LECTURE PRESENTATIONS
For CAMPBELL BIOLOGY, NINTH EDITION
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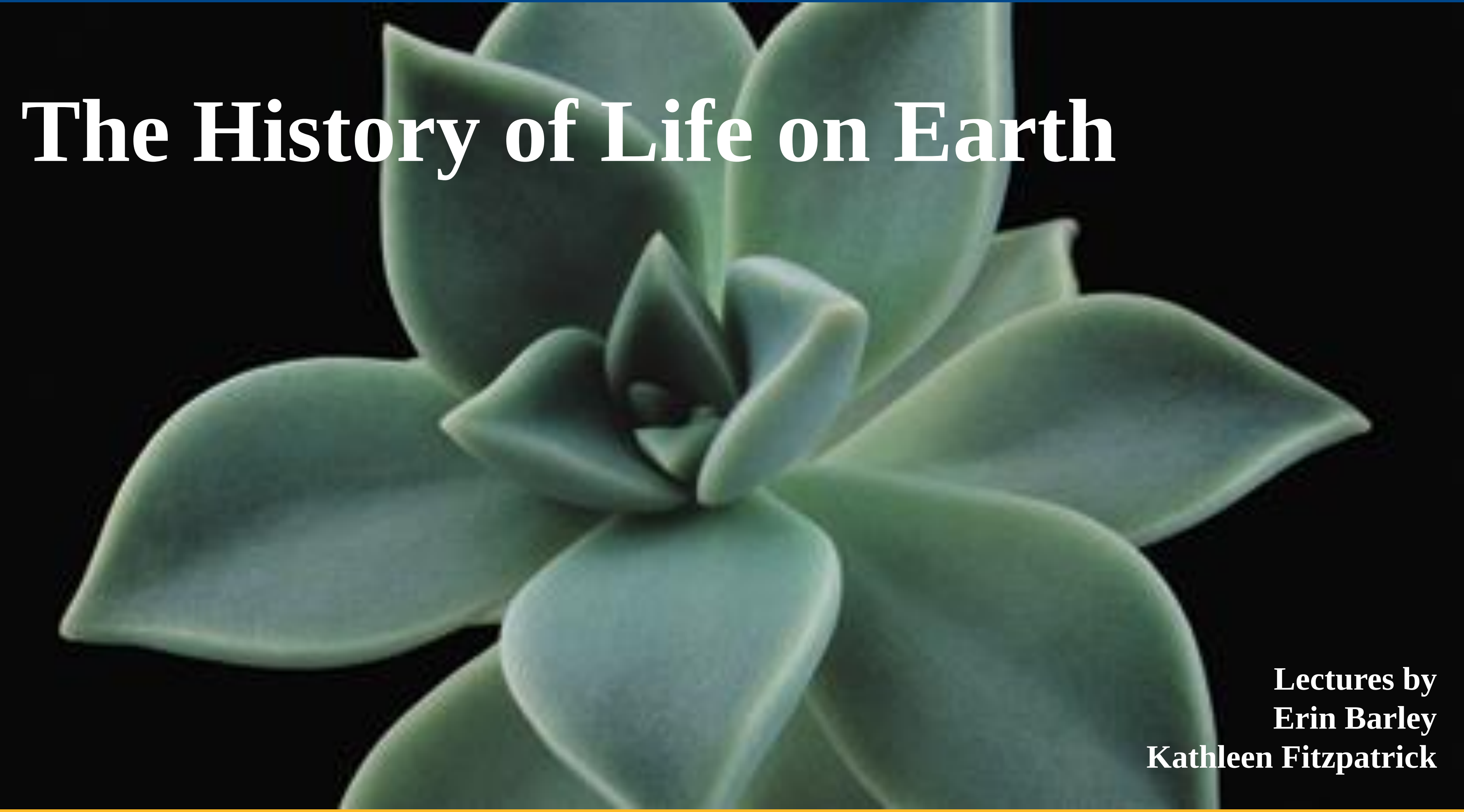
Chapter 25

The History of Life on Earth



Lectures by
Erin Barley
Kathleen Fitzpatrick

Overview: 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

Figure 25.1

Figure 25.UN01

▲ ***Cryolophosaurus* skull**

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

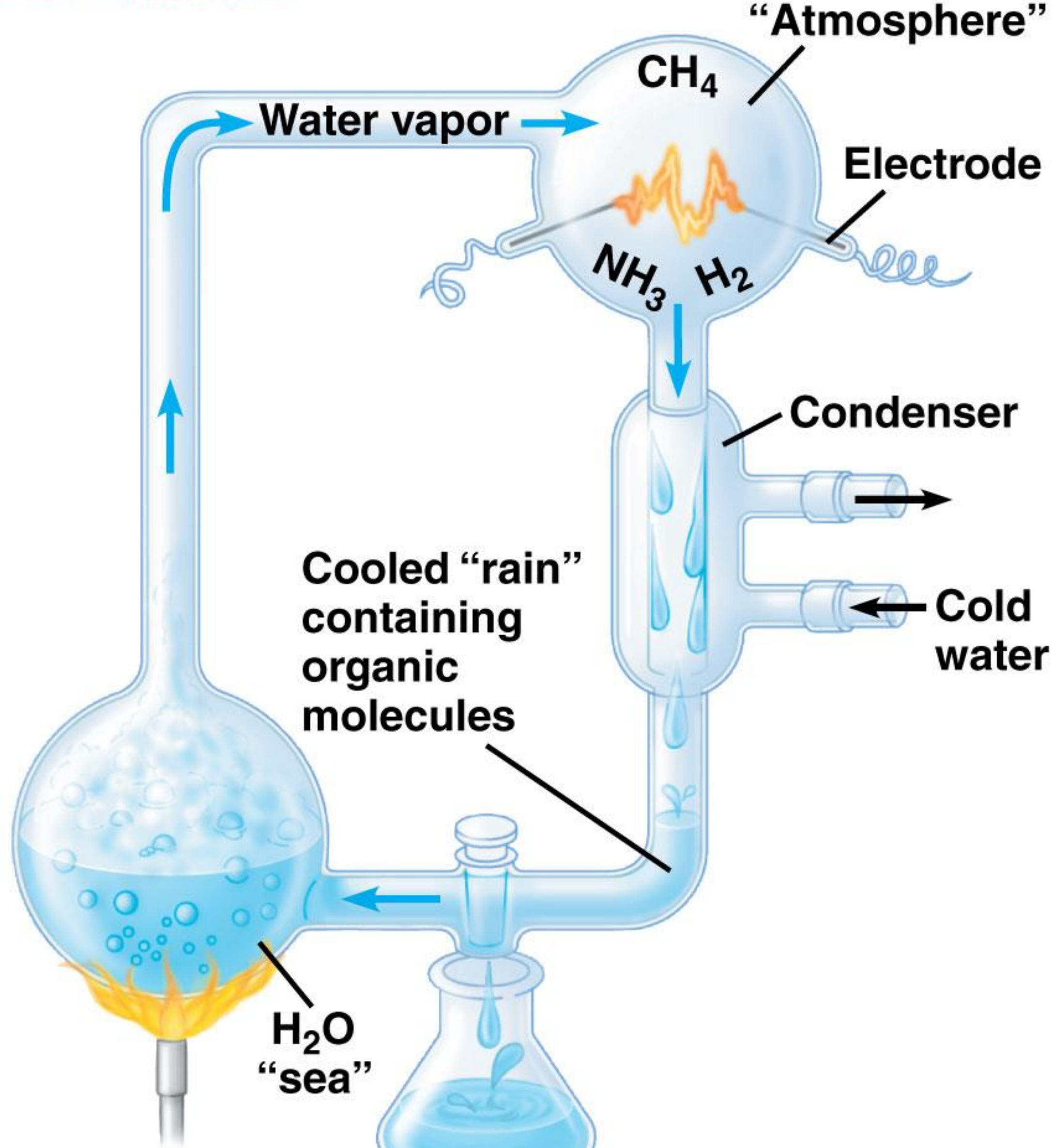
- Chemical and physical processes on early Earth may have produced very simple cells through a sequence of stages:
  1. Abiotic synthesis of small organic molecules
  2. Joining of these small molecules into macromolecules
  3. Packaging of molecules into **protocells**
  4. Origin of self-replicating molecules

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 4.2 to 3.9 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, hydrogen sulfide)

- 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

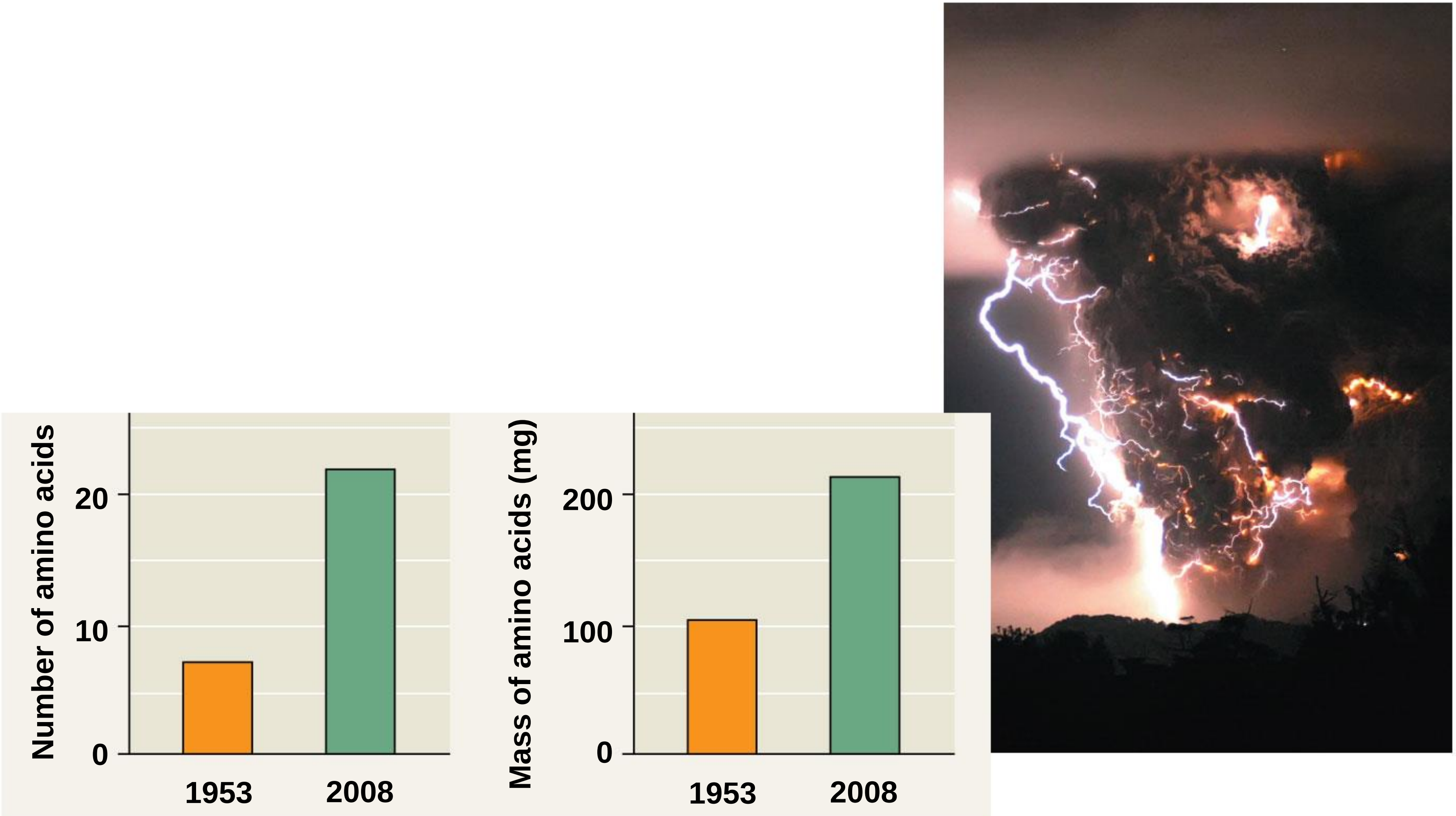
EXPERIMENT



Sample for chemical analysis

- 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

Figure 25.2



Number of amino acids
20
10
0
1953
2008
Mass of amino acids (mg)
200
100
0
1953
2008

- Amino acids have also been found in meteorites

Abiotic Synthesis of Macromolecules

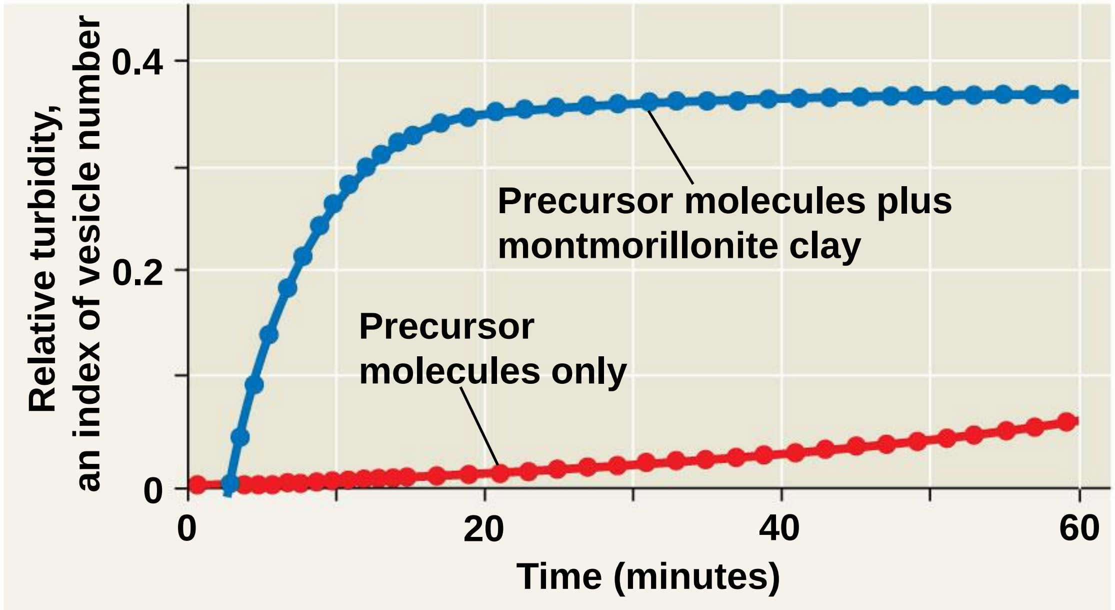
- RNA monomers have been produced spontaneously from simple molecules
- Small organic molecules polymerize when they are concentrated on hot sand, clay, or rock

Protocells

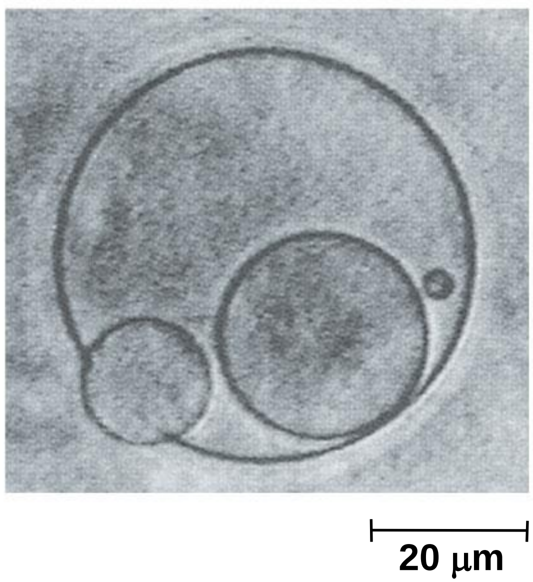
- Replication and metabolism are key properties of life and may have appeared together
- Protocells may have been fluid-filled vesicles with a membrane-like structure
- In water, lipids and other organic molecules can spontaneously form vesicles with a lipid bilayer

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

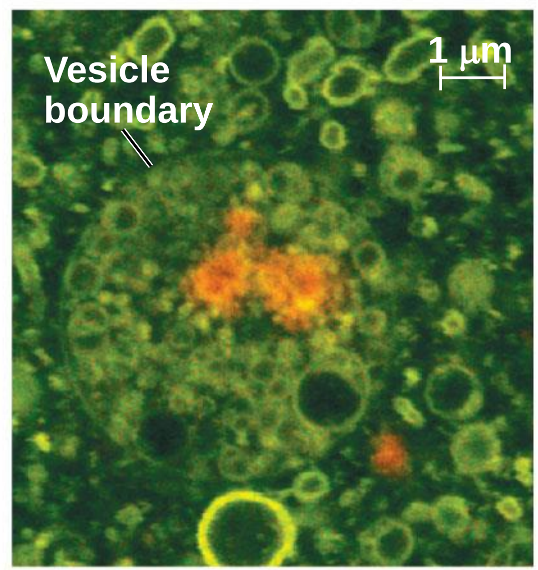
Figure 25.3



(a) Self-assembly



(b) Reproduction



(c) Absorption of RNA

Self-Replicating RNA and the Dawn of Natural Selection

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

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

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

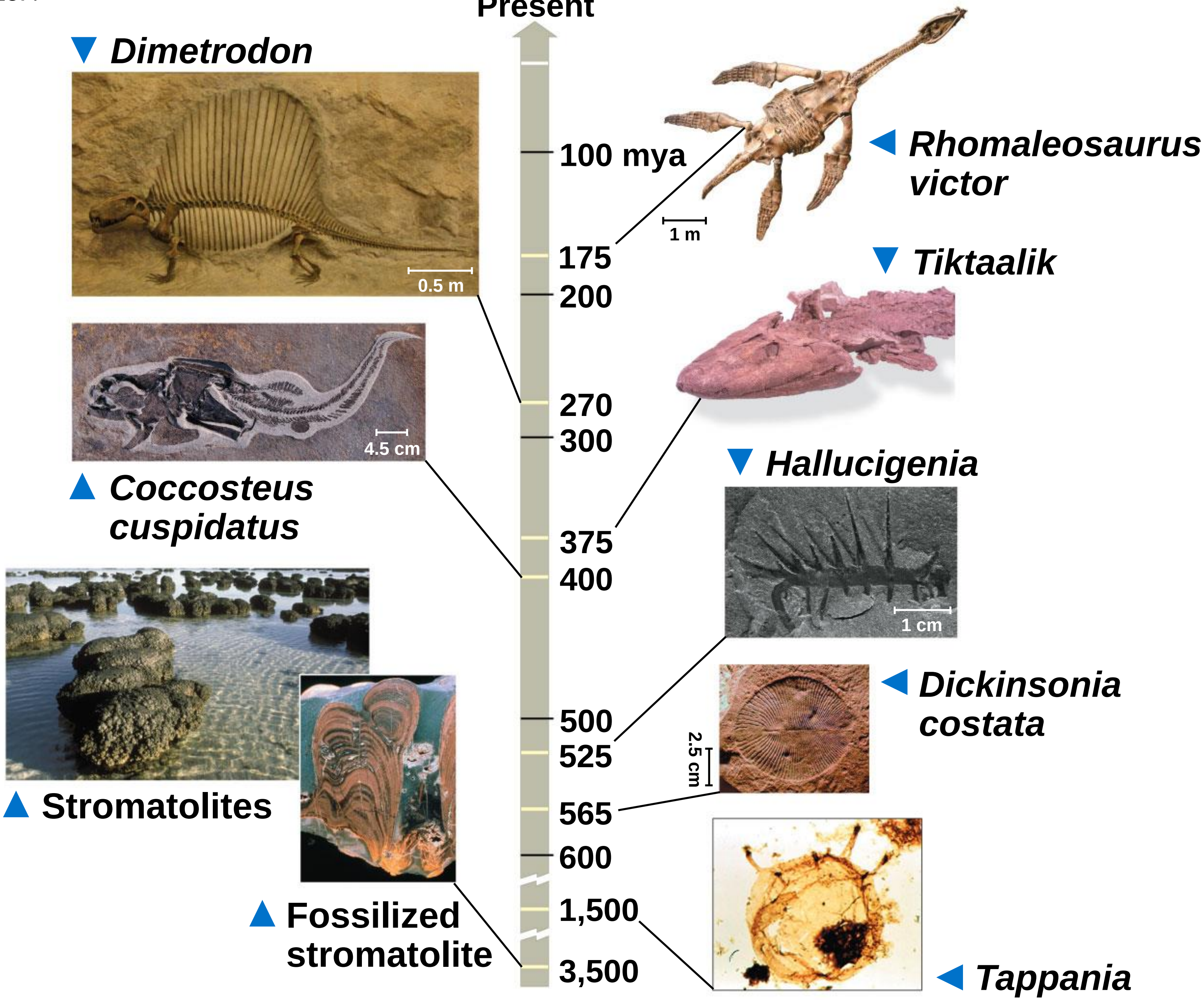
Concept 25.2: The fossil record documents the history of life

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

The Fossil Record

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

Figure 25.4


Present
Dimetrodon
0.5 m
Coccosteus cuspidatus
4.5 cm
Stromatolites
Fossilized stromatolite
100 mya
175
200
270
300
375
400
500
525
565
600
1,500
3,500
Rhomaleosaurus victor
1 m
Tiktaalik
Hallucigenia
1 cm
Dickinsonia costata
2.5 cm
Tappania

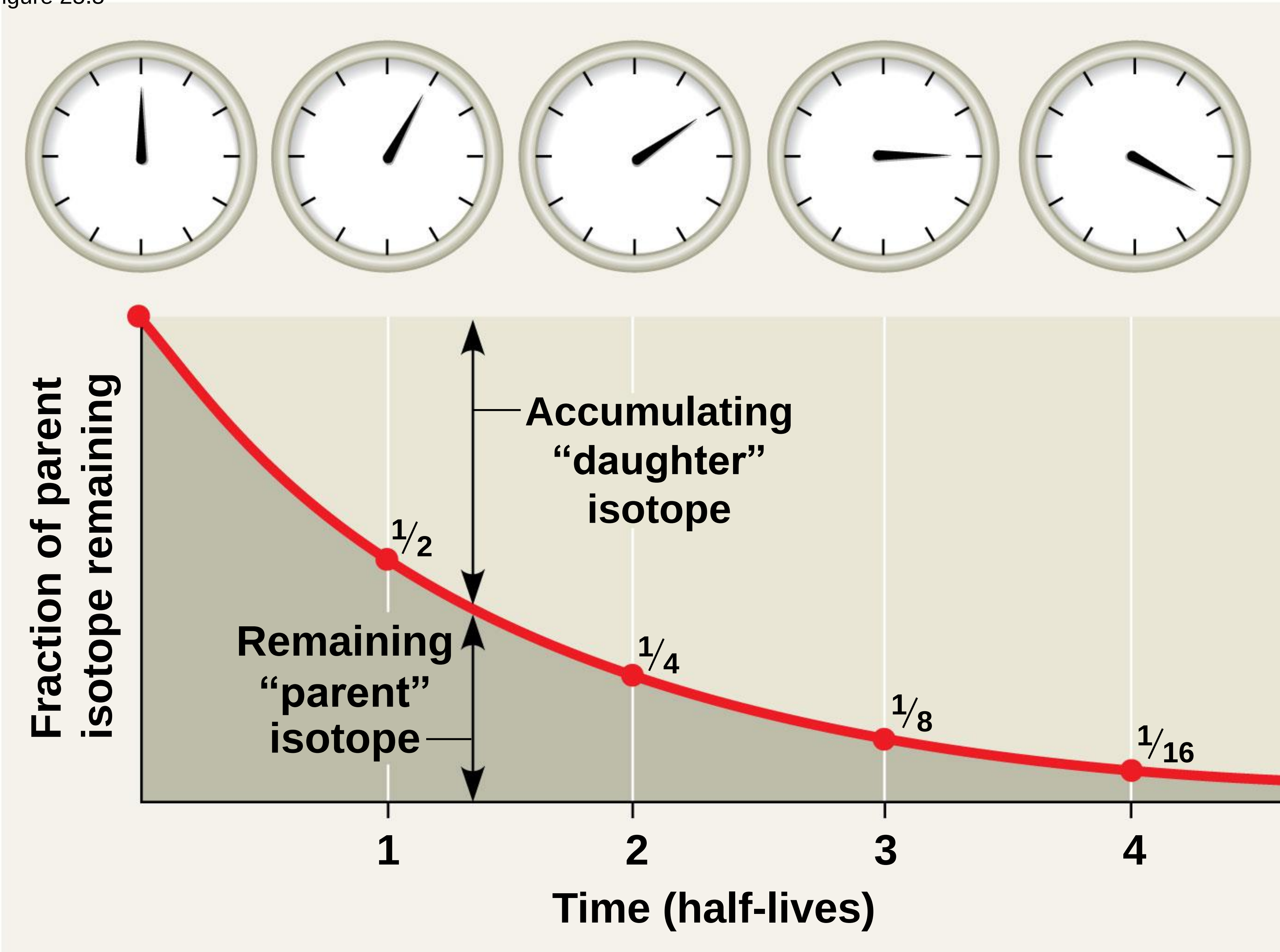
- Few individuals have fossilized, and even fewer have been discovered
- The fossil record is biased in favor of species that
  - Existed for a long time
  - Were abundant and widespread
  - Had hard parts

- Fossil discoveries can be a matter of chance or prediction
  - For example, paleontologists found *Tiktaalik*, an early terrestrial vertebrate, by targeting sedimentary rock from a specific time and environment

How Rocks and Fossils Are Dated

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

Figure 25.5



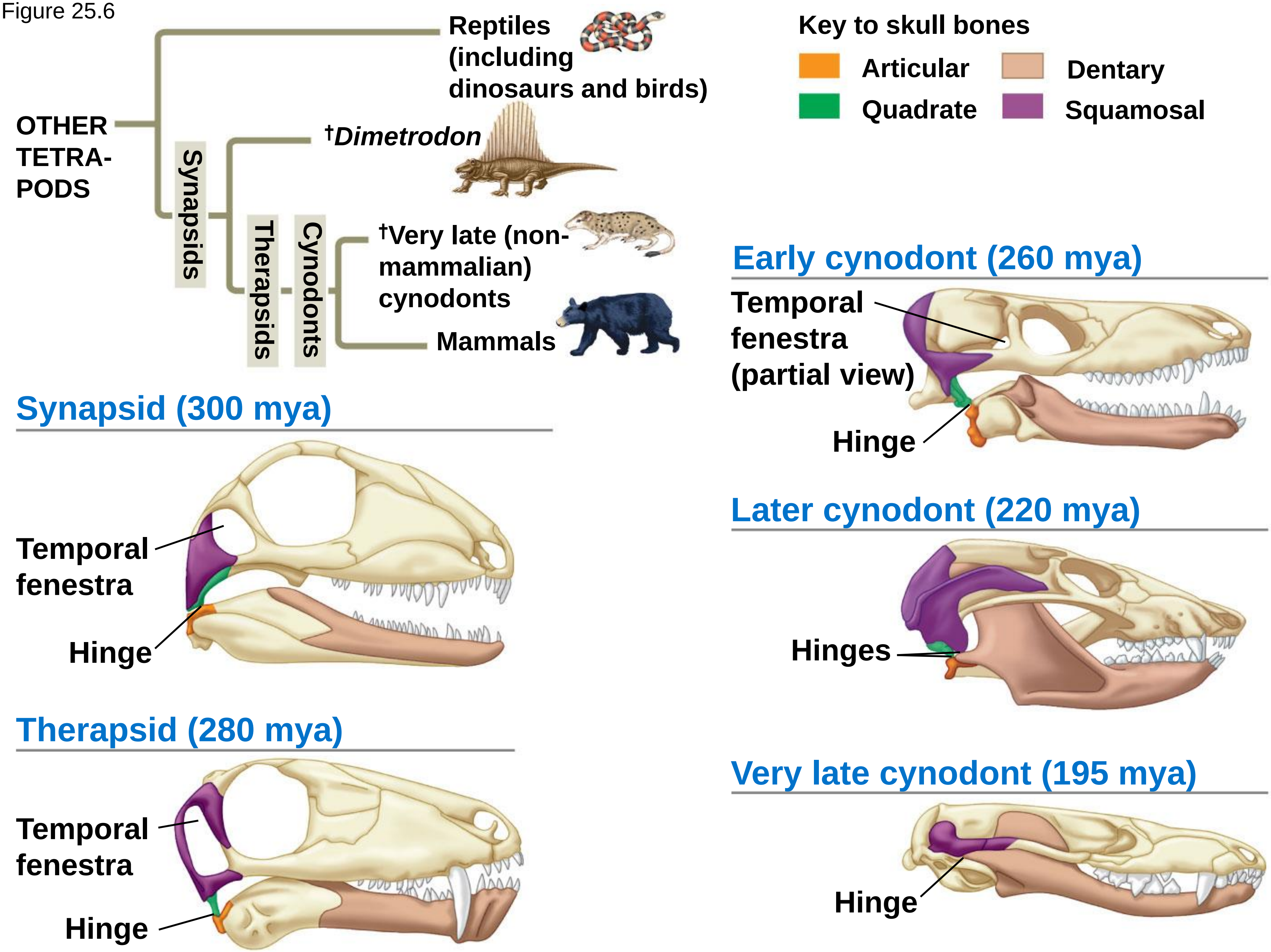
Accumulating
"daughter"
isotope
Remaining
"parent"
isotope
1/2
1/4
1/8
1/16
Fraction of parent isotope remaining
1
2
3
4
Time (half-lives)

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

The Origin of New Groups of Organisms

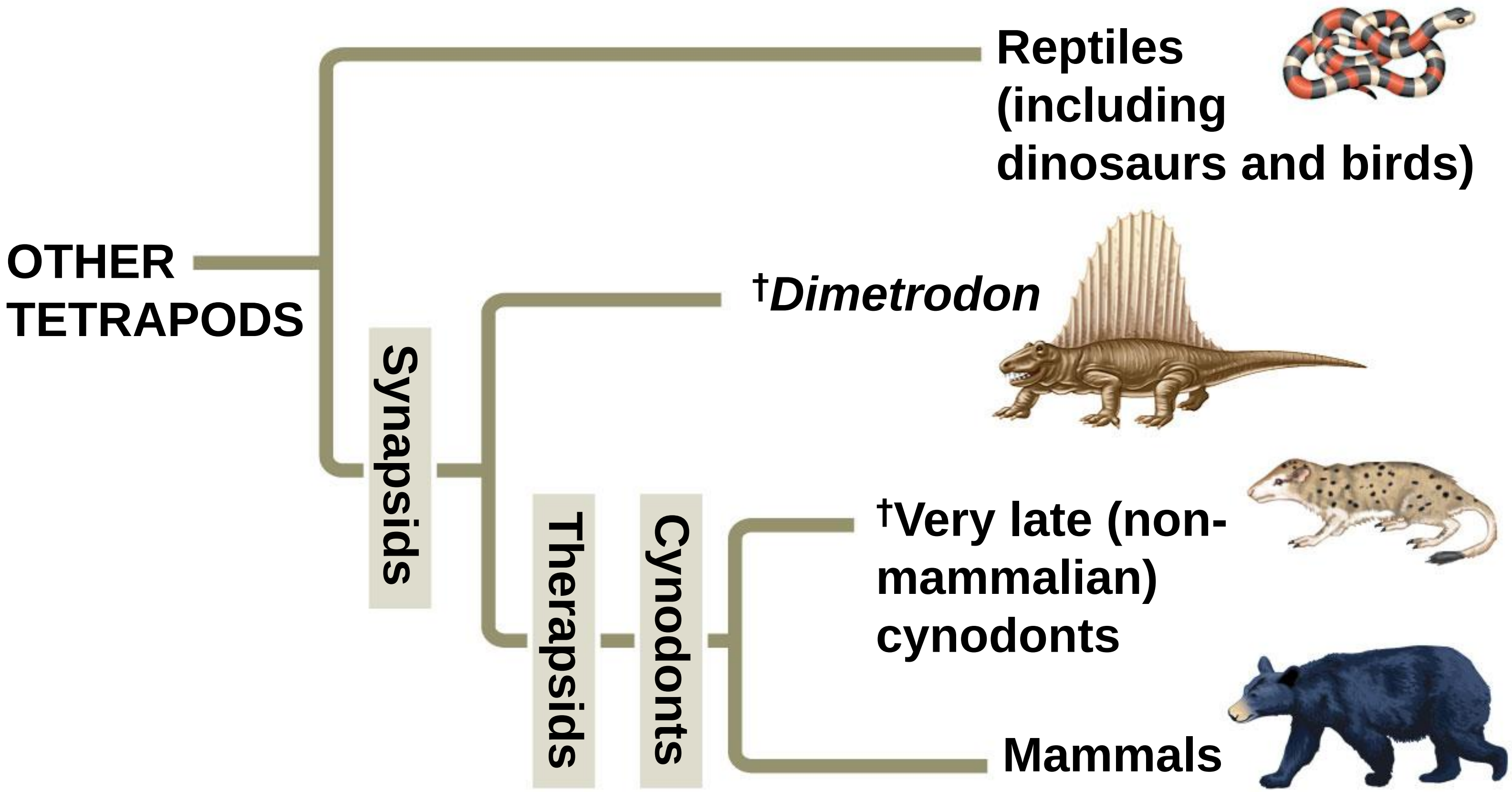
- Mammals belong to the group of animals called tetrapods
- The evolution of unique mammalian features can be traced through gradual changes over time

Figure 25.6



Reptiles (including dinosaurs and birds)
OTHER TETRA-PODS
†Dimetrodon
Synapsids
Therapsids
Cynodonts
†Very late (non-mammalian) cynodonts
Mammals
Key to skull bones
Articular
Dentary
Quadrate
Squamosal
Synapsid (300 mya)
Temporal fenestra
Hinge
Therapsid (280 mya)
Temporal fenestra
Hinge
Early cynodont (260 mya)
Temporal fenestra (partial view)
Hinge
Later cynodont (220 mya)
Hinges
Very late cynodont (195 mya)
Hinge

Figure 25.6a


OTHER TETRAPODS
Reptiles (including dinosaurs and birds)
†Dimetrodon
†Very late (non-mammalian) cynodonts
Mammals
Synapsids
Therapsids
Cynodonts

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

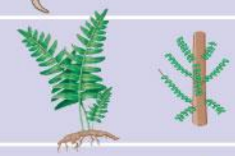
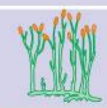
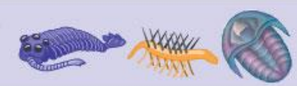
- The **geologic record** is divided into the Archaean, the Proterozoic, and the Phanerozoic eons
- The Phanerozoic encompasses multicellular eukaryotic life
- The Phanerozoic is divided into three eras: the Paleozoic, Mesozoic, and Cenozoic

Table 25.1

Table 25.1 The Geologic Record

Relative Duration of Eons	Era	Period	Epoch	Age (Millions of Years Ago)	Some Important Events in the History of Life
Phanerozoic	Cenozoic	Quaternary	Holocene	0.01	Historical time
			Pleistocene	2.6	Ice ages; origin of genus *Homo*
		Neogene	Pliocene	5.3	Appearance of bipedal human ancestors
			Miocene	23	Continued radiation of mammals and angiosperms; earliest direct human ancestors
		Paleogene	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 25.1a

Era	Period	Epoch	Age (Millions of Years Ago)	Some Important Events in the History of Life
			251	
Paleozoic	Permian			Radiation of reptiles; origin of most present-day groups of insects; extinction of many marine and terrestrial organisms at end of period 
			299	
	Carboniferous			Extensive forests of vascular plants form; first seed plants appear; origin of reptiles; amphibians dominant 
			359	
	Devonian			Diversification of bony fishes; first tetrapods and insects appear 
			416	
	Silurian			Diversification of early vascular plants 
			444	
	Ordovician			Marine algae abundant; colonization of land by diverse fungi, plants, and animals 
			488	
	Cambrian			Sudden increase in diversity of many animal phyla (Cambrian explosion) 
			542	
(Proterozoic eon)	Ediacaran			Diverse algae and soft-bodied invertebrate animals appear 
			635	
			2,100	Oldest fossils of eukaryotic cells appear 
			2,500	
(Archaean eon)			2,700	Concentration of atmospheric oxygen begins to increase
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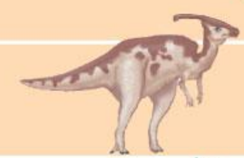
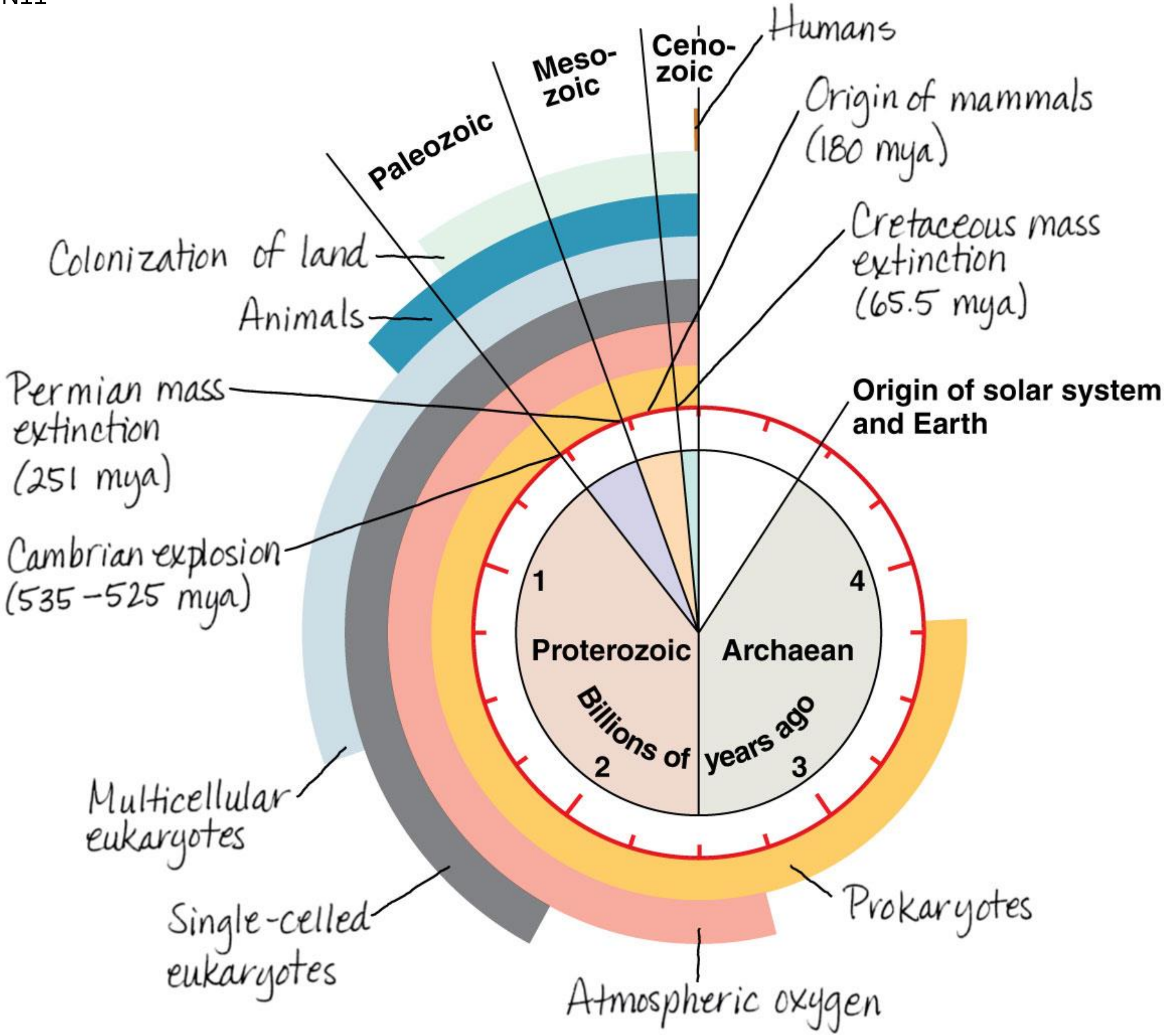
			3,800	Oldest known rocks on Earth's surface
			Approx. 4,600	Origin of Earth

Table 25.1b

Era	Period	Epoch	Age (Millions of Years Ago)	Some Important Events in the History of Life
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 
			251	

- Major boundaries between geological divisions correspond to extinction events in the fossil record

Figure 25.UN11



The First Single-Celled Organisms

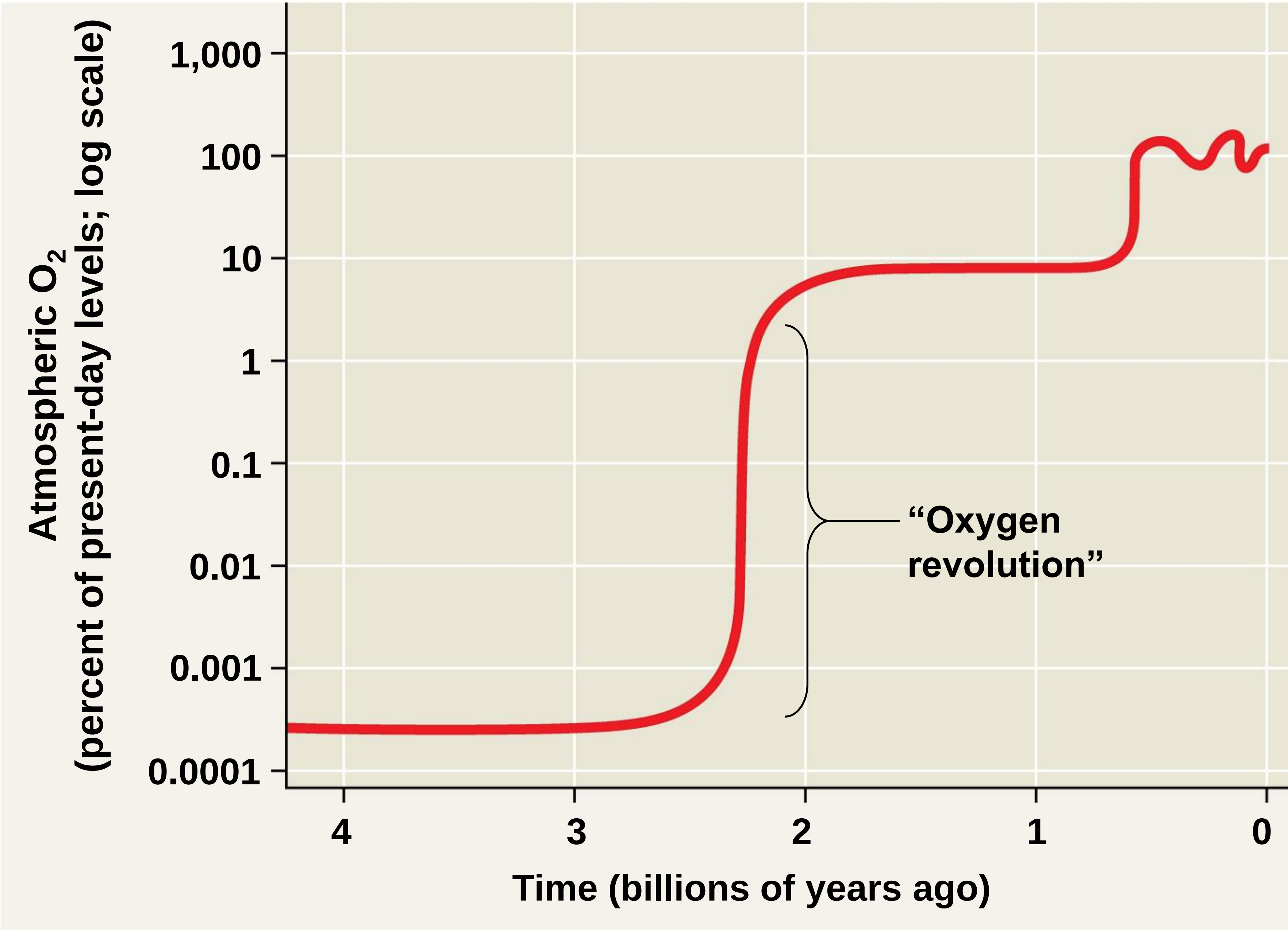
- The oldest known fossils are **stromatolites**, rocks formed by the accumulation of sedimentary layers on bacterial mats
- Stromatolites date back 3.5 billion years ago
- Prokaryotes were Earth’s sole inhabitants from 3.5 to about 2.1 billion years ago

Photosynthesis and the Oxygen Revolution

- Most atmospheric oxygen (O_2) is of biological origin
- O_2 produced by oxygenic photosynthesis reacted with dissolved iron and precipitated out to form banded iron formations

- 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

Figure 25.8



Atmospheric O_2
(percent of present-day levels; log scale)
1,000
100
10
1
0.1
0.01
0.001
0.0001
"Oxygen revolution"
4
3
2
1
0
Time (billions of years ago)

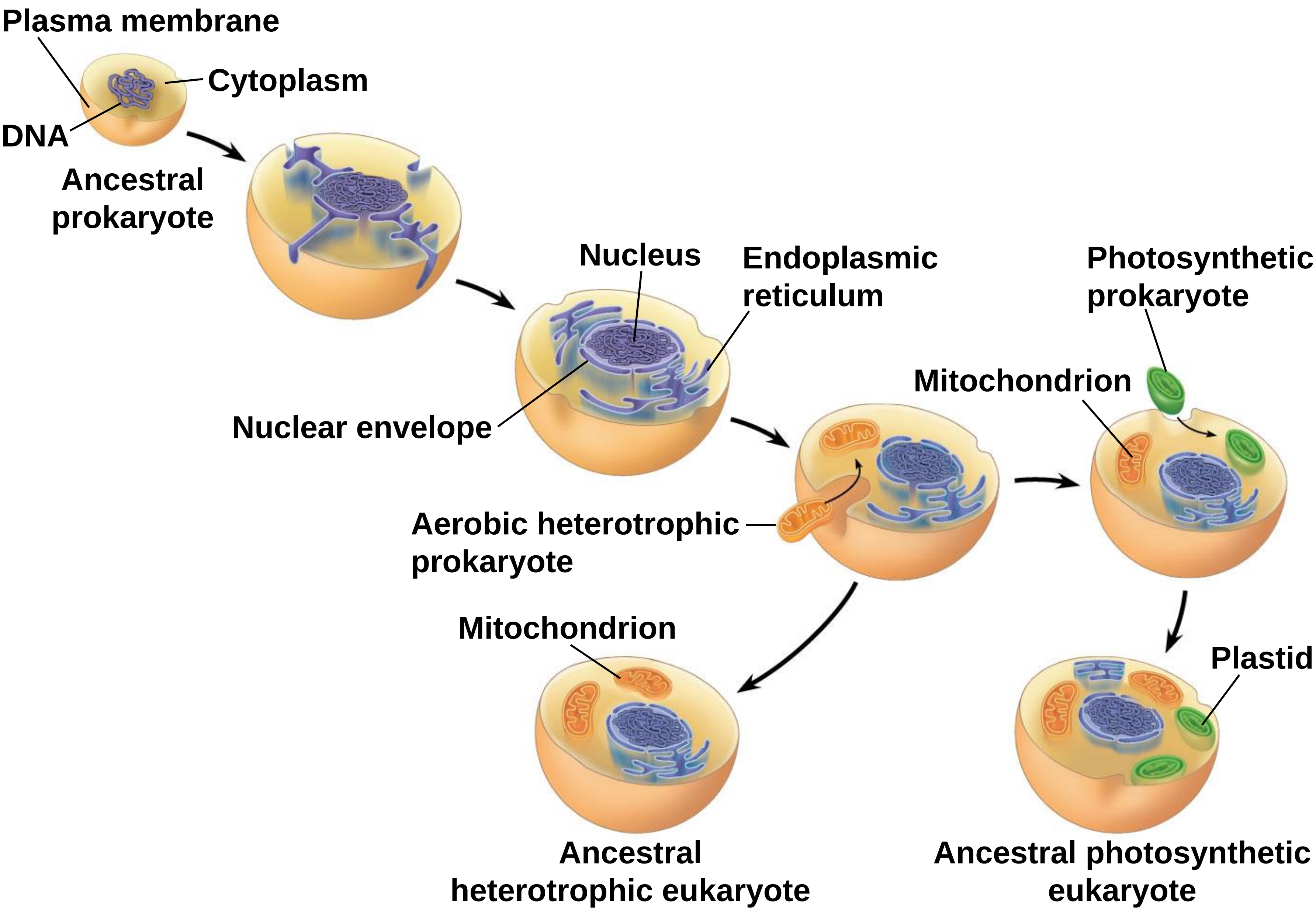
- The early rise in O_2 was likely caused by ancient cyanobacteria
- A later increase in the rise of O_2 might have been caused by the evolution of eukaryotic cells containing chloroplasts

The First Eukaryotes

- The oldest fossils of eukaryotic cells date back 2.1 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

- 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

Figure 25.9-3


Plasma membrane
Cytoplasm
DNA
Ancestral prokaryote
Nucleus
Endoplasmic reticulum
Photosynthetic prokaryote
Mitochondrion
Nuclear envelope
Aerobic heterotrophic prokaryote
Mitochondrion
Plastid
Ancestral heterotrophic eukaryote
Ancestral photosynthetic eukaryote

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

The Origin of Multicellularity

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

The Earliest Multicellular Eukaryotes

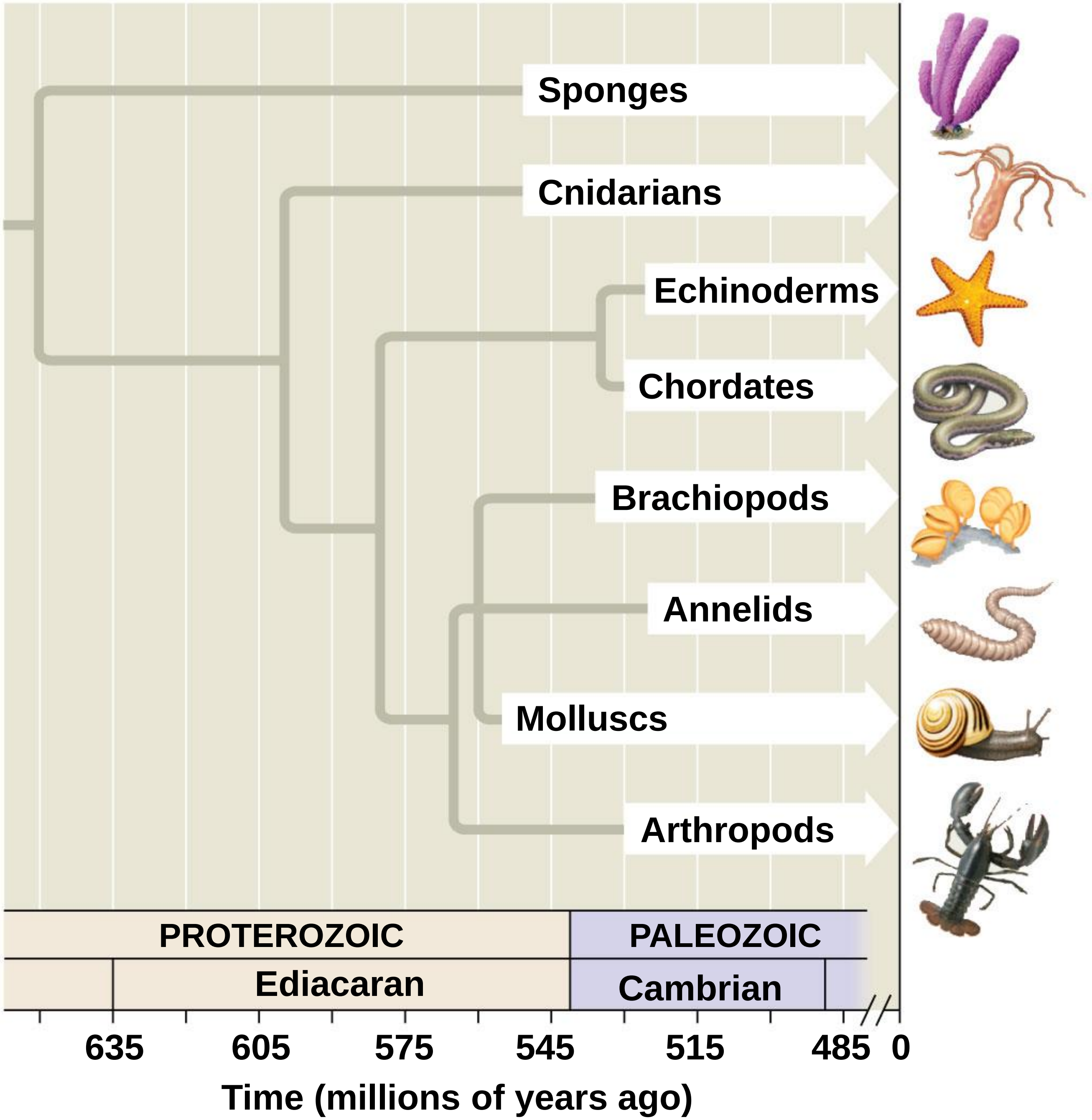
- Comparisons of DNA sequences date the common ancestor of multicellular eukaryotes to 1.5 billion years ago
- The oldest known fossils of multicellular eukaryotes are of small algae that lived about 1.2 billion years ago

- The “snowball Earth” hypothesis suggests that periods of extreme glaciation confined life to the equatorial region or deep-sea vents from 750 to 580 million years ago
- The Ediacaran biota were an assemblage of larger and more diverse soft-bodied organisms that lived from 575 to 535 million years ago

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

Figure 25.10


Sponges
Cnidarians
Echinoderms
Chordates
Brachiopods
Annelids
Molluscs
Arthropods
PROTEROZOIC
PALEOZOIC
Ediacaran
Cambrian
635
605
575
545
515
485
0
Time (millions of years ago)

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

The Colonization of Land

- Fungi, plants, and animals began to colonize land about 500 million years ago
- Vascular tissue in plants transports materials internally and appeared by about 420 million years ago
- Plants and fungi today form mutually beneficial associations and likely colonized land together

- Arthropods and tetrapods are the most widespread and diverse land animals
- Tetrapods evolved from lobe-finned fishes around 365 million years ago

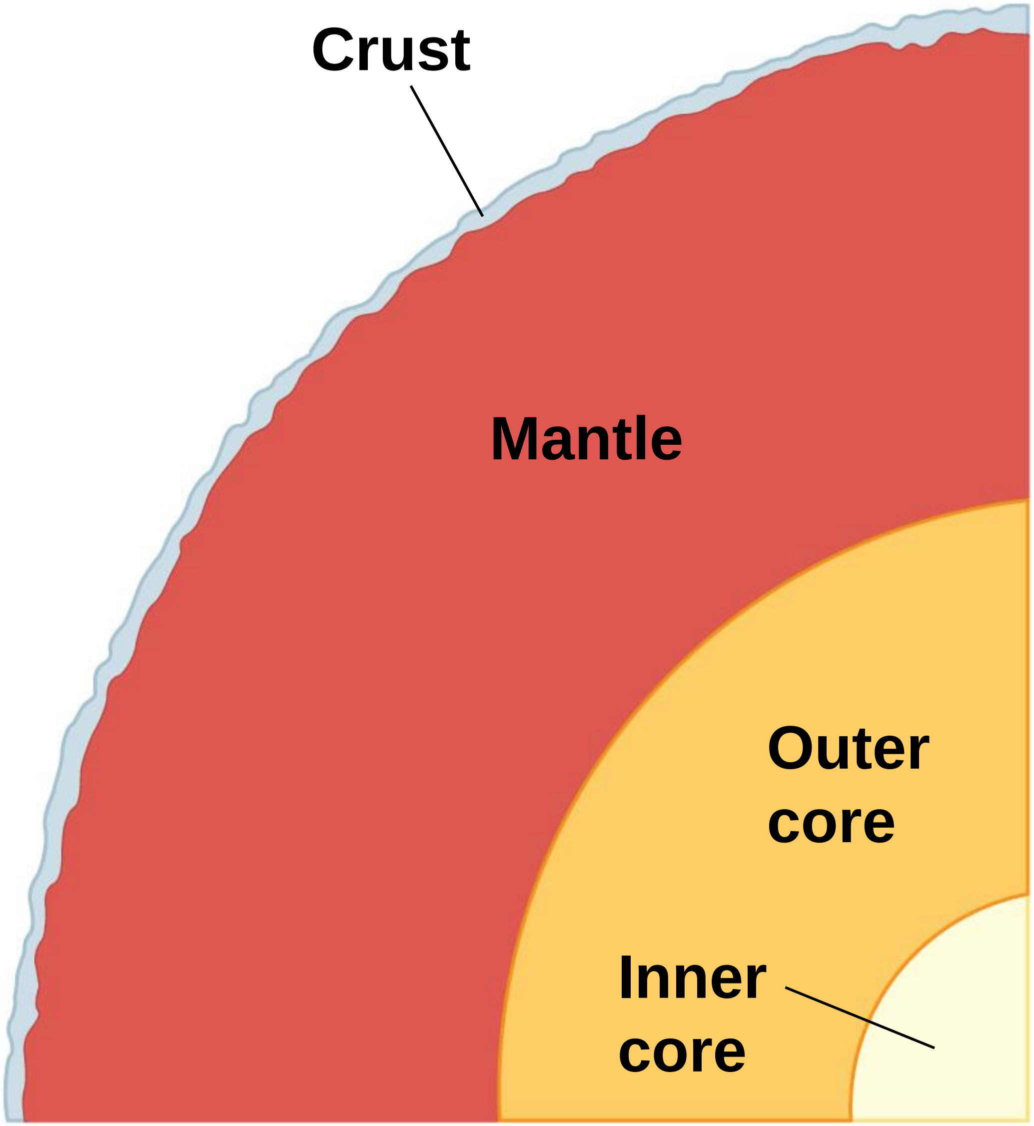
Concept 25.4: The rise and fall of groups of organisms reflect differences in speciation and extinction rates

- 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

Plate Tectonics

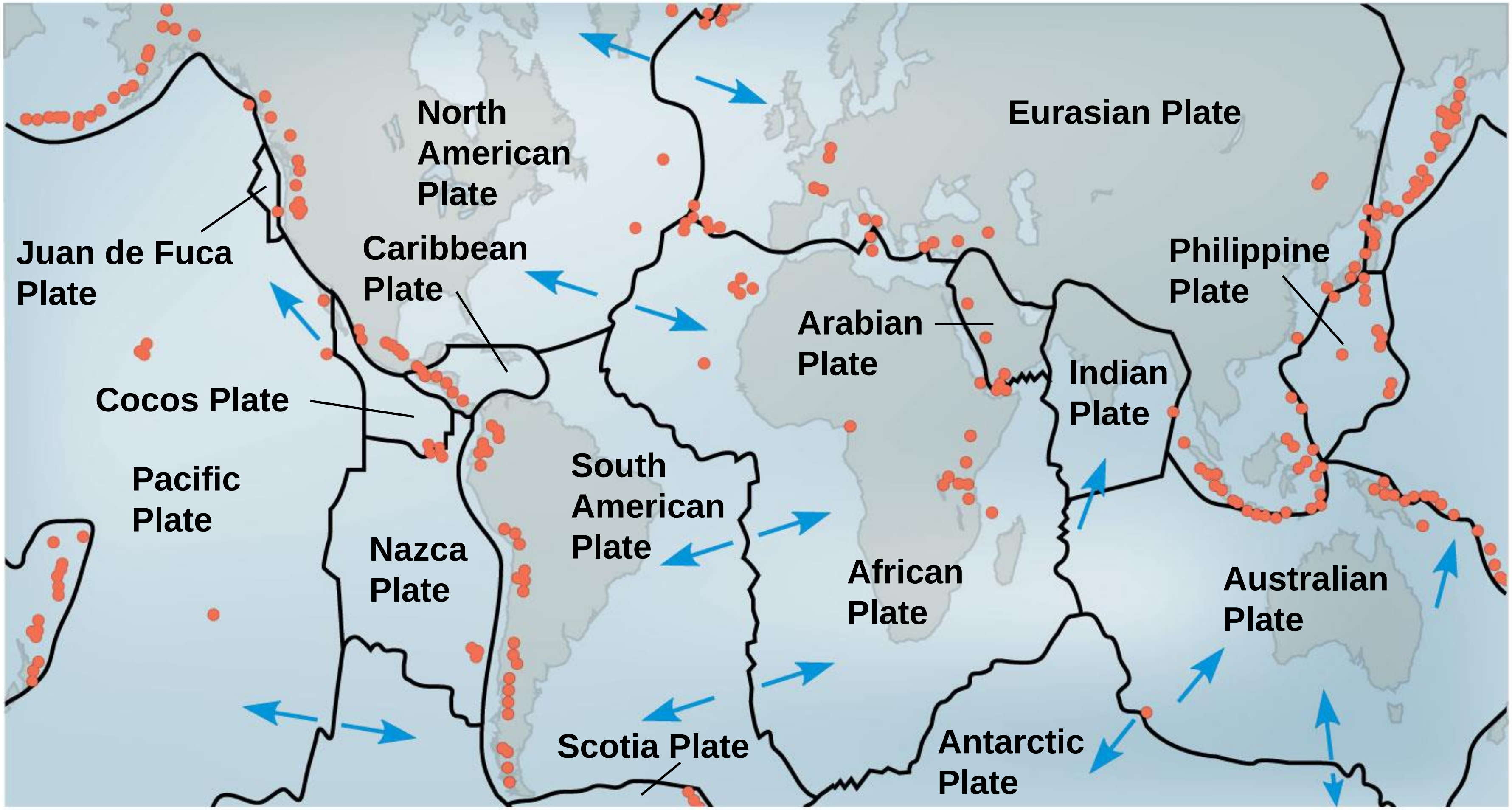
- At three points in time, the land masses of Earth have formed a supercontinent: 1.1 billion, 600 million, and 250 million years ago
- According to the theory of **plate tectonics**, Earth's crust is composed of plates floating on Earth's mantle

Figure 25.12



- 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

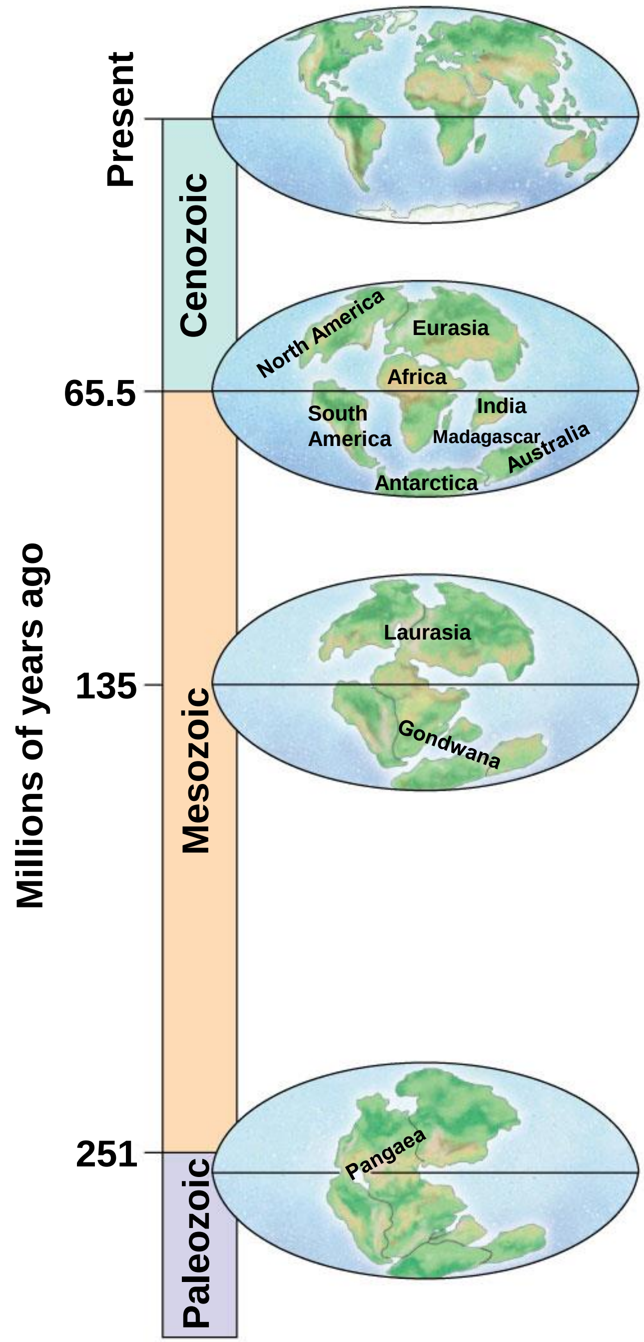
Figure 25.13


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

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

Figure 25.14


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

- 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

- 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

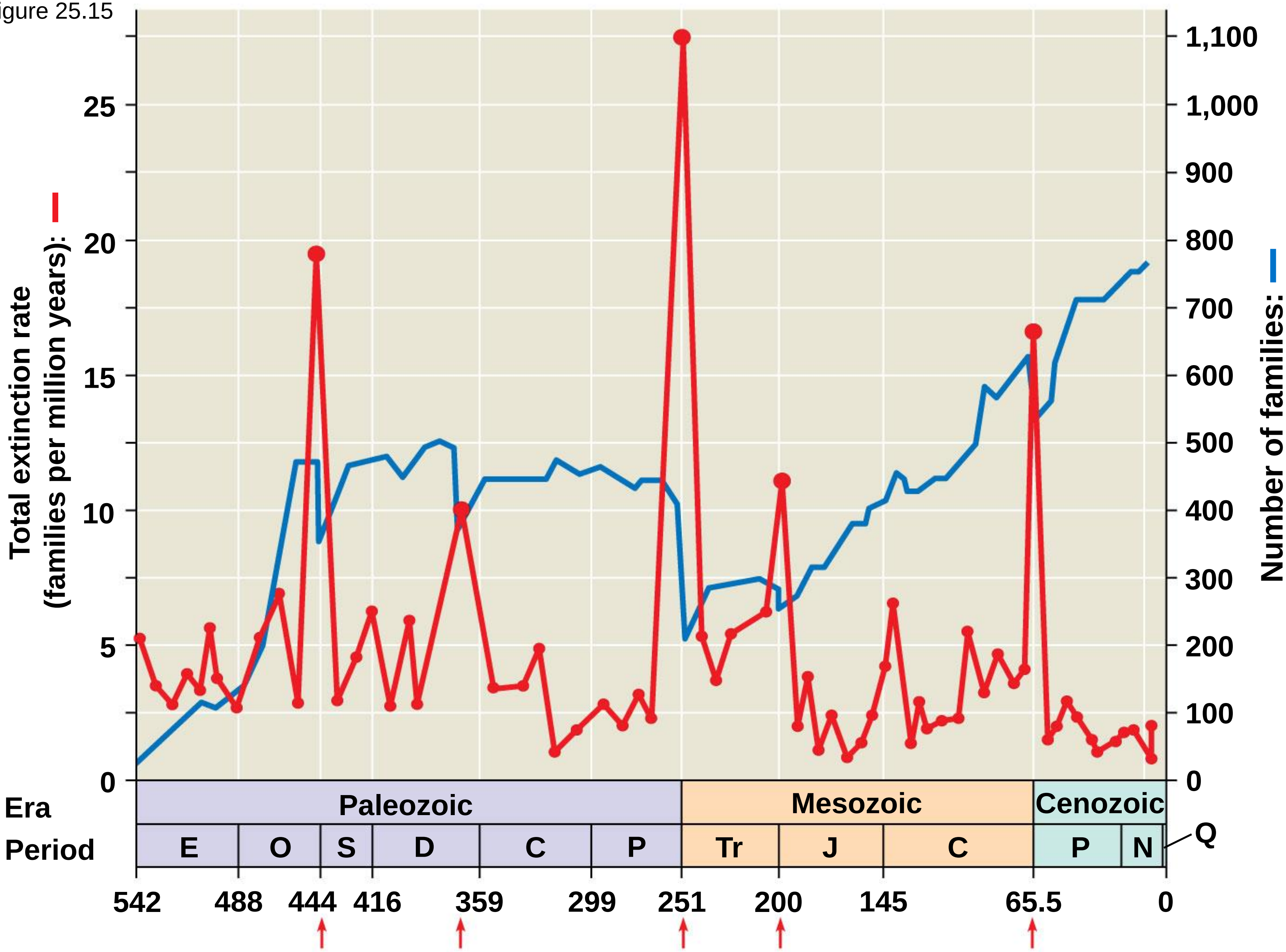
Mass Extinctions

- 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

The "Big Five" Mass Extinction Events

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

Figure 25.15



Total extinction rate (families per million years):
Number of families:
0
5
10
15
20
25
0
100
200
300
400
500
600
700
800
900
1,000
1,100
Era
Period
Paleozoic
Mesozoic
Cenozoic
E
O
S
D
C
P
Tr
J
C
P
N
Q
542
488
444
416
359
299
251
200
145
65.5
0

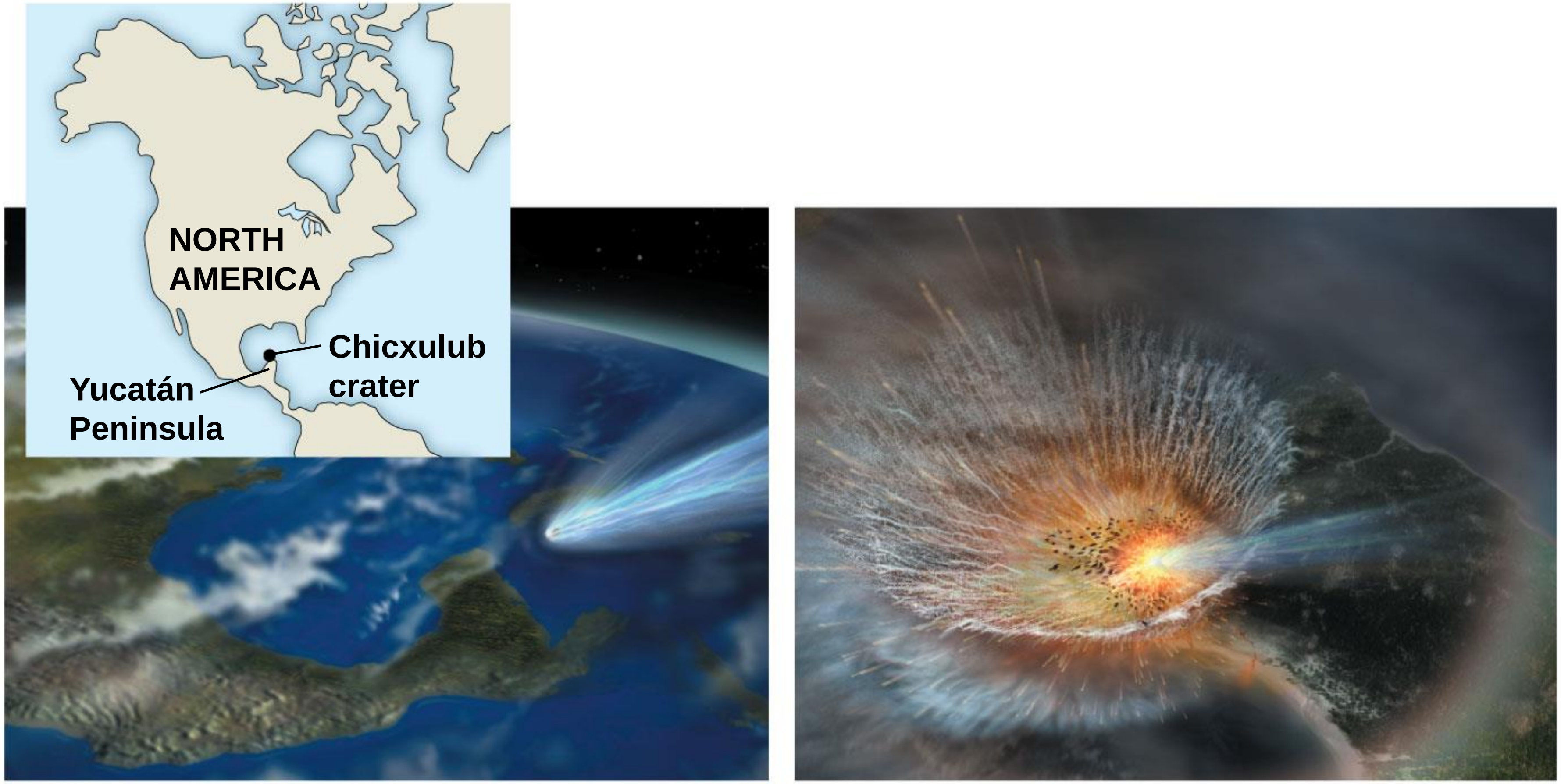
- The Permian extinction defines the boundary between the Paleozoic and Mesozoic eras 251 million years ago
- This mass extinction occurred in less than 5 million years and caused the extinction of about 96% of marine animal species

- A number of factors might have contributed to these extinctions
  - Intense volcanism in what is now Siberia
  - Global warming resulting from the emission of large amounts of CO_2 from the volcanoes
  - Reduced temperature gradient from equator to poles
  - Oceanic anoxia from reduced mixing of ocean waters

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

- The presence of iridium in sedimentary rocks suggests a meteorite impact about 65 million years ago
- 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

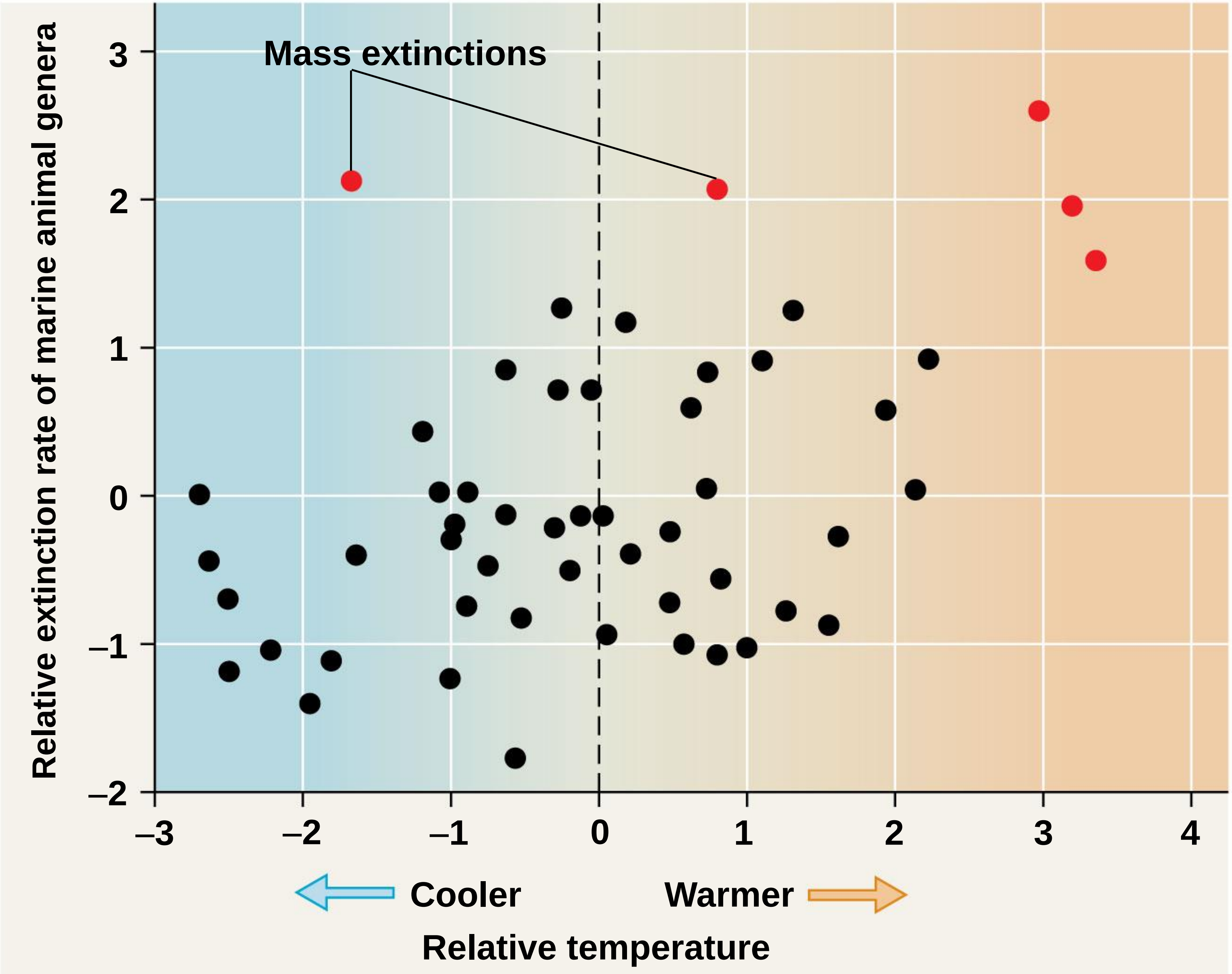
Figure 25.16



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

Figure 25.17

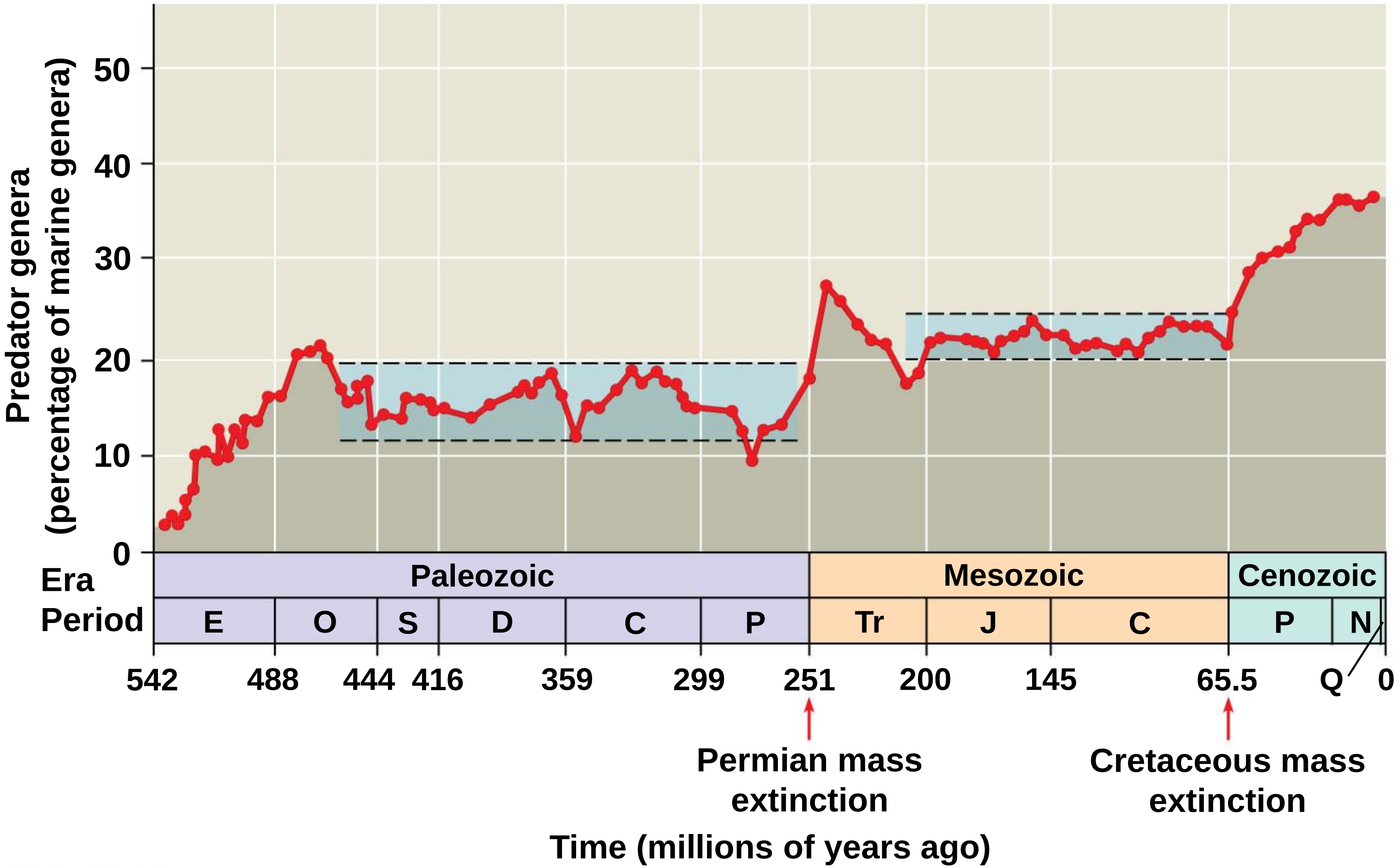


Mass extinctions
Relative extinction rate of marine animal genera
3
2
1
0
–1
–2
–3
–2
–1
0
1
2
3
4
Cooler
Warmer
Relative temperature

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
- The percentage of marine organisms that were predators increased after the Permian and Cretaceous mass extinctions
- Mass extinction can pave the way for adaptive radiations

Figure 25.18


Predator genera
(percentage of marine genera)
50
40
30
20
10
0
Era
Period
Paleozoic
Mesozoic
Cenozoic
E
O
S
D
C
P
Tr
J
C
P
N
542
488
444
416
359
299
251
200
145
65.5
Q
0
Permian mass extinction
Cretaceous mass extinction
Time (millions of years ago)

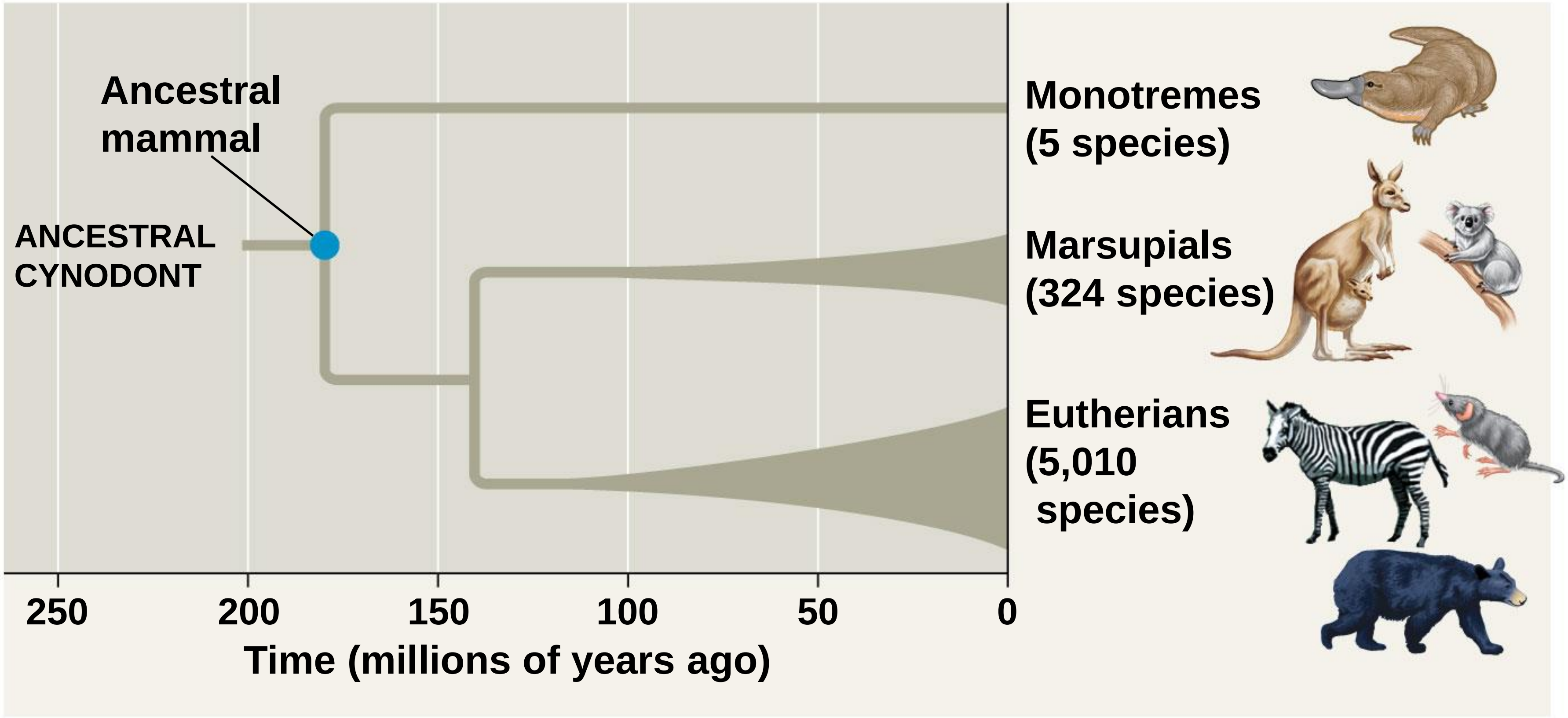
Adaptive Radiations

- **Adaptive radiation** is the 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

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

Figure 25.19



Ancestral mammal
ANCESTRAL CYNODONT
Monotremes (5 species)
Marsupials (324 species)
Eutherians (5,010 species)
250
200
150
100
50
0
Time (millions of years ago)

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

Figure 25.20

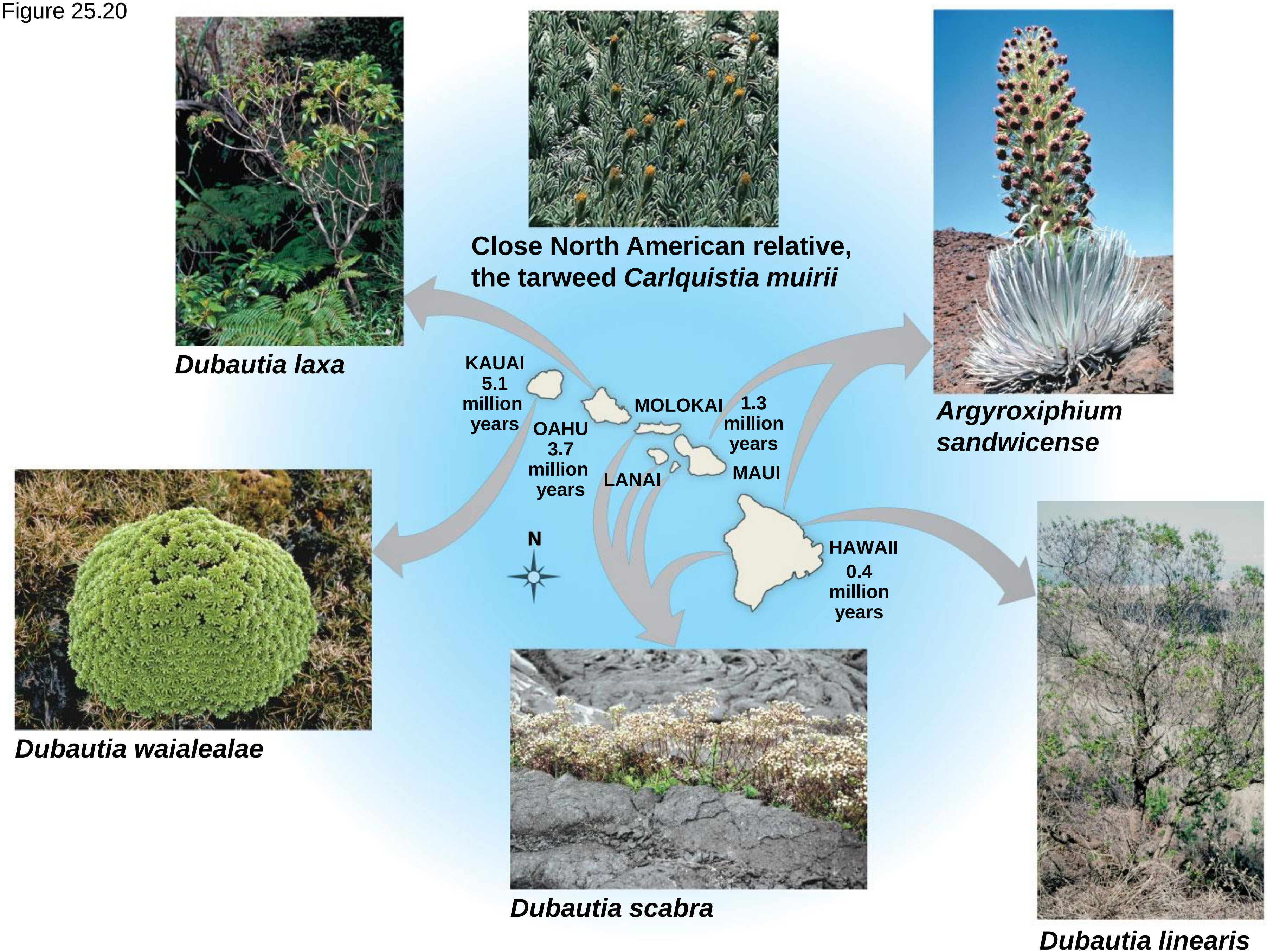
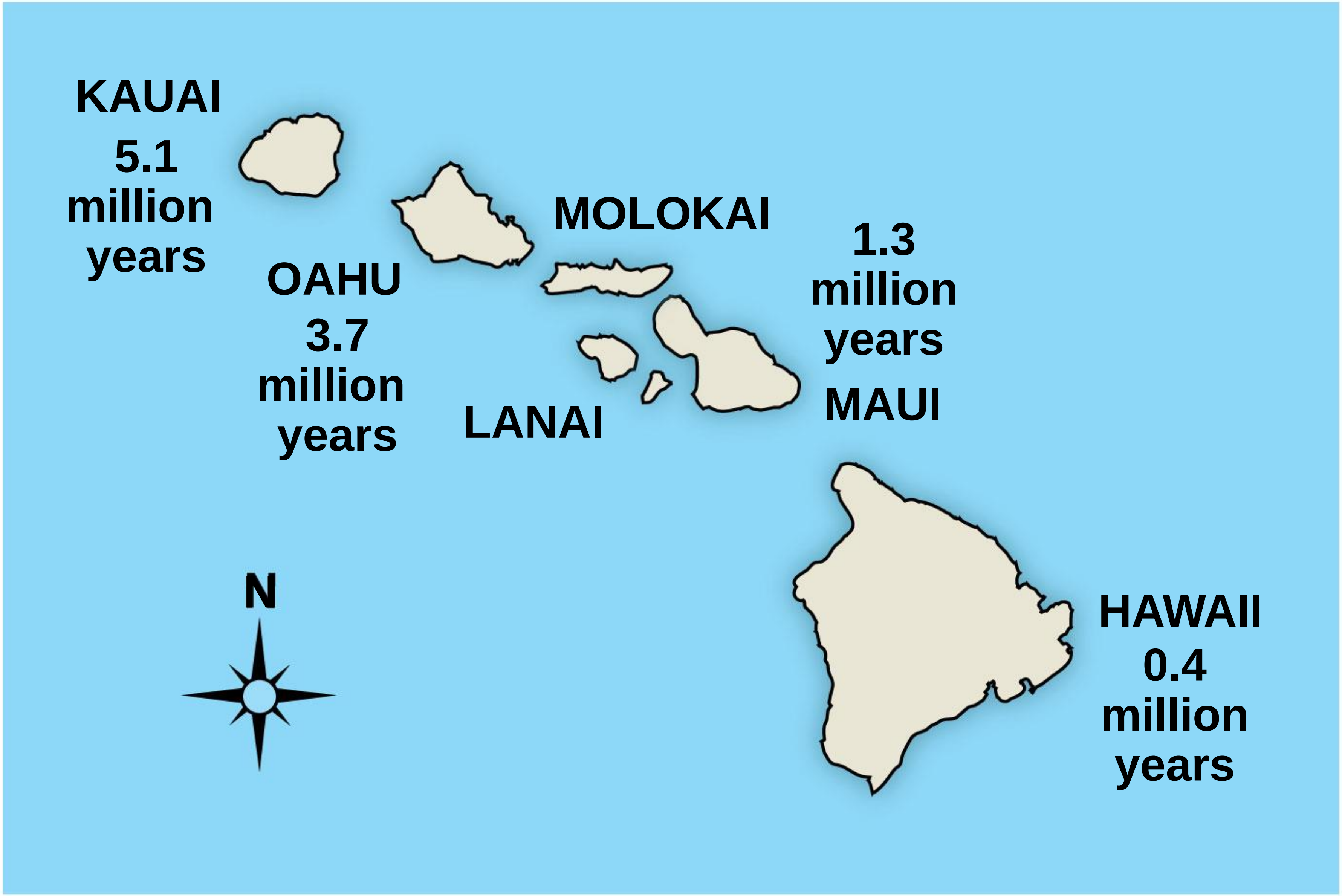

Close North American relative, the tarweed *Carlquistia muirii*
Dubautia laxa
Argyroxiphium sandwicense
KAUAI 5.1 million years
OAHU 3.7 million years
MOLOKAI
1.3 million years
LANAI
MAUI
N
HAWAII 0.4 million years
Dubautia waialealae
Dubautia scabra
Dubautia linearis

Figure 25.20a



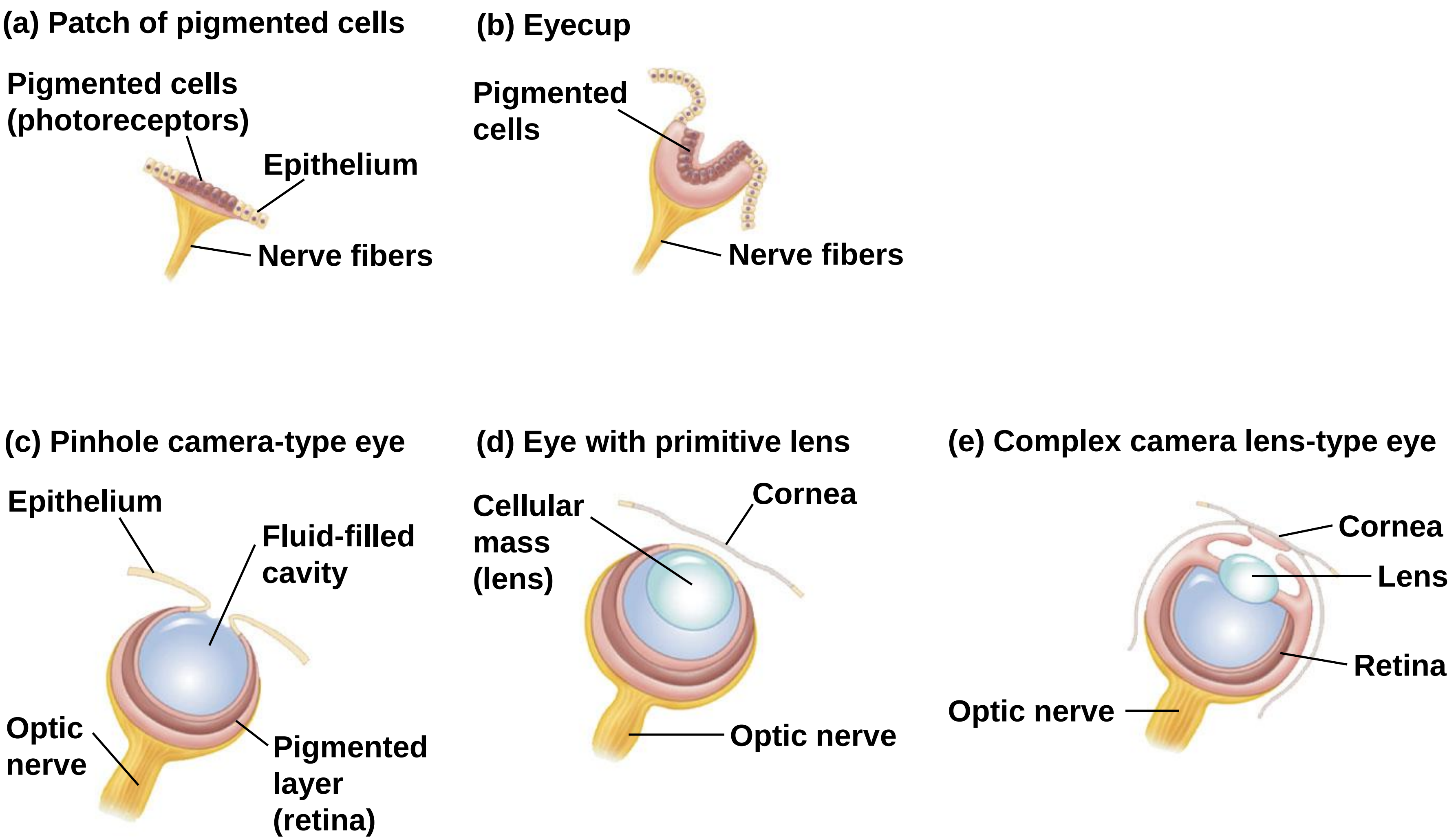
Concept 25.6: Evolution is not goal oriented

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

Evolutionary Novelties

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

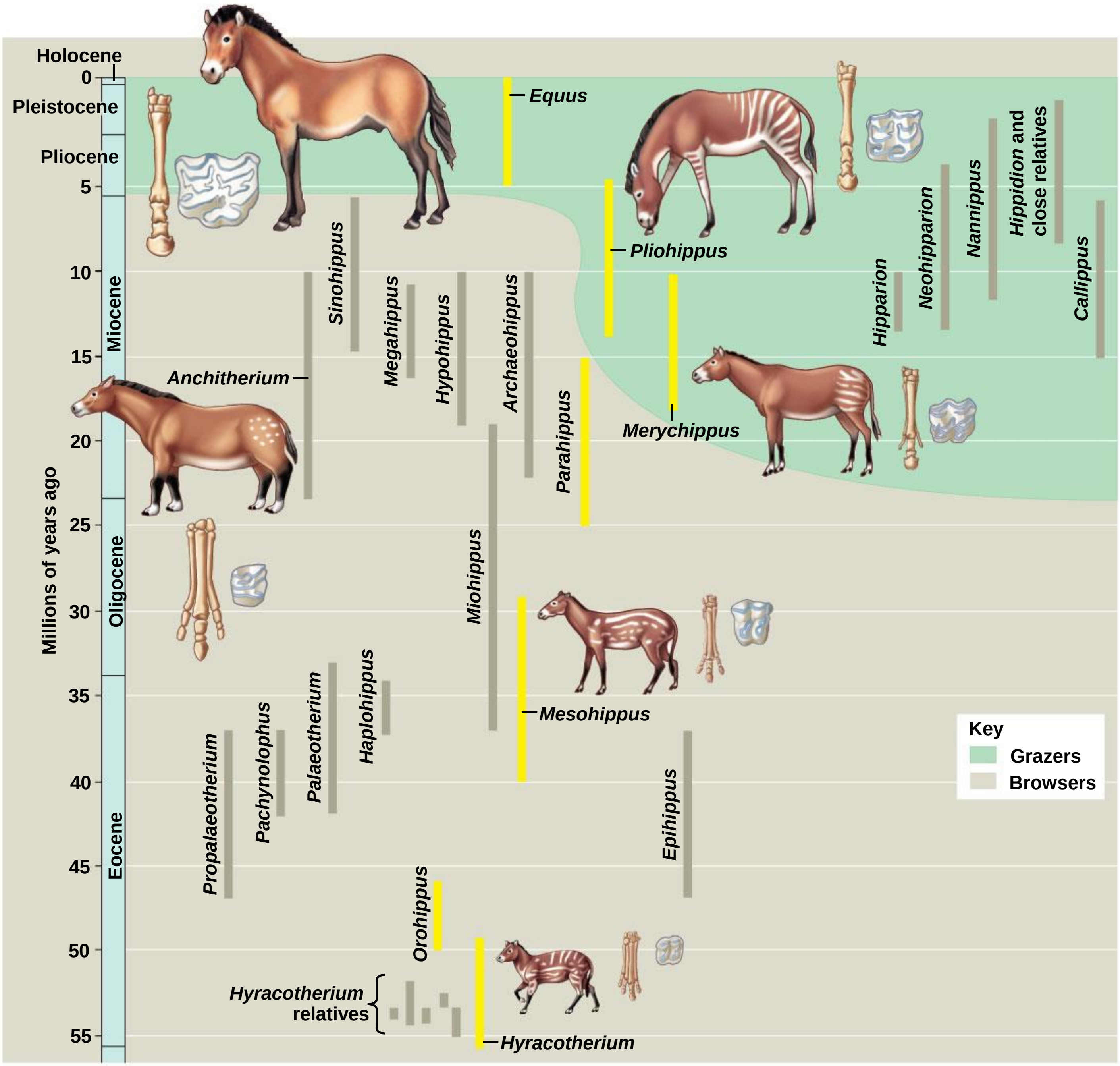
Figure 25.26


(a) Patch of pigmented cells
Pigmented cells (photoreceptors)
Epithelium
Nerve fibers
(b) Eyecup
Pigmented cells
Nerve fibers
(c) Pinhole camera-type eye
Epithelium
Fluid-filled cavity
Optic nerve
Pigmented layer (retina)
(d) Eye with primitive lens
Cellular mass (lens)
Cornea
Optic nerve
(e) Complex camera lens-type eye
Cornea
Lens
Retina
Optic nerve

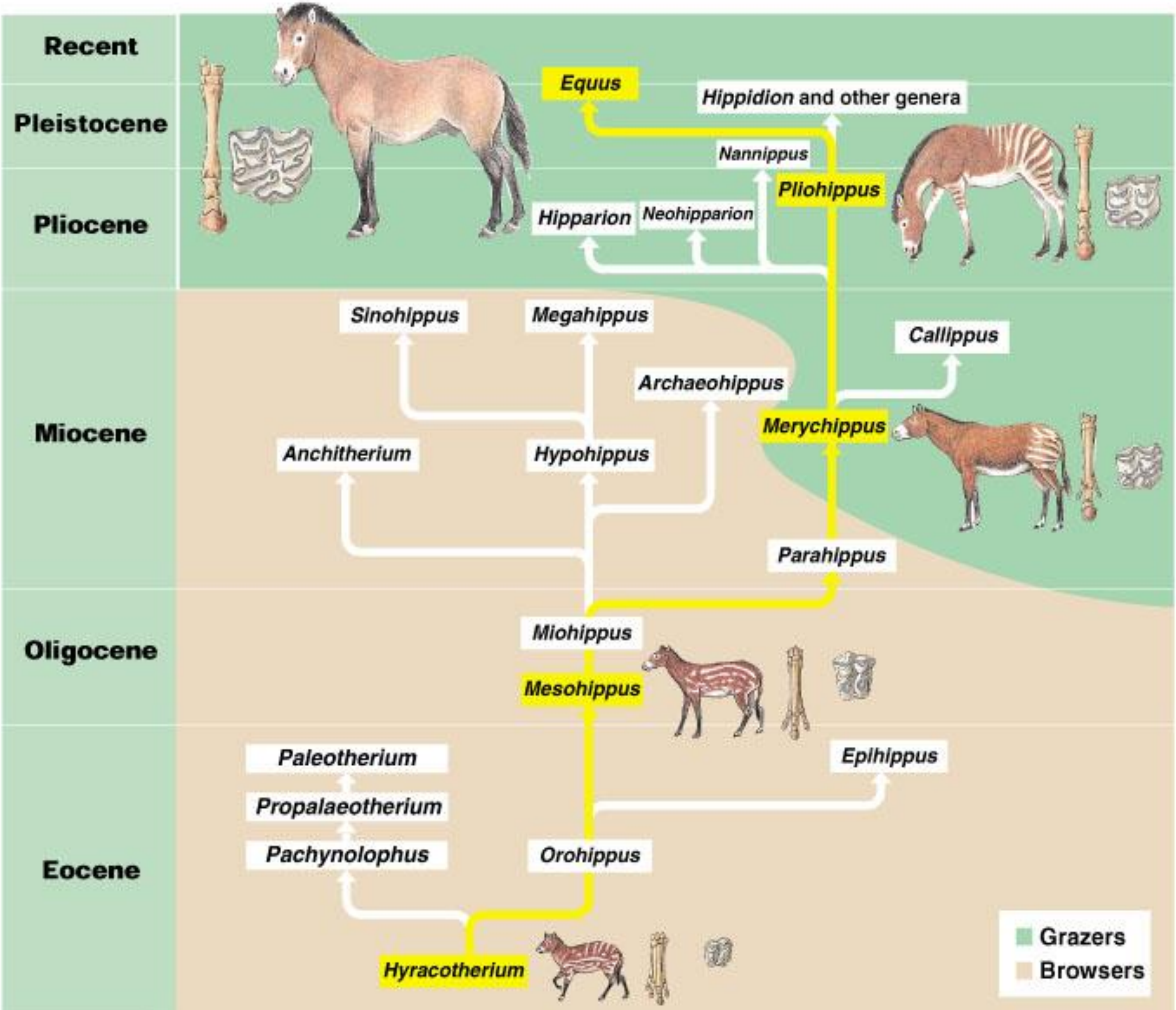
Evolutionary Trends

- 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

Figure 25.27



Holocene
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Millions of years ago
0
5
10
15
20
25
30
35
40
45
50
55
Equus
Pliohippus
Merychippus
Anchitherium
Sinohippus
Megahippus
Hypohippus
Archaeohippus
Parahippus
Hipparion
Neohipparion
Nannippus
Hippidion and close relatives
Callippus
Miohippus
Mesohippus
Epihippus
Propalaeotherium
Pachynolophus
Palaeotherium
Haplohippus
Orohippus
Hyracotherium relatives
Hyracotherium
Key
Grazers
Browsers



Recent
Pleistocene
Pliocene
Miocene
Oligocene
Eocene
Equus
Hippidion and other genera
Nannippus
Pliohippus
Hipparion
Neohipparion
Sinohippus
Megahippus
Callippus
Archaeohippus
Merychippus
Anchitherium
Hypohippus
Parahippus
Miohippus
Mesohippus
Paleotherium
Epihippus
Propalaeotherium
Pachynolophus
Orohippus
Hyracotherium
Grazers
Browsers