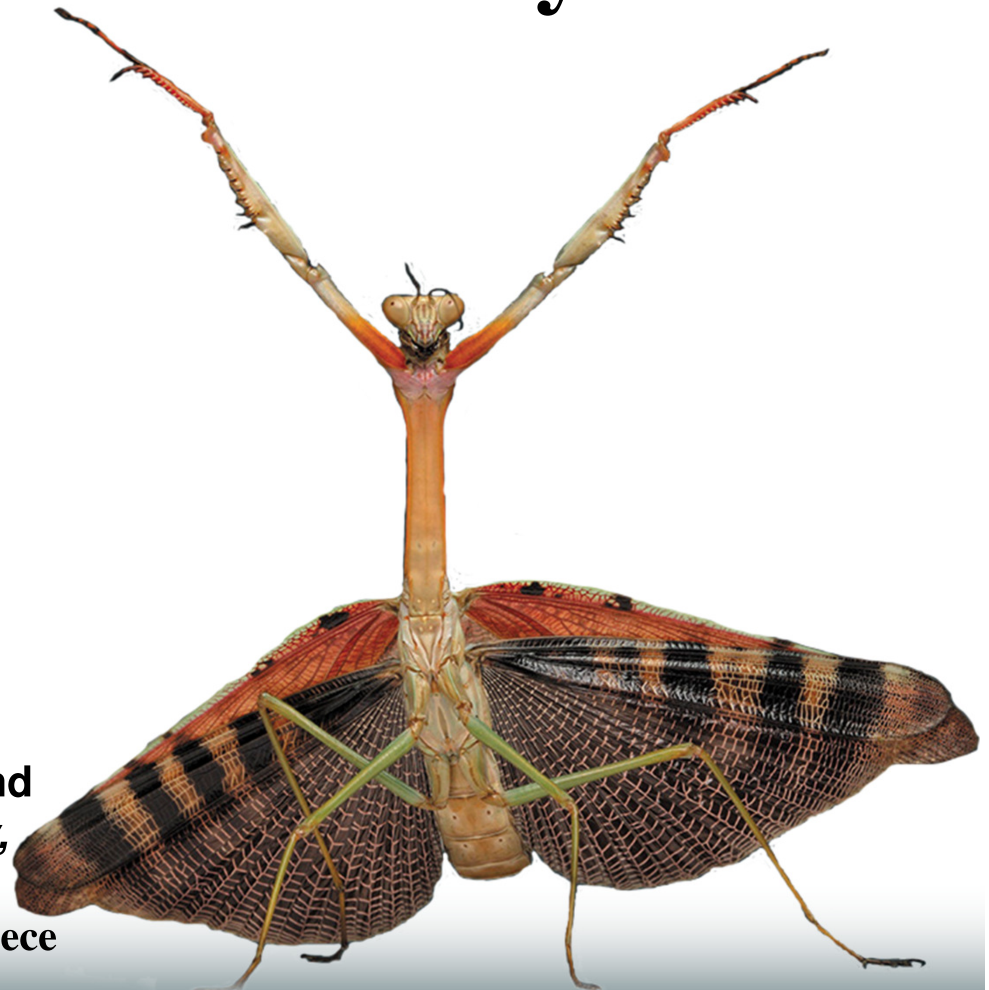
Chapter 14

How Biological Diversity Evolves



PowerPoint® Lectures for

***Campbell Essential Biology,* Fifth Edition, and**
Campbell Essential Biology with Physiology,
Fourth Edition

– Eric J. Simon, Jean L. Dickey, and Jane B. Reece

Lectures by Edward J. Zalisko

ALWAYS LEARNING

PEARSON

Biology and Society: The Sixth Mass Extinction

- Over the past 540 million years, the fossil record reveals five periods of extinction when 50–90% of living species suddenly died out.

Figure 14.0

Biology and Society: The Sixth Mass Extinction

- Our current rate of extinction, over the past 400 years, indicates that we may be living in, and contributing to, the sixth mass extinction period.
- Mass extinctions pave the way for the evolution of new and diverse forms, but it takes millions of years for Earth to recover.

THE ORIGIN OF SPECIES

- When Darwin visited the Galápagos Islands, he realized that he was visiting a place of origins.
  - Although the volcanic islands were geologically young, they were home to many plants and animals known nowhere else in the world.
  - Darwin thought it unlikely that all of these species could have been among the original colonists of the islands.

Figure 14.1

THE ORIGIN OF SPECIES

- In the 150 years since the publication of Darwin's book *On the Origin of Species by Means of Natural Selection*, new discoveries and technological advances have given scientists a wealth of new information about the evolution of life.
- The diversity of life evolved through **speciation**, the process in which one species splits into two or more species.

What Is a Species?

- *Species* is a Latin word meaning
  - “kind” or
  - “appearance.”
- The **biological species concept** defines a **species** as “A group of populations whose members have the potential to interbreed with one another in nature to produce fertile offspring.”

Figure 14.2

Similarity between different species

Diversity within one species

Figure 14.2a

Similarity between different species

Figure 14.2b

Diversity within one species

What Is a Species?

- The biological species concept cannot be applied in all situations, including
  - fossils and
  - asexual organisms.

What Is a Species?

- Some other definitions of species are based on
  - measurable physical traits,
  - the use of ecological resources, or
  - unique adaptations to particular roles in a biological community.

Reproductive Barriers between Species

- **Prezygotic barriers** prevent mating or fertilization between species.

Figure 14.3

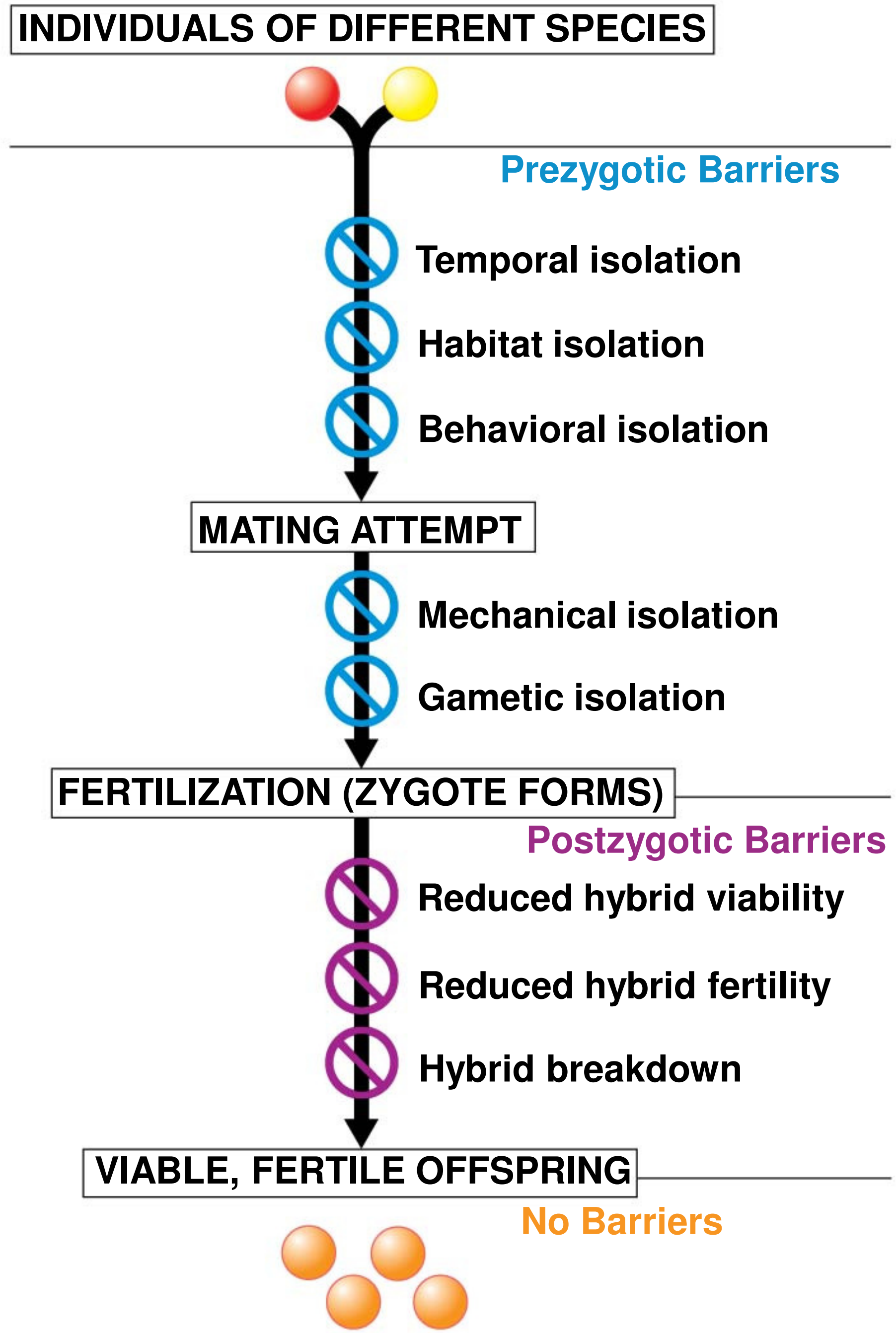
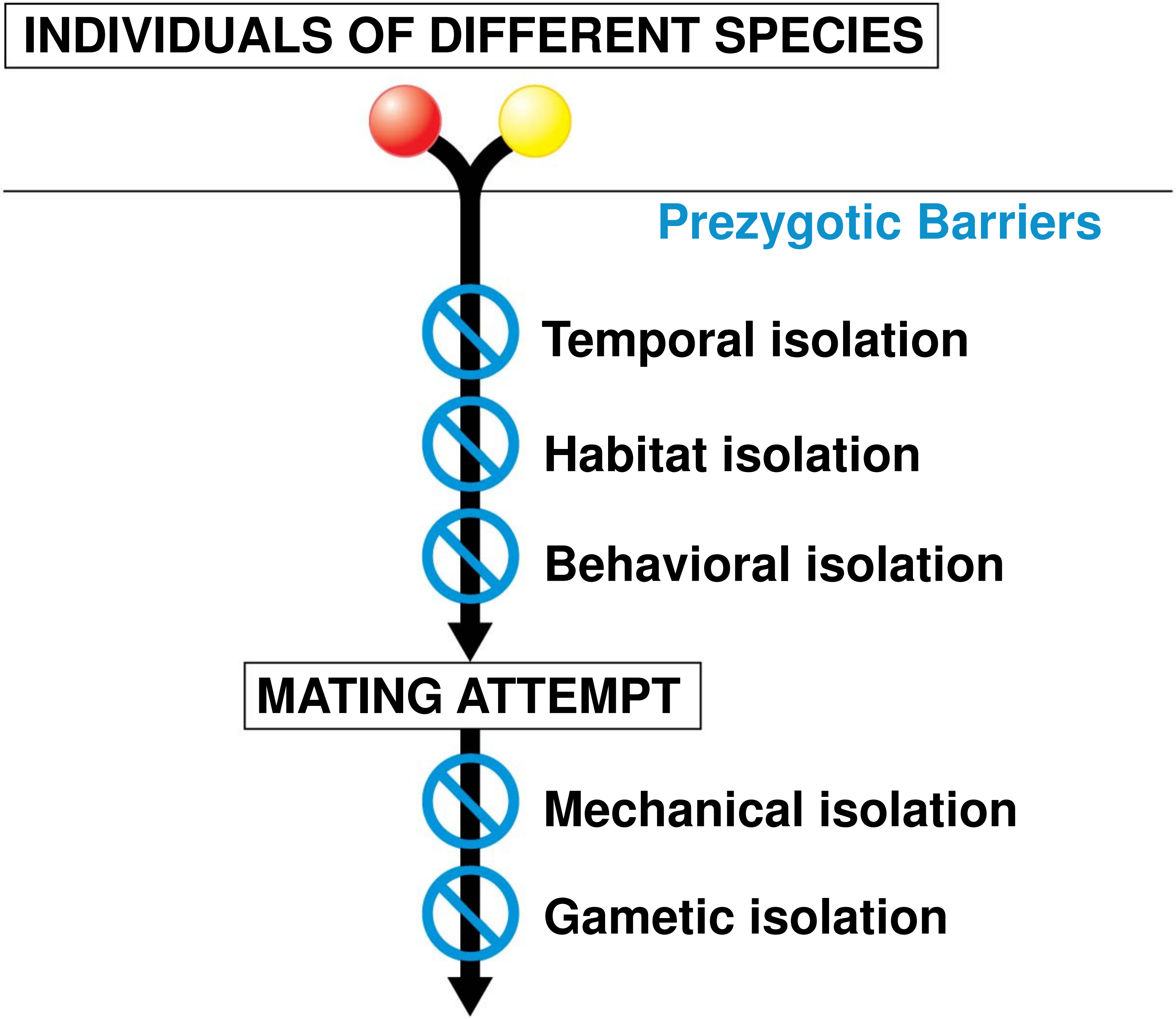

INDIVIDUALS OF DIFFERENT SPECIES
Prezygotic Barriers
Temporal isolation
Habitat isolation
Behavioral isolation
MATING ATTEMPT
Mechanical isolation
Gametic isolation
FERTILIZATION (ZYGOTE FORMS)
Postzygotic Barriers
Reduced hybrid viability
Reduced hybrid fertility
Hybrid breakdown
VIABLE, FERTILE OFFSPRING
No Barriers

Figure 14.3a


INDIVIDUALS OF DIFFERENT SPECIES
Prezygotic Barriers
Temporal isolation
Habitat isolation
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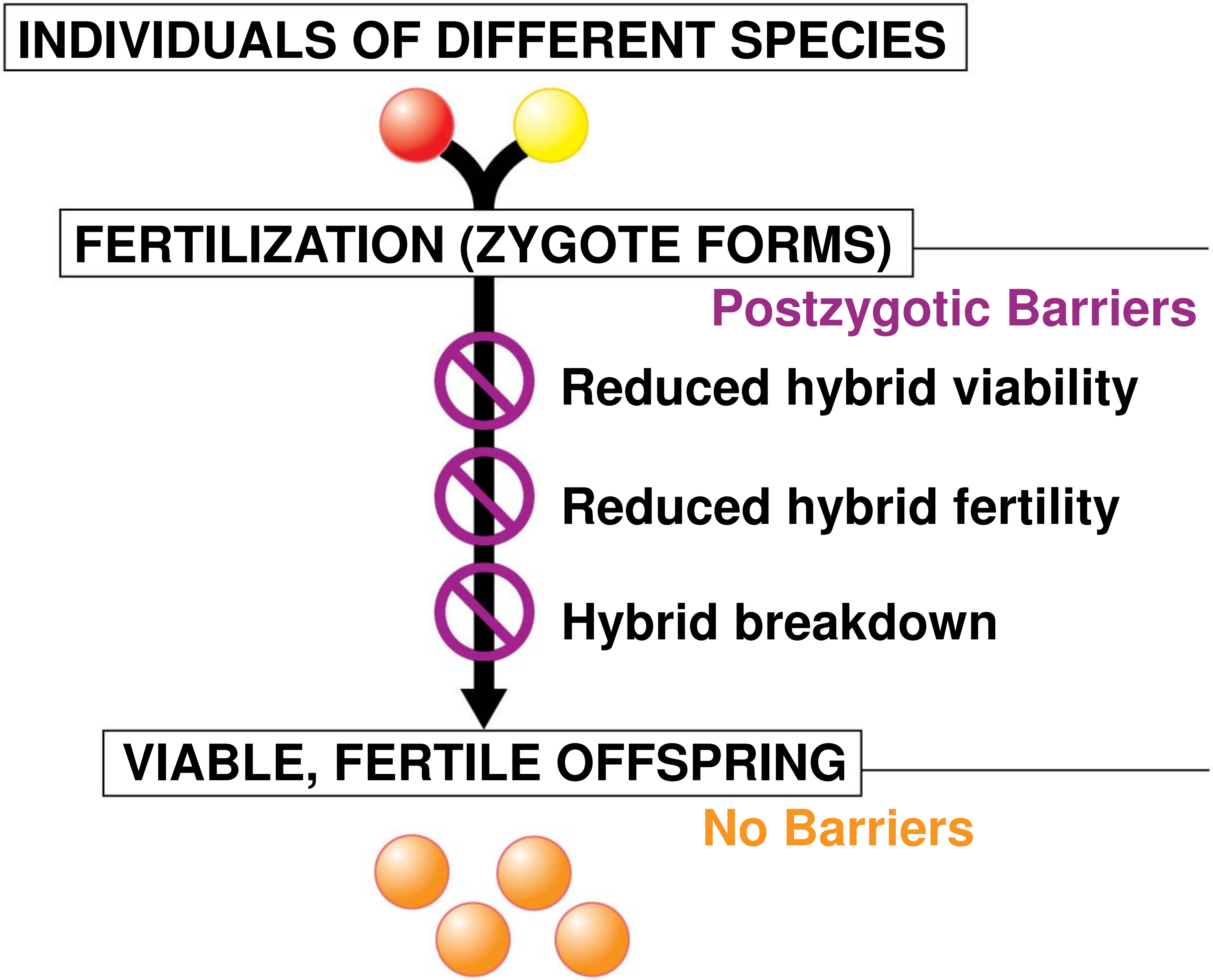
MATING ATTEMPT
Mechanical isolation
Gametic isolation

Figure 14.3b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FERTILIZATION (ZYGOTE FORMS)
Postzygotic Barriers
Reduced hybrid viability
Reduced hybrid fertility
Hybrid breakdown
VIABLE, FERTILE OFFSPRING
No Barriers

Reproductive Barriers between Species

- Prezygotic barriers include
  - temporal isolation,
  - habitat isolation,
  - behavioral isolation,
  - mechanical isolation, and
  - gametic isolation.

Figure 14.4

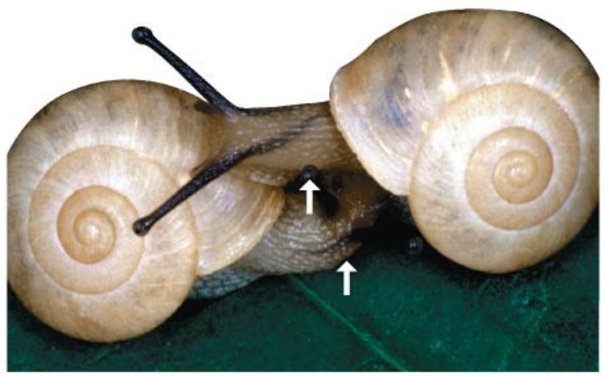
PREZYGOTIC BARRIERS

Temporal Isolation

Habitat Isolation

Behavioral Isolation

Mechanical Isolation



Gametic Isolation

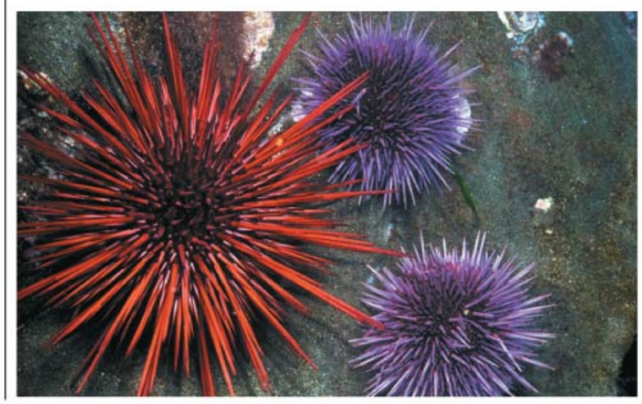


Figure 14.4a

Temporal Isolation

Skunk species that mate at different times

Habitat Isolation

Garter snake species from different habitats

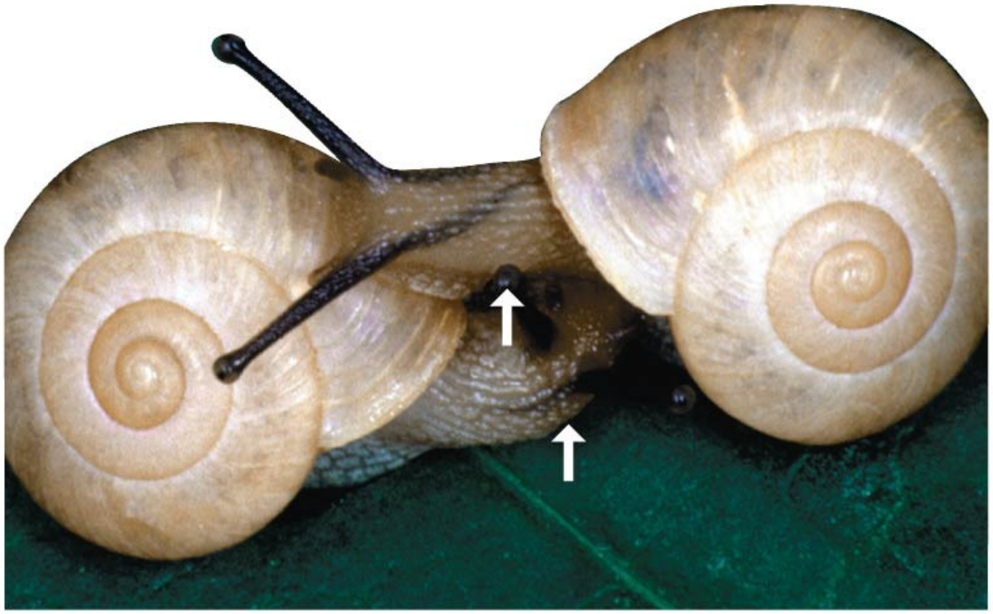
Figure 14.4c

Behavioral Isolation

Mating ritual of blue-footed boobies

Figure 14.4d

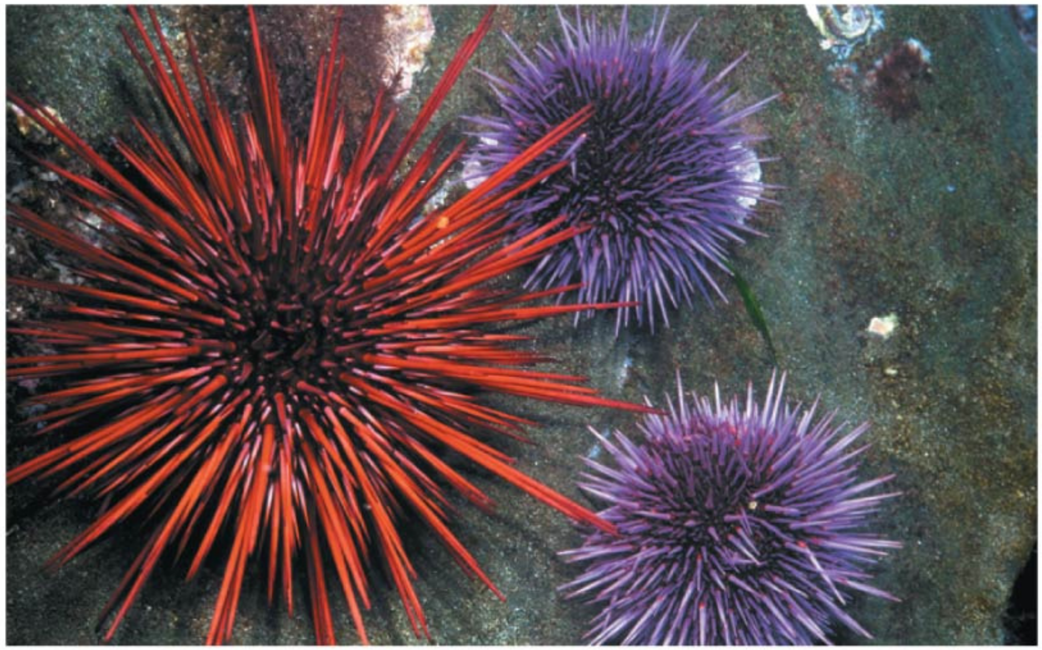
Mechanical Isolation



Snail species whose genital openings cannot align

Figure 14.4e

Gametic Isolation



Sea urchin species whose gametes cannot fuse

Reproductive Barriers between Species

- **Postzygotic barriers** operate if
  - interspecies mating occurs and
  - hybrid zygotes form.

Reproductive Barriers between Species

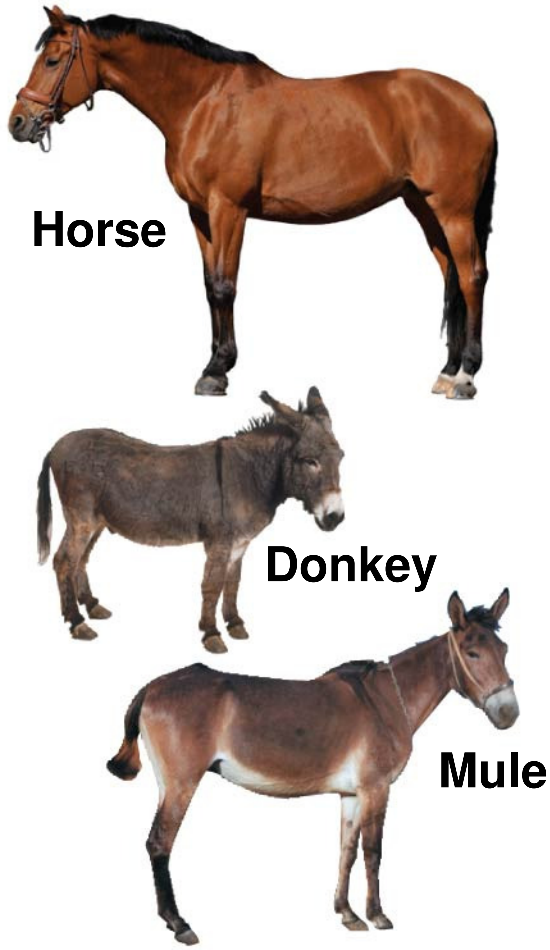
- Postzygotic barriers include
  - reduced hybrid viability,
  - reduced hybrid fertility, and
  - hybrid breakdown.

Figure 14.5

POSTZYGOTIC BARRIERS

Reduced Hybrid Viability

Reduced Hybrid Fertility



Hybrid Breakdown

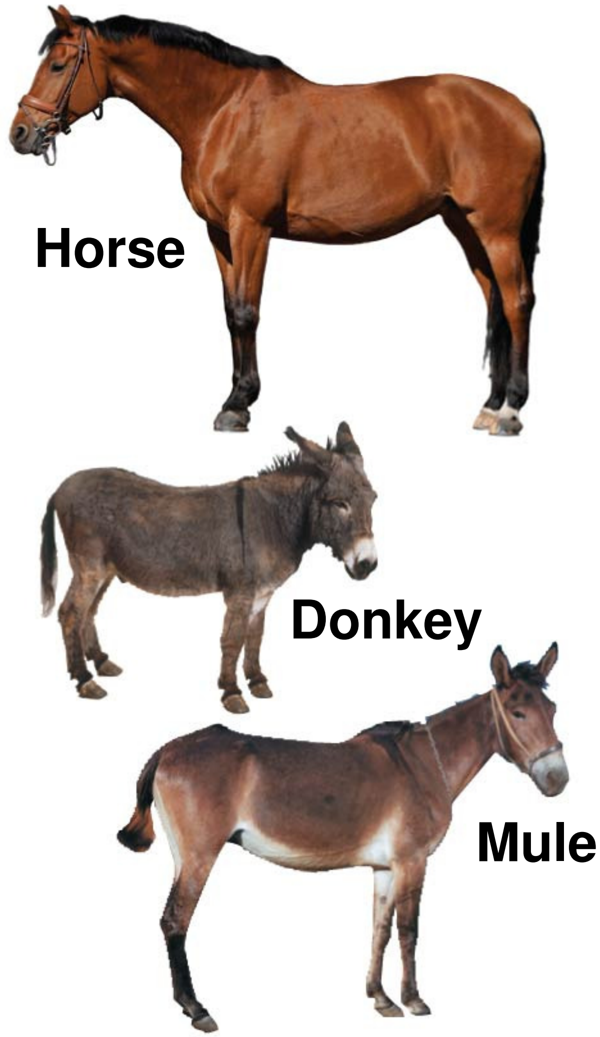
Figure 14.5a

Reduced Hybrid Viability

Frail hybrid salamander offspring

Figure 14.5b

Reduced Hybrid Fertility



Mule (sterile hybrid of horse and donkey)

Figure 14.5c

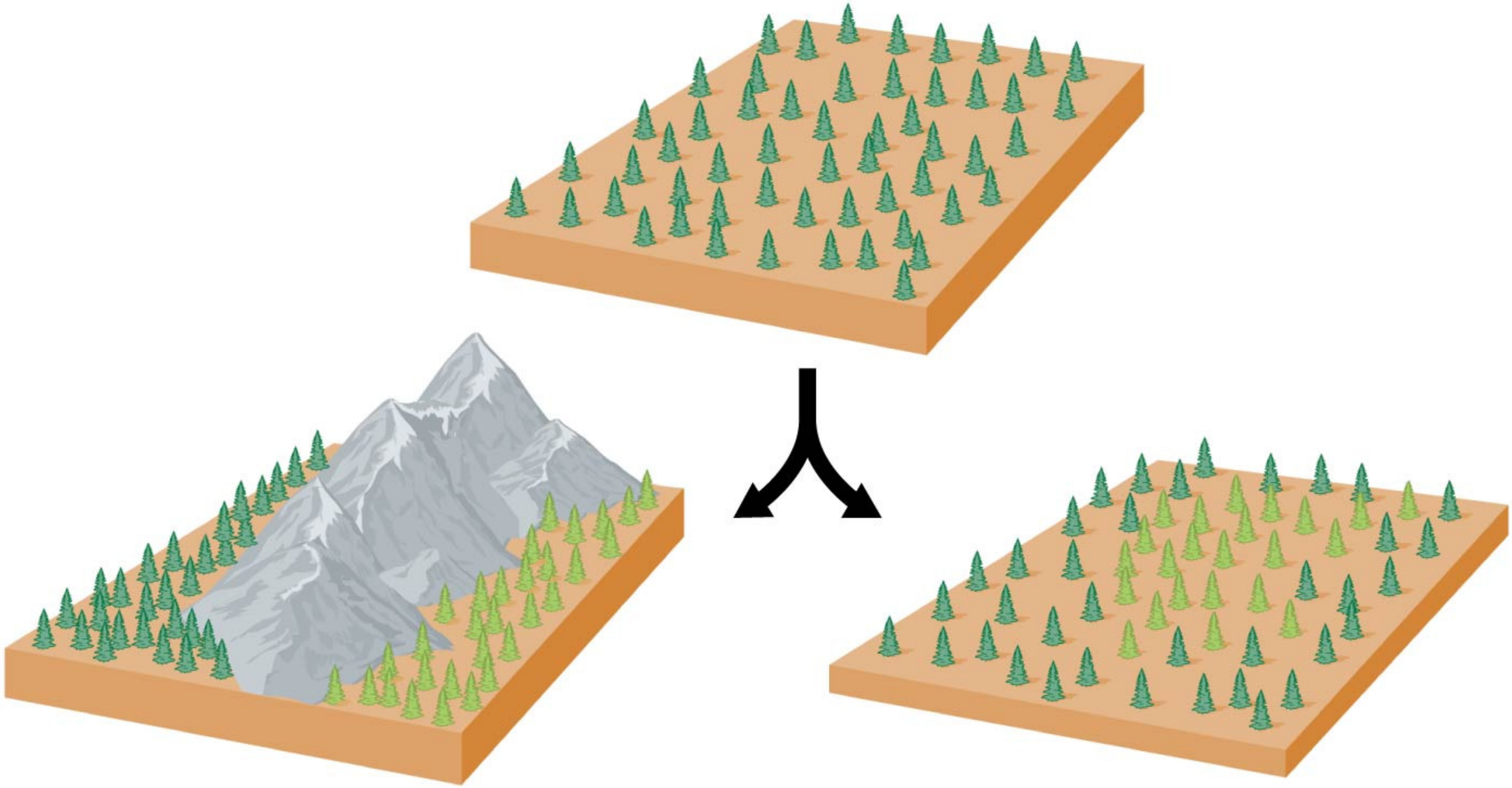
Hybrid Breakdown

Sterile next-generation rice hybrid

Mechanisms of Speciation

- A key event in the potential origin of a species occurs when a population is somehow cut off from other populations of the parent species.
- Species can form by
  - **allopatric speciation**, due to geographic isolation, or
  - **sympatric speciation**, without geographic isolation.

Figure 14.6

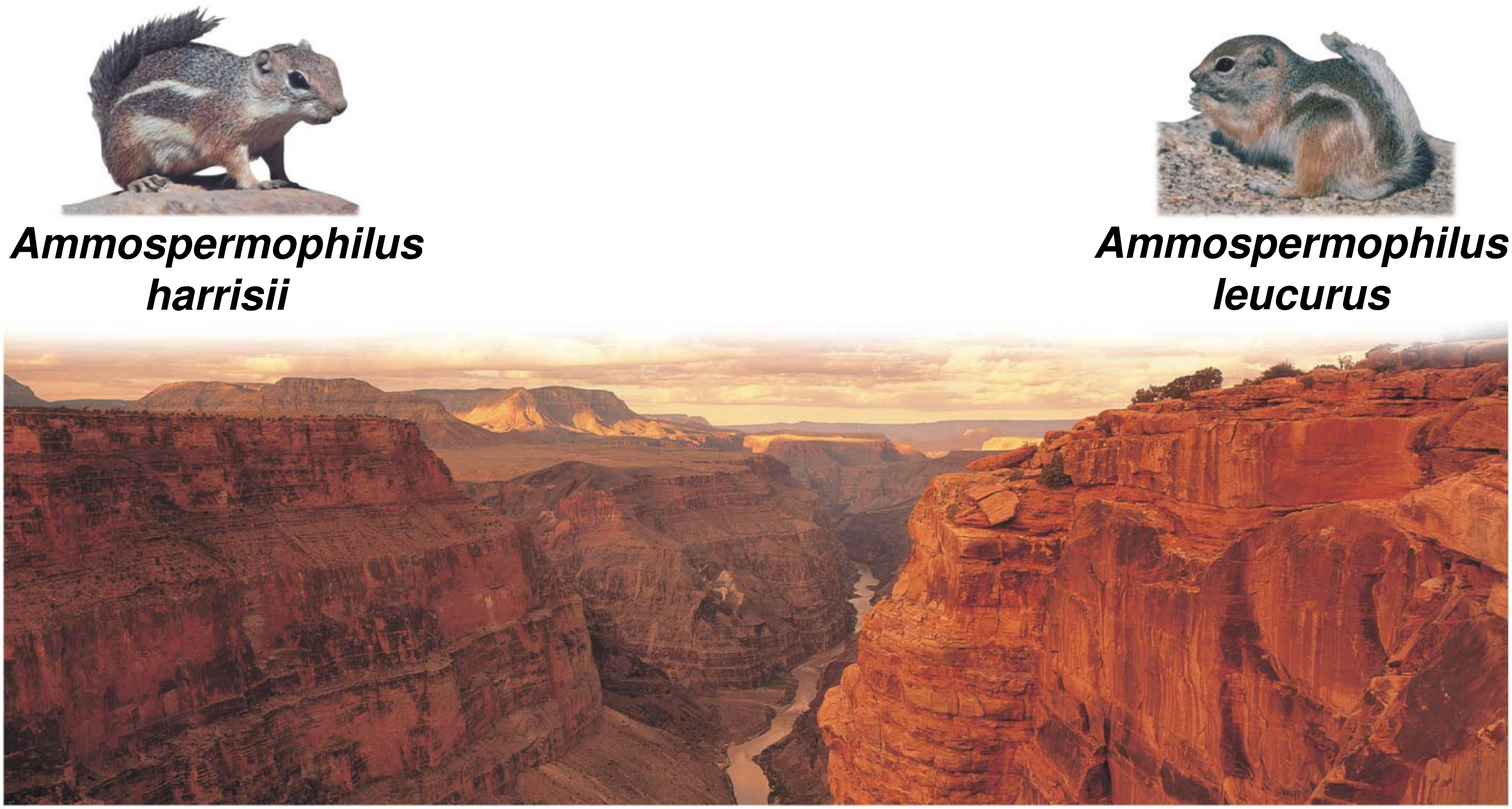


Allopatric speciation **Sympatric speciation**

Allopatric Speciation

- Geologic processes can
  - fragment a population into two or more isolated populations and
  - contribute to allopatric speciation.

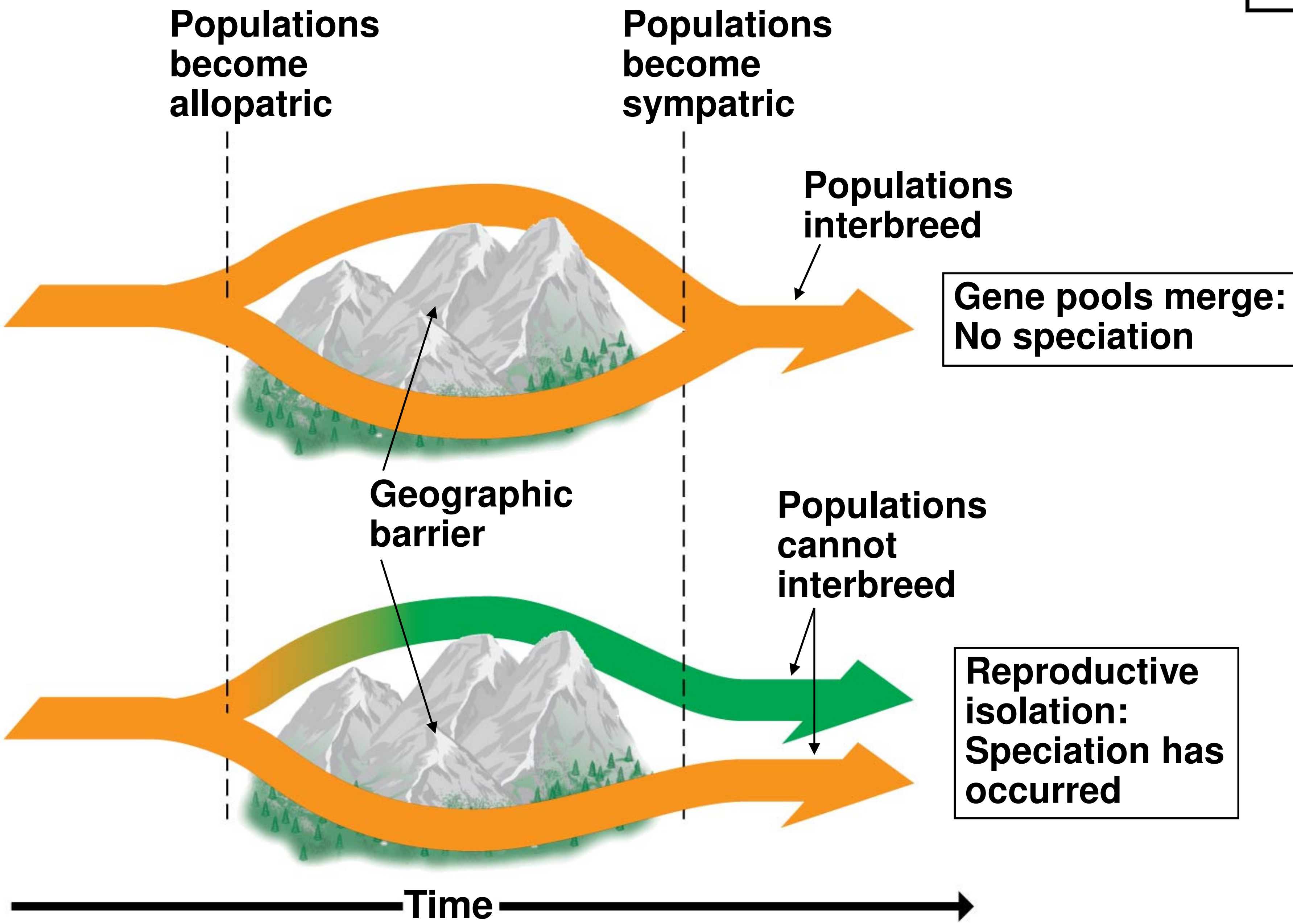
Figure 14.7



Allopatric Speciation

- Speciation occurs with the evolution of reproductive barriers between
  - the isolated population and
  - its parent population.
- Even if the two populations should come back into contact at some later time, the reproductive barriers will keep them as separate species.

Figure 14.8


Populations become allopatric
Populations become sympatric
Populations interbreed
Gene pools merge: No speciation
Geographic barrier
Populations cannot interbreed
Reproductive isolation: Speciation has occurred
Time

What Is the Pace of Speciation?

- There are two contrasting patterns for the pace of evolution:

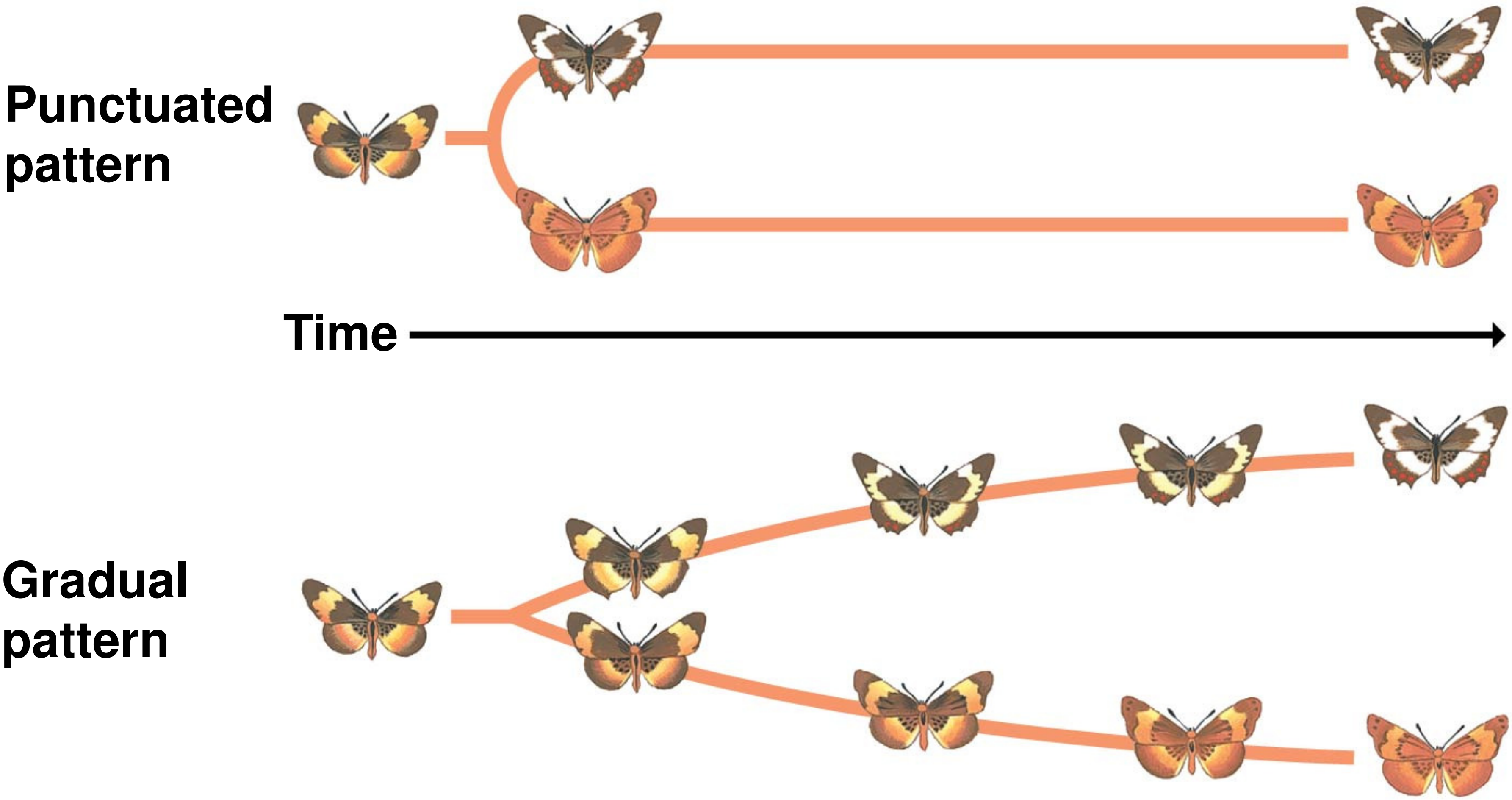
  1. the gradual pattern, in which big changes (speciations) occur by the steady accumulation of many small changes, and

  2. the **punctuated equilibria** pattern, in which there are

     – long periods of little apparent change (equilibria) interrupted (punctuated) by

     – relatively brief periods of rapid change.

Figure 14.10



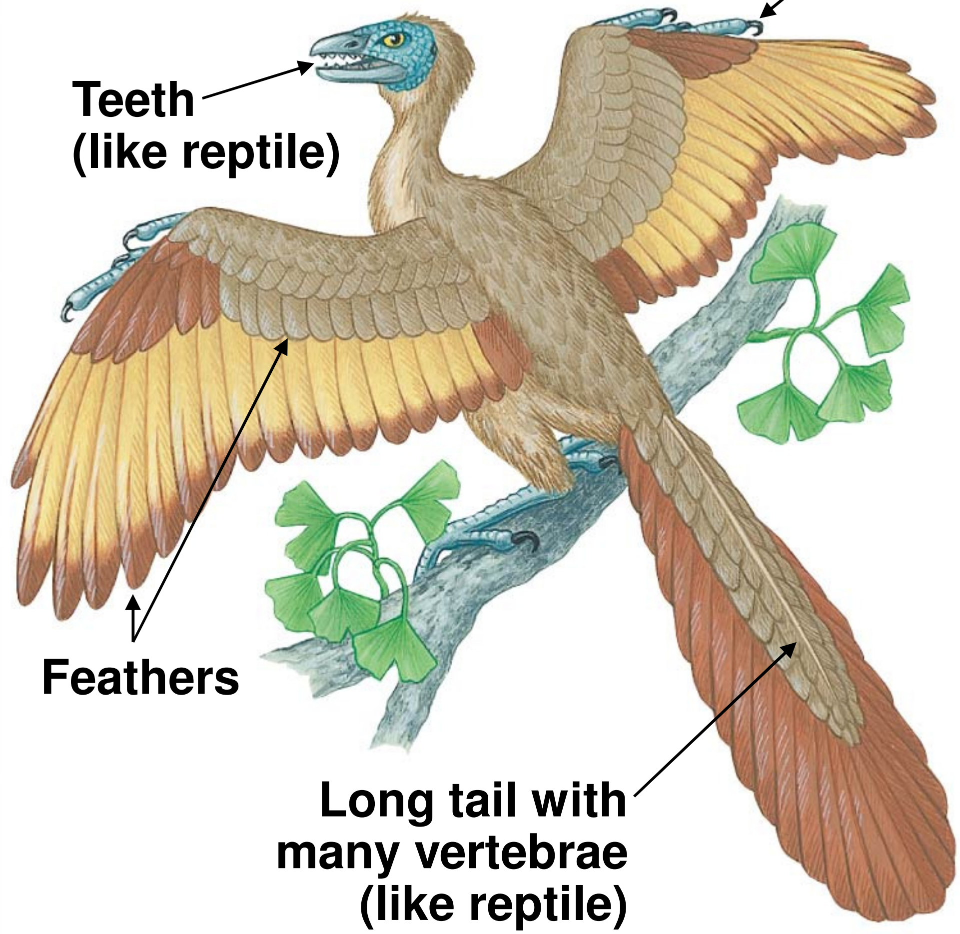
THE EVOLUTION OF BIOLOGICAL NOVELTY

- What accounts for the dramatic differences between dissimilar groups?

Adaptation of Old Structures for New Functions

- Birds
  - are derived from a lineage of earthbound reptiles and
  - evolved flight from flightless ancestors.

Figure 14.11



Artist's reconstruction

Adaptation of Old Structures for New Functions

- An exaptation is
  - a structure that evolves in one context but becomes adapted for another function and
  - a type of evolutionary remodeling.
- Exaptations can account for the evolution of novel structures.

Adaptation of Old Structures for New Functions

- Bird wings are modified forelimbs that were previously adapted for non-flight functions, such as
  - thermal regulation,
  - courtship displays, and/or
  - camouflage.
- The first flights may have been only glides or extended hops as the animal pursued prey or fled from a predator.

EARTH HISTORY AND MACROEVOLUTION

- Macroevolution is closely tied to the history of Earth.

Geologic Time and the Fossil Record

- The fossil record is
  - the sequence in which fossils appear in rock strata and
  - an archive of macroevolution.

Figure 14.14

A sedimentary fossil formed by minerals replacing the organic matter of a tree

A researcher excavating a fossilized dinosaur skeleton from sandstone

A 45-million-year-old insect embedded in amber

Trace fossils: footprints, burrows, or other remnants of an ancient organism's behavior

Tusks of a 23,000-year-old mammoth discovered in Siberian ice

Geologic Time and the Fossil Record

- Geologists have established a **geologic time scale** that divides Earth's history into a consistent sequence of geologic periods.

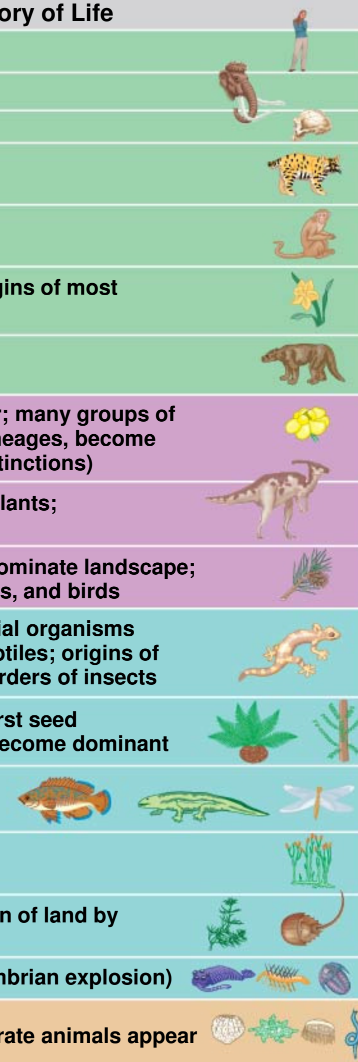
Animation: Macroevolution

Right click slide / select “Play”

Table 14.1

Table 14.1 The Geologic Time Scale

Geologic Time	Period	Epoch	Age (millions of years ago)	Some Important Events in the History of Life
Cenozoic era	Quaternary	Recent		Historical time
		Pleistocene	0.01	Ice ages; humans appear
	Tertiary	Pliocene	1.8	Origin of genus *Homo*
		Miocene	5	Continued speciation of mammals and angiosperms
		Oligocene	23	Origins of many primate groups, including apes
		Eocene	34	Angiosperm dominance increases; origins of most living mammalian orders
		Paleocene	56	Major speciation of mammals, birds, and pollinating insects
Mesozoic era	Cretaceous		65	Flowering plants (angiosperms) appear; many groups of organisms, including most dinosaur lineages, become extinct at end of period (Cretaceous extinctions)
	Jurassic		145	Gymnosperms continue as dominant plants; dinosaurs become dominant
	Triassic		200	Cone-bearing plants (gymnosperms) dominate landscape; speciation of dinosaurs, early mammals, and birds
Paleozoic era	Permian		251	Extinction of many marine and terrestrial organisms (Permian extinctions); speciation of reptiles; origins of mammal-like reptiles and most living orders of insects
	Carboniferous		299	Extensive forests of vascular plants; first seed plants; origin of reptiles; amphibians become dominant
	Devonian		359	Diversification of bony fishes; first amphibians and insects
	Silurian		416	Early vascular plants dominate land
	Ordovician		444	Marine algae are abundant; colonization of land by diverse fungi, plants, and animals
	Cambrian		488	Origin of most living animal phyla (Cambrian explosion)
Precambrian			542	
			600	Diverse algae and soft-bodied invertebrate animals appear
			635	Oldest animal fossils
			2,100	Oldest eukaryotic fossils
			2,700	Oxygen begins accumulating in atmosphere
			3,500	Oldest fossils known (prokaryotes)
			4,600	Approximate time of origin of Earth



Precambrian	542	
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Table 14.1b

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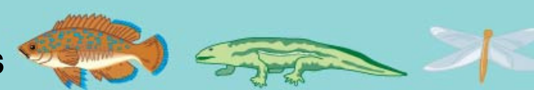
	Devonian	359	Diversification of bony fishes; first amphibians and insects	
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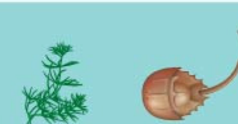
	Ordovician	444	Marine algae are abundant; colonization of land by diverse fungi, plants, and animals	
	Cambrian	488	Origin of most living animal phyla (Cambrian explosion)	
		542		

Table 14.1c

		65		
Mesozoic era	Cretaceous		Flowering plants (angiosperms) appear; many groups of organisms, including most dinosaur lineages, become extinct at end of period (Cretaceous extinctions)	
		145		
	Jurassic		Gymnosperms continue as dominant plants; dinosaurs become dominant	
		200		
	Triassic		Cone-bearing plants (gymnosperms) dominate landscape; speciation of dinosaurs, early mammals, and birds	
		251		

Cenozoic era	**Quaternary**	**Recent**	**0.01**	**Historical time**	
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		Paleocene	**65**	**Major speciation of mammals, birds, and pollinating insects**	

Geologic Time and the Fossil Record

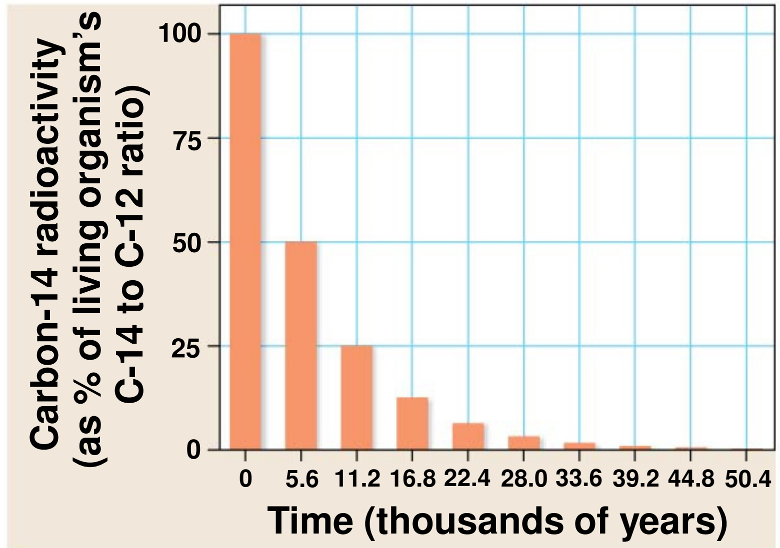
- Fossils are reliable chronological records only if we can determine their ages, using
  - the *relative age* of fossils, revealing the order in which groups of species evolved, and/or
  - the *absolute age* of fossils, requiring other methods such as radiometric dating.

Geologic Time and the Fossil Record

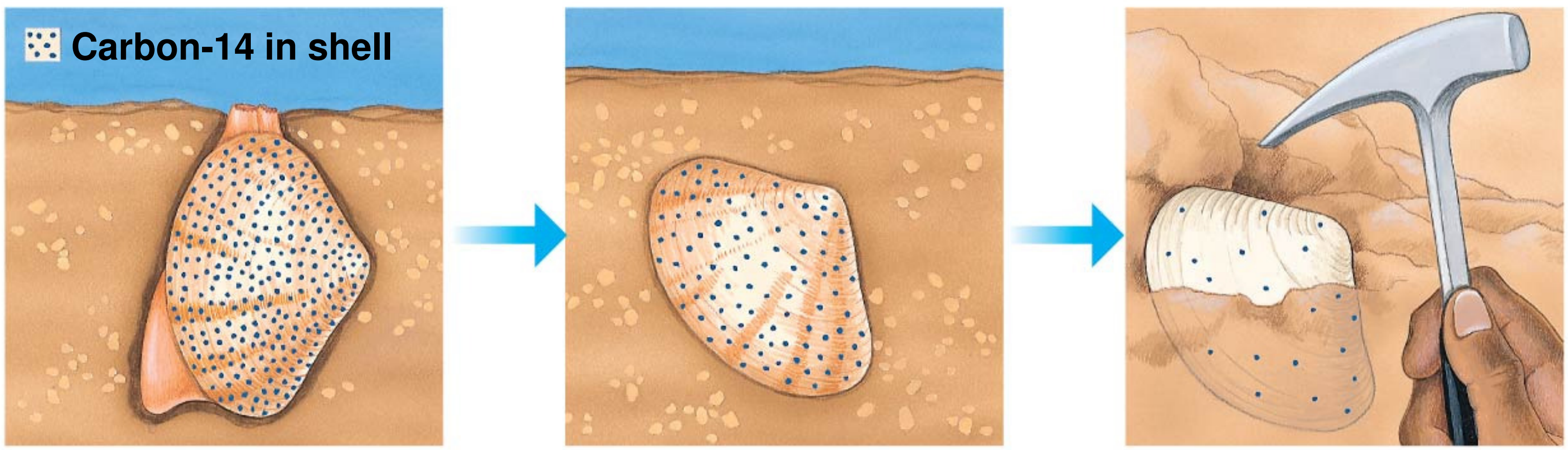
- **Radiometric dating**
  - is the most common method for dating fossils,
  - is based on the decay of radioactive isotopes, and
  - helped establish the geologic time scale.

Figure 14.15

Radioactive decay of carbon-14



How carbon-14 dating is used to determine the vintage of a fossilized clam shell

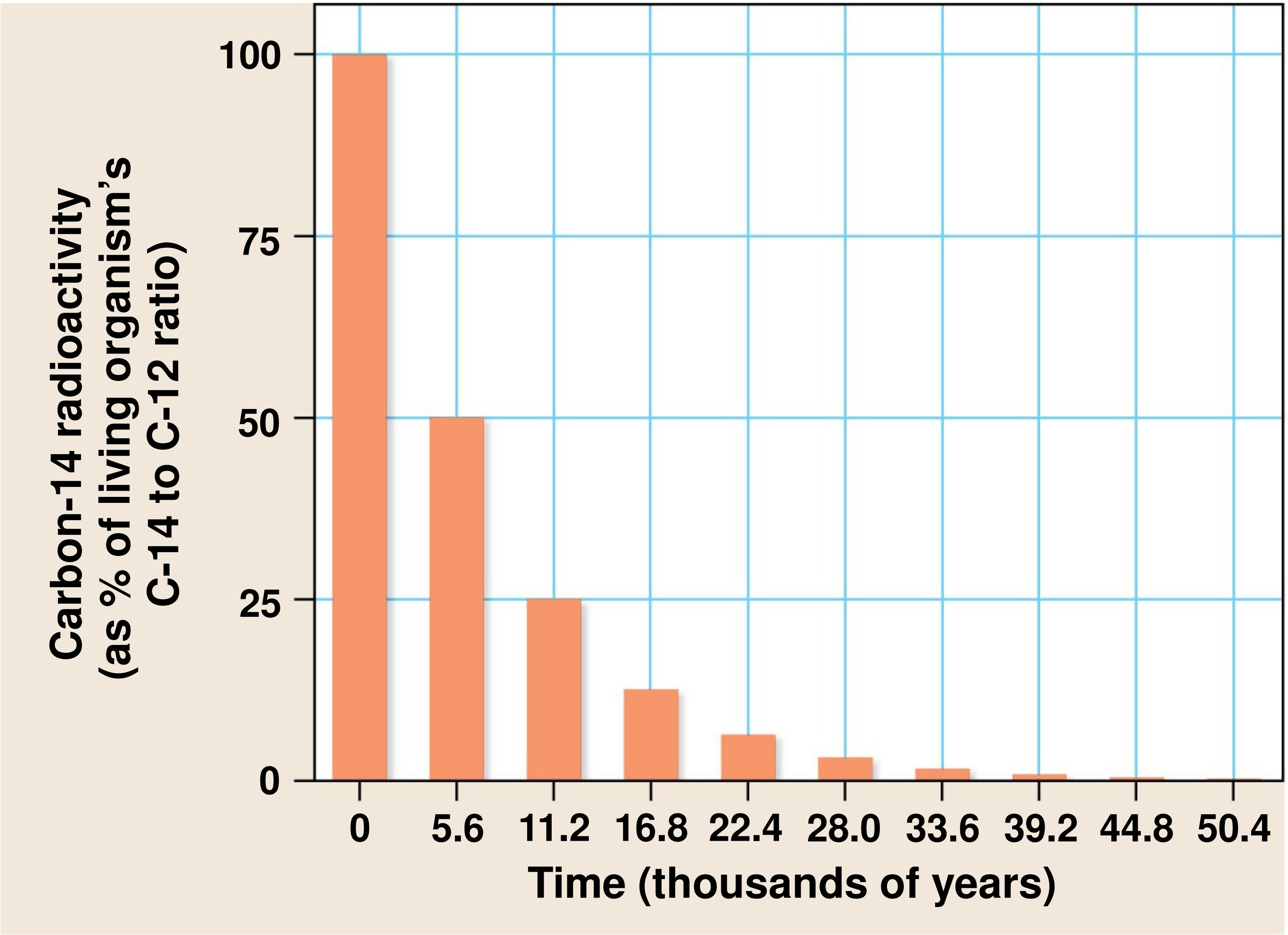


Carbon-14 is taken up by the clam in trace quantities, along with much larger quantities of carbon-12.

After the clam dies, carbon-14 amounts decline due to radioactive decay.

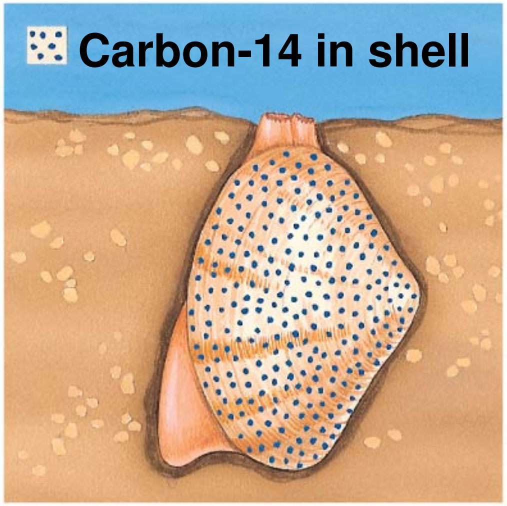
Measuring the ratio of carbon-14 to carbon-12 reveals how many half-life reductions have occurred since the clam's death.

Figure 14.15a



Radioactive decay of carbon-14

How carbon-14 dating is used to determine the vintage of a fossilized clam shell



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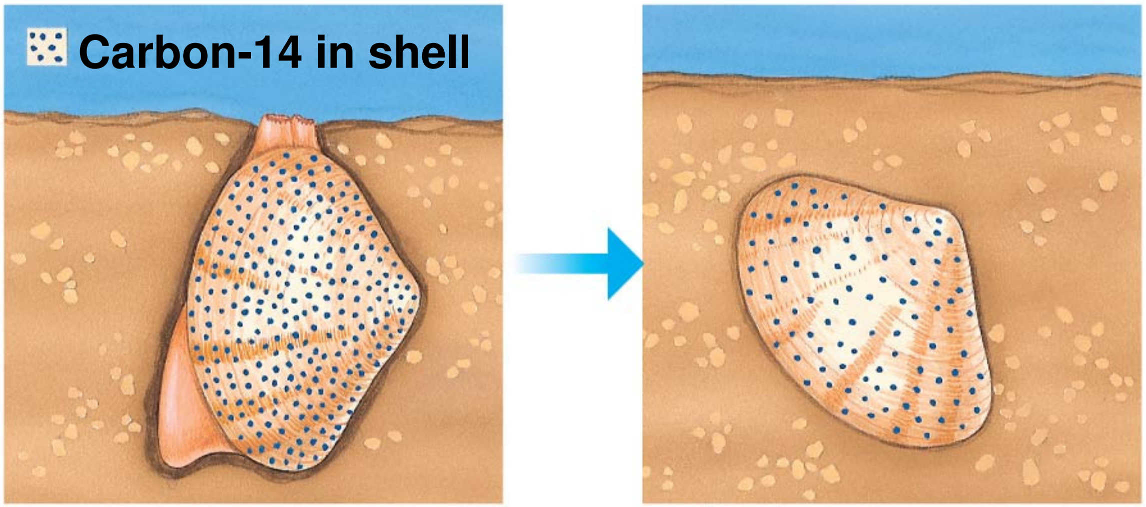
How carbon-14 dating is used to determine the vintage of a fossilized clam shell



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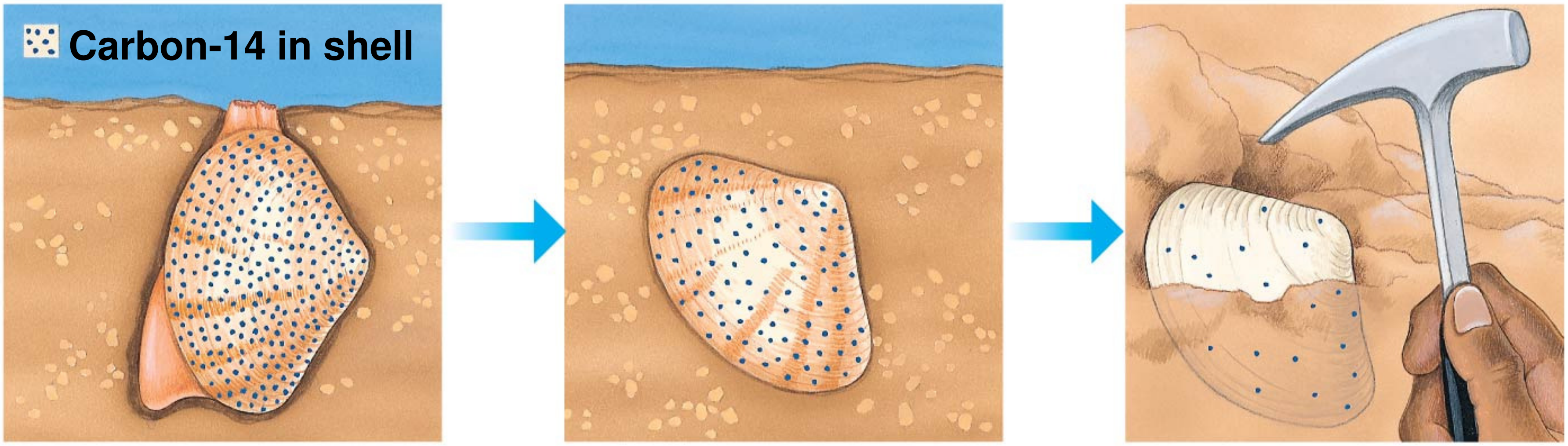
How carbon-14 dating is used to determine the vintage of a fossilized clam shell



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Measuring the ratio of carbon-14 to carbon-12 reveals how many half-life reductions have occurred since the clam's death.

Plate Tectonics and Macroevolution

- The continents are not locked in place.
  - Continents drift about Earth's surface on plates of crust floating on a flexible layer of hot, underlying material called the mantle.

Plate Tectonics and Macroevolution

- Japan sits atop four different plates.
  - A tsunami, caused by an earthquake off the coast of Japan, resulted in the disaster of March 2011.
  - Frequent earthquakes occur as the plates move and bump against each other.

Figure 14.16

Plate Tectonics and Macroevolution

- About 250 million years ago,
  - plate movements formed the supercontinent Pangaea,
  - the total amount of shoreline was reduced,
  - ocean basins increased in depth,
  - sea levels dropped,
  - the dry continental interior increased in size, and
  - many extinctions occurred.

Figure 14.17

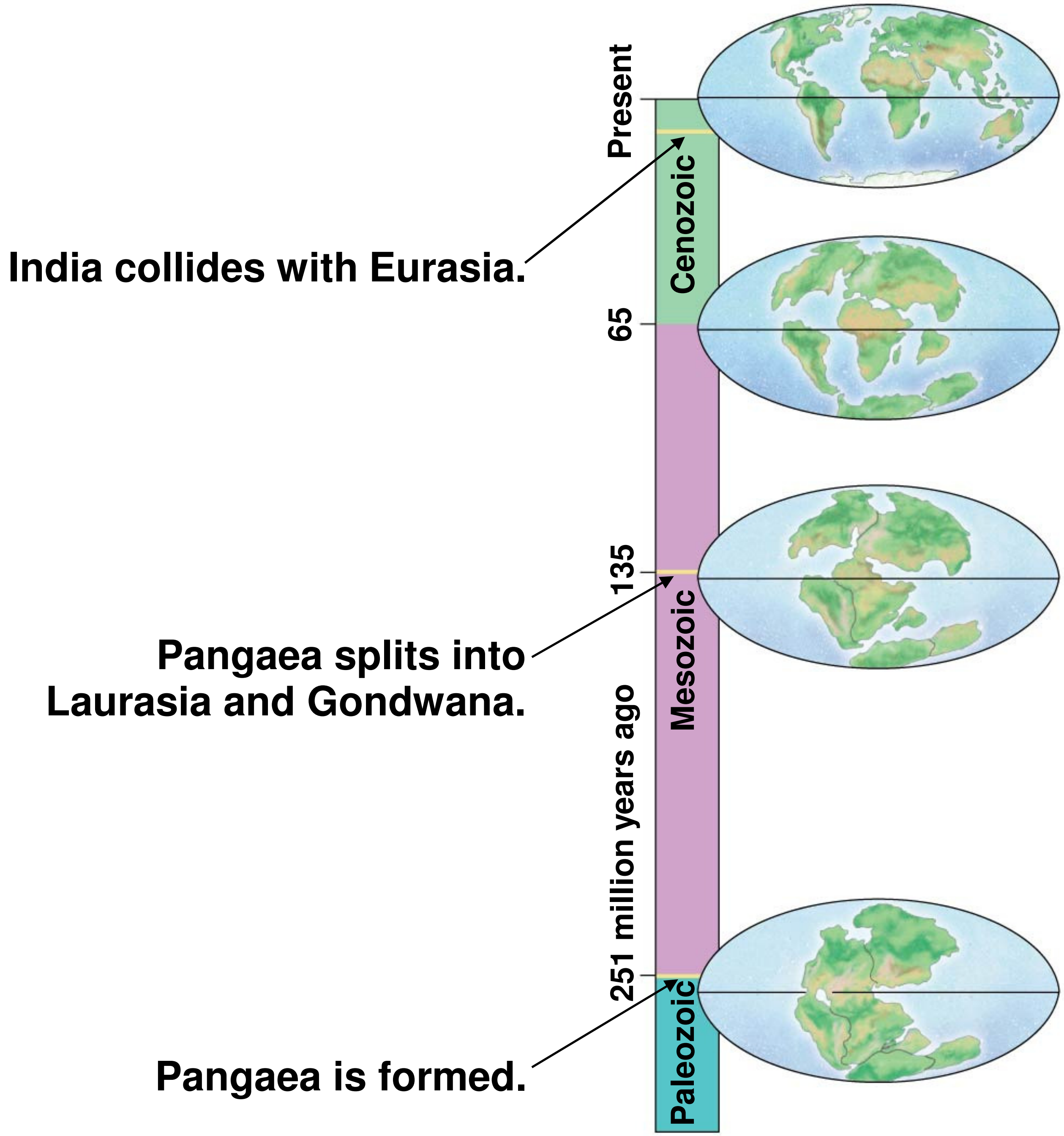

Present
65
135
251 million years ago
Cenozoic
Mesozoic
Paleozoic
India collides with Eurasia.
Pangaea splits into
Laurasia and Gondwana.
Pangaea is formed.

Figure 14.17a

India collides with Eurasia.

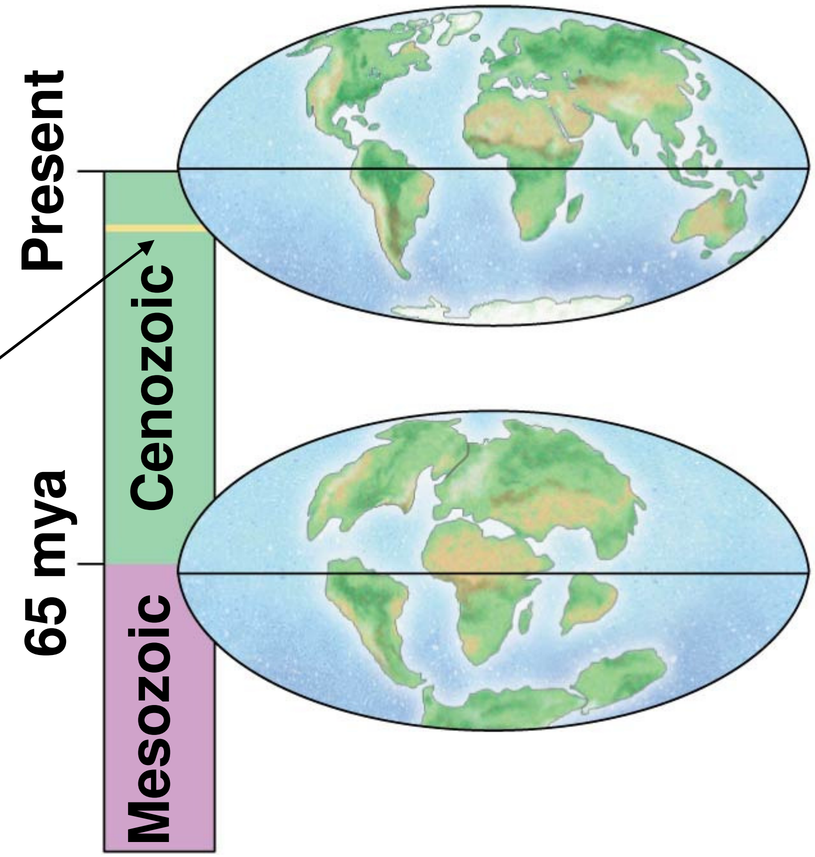


Figure 14.17b

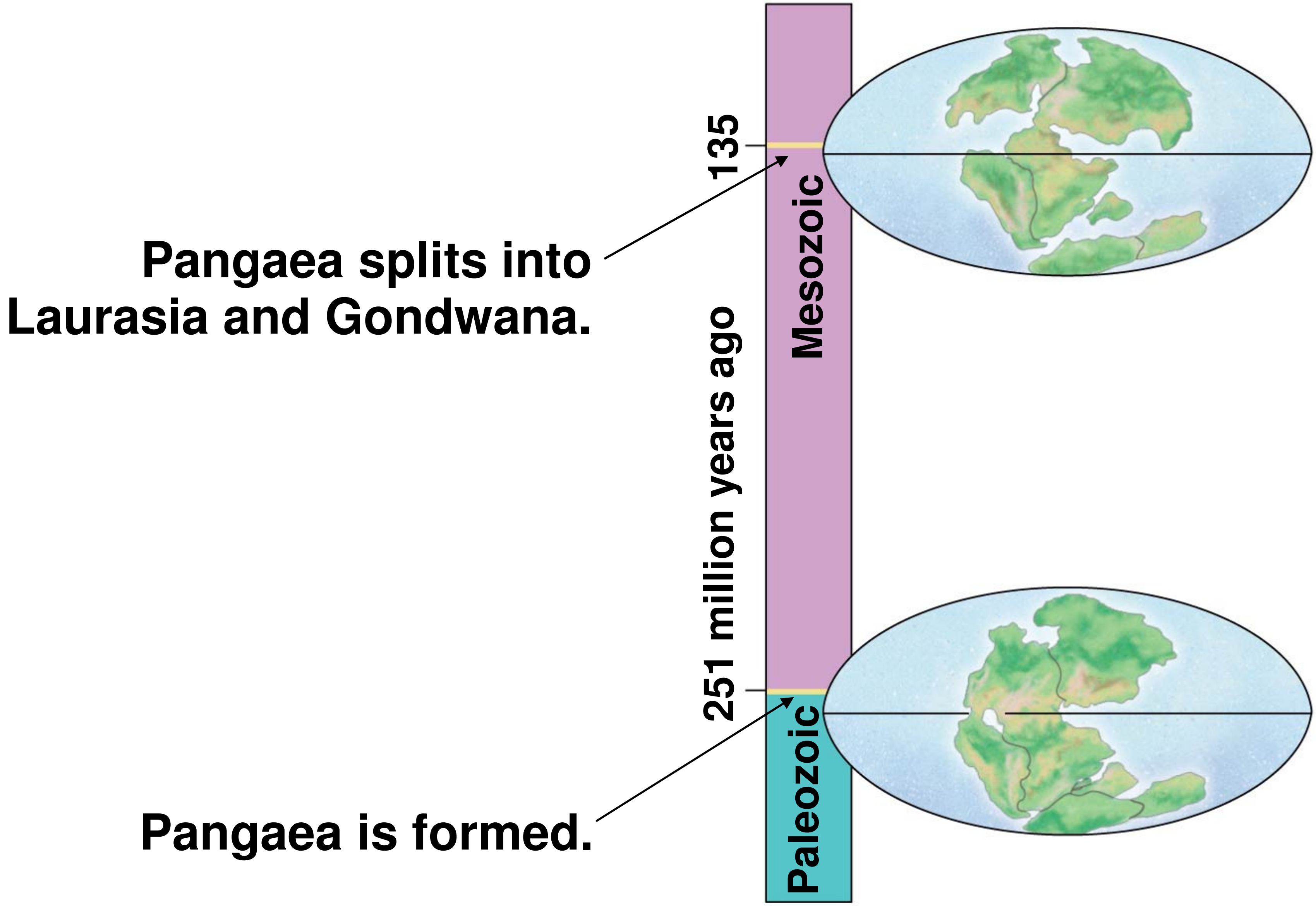


Plate Tectonics and Macroevolution

- About 180 million years ago,
  - Pangaea began to break up,
  - large continents drifted increasingly apart,
  - climates changed, and
  - the organisms of the different biogeographic realms diverged.

Plate Tectonics and Macroevolution

- Plate tectonics helps to explain
  - why Mesozoic reptiles in Ghana (West Africa) and Brazil look so similar and
  - how marsupials were free to evolve in isolation in Australia.

Mass Extinctions and Explosive Diversifications of Life

- The fossil record reveals that five mass extinctions have occurred over the last 540 million years.
- The Permian mass extinction
  - occurred at about the time the merging continents formed Pangaea (250 million years ago) and
  - claimed about 96% of marine species.

Mass Extinctions and Explosive Diversifications of Life

- The Cretaceous extinction
  - occurred at the end of the Cretaceous period, about 65 million years ago,
  - included the extinction of all the dinosaurs except birds, and
  - permitted the rise of mammals.

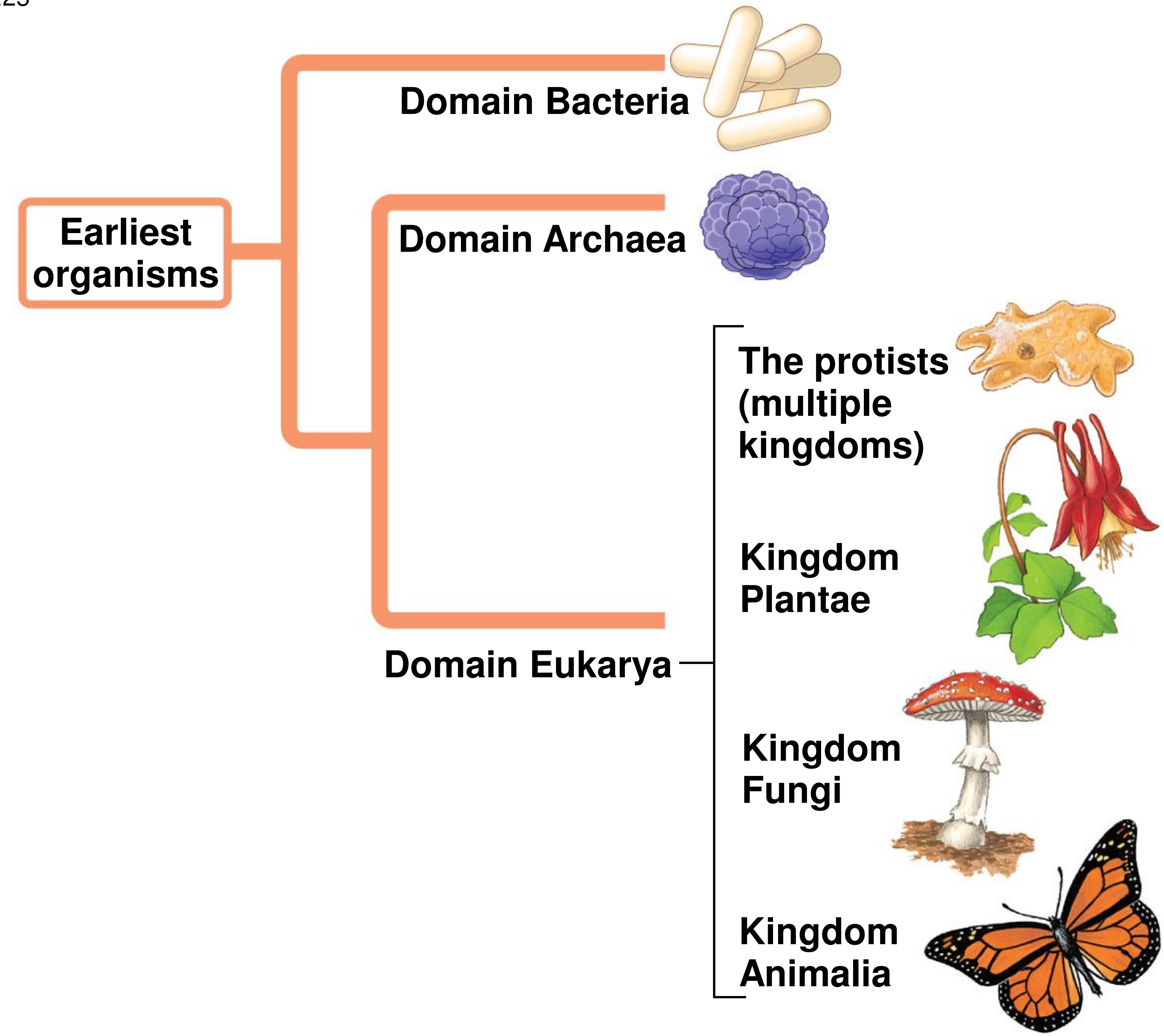
Sorting Homology from Analogy

- Homologous structures
  - reflect variations of a common ancestral plan and
  - are one of the best sources of information used to
    - develop phylogenetic trees and
    - classify organisms according to their evolutionary history.

Sorting Homology from Analogy

- **Convergent evolution** involves superficially similar structures from different evolutionary branches that result from natural selection shaping analogous adaptations.
- Similarity due to convergence is called **analogy**, not homology.
- To develop phylogenetic trees and classify organisms according to their evolutionary history, we use only homologous similarities.

Figure 14.25


Earliest organisms
Domain Bacteria
Domain Archaea
Domain Eukarya
The protists (multiple kingdoms)
Kingdom Plantae
Kingdom Fungi
Kingdom Animalia

Evolution Connection: Rise of the Mammals

- Mass extinctions
  - have repeatedly occurred throughout Earth’s history and
  - were followed by a period of evolutionary change.

Evolution Connection: Rise of the Mammals

- Fossil evidence indicates that
  - mammals first appeared about 180 million years ago but
  - the number of mammalian species
    - remained steady and low in number until about 65 million years ago and
    - greatly increased after most of the dinosaurs became extinct.

Evolution Connection: Rise of the Mammals

- Throughout the process of evolution by natural selection, this pattern of death and renewal is repeated throughout the history of life on Earth.

Figure 14.26

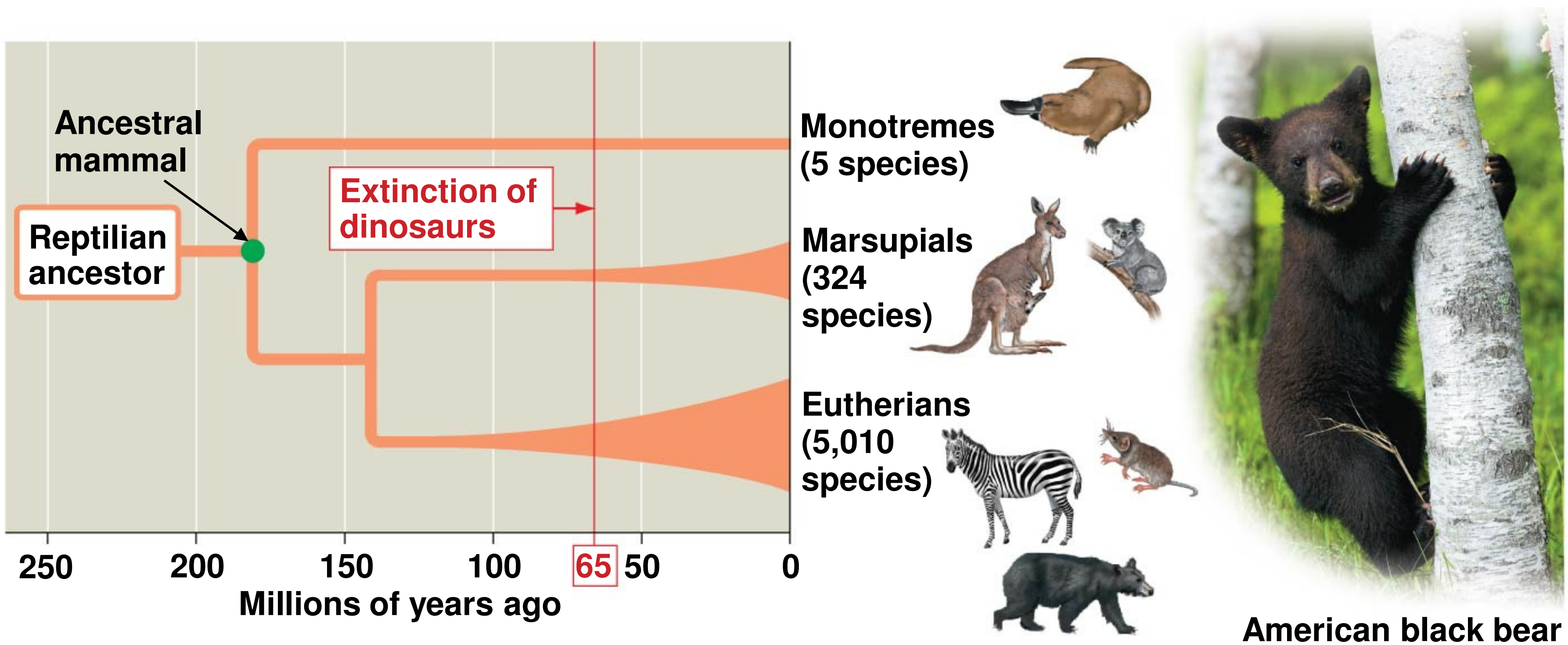

Ancestral mammal
Reptilian ancestor
Extinction of dinosaurs
Monotremes (5 species)
Marsupials (324 species)
Eutherians (5,010 species)
250
200
150
100
65
50
0
Millions of years ago
American black bear

Figure 14.26a

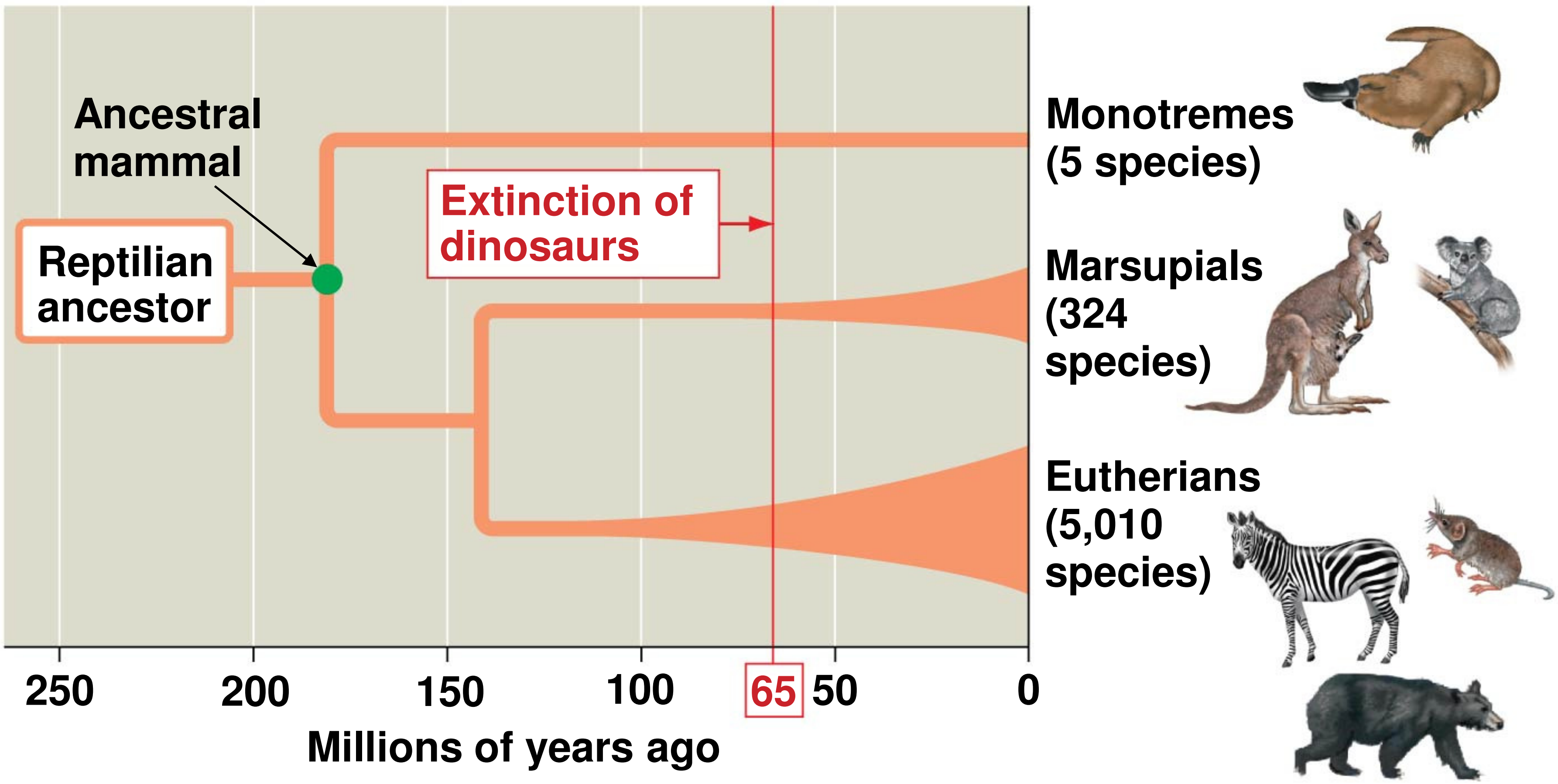
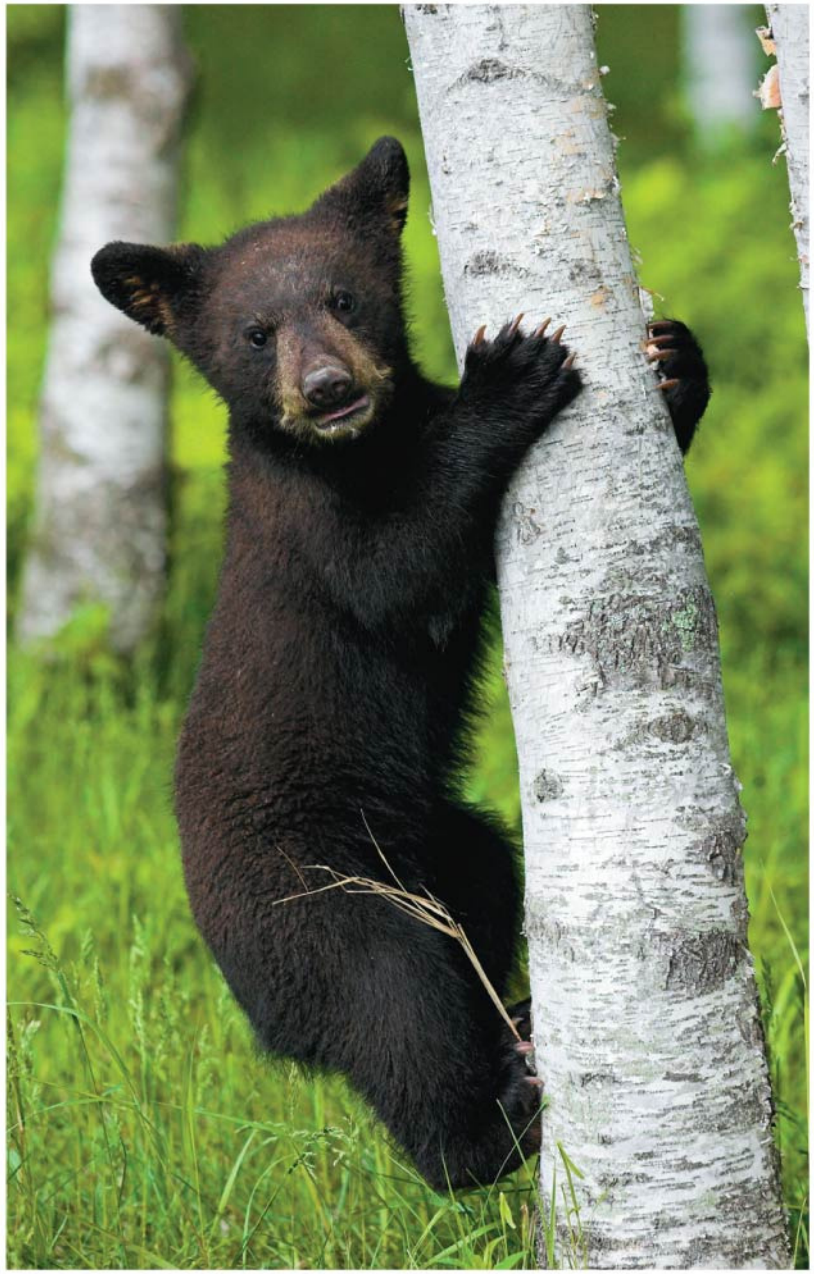


Figure 14.26b



American black bear

Figure 14.UN01