

1) Overview: Lost Worlds

- Past organisms were very different from those now alive
- The fossil record shows **macroevolutionary** changes over large time scales including
 - The emergence of terrestrial vertebrates
 - The origin of photosynthesis
 - Long-term impacts of mass extinctions

2) One example of the growing body of fossil evidence: new discoveries from Antarctica



Cryolophosaurus

- The fossils being discovered in Antarctica are revealing a remarkable history
- 500 MYA the ocean surrounding Antarctica was warm and teeming with tropical invertebrates
- Later Antarctica was covered in forests for millions of years
- During parts of this era, a wide range of organisms stalked these forests, including 3-m predatory “terror birds” and the dinosaurs shown to the left, a 7-m-long relative of *T. rex*--
Cryolophosaurus

3) Fossils in other parts of the world tell a similar story

- Fossils in lower, older strata are mostly extinct and utterly dissimilar, and simpler, than organisms now on planet Earth
- The documentation of the fossil record shows sweeping changes, and these changes illustrate what science calls **macroevolution**
- The fossil record also demonstrates major evolutionary changes including
 - The beginning of key events like the beginning of photosynthesis
 - The emergence of terrestrial vertebrates
 - Impact of mass extinctions
- Note that no fossil record exists of the origin of life, and much of the research on that seminal episode is preliminary and often speculative

4) The difficulty of discovering ultimate origin of life

- The earliest fossils are microorganisms dated at ~ 3.5 billion yrs BP (“before present”)
- Speculation by most scientists working on this issue is that life first appeared on planet Earth ~ 3.6-3.9 billion yrs BP
- What can we determine about the conditions on planet Earth at that time?

5) Early Earth physical conditions

- Evidence indicates that planet Earth and its solar system formed ~ 4.6 billion yrs ago
- Oldest dated rocks (from Greenland) date ~ 4.4 billion; moon rocks date about the same
- Between 4.6 and 3.9 billion yrs BP, the planet was being bombarded by huge chunks of material & ice left over from the formation of the solar system

6) Early Earth physical conditions—cont.

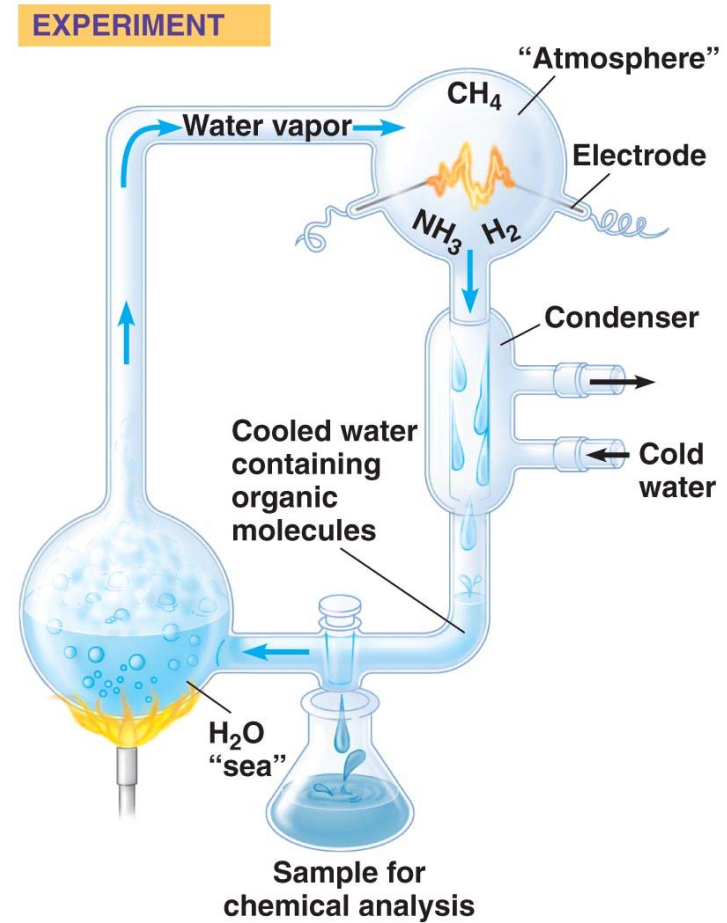
- When the space debris bombardment slowed (<3.9 billion yrs BP), the atmosphere was thick with water vapor along with various compounds released by volcanic eruptions—esp. N and N oxides, CO₂, CH₄, NH₃, H, and H₂S
- As Earth cooled, the water vapor condensed into oceans and much of the H escaped into space

7) Such early conditions have led to hypotheses about how early molecules may have formed

- The Russian chemist A.I. Oparin and British scientist J.B.S. Haldane independently hypothesized that the early atmosphere of planet Earth was a reducing (electron-adding) one, in which organic compounds could have formed from simple molecules
- The energy necessary could have come from lightning and intense UV radiation
- Haldane also hypothesized that the early ocean was a solution of organic molecules that may have also contributed to simple molecules

8) Urey & Miller's famous experiment

- This was an experiment designed to test the Oparin-Haldane hypothesis
- Urey & Miller obtained a variety of amino acids found in organisms today, along with other organic compounds
- But it's unclear whether the atmosphere of early Earth had sufficient CH_4 & NH_3 to be reducing
- Moreover there's growing evidence that the early atmosphere was neither reducing nor oxidizing, and was made up instead of primarily of N and CO_2



9) More recent hypotheses

- If a reducing atmosphere is necessary, it's possible that reducing pockets were present near volcanic openings would have provided the right conditions
- A current hypothesis is that deep ocean "black smoker" vents that produce H_2S & FeS , both important in ATP synthesis, may have provided suitable conditions



10) These hypotheses and incomplete results have generated the following additional speculations

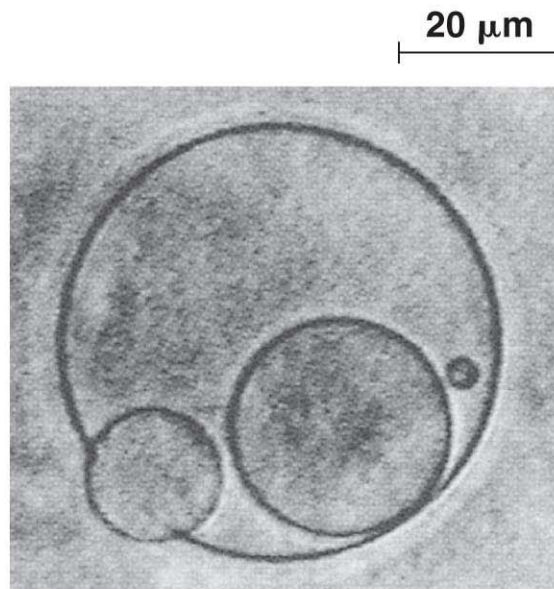
- Chemical and physical processes on early Earth may have produced very simple cells through a sequence of stages:
 1. Abiotic synthesis of small organic molecules
 2. Joining of these small molecules into macromolecules
 - Small organic molecules polymerize when they are concentrated on hot sand, clay, or rock
 3. Packaging of molecules into “protobionts”
 4. Origin of self-replicating molecules

11) Protobionts

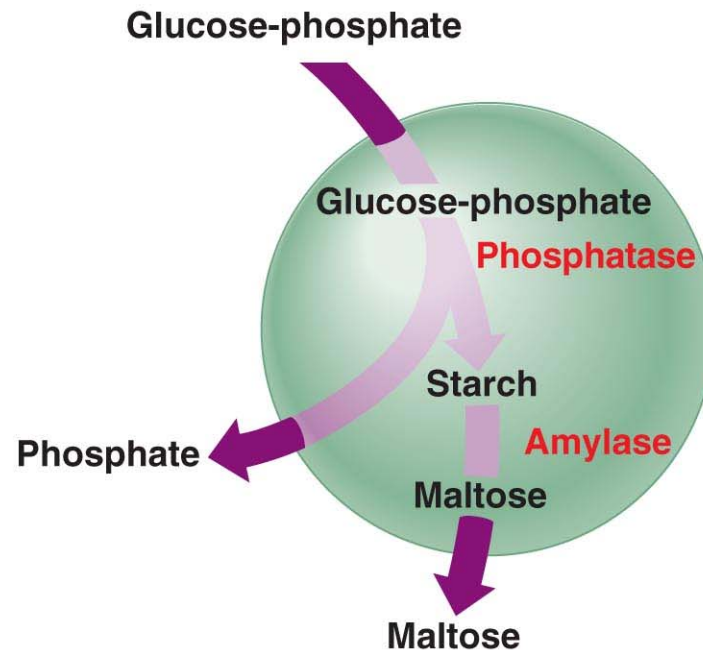
- Replication and metabolism are key properties of life
- **Protobionts** are aggregates of abiotically produced molecules surrounded by a membrane or membrane-like structure
- Protobionts exhibit simple reproduction and metabolism and maintain an internal chemical environment

12) Protobionts—cont.

- Experiments demonstrate that protobionts could have formed spontaneously from abiotically produced organic compounds
- For example, small membrane-bounded droplets called liposomes can form when lipids or other organic molecules are added to water



(a) Simple reproduction by liposomes



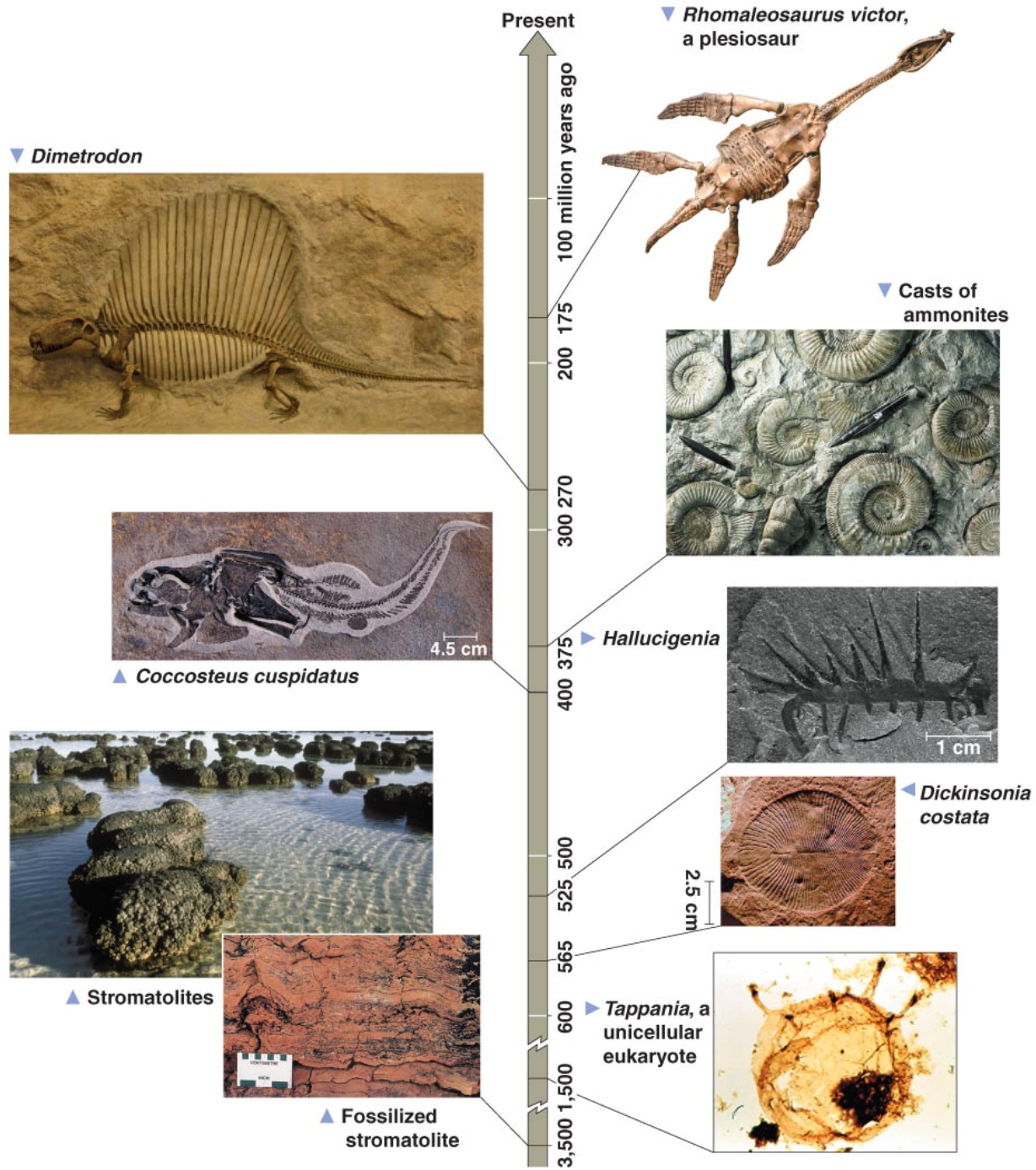
(b) Simple metabolism

13) 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 their own sequence or other short pieces of RNA
- Early protobionts with self-replicating, catalytic RNA would have been more effective at using resources and would have increased in number through natural selection
- The early genetic material might have formed an “RNA world”

14) Fossils and the Fossil Record

- The fossil record reveals changes in the history of life on earth
- Sedimentary rocks are deposited into layers called *strata* and are the richest source of fossils
- Insects preserved in amber (fossilized tree sap) and organisms frozen in ice are other sources of fossils



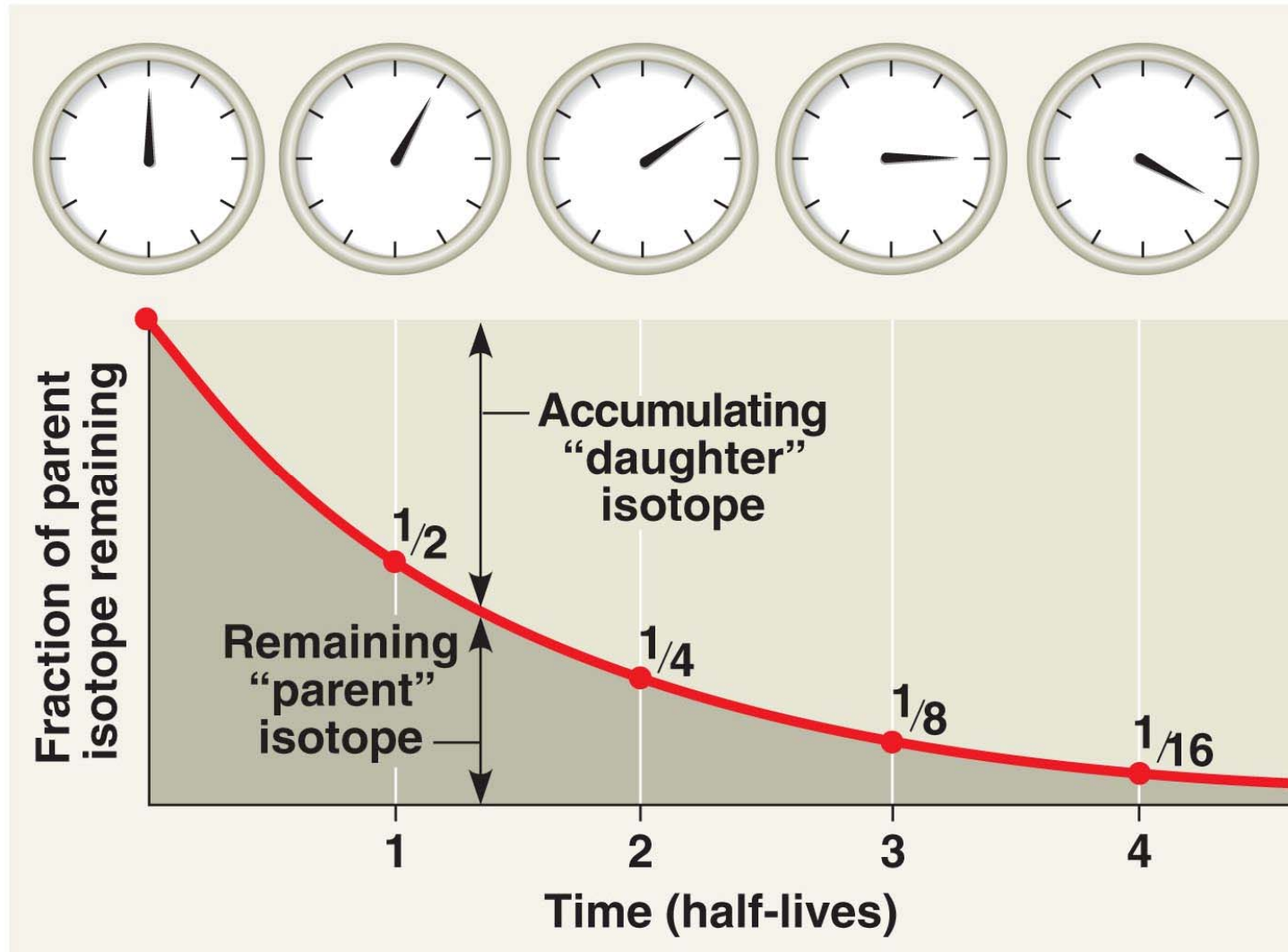
16) Bias in the fossil record

- Relatively 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

17) 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
- See Fig. 25.5 (next slide)

18) Radiometric dating is based on the rate of decay and the **half-life** of isotopes



19) Radiometric dating

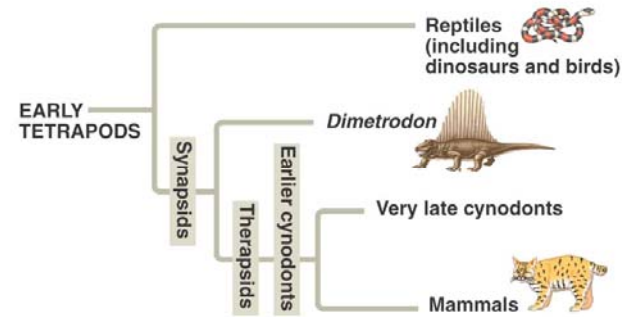
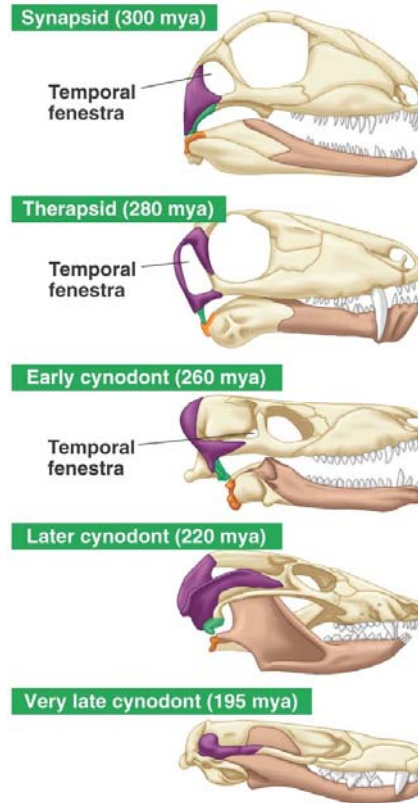
- Radiocarbon dating can be used to date fossils up to 75,000 years old
- For older fossils, some isotopes can be used to date sedimentary rock layers above and below the fossil
- There are now about 50 different isotope dating methods, which now, routinely, are used independently to confirm dates

20) Other methods of dating

- The magnetism of rocks can provide dating information
- Reversals of the magnetic poles leave their record on rocks throughout the world
- Ice core dating, based on tree-ring-like ice layers, have now been counted to ~800,000 yrs BP
- Tree ring data from Bristlecone Pines and adjacent fossilized trees have been reconstructed back to ~15,000 yrs BP
- Coral reef borings date back to the late Mesozoic (~70 million yrs BP)

21) Appearance in the fossil record of new groups of organisms—one case history example



















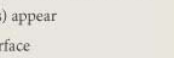
- Mammals belong to the group of animals called *tetrapods*
- The evolution of unique mammalian features through gradual modifications can be traced from ancestral synapsids through the present



22) The Geologic Record

















- Table 25.1 (right) shows the major events of life's history
- The so-called **geologic record** is divided into 3 *eons*—Archaean, Proterozoic, and Phanerozoic eons

Table 25.1 The Geologic Record

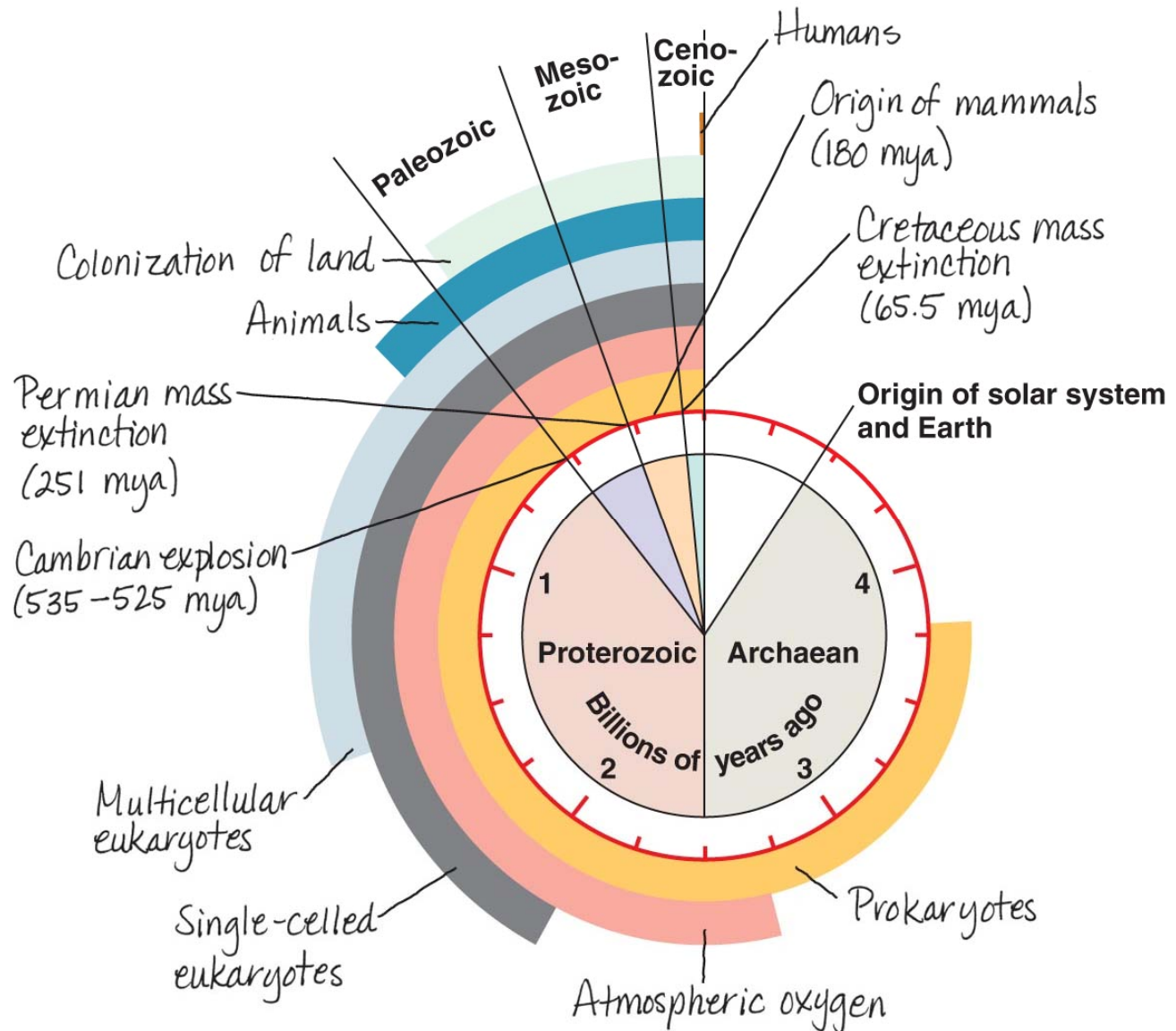
Relative Duration of Eons	Era	Period	Epoch	Age (Millions of Years Ago)	Some Important Events in the History of Life		
Phanerozoic	Cenozoic	Neogene	Holocene	0.01	Historical time		
			Pleistocene	1.8	Ice ages; humans appear		
			Pliocene	5.3	Origin of genus <i>Homo</i>		
			Miocene	23	Continued radiation of mammals and angiosperms; apelike ancestors of humans appear		
		Paleogene	Oligocene	23	Origins of many primate groups, including apes		
			Eocene	33.9	Angiosperm dominance increases; continued radiation of most present-day mammalian orders		
			Paleocene	55.8	Major radiation of mammals, birds, and pollinating insects		
			Mesozoic	Cretaceous	65.5	Flowering plants (angiosperms) appear and diversify; many groups of organisms, including most dinosaurs, become extinct at end of period	
				Jurassic	145.5	Gymnosperms continue as dominant plants; dinosaurs abundant and diverse	
				Triassic	199.6	Cone-bearing plants (gymnosperms) dominate landscape; dinosaurs evolve and radiate; origin of mammals	
Proterozoic	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	299	Extensive forests of vascular plants form; first seed plants appear; origin of reptiles; amphibians dominant			
		Devonian	359.2	Diversification of bony fishes; first tetrapods and insects appear			
		Silurian	416	Diversification of early vascular plants			
		Ordovician	443.7	Marine algae abundant; colonization of land by diverse fungi, plants, and animals			
		Cambrian	488.3	Sudden increase in diversity of many animal phyla (Cambrian explosion)			
		Archaean	Ediacaran	542	Diverse algae and soft-bodied invertebrate animals appear		
				635	Oldest fossils of eukaryotic cells appear		
				2,100	Oldest fossils of eukaryotic cells appear		
				2,500	Concentration of atmospheric oxygen begins to increase		
			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			

23) Some details of the Phanerozoic

- The Phanerozoic encompasses multicellular eukaryotic life
- The Phanerozoic is divided into three *eras*: the **Paleozoic**, **Mesozoic**, and **Cenozoic**
- Major boundaries between geological divisions correspond to extinction events in the fossil record

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24) A time perspective for the Phanerozoic



25) Back to the first single-celled fossils (in the Proterozoic)

- The oldest known fossils are **stromatolites**, rock-like structures composed of many layers of bacteria and sediment
- Stromatolites date back 3.5 billion years ago
- Prokaryotes were Earth's sole inhabitants from 3.5 to about 2.1 billion years ago



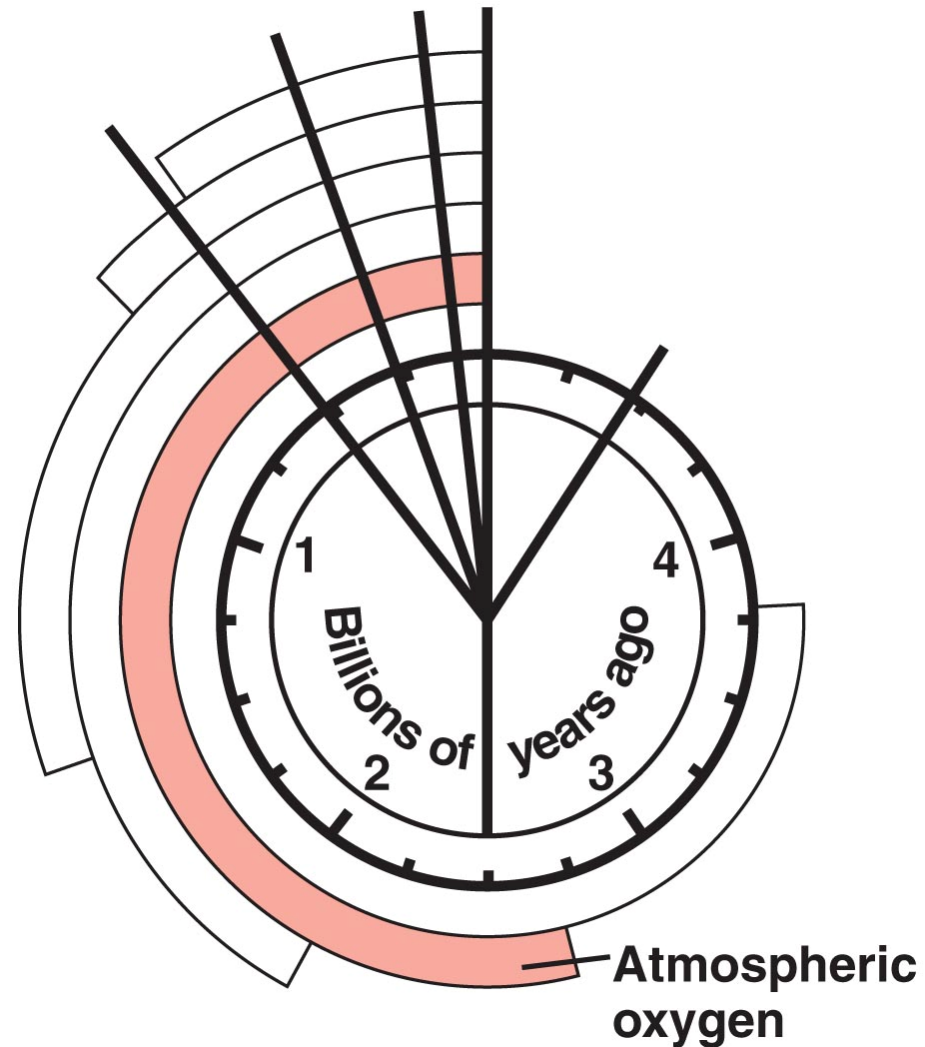
Stromatolites

26) Photosynthesis & 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
- The source of O_2 was likely bacteria similar to modern cyanobacteria

27) Photosynthesis & the O₂ Revolution—cont.

- By about 2.7 billion years ago, O₂ began accumulating in the atmosphere and rusting iron-rich terrestrial rocks
- This “oxygen revolution” took place from 2.7 to 2.2 billion years ago
 - Posed a challenge for life
 - Provided opportunity to gain energy from light
 - Allowed organisms to exploit new ecosystems

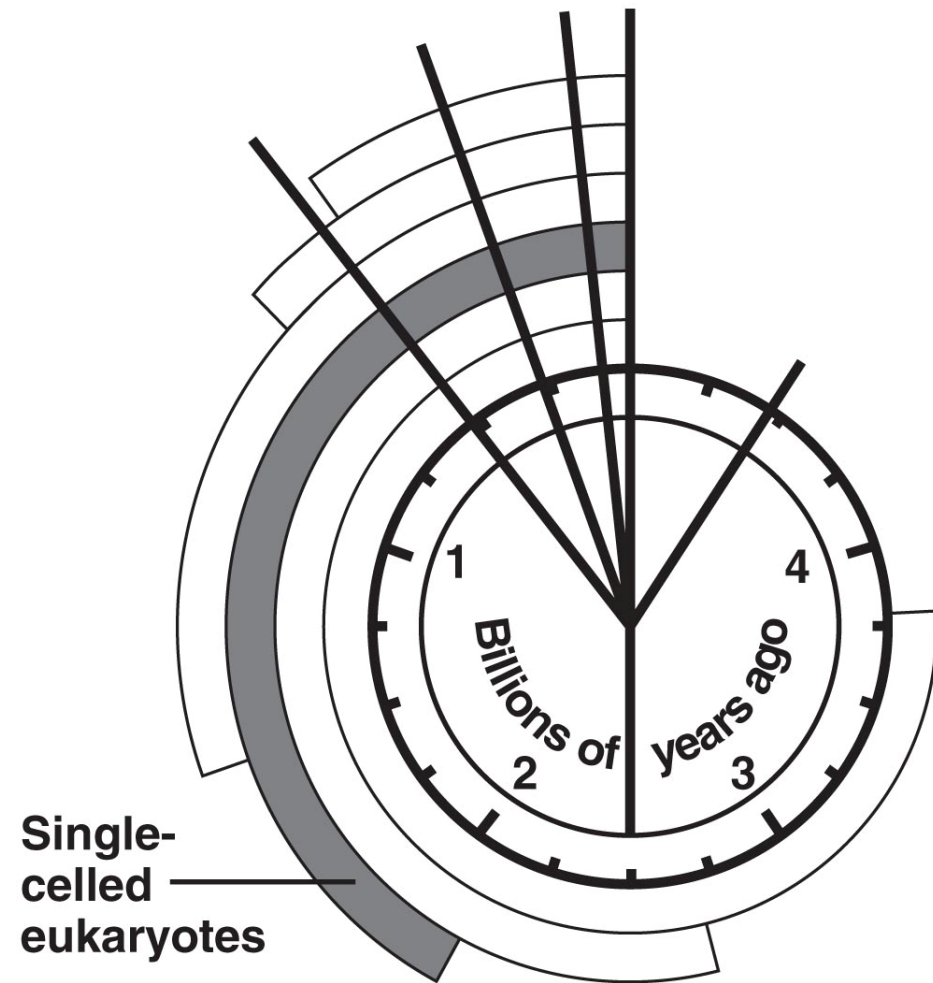




**28) Banded iron formations:
evidence of oxygen photosynthesis**

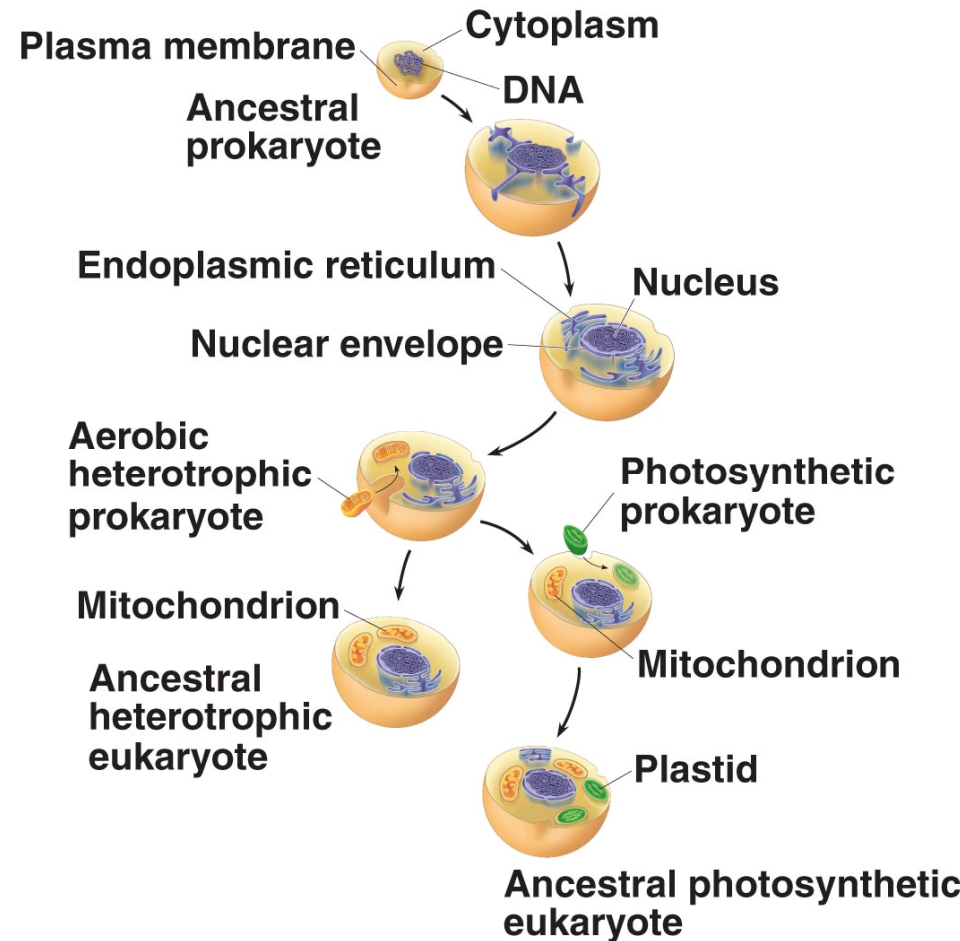
29) The First Eukaryotes

- The oldest fossils of eukaryotic cells date back 2.1 billion years
- The hypothesis of **endosymbiosis** 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



30) The First Eukaryotes—cont.

- 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



31) The evidence supporting an endosymbiotic origin of mitochondria & plastids:

- Similarities in inner membrane structures and functions
- 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