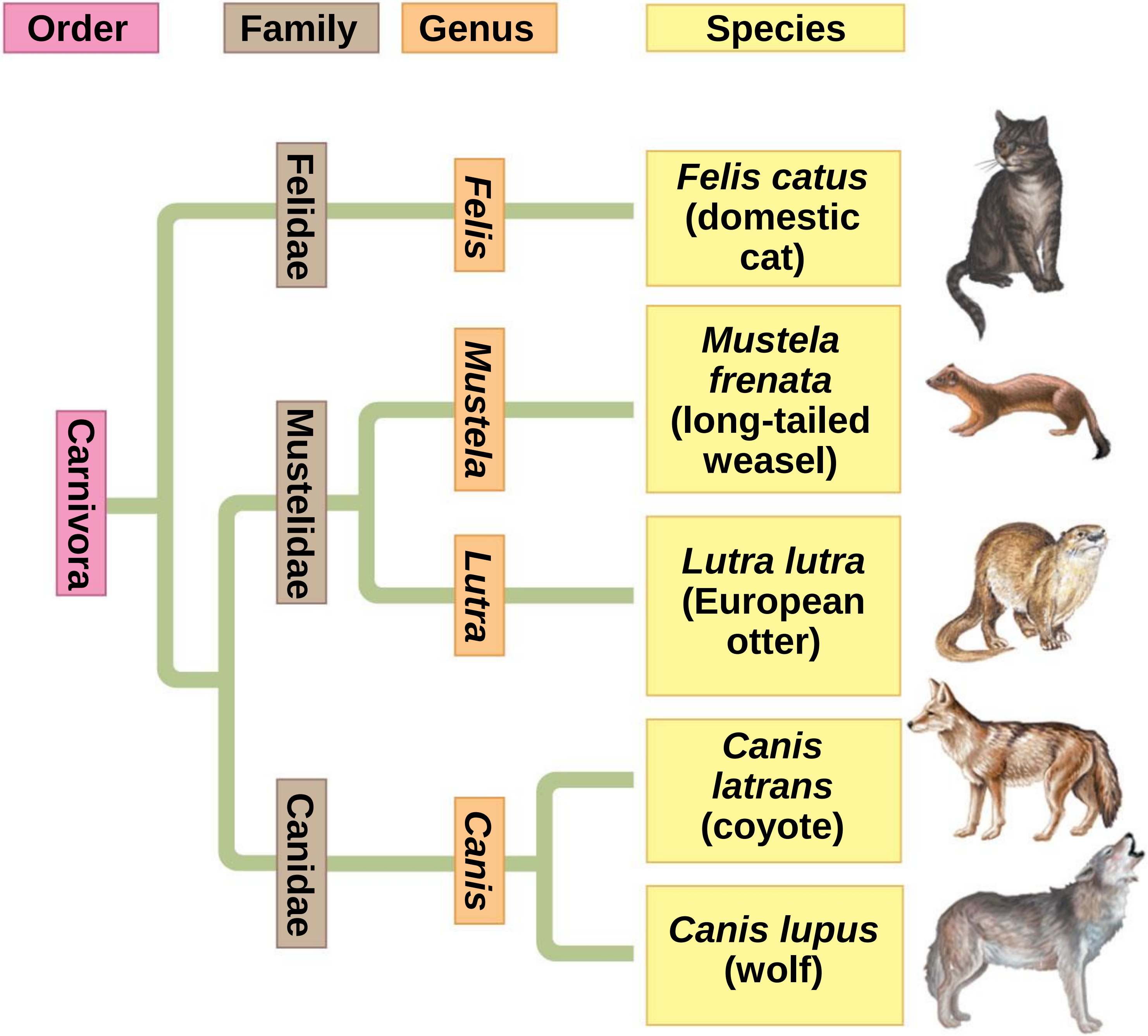
Figure 15.15A



15.15 Systematics connects classification with evolutionary history

- Biologists traditionally use **phylogenetic trees** to depict hypotheses about the evolutionary history of species.
  - The branching diagrams reflect the hierarchical classification of groups nested within more inclusive groups.
  - Phylogenetic trees indicate the probable evolutionary relationships among groups and patterns of descent.

Figure 15.15B



15.16 Shared characters are used to construct phylogenetic trees

- **Cladistics**
  - is the most widely used method in systematics and
  - groups organisms into **clades**.
- Each clade is a **monophyletic** group of species that
  - includes an ancestral species and
  - all of its descendants.

15.16 Shared characters are used to construct phylogenetic trees

- Cladistics is based on the Darwinian concept that organisms share characteristics with their ancestors and differ from them. Thus, there are two main types of characters.

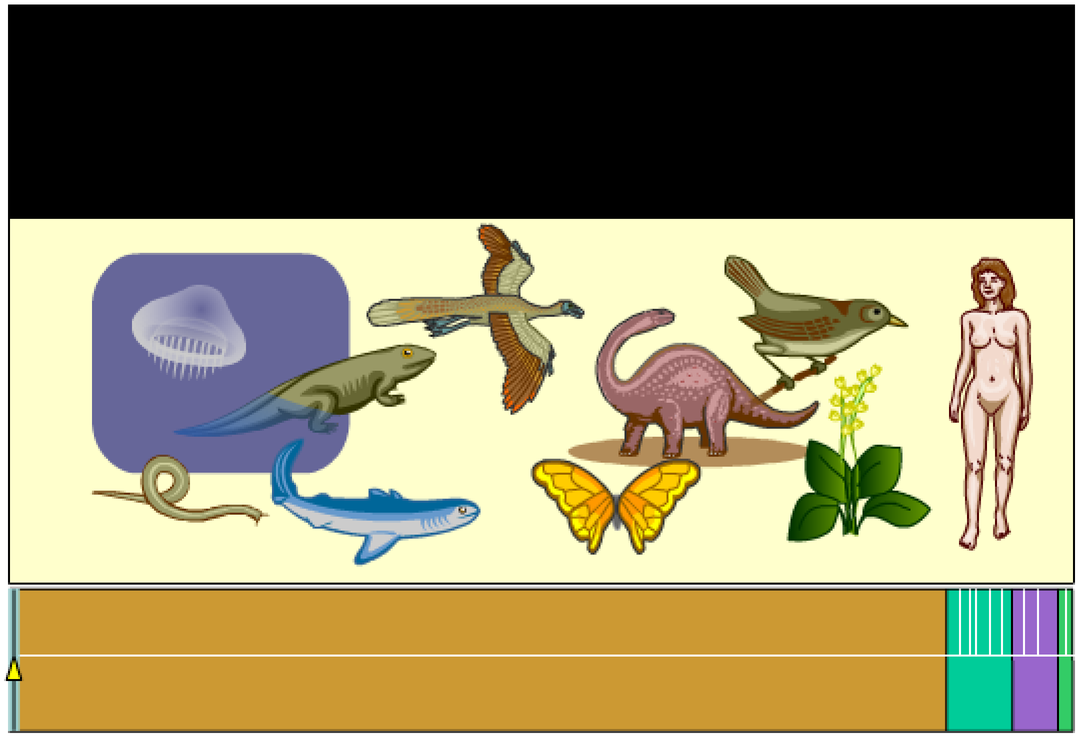
  1. **Shared ancestral characters** group organisms into **clades**.
  2. **Shared derived characters** distinguish clades and form the branching points in the tree of life.

15.16 Shared characters are used to construct phylogenetic trees

- An important step in cladistics is the comparison of the
  - **ingroup** (the taxa whose phylogeny is being investigated) and
  - **outgroup** (a taxon that diverged before the lineage leading to the members of the ingroup),
  - to identify the derived characters that define the branch points in the phylogeny of the ingroup.

15.16 Shared characters are used to construct phylogenetic trees

- As an example, consider
  - a frog representing the outgroup and
  - four other tetrapods representing the ingroup.
- The presence or absence of traits is indicated as
  - 1 if the trait is present or
  - 0 if the trait is absent.



Geologic record

Animation: Geologic Record

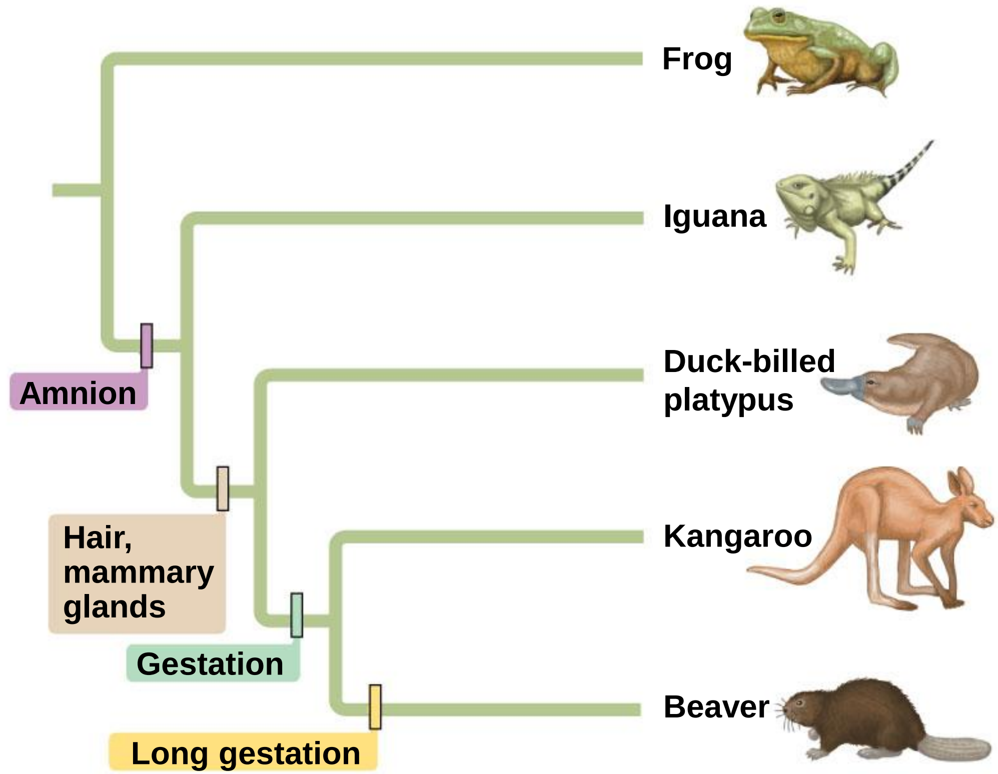
Right click on animation / Click play

Figure 15.16A

TAXA

CHARACTERS	Frog	Iguana	Duck-billed platypus	Kangaroo	Beaver
Amnion	0	1	1	1	1
Hair, mammary glands	0	0	1	1	1
Gestation	0	0	0	1	1
Long gestation	0	0	0	0	1

Character Table



Phylogenetic Tree

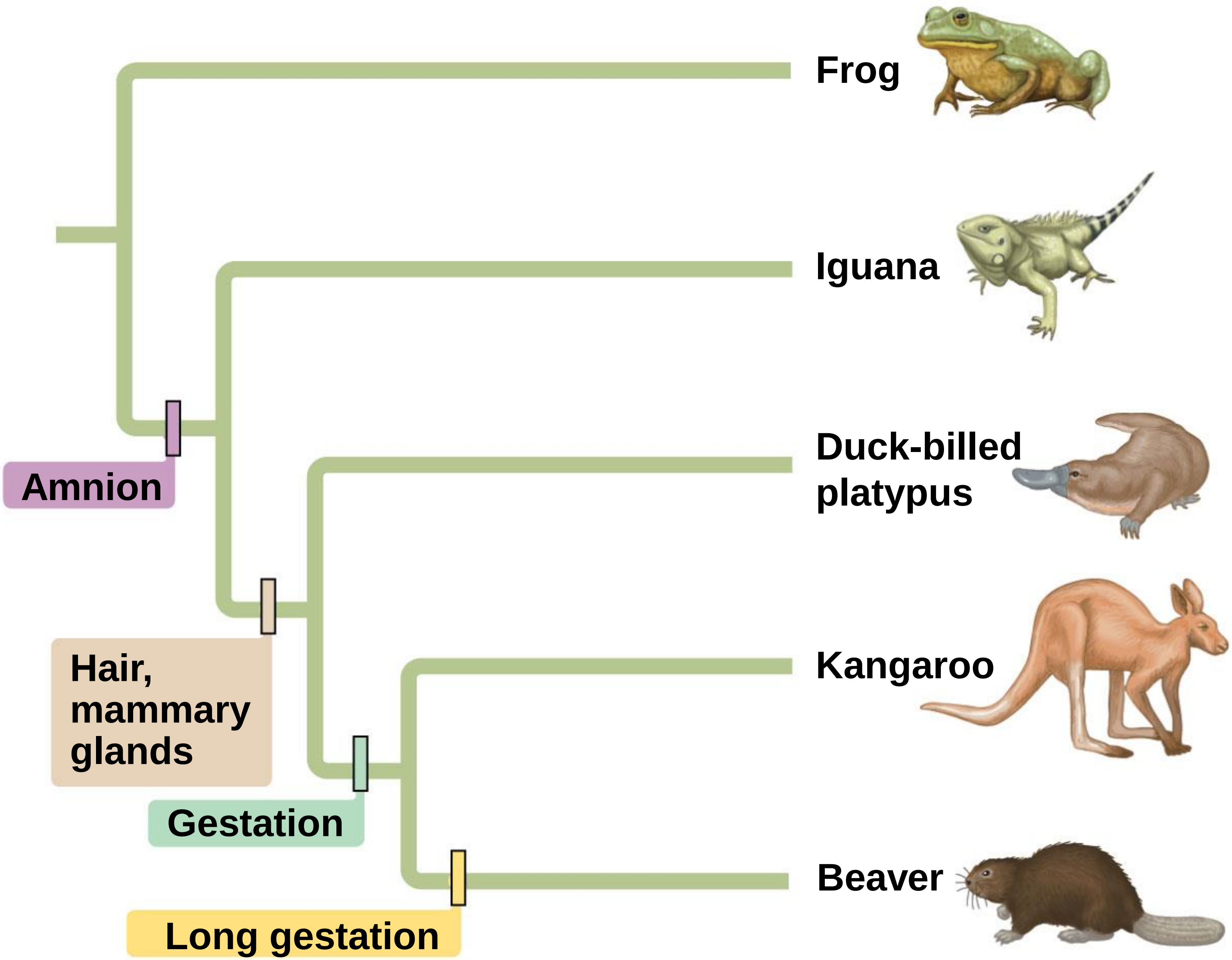
Figure 15.16A_1

TAXA

CHARACTERS	Frog	Iguana	Duck-billed platypus	Kangaroo	Beaver
Amnion	0	1	1	1	1
Hair, mammary glands	0	0	1	1	1
Gestation	0	0	0	1	1
Long gestation	0	0	0	0	1

Character Table

Figure 15.16A_2



Phylogenetic Tree

15.16 Shared characters are used to construct phylogenetic trees

- In our example, the phylogenetic tree is constructed from a series of branch points, represented by the emergence of a lineage with a new set of derived traits.
- When constructing a phylogenetic tree, scientists use **parsimony**, looking for the simplest explanation for observed phenomena.

- Systematists use many kinds of evidence. However, even the best tree represents only the most likely hypothesis.

15.16 Shared characters are used to construct phylogenetic trees

- The phylogenetic tree of reptiles shows that crocodilians are the closest *living* relatives of birds.
  - They share numerous features, including
    - four-chambered hearts,
    - "singing" to defend territories, and
    - parental care of eggs within nests.
  - These traits were likely present in the common ancestor of birds, crocodiles, and dinosaurs.

Figure 15.16B

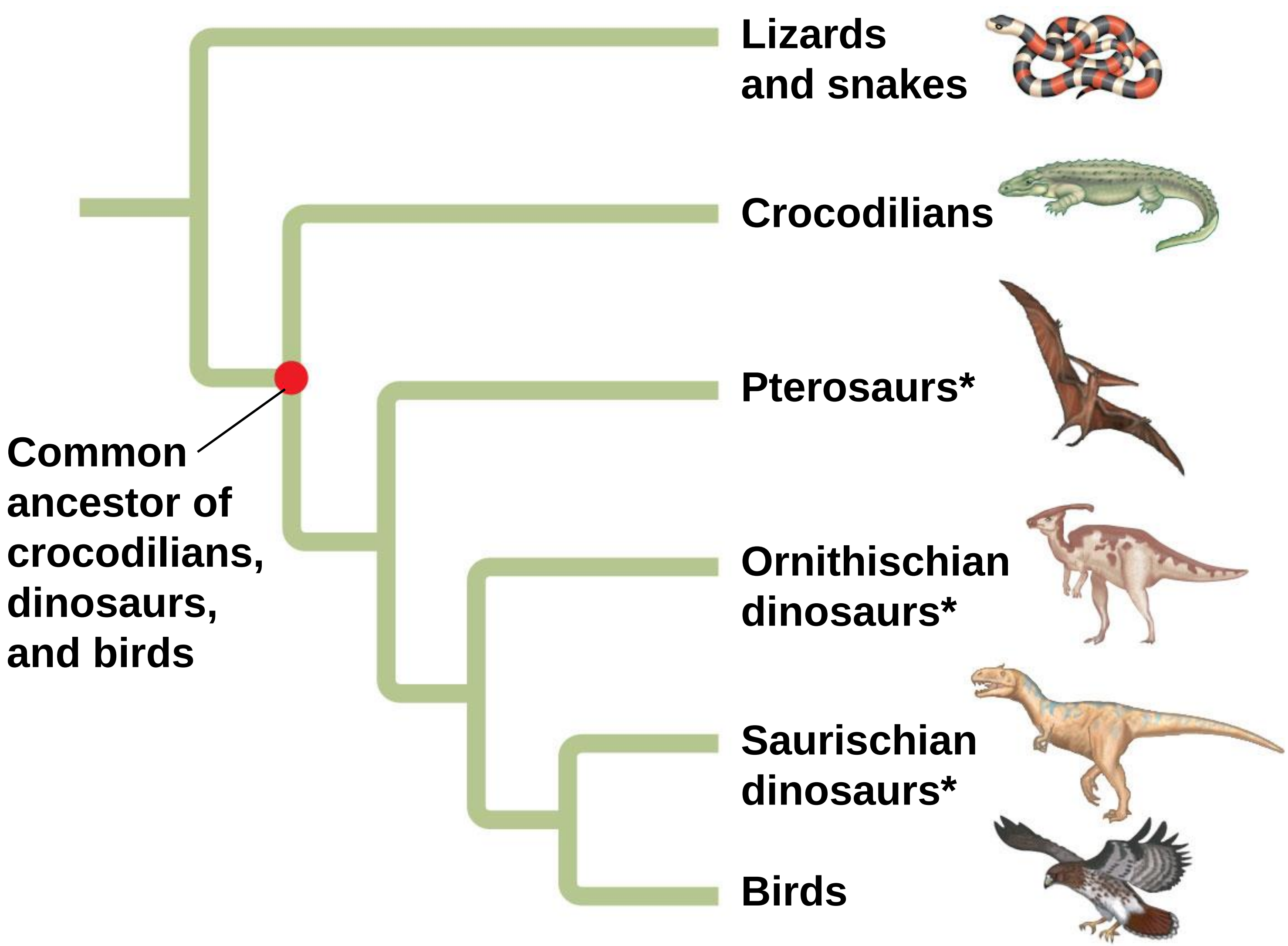
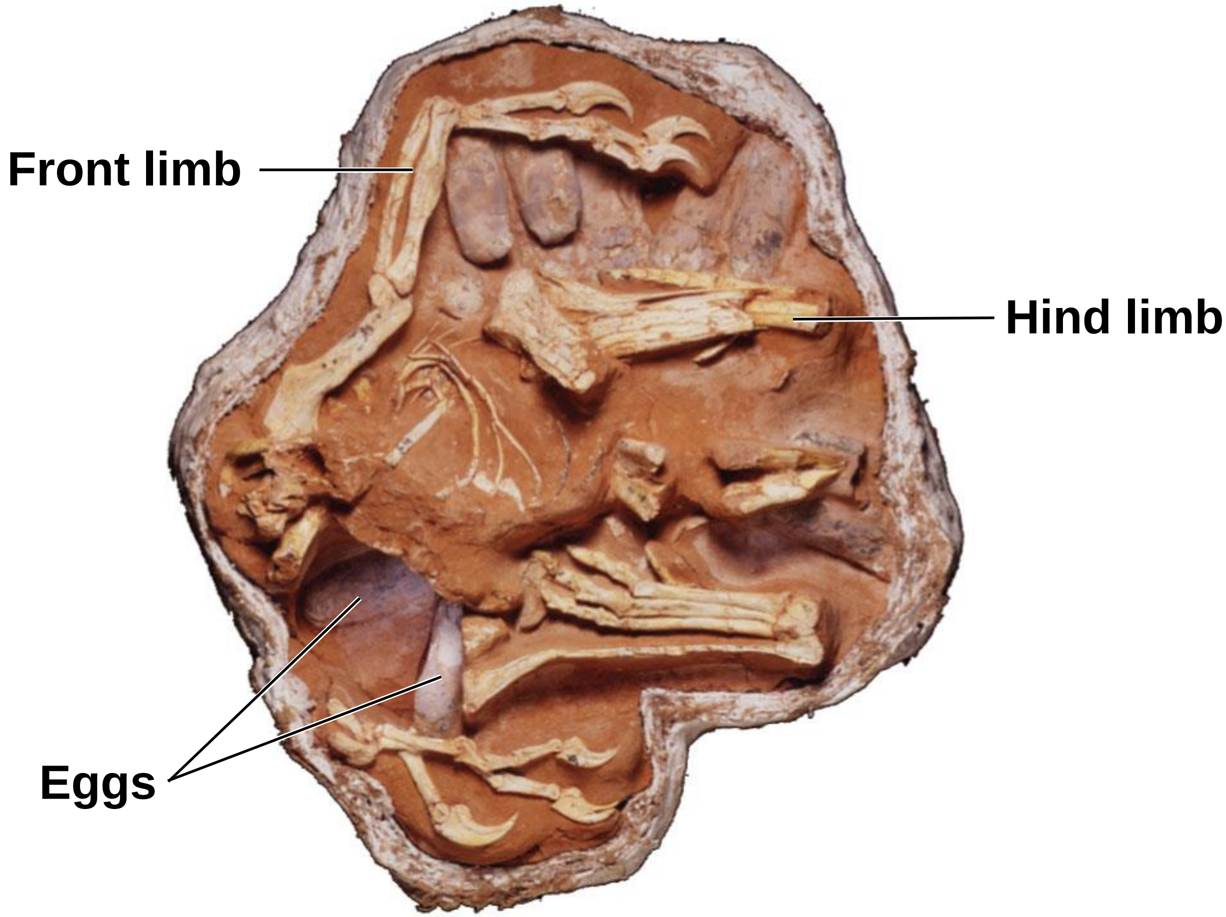


Figure 15.16C



15.17 An organism's evolutionary history is documented in its genome

- **Molecular systematics** uses DNA and other molecules to infer relatedness.
  - Scientists have sequenced more than 110 billion bases of DNA from thousands of species.
  - This enormous database has fueled a boom in the study of phylogeny and clarified many evolutionary relationships.

Figure 15.17

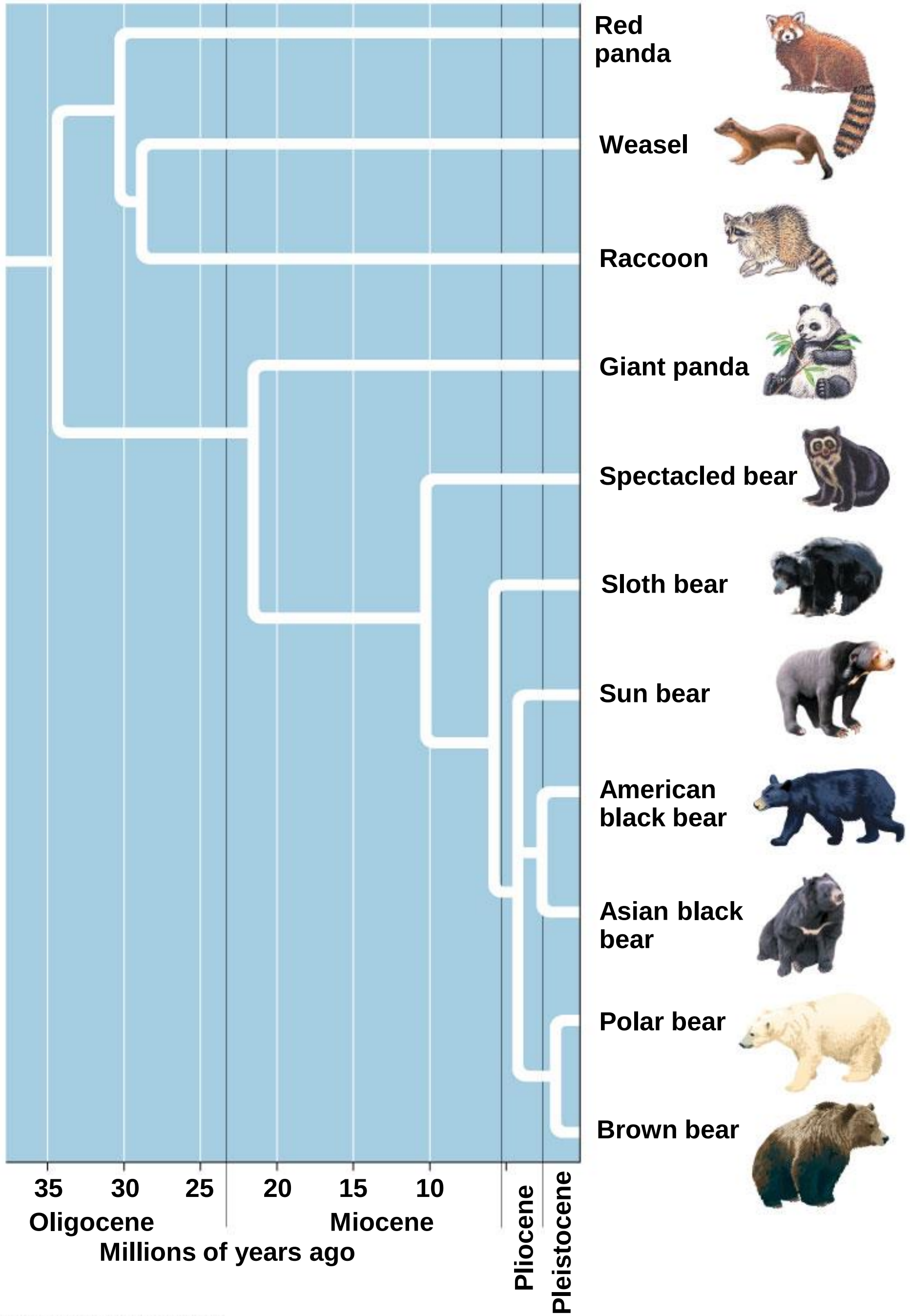

Red panda
Weasel
Raccoon
Giant panda
Spectacled bear
Sloth bear
Sun bear
American black bear
Asian black bear
Polar bear
Brown bear
35
30
25
20
15
10
Oligocene
Miocene
Millions of years ago
Pliocene
Pleistocene

Figure 15.17_2

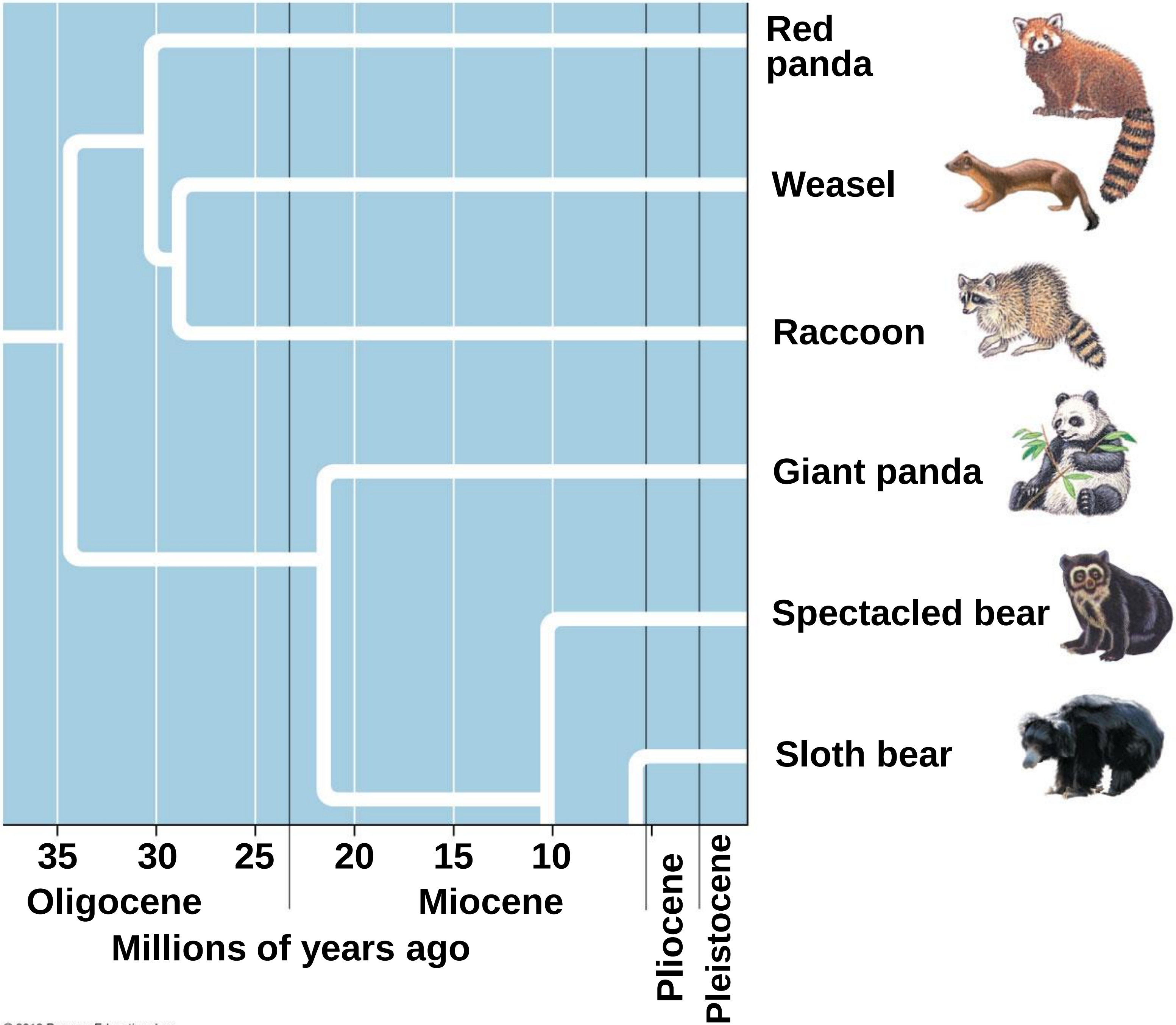
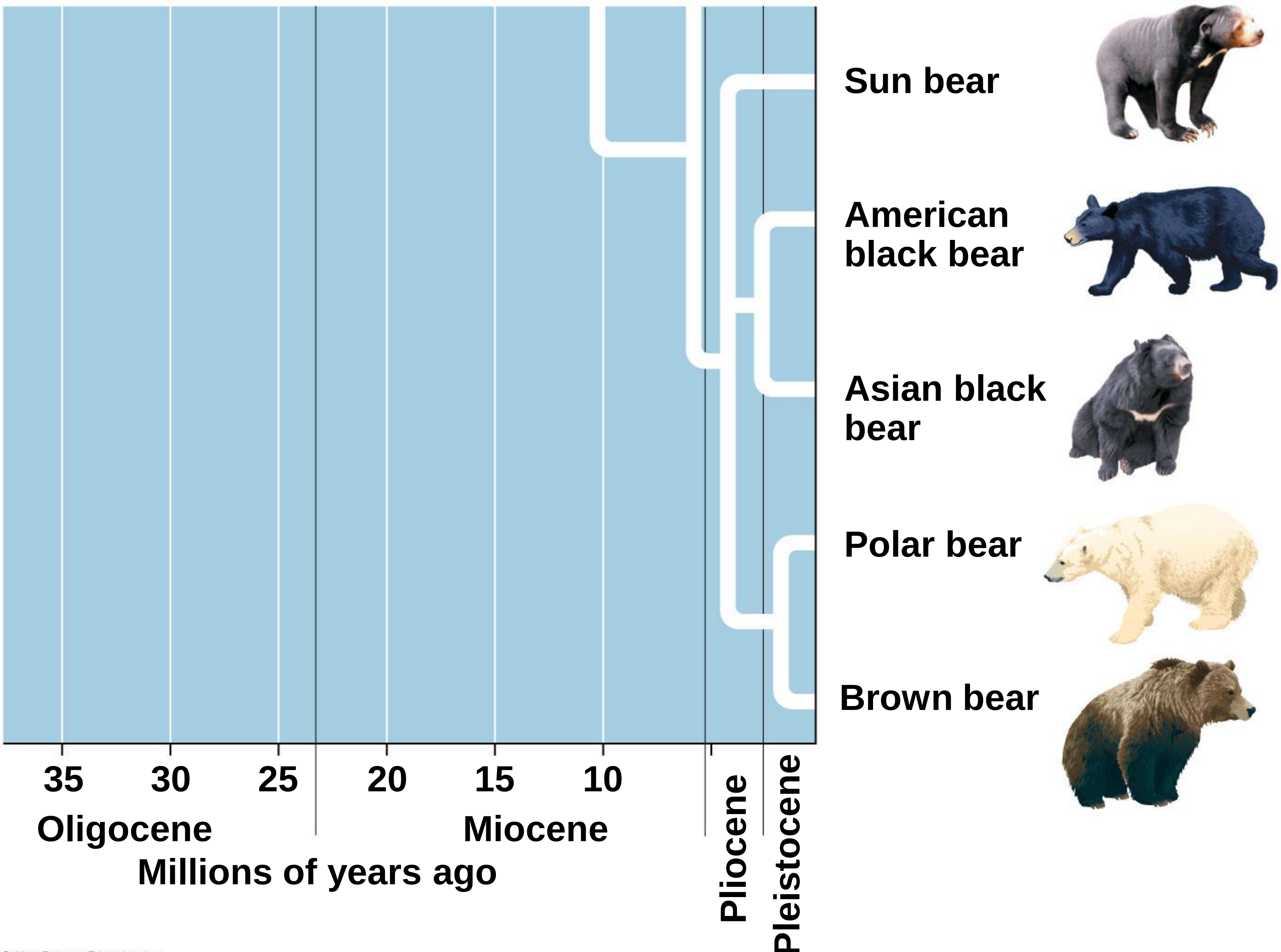


Figure 15.17_1



15.17 An organism's evolutionary history is documented in its genome

- The more recently two species have branched from a common ancestor, the more similar their DNA sequences should be.
- The longer two species have been on separate evolutionary paths, the more their DNA should have diverged.

15.17 An organism's evolutionary history is documented in its genome

- Different genes evolve at different rates.
  - DNA coding for ribosomal RNA (rRNA)
    - changes slowly and
    - is useful for investigating relationships between taxa that diverged hundreds of millions of years ago.
  - In contrast, DNA in mitochondria (mtDNA)
    - evolves rapidly and
    - is more useful to investigate more recent evolutionary events.

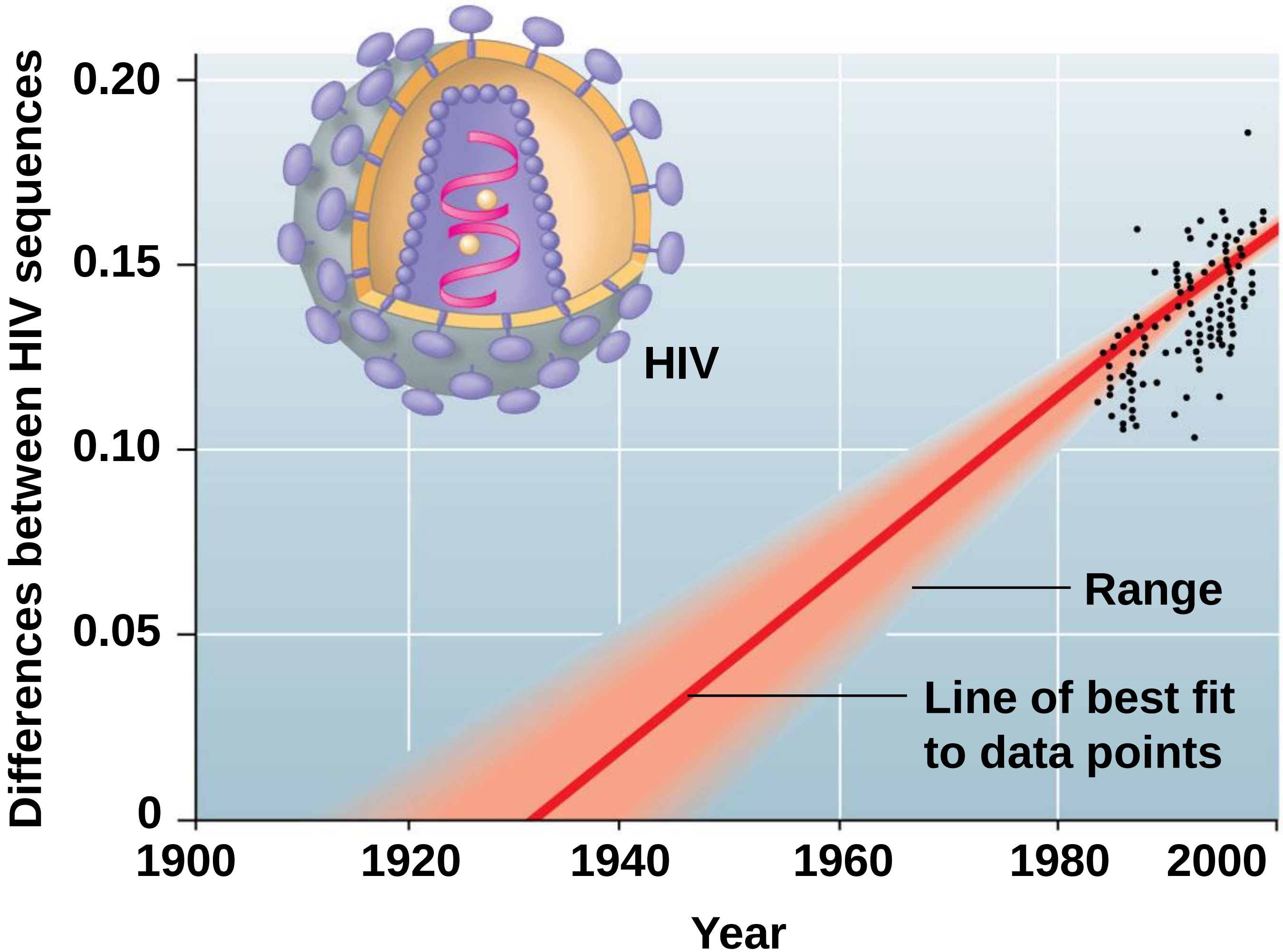
15.17 An organism's evolutionary history is documented in its genome

- The remarkable commonality of molecular biology demonstrates that all living organisms share many biochemical and developmental pathways and provides overwhelming support of evolution.
  - The genomes of humans and chimpanzees are amazingly similar.
  - About 99% of the genes of humans and mice are detectably homologous.
  - About 50% of human genes are homologous with those of yeast.

15.18 Molecular clocks help track evolutionary time

- **Molecular clocks**
  - rely on genes that have a reliable average rate of change,
  - can be calibrated in real time by graphing the number of nucleotide differences against the dates of evolutionary branch points known from the fossil record,
  - are used to estimate dates of divergences without a good fossil record, and
  - have been used to date the origin of HIV infection in humans.

Figure 15.18


HIV
Differences between HIV sequences
0.20
0.15
0.10
0.05
0
1900
1920
1940
1960
1980
2000
Year
Range
Line of best fit
to data points

15.19 Constructing the tree of life is a work in progress

- Molecular systematics and cladistics are remodeling some trees.
- Biologists currently recognize a **three-domain system** consisting of
  - two domains of prokaryotes: Bacteria and Archaea, and
  - one domain of eukaryotes called Eukarya including
    - fungi,
    - plants, and
    - animals.

15.19 Constructing the tree of life is a work in progress

- Molecular and cellular evidence indicates that
  - Bacteria and Archaea diverged very early in the evolutionary history of life and
  - Archaea are more closely related to eukaryotes than to bacteria.

15.19 Constructing the tree of life is a work in progress

- Comparisons of complete genomes from all three domains show that
  - there have been substantial interchanges of genes between organisms in different domains and
  - these took place through **horizontal gene transfer**, a process in which genes are transferred from one genome to another through mechanisms such as plasmid exchange and viral infection.
- Some biologists suggest that the early history of life may be best represented by a ring, from which the three domains emerge.

Figure 15.19A

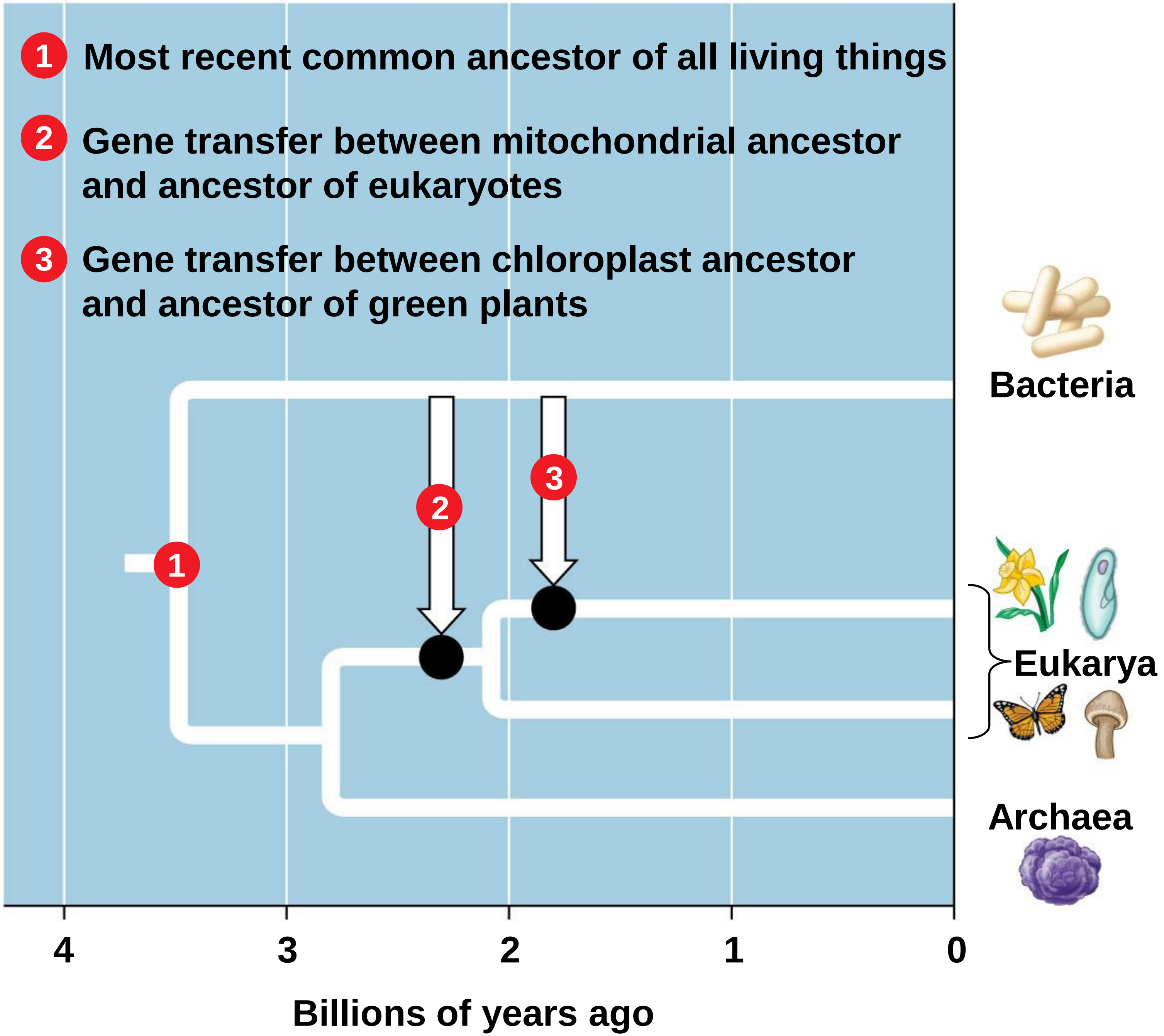
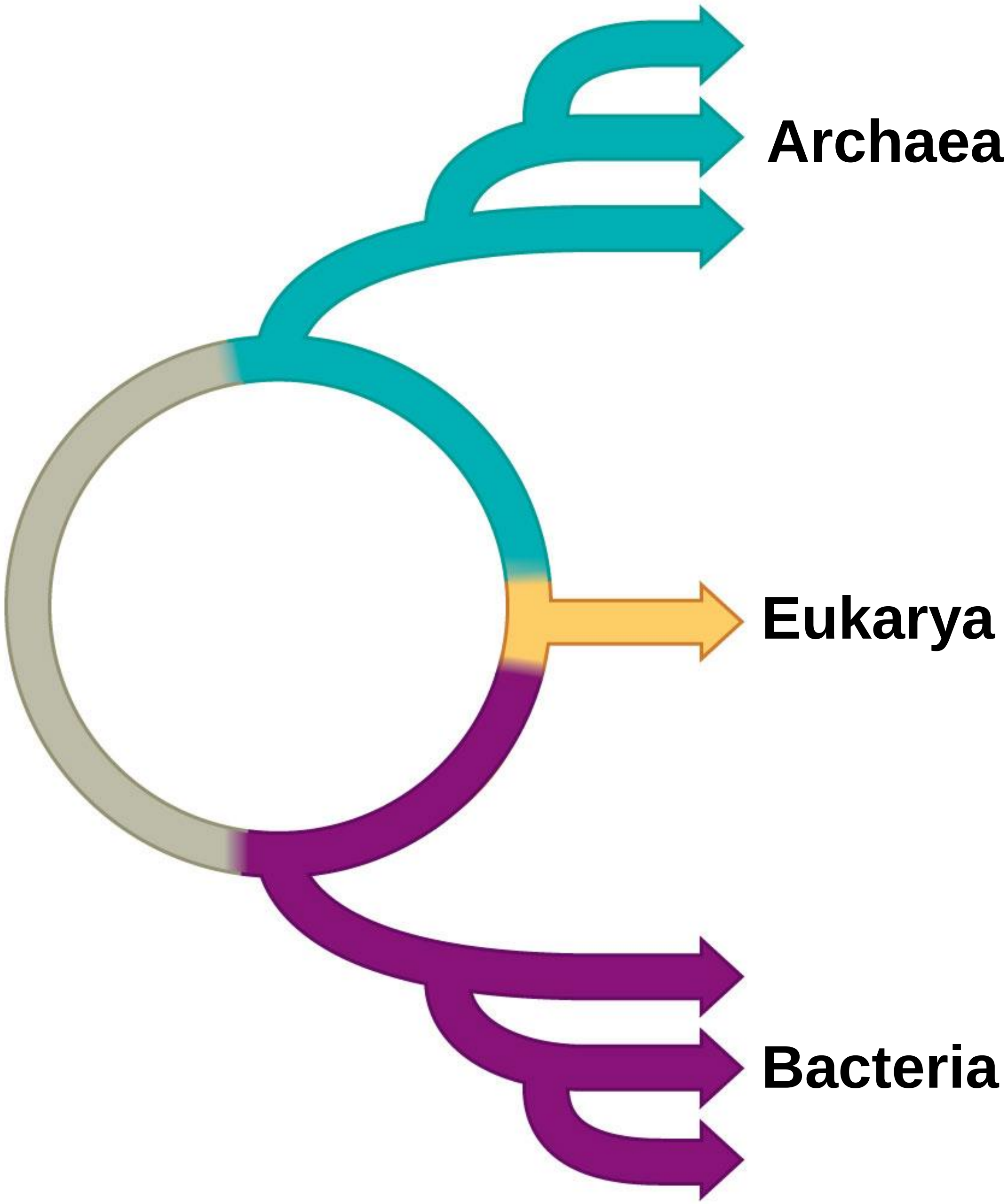


Figure 15.19B



You should now be able to

1. Describe the conditions on the surface of the early Earth. Describe the evidence that life on Earth existed at least 3.5 billion years ago.
2. Describe the four stages that might have produced the first cells on Earth.
3. Describe the experiments of Stanley Miller and others in understanding how life might have first evolved on Earth.
4. Describe the significance of protocells and ribozymes in the origin of the first cells.
5. Describe the key events in the history of life on Earth.

You should now be able to

6. Explain how radiometric dating and the relative position of a fossil within rock strata are used to determine the age of rocks.
7. Briefly describe the history of life on Earth. Describe the key events that serve to divide the eras.
8. Describe how Earth's continents have changed over the past 250 million years and the consequences of these changes for life on Earth.
9. Explain how volcanoes and earthquakes result from plate tectonics.
10. Describe the causes, frequency, and consequences of mass extinctions over the last 500 million years.

You should now be able to

11. Explain how and why adaptive radiations occur.
12. Explain how genes that program development function in the evolution of life. Define and describe examples of paedomorphosis.
13. Define exaptation and describe two examples in birds.
14. Explain why evolutionary trends do not reflect "directions" or "goals."
15. Distinguish between homologous and analogous structures and provide examples of each. Describe the process of convergent evolution.

You should now be able to

16. Describe the goals of systematics. List the progressively broader categories of classification used in systematics in order, from most specific to most general.
17. Define the terms clade, monophyletic groups, shared derived characters, shared ancestral characters, ingroup, outgroup, phylogenetic trees, and parsimony.
18. Explain how molecular biology is used as a tool in systematics.
19. Explain how molecular clocks are used to track evolutionary time.
20. Explain why a diagram of the tree of life is difficult to construct.

Figure 15.UN01

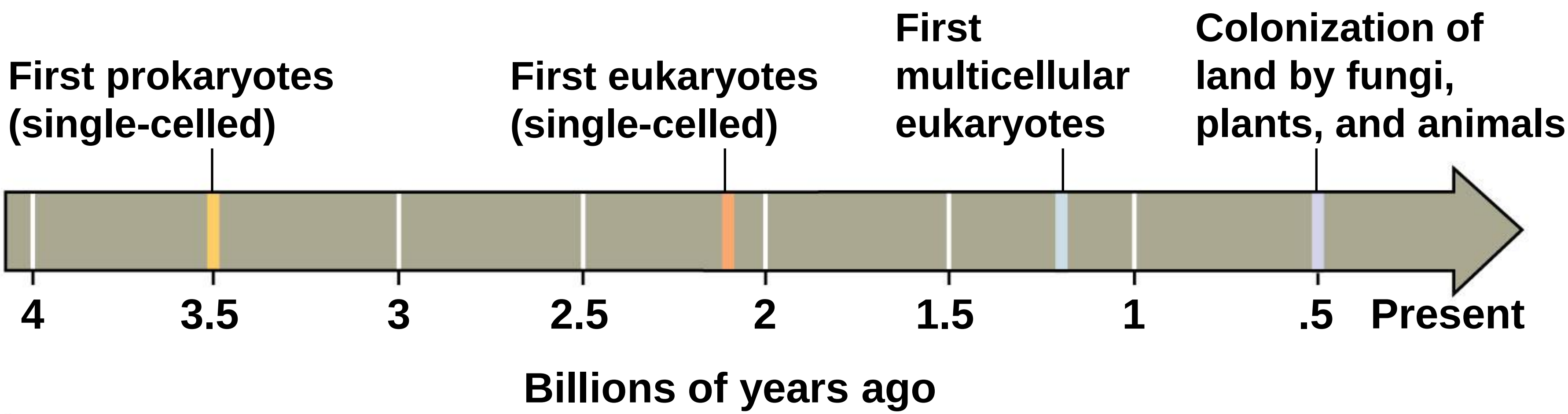


Figure 15.UN02

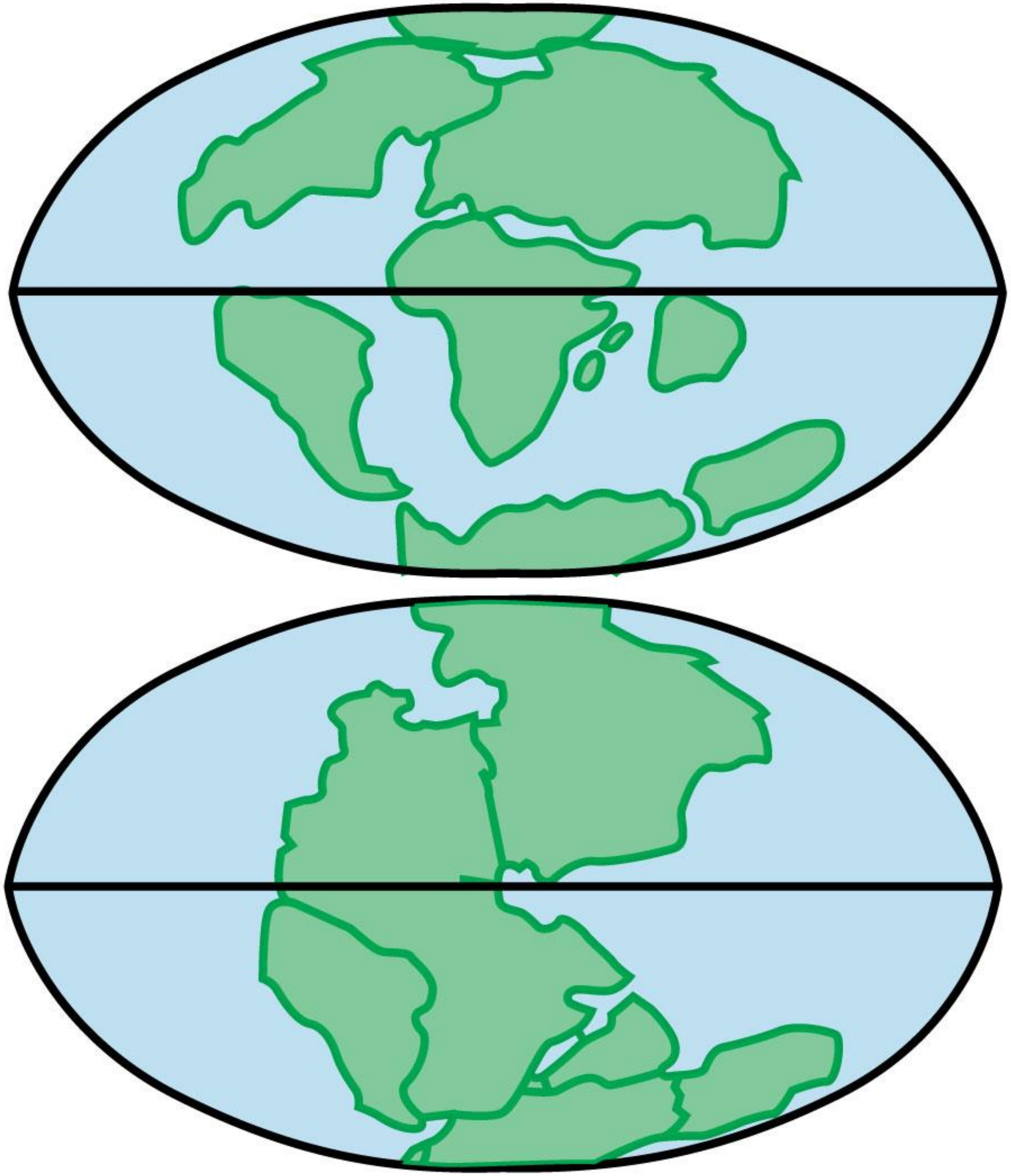


Figure 15.UN03

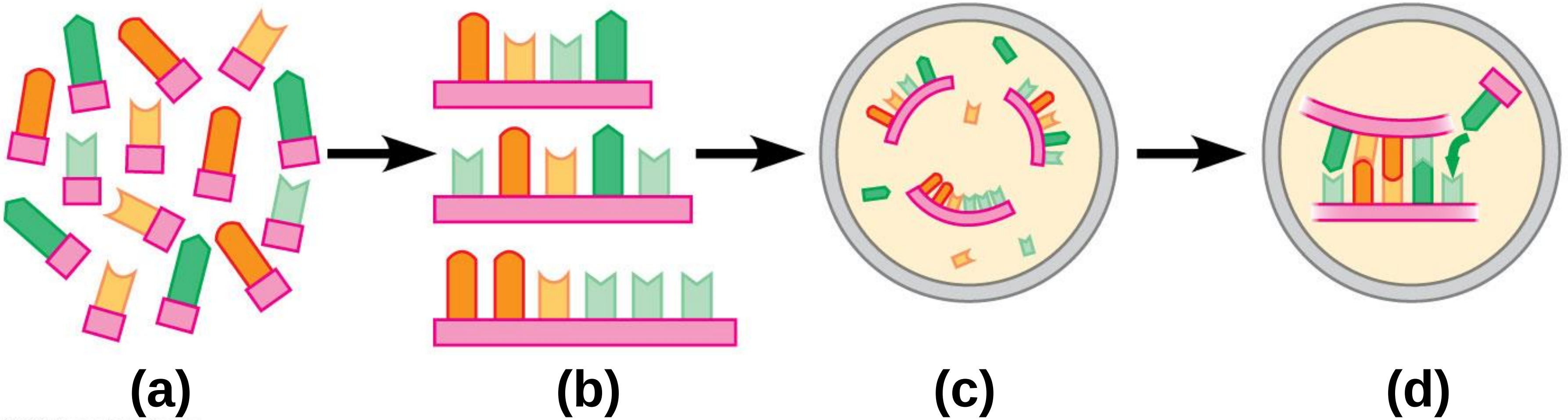


Figure 15.UN04

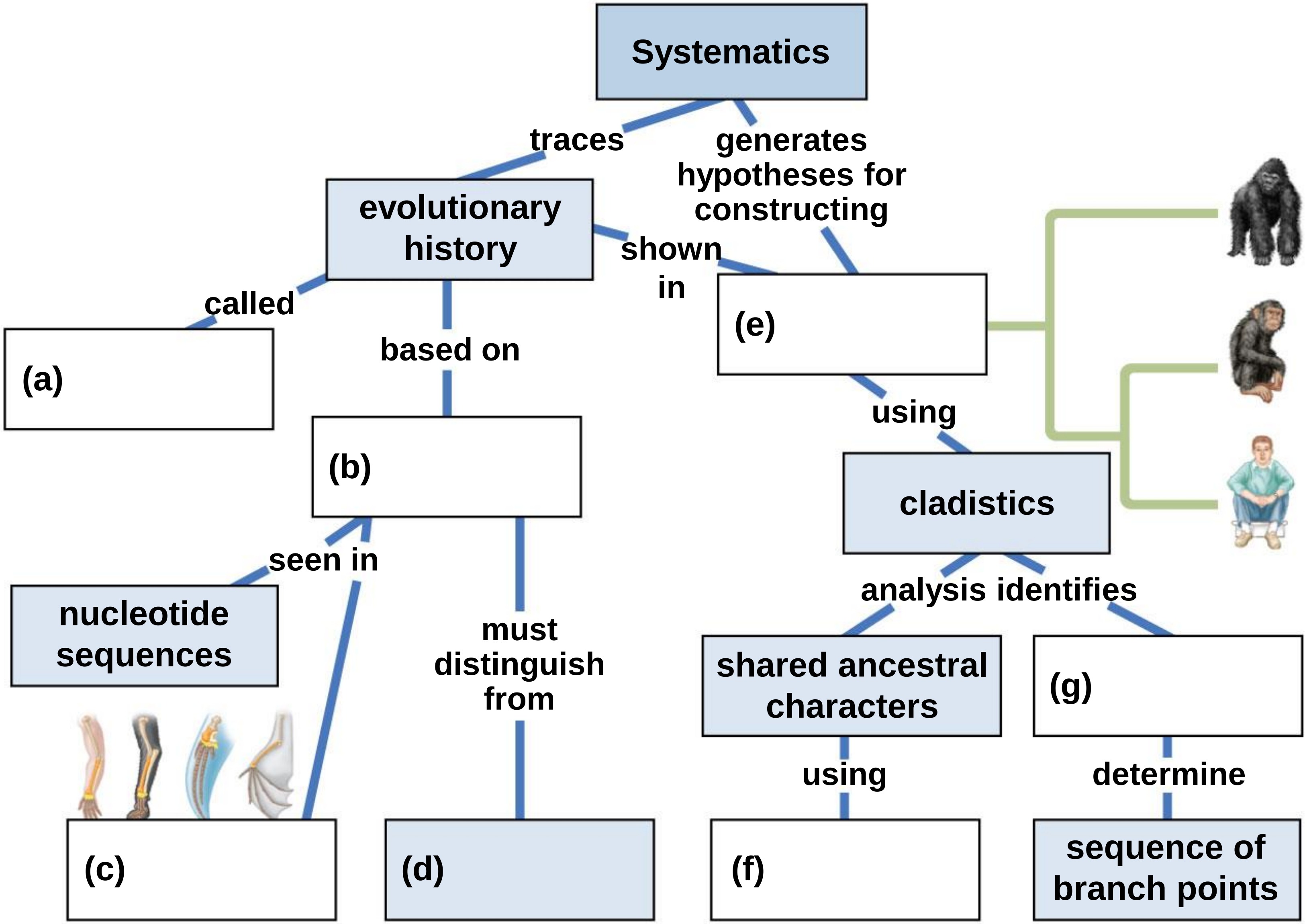


Figure 15.UN05

Trait	*Velociraptor*	*Coelophysis*	*Archaeopteryx*	*Allosaurus*
Hollow bones	1	1	1	1
Three-fingered hand	1	0	1	1
Half-moon-shaped wrist bone	1	0	1	0
Reversed first toe	0	0	1	0