the
exam
covers
up to chapter
25

LSU BIOL 1202

General Biology II Lecture

CHAPTER 25

The History of Life on Earth

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CH 25 Learning Objectives

1. Describe steps by which simple cells may have originated from nonliving materials.
2. Explain what fossils are, how they are dated, and what the fossil record can reveal about life's history.
3. Identify when the origin of single and multi-celled organisms and the colonization of land occurred, and explain the significance of these events.
4. Explain how plate tectonics, mass extinctions, and adaptive radiations have affected Earth's life.
5. Describe how changes in the sequence or regulation of genes can result in major changes in body form.
6. Use examples to show how novel and complex structures can arise by descent with modification.

I would suggest completing the crossword puzzle to help you understand the terminology and correlate how the terms relate to topics covered in this chapter.

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

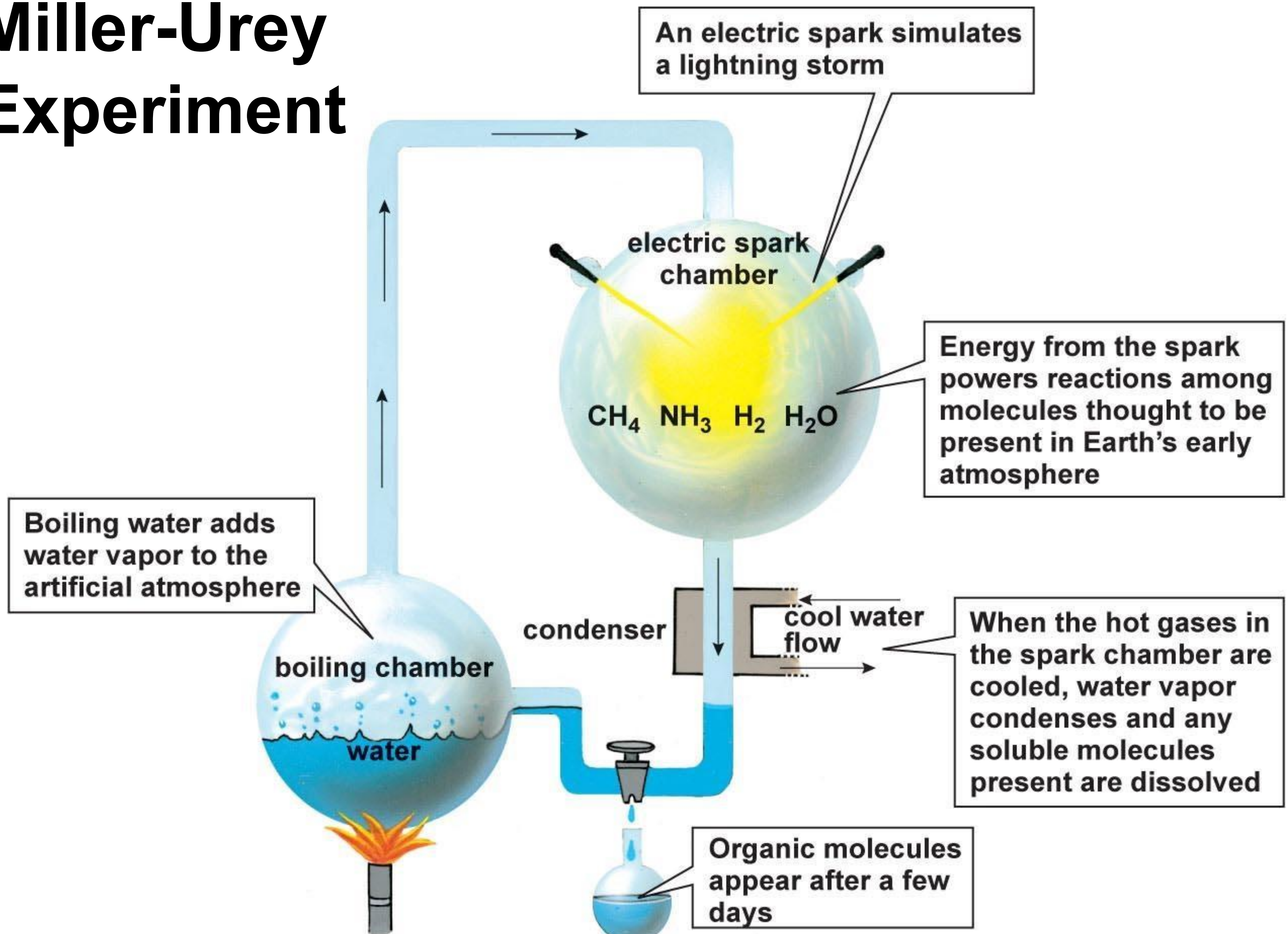
- Chemical and physical processes on early Earth may have produced very simple cells through a sequence of stages
  1. Abiotic synthesis of small organic molecules
  2. Joining of these small molecules into macromolecules
  3. Packaging of molecules into **protocells**
  4. Origin of self-replicating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

Synthesis of Organic Compounds on Early Earth

- Earth formed about 4.6 billion years ago (BYA)
- Earth was bombarded by rocks and ice vaporized water which prevented seas from forming before about 4 BYA
- Earth's early atmosphere had little oxygen and likely contained water vapor and chemicals released by volcanic eruptions
  - EX: nitrogen and its oxides, carbon dioxide, methane, ammonia, hydrogen

- In the 1920s, **Oparin & Haldane** independently hypothesized that the early atmosphere was a <u>reducing environment</u>
- In 1953, the experiments of **Miller & Urey** showed that the abiotic synthesis of organic molecules in a reducing <u>atmosphere was possible</u>
- However, some evidence suggests that the early atmosphere was <u>neither reducing nor oxidizing</u>
- The first organic compounds may have formed in reducing conditions near <u>the openings of volcanoes</u>
- Reanalysis of molecules formed in Miller's experiments found that numerous amino acids formed under conditions <u>simulating volcanic eruption</u>

Miller-Urey Experiment



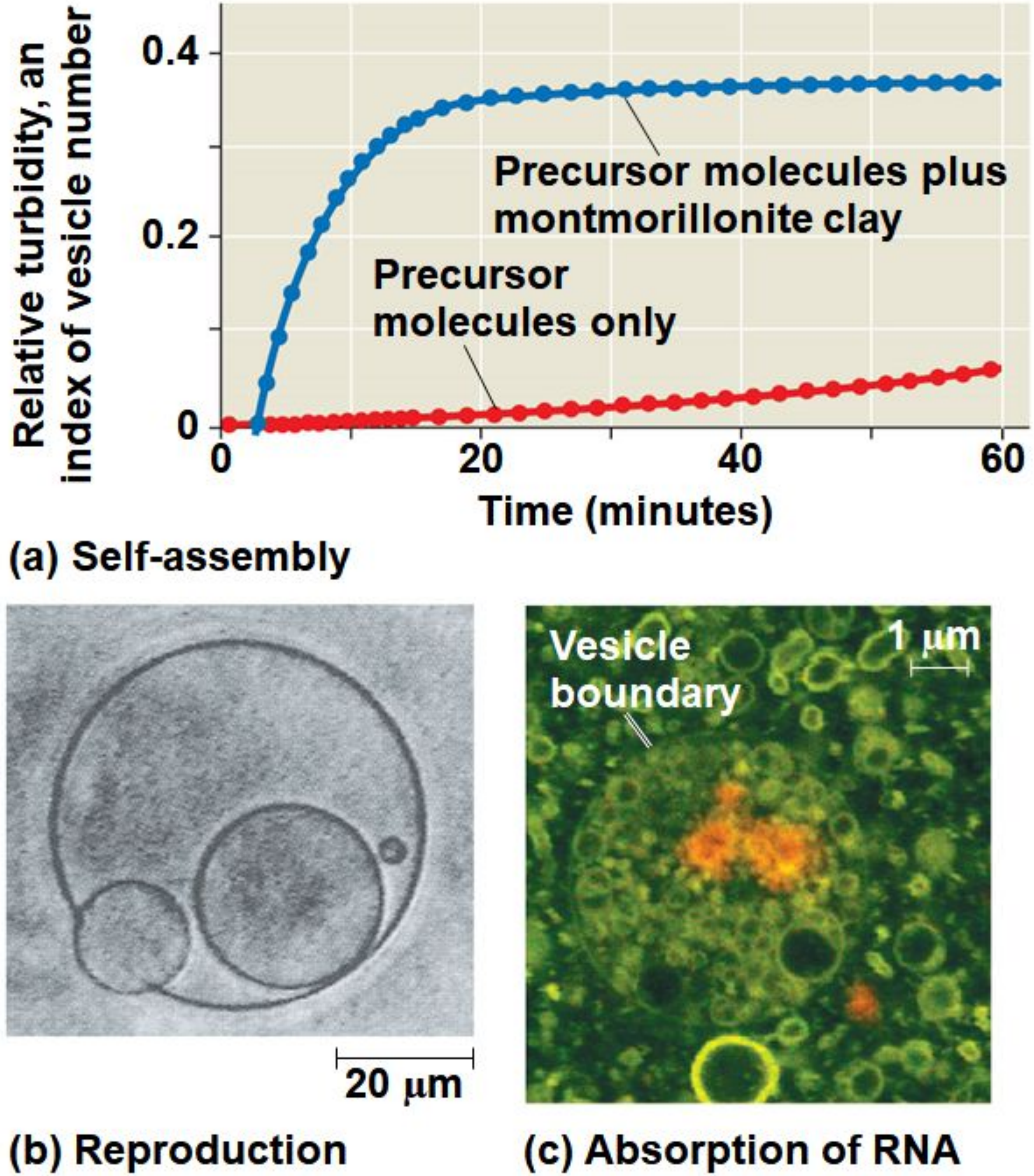
- Organic compounds may have been produced in deep-sea **hydrothermal vents**, areas on the seafloor where hot water and <u>minerals gush from Earth’s interior into the ocean</u>
- Environmental conditions produced near <u>deep-sea vents vary</u>
- “Black smokers” release <u>water at 300-400°C</u>
- **Alkaline vents** release water with high pH (9–11) and <u>warm water (40-90°C)</u>
- Conditions near alkaline vents were likely more suitable for the formation of <u>stable organic compounds</u>

- Meteorites may have been another source of <u>organic molecules</u>
- Murchison meteorite is very well <u>studied space object</u>
  - Fell in <u>Victoria, Australia in 1969</u>
  - It was a documented and <u>directly observed fall</u>
  - Relatively <u>large mass (>100 kg)</u>
  - Contain 80+ amino acids, other key organic molecules, including <u>lipids, simple sugars, and nitrogenous bases</u>

Protocells

- Replication and metabolism are key properties of life and may have appeared together in protocells
- Protocells may have formed from fluid-filled vesicles with a membrane-like structure
- In water, lipids and other organic molecules can spontaneously form vesicles with a lipid bilayer
- Adding ***montmorillonite***, a soft mineral clay common on early Earth, increases the rate of vesicle formation
- Vesicles show simple growth, reproduction, and metabolism and can absorb organic molecules attached to clay through a selectively permeable membrane

Figure 25.4


Relative turbidity, an index of vesicle number
0.4
0.2
0
0
20
40
60
Time (minutes)
Precursor molecules plus montmorillonite clay
Precursor molecules only
(a) Self-assembly
20 µm
(b) Reproduction
Vesicle boundary
1 µm
(c) Absorption of RNA

Self-Replicating RNA

- The first genetic material was likely RNA, not DNA
- RNA plays a central role in protein synthesis
- RNA molecules called **ribozymes** have been found to catalyze many different reactions
  - EX: ribozymes can make complimentary copies of short stretches of RNA
- Natural selection has produced self-replicating RNA molecules
- Copying errors would have occasionally resulted in RNA molecules more adept at self-replication

- RNA molecules that were more stable or replicated more quickly would have left the most descedant RNA molecule
- In 2013, researchers constructed a vesicle whose RNA could self-replicate within the vesicle
- If a vesicle on early Earth could grow, split, and pass on its RNA to its “daughters,” the daughters would be protocells
- The most successful of the early protocells could have increased through natural selection
- RNA could have provided the template for the formation of DNA
- Double-stranded DNA is more chemically stable and can be replicated more accurately than RNA

Concept 25.2: The fossil record documents the history of life

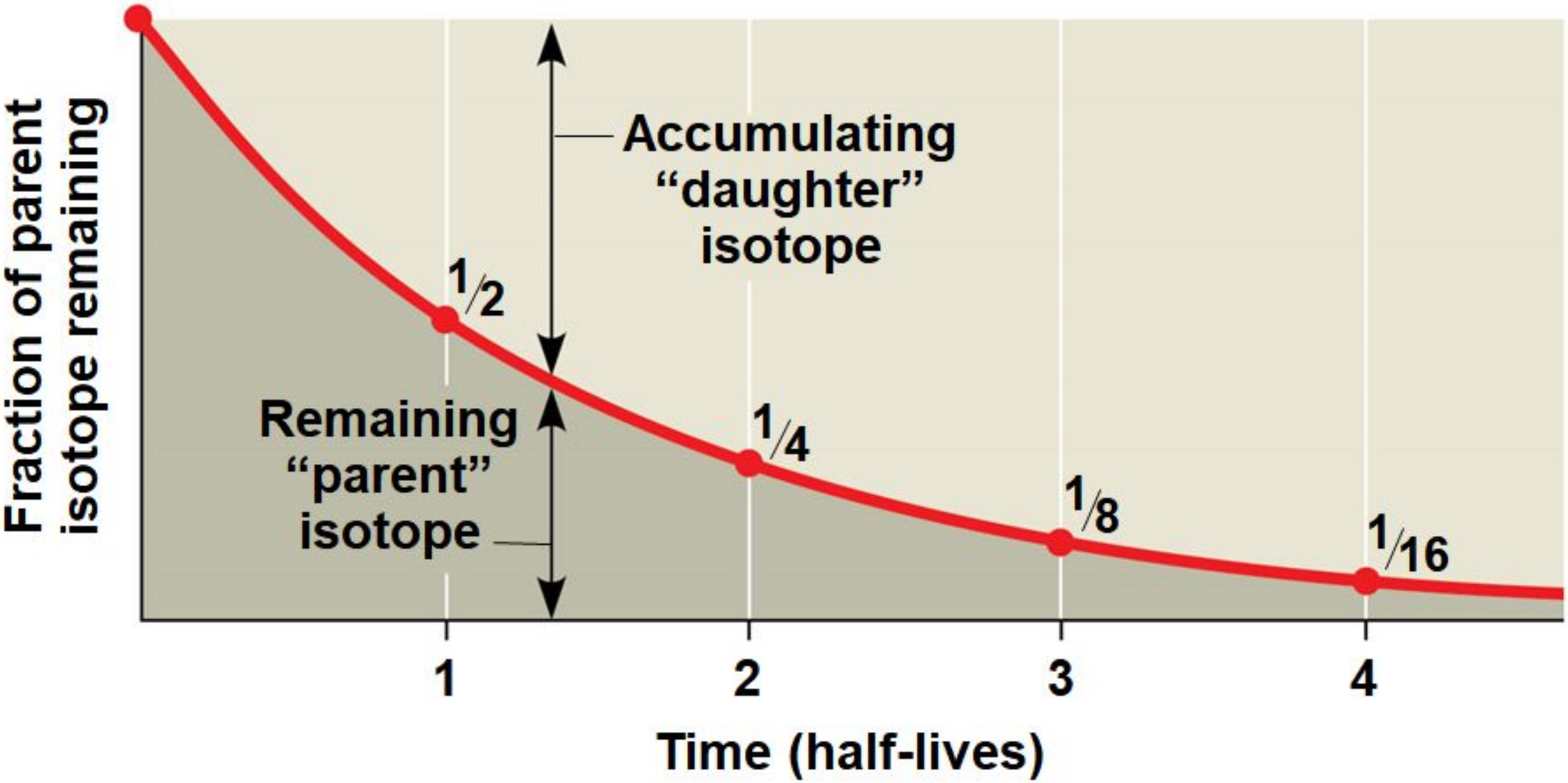
- Few organisms have fossilized, and even fewer of the fossils that *did* form have been discovered
- The fossil record is biased in favor of species that
  - Existed for a long time
  - Were abundant and widespread
  - Had hard parts, such as shells or skeletons



How Rocks and Fossils Are Dated

- The order of fossils in rock strata tells us the order in which they were formed
- We can infer relative ages of fossils using this method, but not their actual ages
- The age of a fossil can be determined using radiometric dating
- A radioactive “parent” isotope decays to a “daughter” isotope at a characteristic rate
- Each isotope has a known **half-life**, the time required for half the parent isotope to decay
  - EX: Li^{8} = < 1 second, Na^{24} = 15 hrs, Ra^{228} = 1600 yrs

Figure 25.6



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

- Fossils contain isotopes that accumulated in the organisms when <u>they were alive</u>
- Ages are estimated using the ratio of $C^{14}:C^{12}$ radioactive <u>isotope</u>
- Radiocarbon dates <u>fossils up to 75,000 years old</u>
- Radioactive isotopes with longer half-lives are <u>used to date older fossils</u>
- However, organisms do NOT take up <u>isotopes with long half-lives</u>
- How do we date fossils >75,000 years old then?
- The age of older fossils can be estimated by using isotopes with long half-lives to <u>date volcanic rock layers above and below the fossil</u>

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

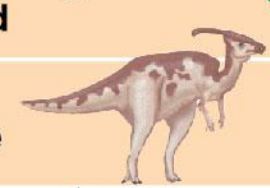
- The **geologic record** is divided into the

  Hadean, Archaean, Proterozoic, and Phanerozoic eons
- The Phanerozoic eon includes the last half billion years
- The Phanerozoic is divided into 3 eras: the Paleozoic, Mesozoic, and Cenozoic
- Major boundaries between eras correspond to major extinction events in the fossil record

Table 25.1b

PRESENT DAY

^^^^^^^^ Phanerozoic eon vvvvvvvvv

Period	Epoch	Start (mya)	Description
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	34	Origins of many primate groups 
	Eocene	56	Angiosperm dominance increases; continued radiation of most present-day mammalian orders 
	Paleocene	66	Major radiation of mammals, birds, and pollinating insects 
Cretaceous		145	Flowering plants (angiosperms) appear and diversify; many groups of organisms, including most dinosaurs, become extinct at end of period 
Jurassic		201	Gymnosperms continue as dominant plants; dinosaurs abundant and diverse 
Triassic		252 mya	Cone-bearing plants (gymnosperms) dominate landscape; dinosaurs evolve and radiate; origin of mammals 

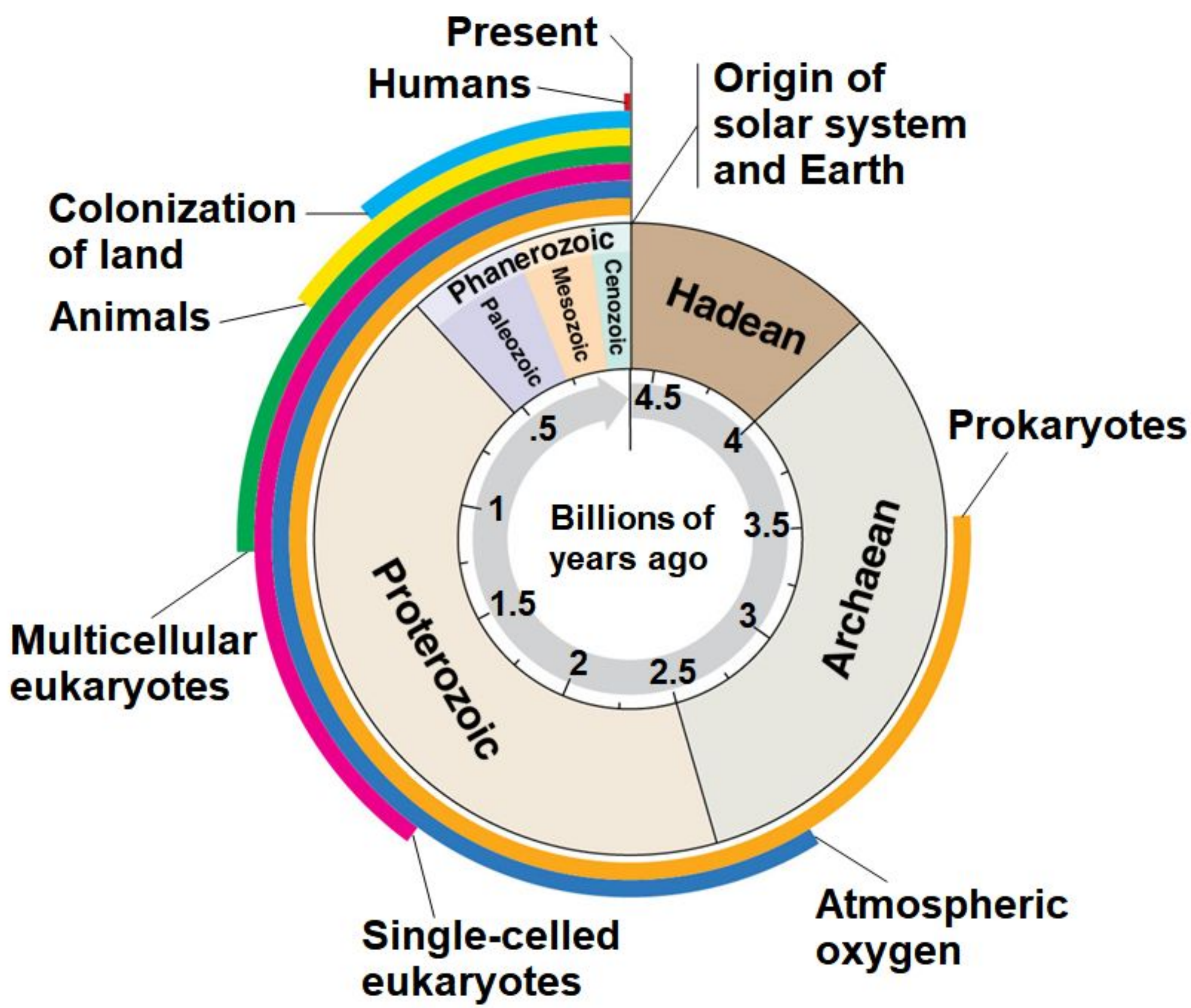
<< Phanerozoic eon >>

Permian	252 mya	Radiation of reptiles; origin of most present-day groups of insects; extinction of many marine and terrestrial organisms at end of period
Carboniferous	299	Extensive forests of vascular plants form; first seed plants appear; origin of reptiles; amphibians dominant
Devonian	359	Diversification of bony fishes; first tetrapods and insects appear
Silurian	419	Diversification of early vascular plants
Ordovician	443	Marine algae abundant; colonization of land by diverse fungi, plants, and animals
Cambrian	485	Sudden increase in diversity of many animal phyla (Cambrian explosion)
Ediacaran	541	Diverse algae and soft-bodied invertebrate animals appear
	635	
	1,000	
	1,800	Oldest fossils of eukaryotic cells appear
	2,500	
	2,700	Concentration of atmospheric oxygen begins to increase
	3,500	Oldest fossils of cells (prokaryotes) appear
	4,000	Oldest known rocks on Earth's surface
	Approx. 4,600	Origin of Earth

<< Hadean, Archaean, Proterozoic eons >>

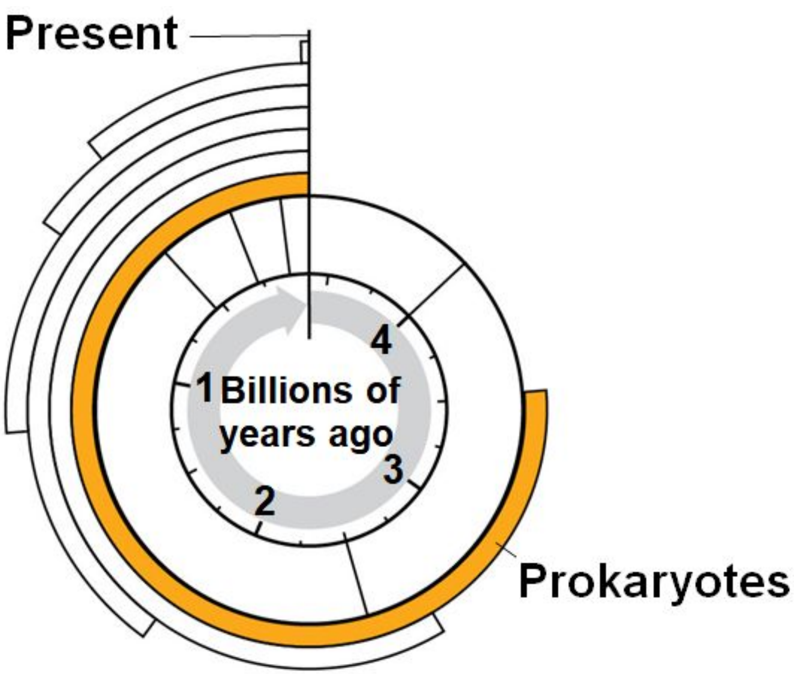
ORIGIN OF EARTH

- The analogy of a clock can be used to place the major events in the history of life on Earth in <u>the context of the geologic record</u>



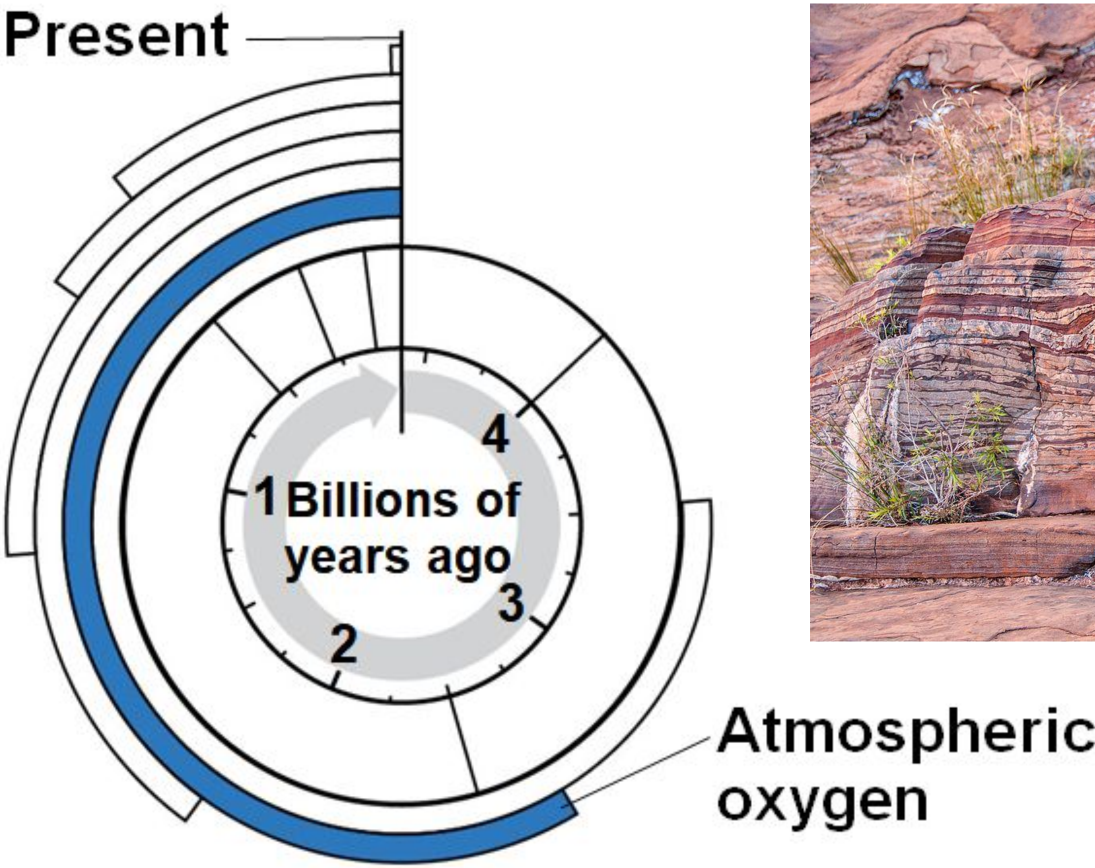
The First Single-Celled Organisms

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

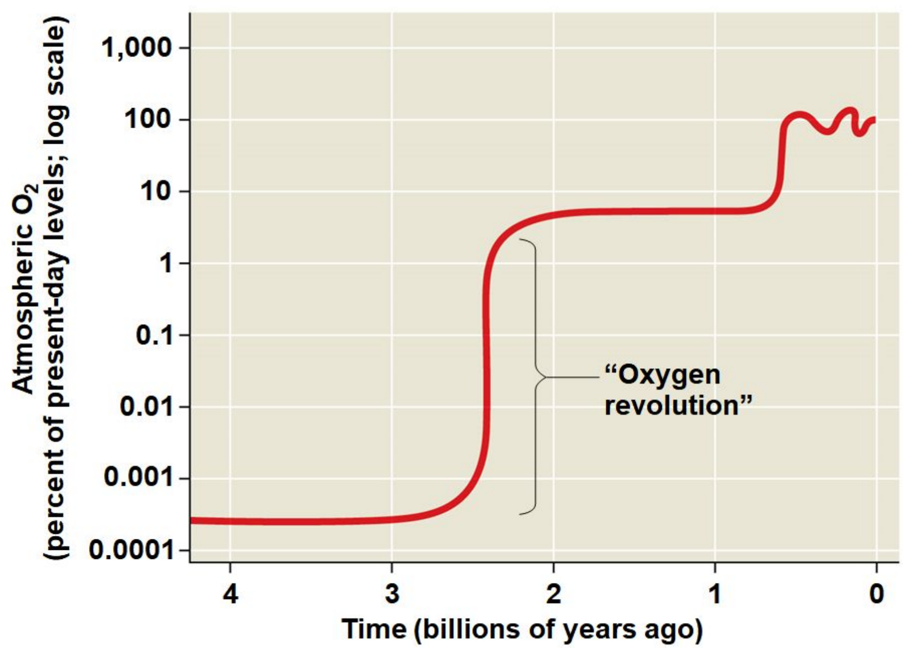


Photosynthesis and the Oxygen Revolution

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

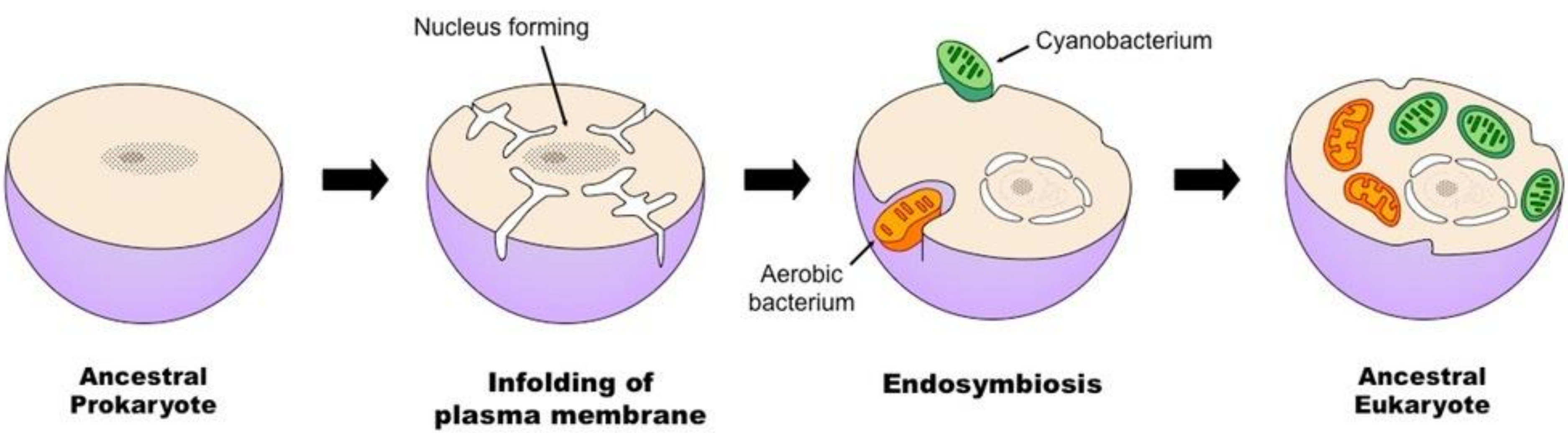


- O_2 accumulated gradually in the atmosphere from about 2.7 to 2.4 BYA, and then shot up rapidly to between <u>1% and 10% of its present level</u>
- This “oxygen revolution” caused <u>the *extinction* of many prokaryotic groups</u>
- Some groups survived in anaerobic environments; others adapted using <u>cellular respiration to harvest energy</u>



The First Eukaryotes

- The oldest fossils of eukaryotic cells date to 1.8 BYA
- Eukaryotic cells have a nuclear envelope, mitochondria, endoplasmic reticulum, cytoskeleton
- Eukaryotes originated by **endosymbiosis** when a prokaryotic cell engulfed a small cell that would evolve into a mitochondrion
- An endosymbiont is a cell that lives within a host cell



- Anaerobic host cells would have benefited from endosymbionts that could use oxygen as it built up in the atmosphere
- Over time, the host and endosymbionts would have become interdependent, forming a single organism
- All eukaryotes have mitochondria or remnants of mitochondria, but not all have plastids
- **Serial endosymbiosis** supposes that mitochondria evolved before plastids through a ***sequence*** of endosymbiotic events
- Mitochondria and plastids likely descended from bacterial cells; the original host is thought to be an Archaean or close relative

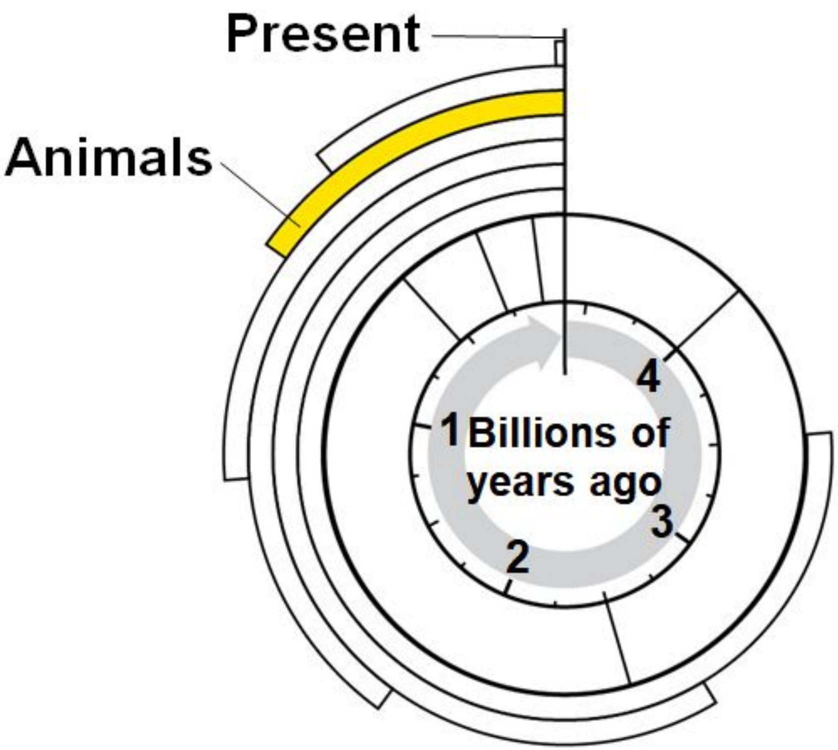
- Key evidence supporting an endosymbiotic origin of mitochondria and plastids:
  1. Inner membranes of both organelles are similar to <u>plasma membranes of living bacteria</u>
  2. DNA structure and cell division are <u>similar to</u> <u>bacteria</u>
  3. Both organelles <u>transcribe and translate their own DNA</u>
  4. Ribosomes are more similar to <u>bacteria than to eukaryotic ribosomes</u>

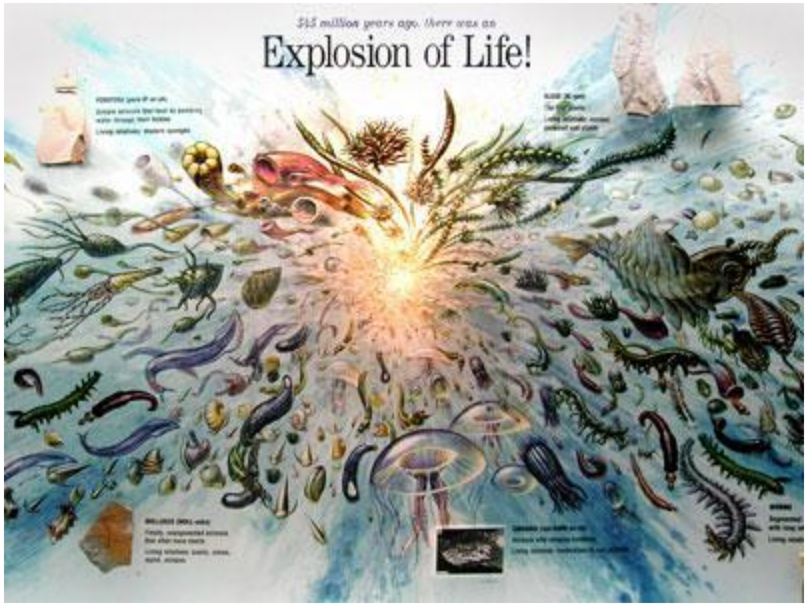
Early Multicellular Eukaryotes

- 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 oldest fossils of multicellular eukaryotes are small red algae, about 1.2 BYA
- Older fossils from about 1.8 BYA may also be multicellular eukaryotes, but they can’t be resolved taxonomically

The Cambrian Explosion

- The **Cambrian explosion** refers to the sudden appearance of fossils resembling modern animal phyla in <u>the Cambrian period (535 to 525 MYA)</u>
- A few animal phyla appear even earlier: <u>sponges, cnidarians, and molluscs</u>

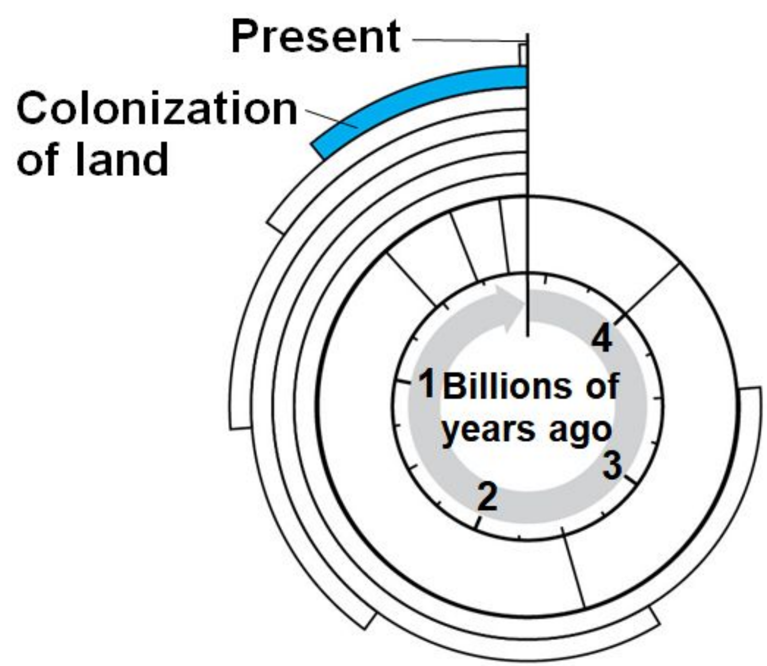




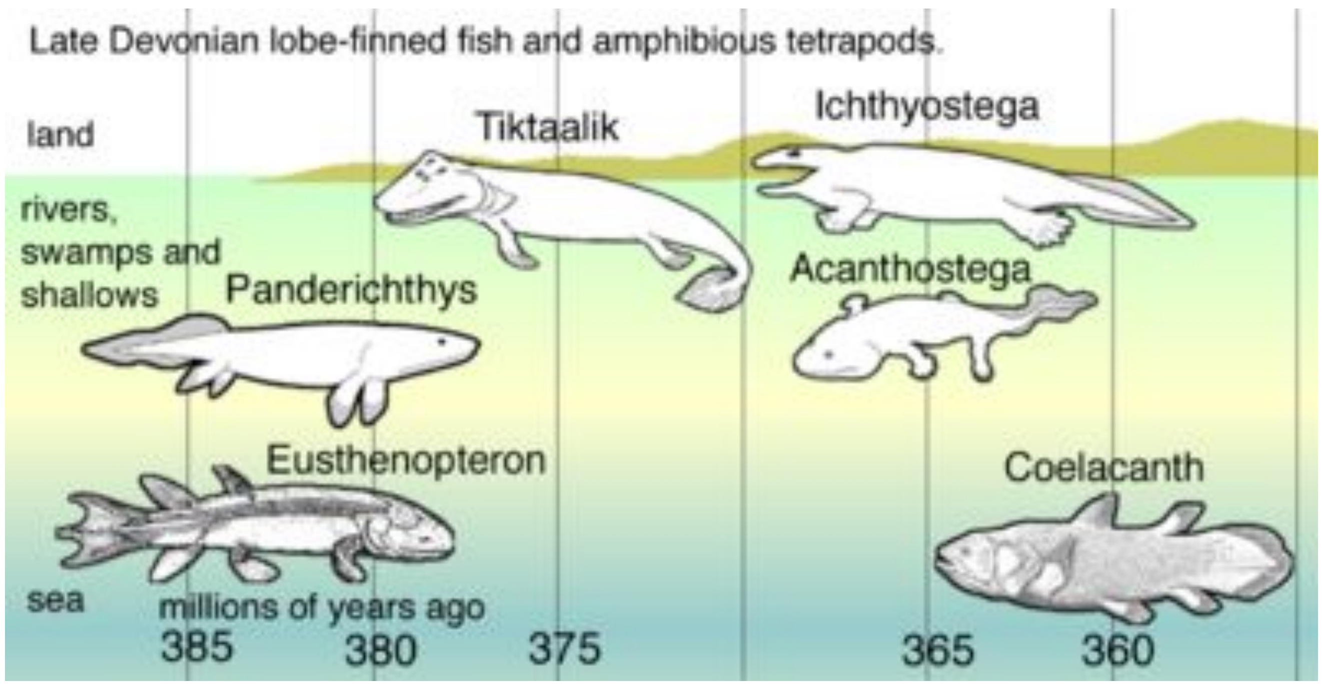
- The Cambrian explosion provides the first <u>evidence of predator-prey interactions</u>
- Large-bodied predators with claws for capturing prey appeared <u>in the fossil record</u>
- New defense adaptations, such as <u>sharp spines and body armor, also appeared</u>
- DNA analyses suggest that sponges evolved 700 MYA and the common ancestor to several other animal phyla <u>lived 670 MYA</u>
- The oldest fossil assigned to an extant animal phyla lived <u>560 MYA</u>
- Molecular and fossil data suggest that the <u>Cambrian explosion had a “long fuse”</u>

The Colonization of Land

- Fungi, plants, and animals began to colonize land about <u>500 MYA</u>
- Many plants evolved adaptations to reproduce on land and <u>avoid dehydration</u>
  - EX: a vascular system for transporting materials appeared by <u>about 420 MYA</u>
- Plants and fungi likely colonized <u>land together</u>
- Fossilized plants show evidence of mutually beneficial associations with <u>fungi (mycorrhizae) that are still seen today</u>



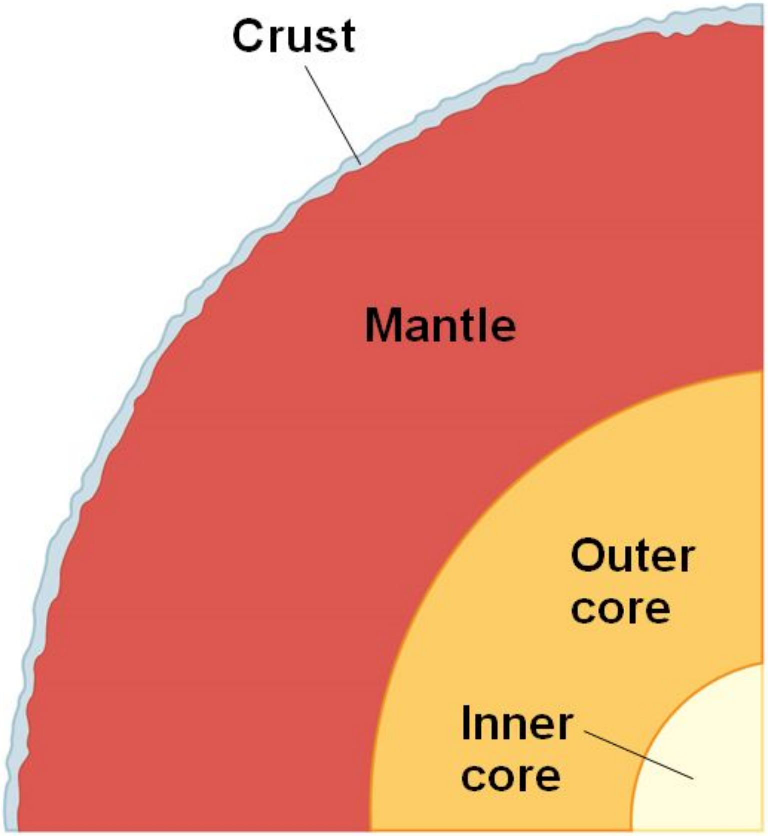
- Arthropods and tetrapods are the most widespread and diverse land animals
- Tetrapods evolved from lobe-finned fishes around 365 MYA
- The human lineage of tetrapods evolved around 6-7 MYA, and modern humans originated only 195,000 years ago



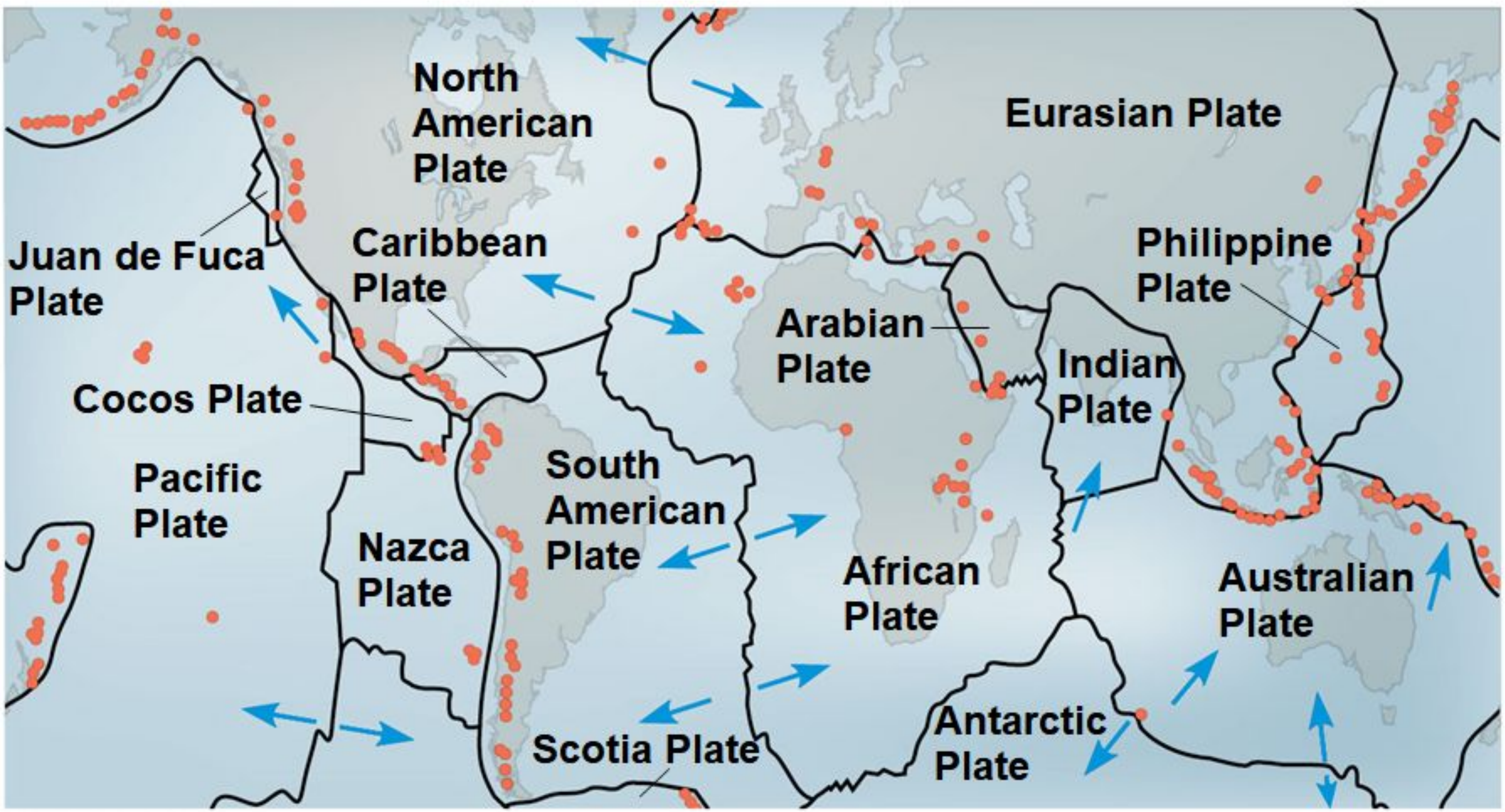
Concept 25.4: The rise and fall of groups of organisms reflect differences in speciation and extinction rates

Plate Tectonics

- The landmasses of Earth have formed a supercontinent three times over the past billion years (1 billion, 600 million, and 250 million years ago)
- According to the theory of **plate tectonics**, Earth's crust is <u>composed of plates floating on Earth's mantle</u>

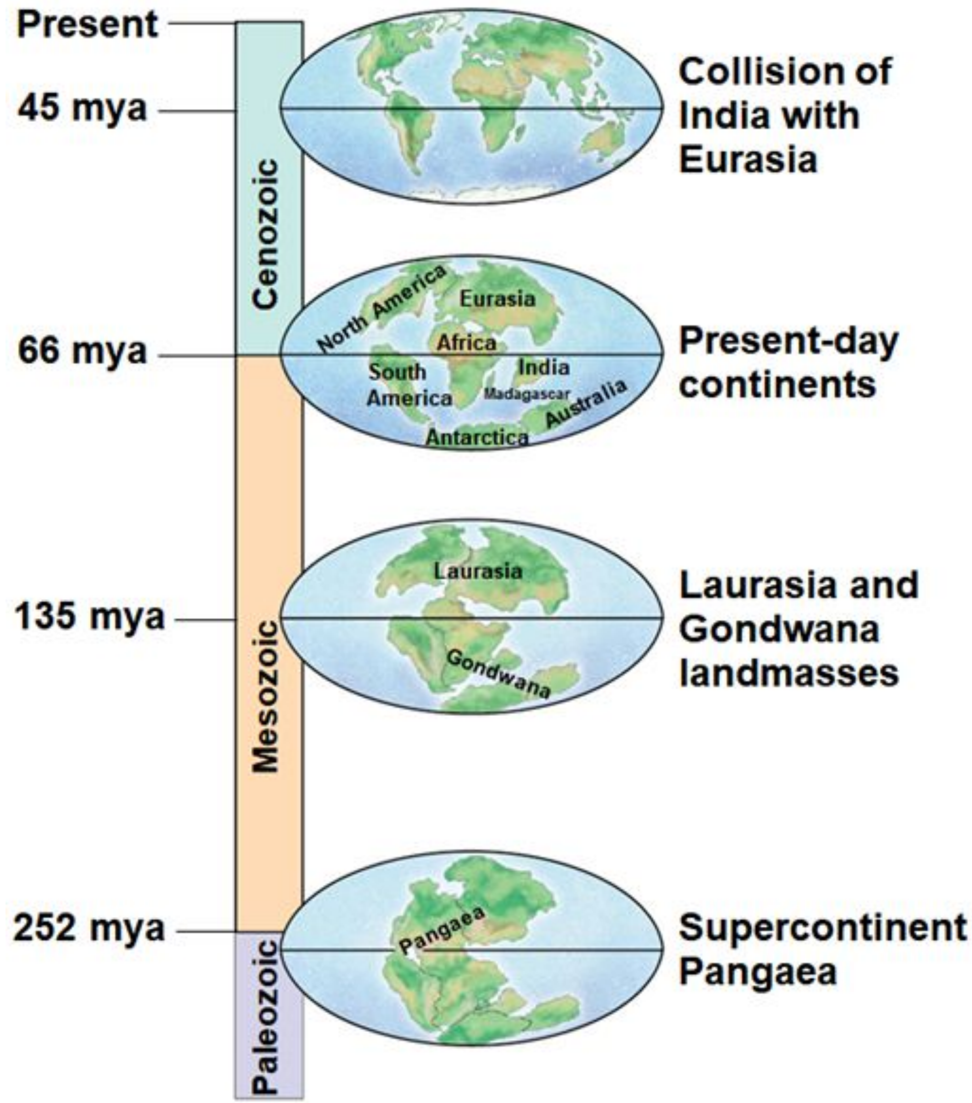


- Movements in the mantle cause the plates to move over time in a process called continent drift
- Oceanic and continental plates can drift apart, collide to form mountains, or slide past each other, causing earthquakes (Pangea rifting animation)



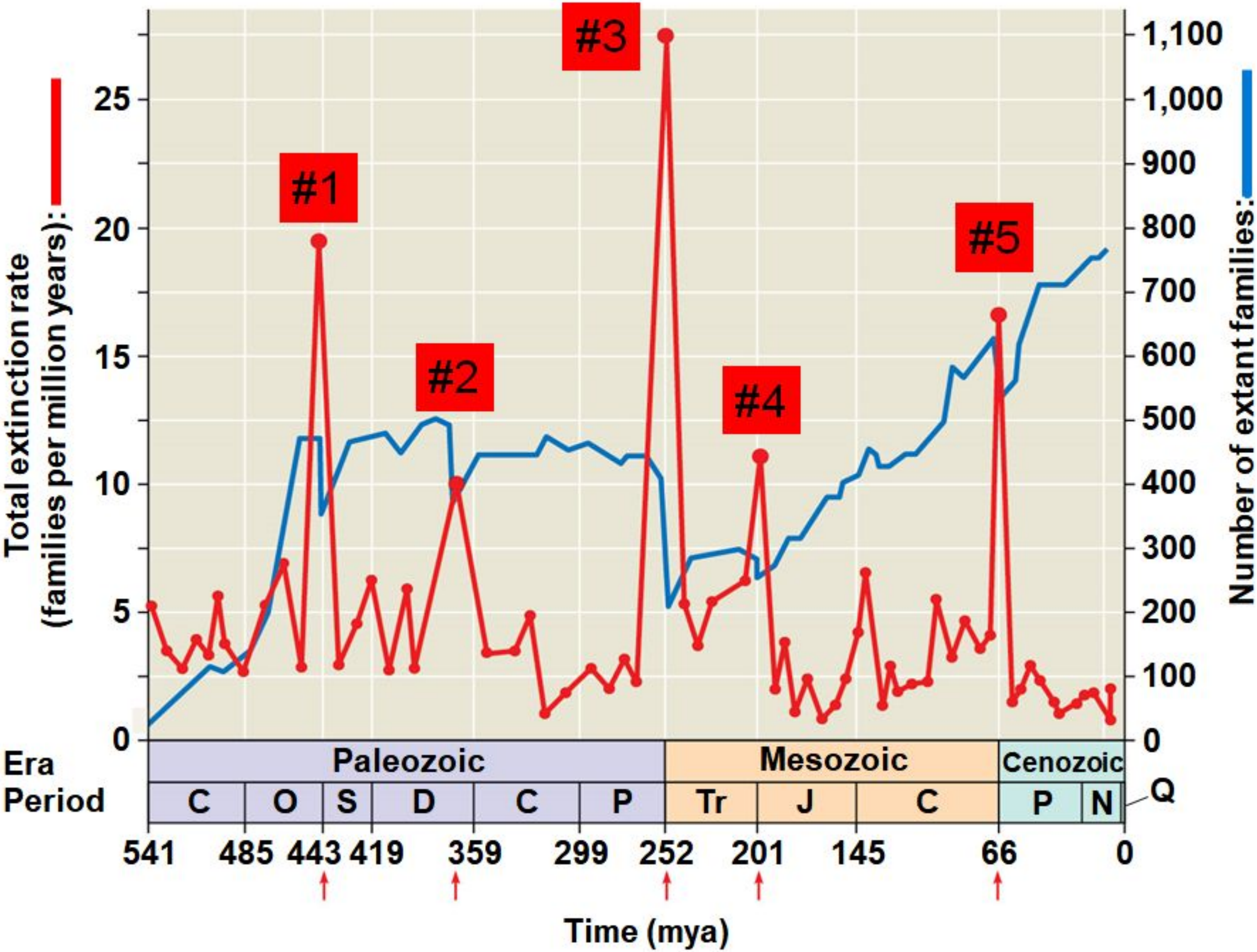
Consequences of Continental Drift

- Formation of the supercontinent **Pangaea** about 250 MYA had many effects:
  - deepening of ocean basins
  - reduction in shallow-water habitat
  - cooler and drier climate inland
  - Separation of landmasses can lead to allopatric speciation



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' biotic or abiotic environment
- At times, the rate of extinction has increased dramatically and caused a **mass extinction**
- Historically, there have been 5 mass extinction events
- In each of the five mass extinction events, 50% or more of marine species became extinct


#1
#2
#3
#4
#5
Total extinction rate (families per million years):
Number of extant 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
C
O
S
D
C
P
Tr
J
C
P
N
Q
541
485
443
419
359
299
252
201
145
66
0
Time (mya)

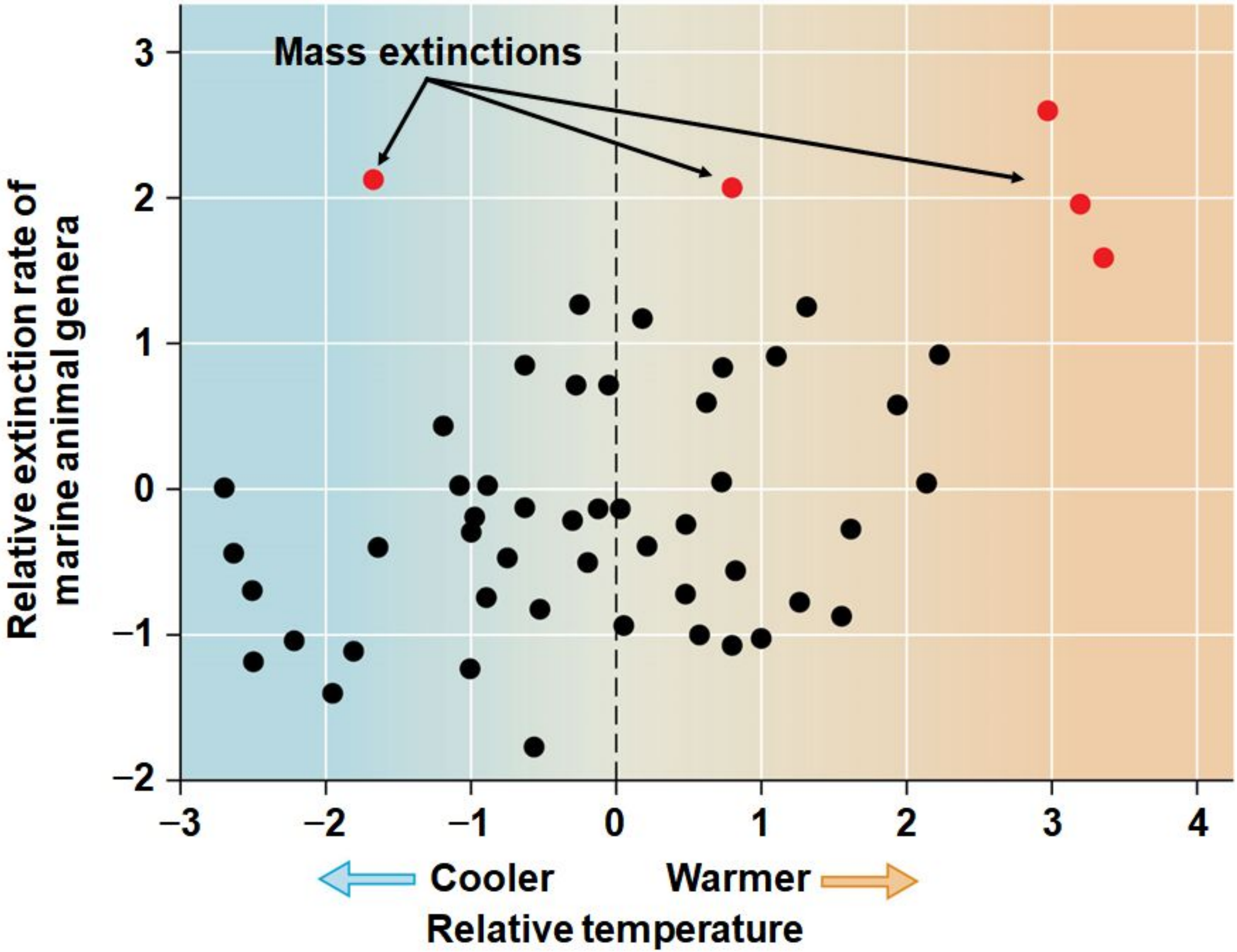
- The Permian extinction (**#3** on the previous graph) defines the boundary between the Paleozoic and Mesozoic eras 252 MYA
- This mass extinction occurred in less than 500,000 years and caused the extinction of about 96% of marine animal species
- A number of factors might have contributed to this mass extinction
  - Extreme volcanism in what is now Siberia
  - Global warming and ocean acidification resulting from the emission of large amounts of CO_2 from volcanoes
  - Anoxic conditions resulting from nutrient enrichment of ecosystems

- The Cretaceous mass extinction (**#5** on the previous graph) occurred 66 MYA
- More than half of all marine species, many families of terrestrial plants and animals, and all of the dinosaurs, except birds, went extinct during this event
- The presence of iridium in sedimentary rocks from that time period suggests a meteorite impact
- The Chicxulub crater off the coast of Mexico is evidence of a massive meteorite collision that dates to the same time
- Dust clouds caused by the impact would have blocked sunlight and disturbed the global climate

Figure 25.18

Is a Sixth Mass Extinction Under Way?

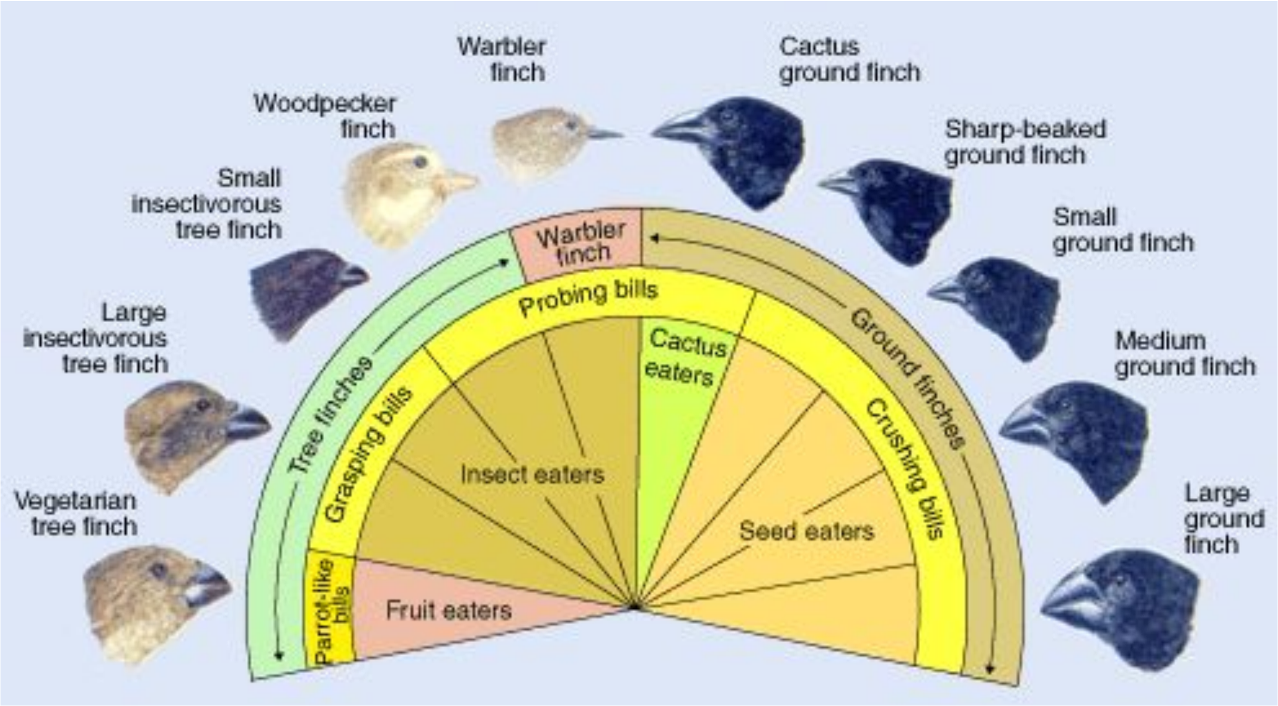
- Scientists estimate that the current rate of extinction is 100 to 1,000 times the typical background rate seen <u>in the fossil record</u>
- It is difficult to estimate current extinction rates because many undiscovered species may be lost through <u>destruction of the tropical rain forest</u>
- Many species are declining rapidly due to habitat loss, introduced <u>species, and overharvesting</u>
- Climate change may hasten declines; extinction rates historically have tended to increase when <u>global temperatures were high</u>
- Data suggest that a 6th, human-caused mass extinction is <u>likely to occur unless action is taken</u>


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

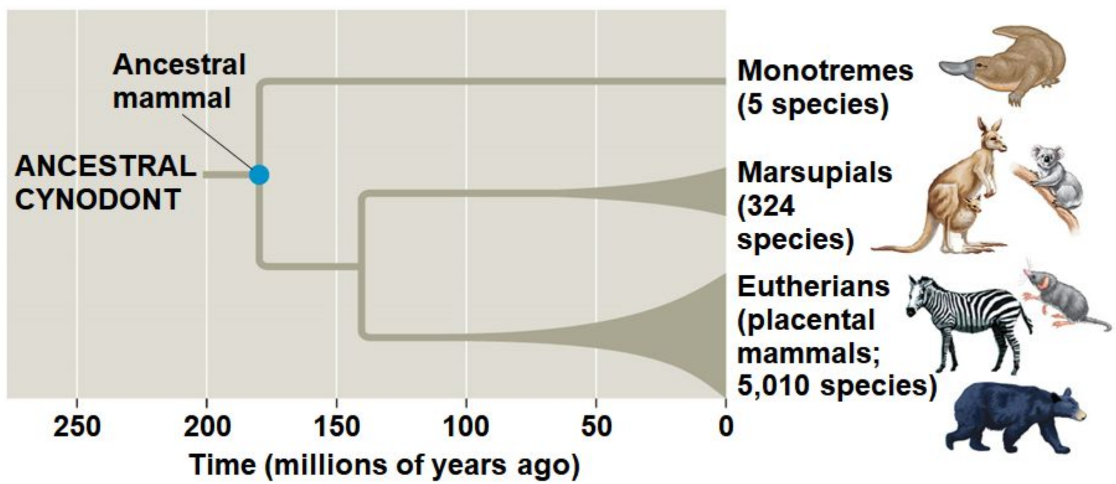
- It typically takes 5-10 million years for diversity to recover following a mass extinction; in some cases up to <u>100 million years</u>
- Mass extinctions can change the types of organisms found <u>in ecological communities</u>
  - EX: the proportion of predators increased in marine communities after the <u>Permian and Cretaceous mass extinctions</u>
- Mass extinctions can also eliminate lineages with <u>novel and advantageous features</u>
  - EX: shell-drilling gastropods were lost in the extinction at the end of the Triassic and did not <u>reappear for 120 million years</u>

- **Adaptive radiation** is the rapid evolution of diversely <u>adapted species from a common ancestor</u>
- Adaptive radiations may follow
  - <u>mass extinctions</u>
  - <u>the evolution of novel characteristics</u>
  - <u>the colonization of new regions</u>



Worldwide Adaptive Radiations

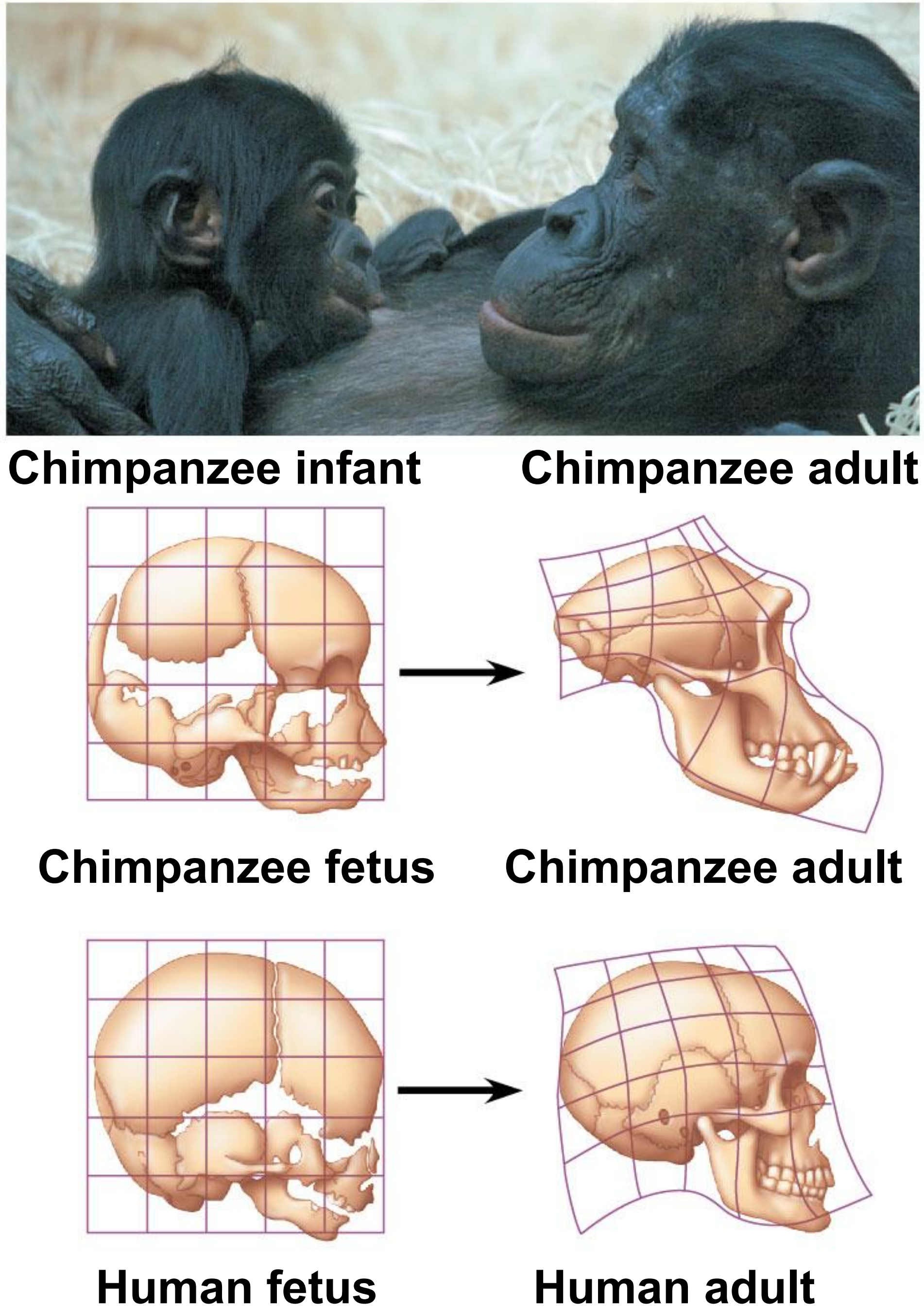
- Mammals underwent an **adaptive radiation** after the extinction of <u>terrestrial dinosaurs</u>
- The *disappearance* of dinosaurs (except birds) opened ecological niches, allowing for the expansion of <u>mammals in diversity and size</u>
- Other notable radiations include photosynthetic prokaryotes, large predators in the <u>Cambrian, land plants, insects, and tetrapods</u>



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

- Studying genetic mechanisms of change can provide insight into large-scale evolutionary change
- **Developmental genes** are those that control the rate, timing, and spatial pattern of changes in an organism's form as it develops to adulthood
- **Heterochrony** is an evolutionary change in the rate or timing of developmental events; it can have a significant impact on body shape
  - EX: Contrasting shapes of human and chimpanzee skulls are the result of small changes in relative growth rates of different body parts

Figure 25.23



Relative skull growth rates

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

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
- Most novel biological structures evolve in many stages from previously existing structures
  - EX: Complex eyes have evolved from simple photosensitive cells independently many times
- Structures do not evolve in anticipation of future use; natural selection can only improve a structure in the context of its current utility
- Fossil records show evolutionary trends in some lines
- Extracting a single evolutionary progression from the fossil record can be misleading