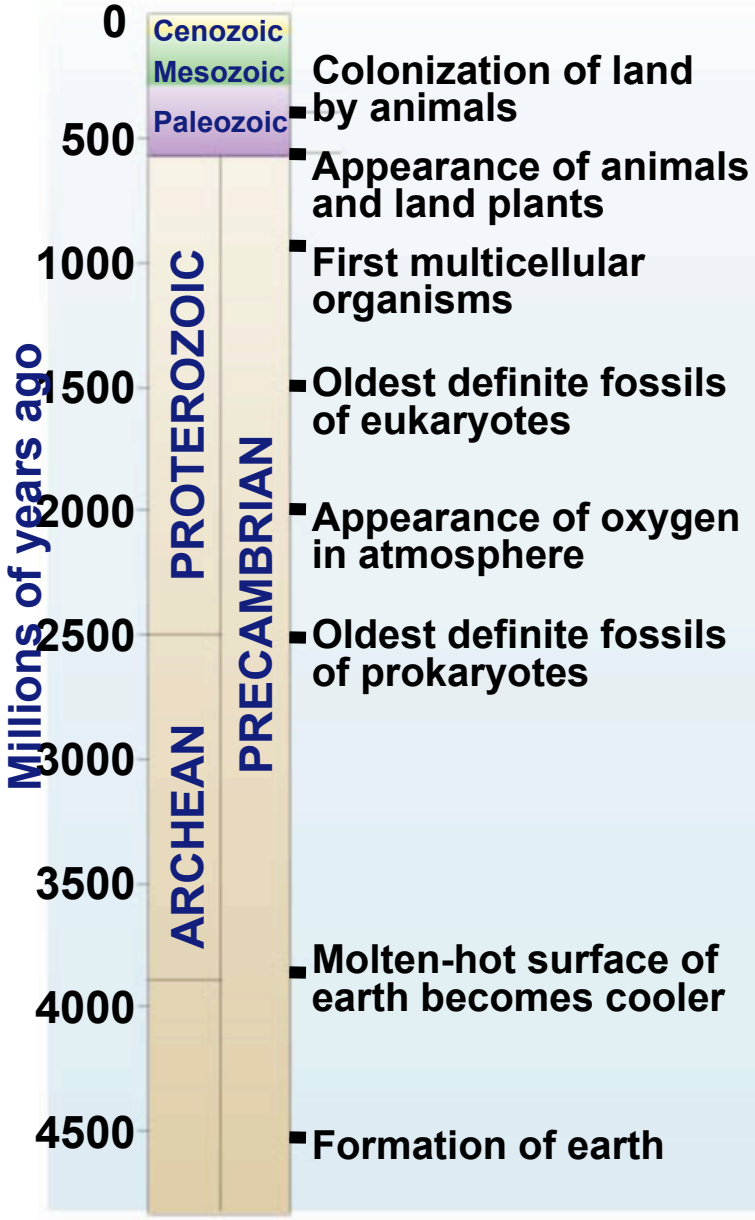
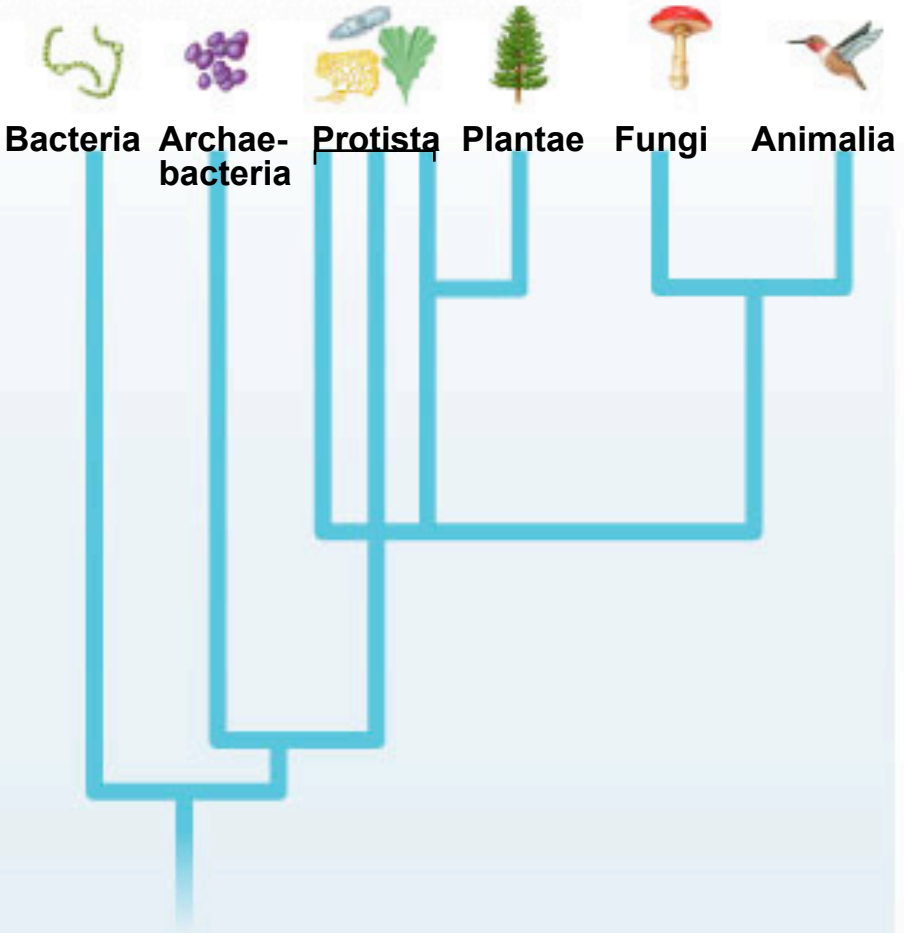
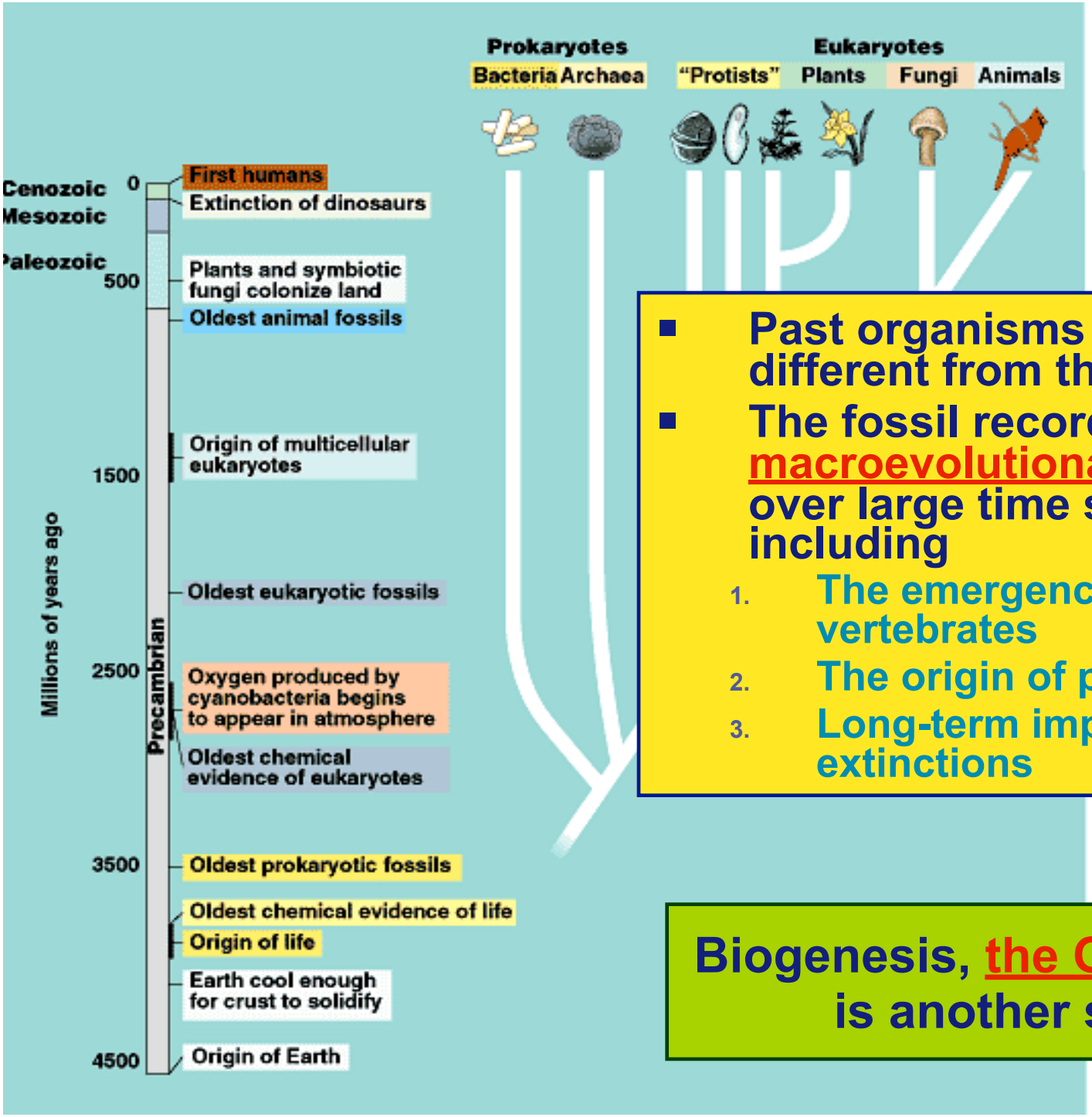
Origin of Life

"…sparked by just the right combination of physical events & chemical processes…"





The evolutionary tree of life can be documented with evidence.

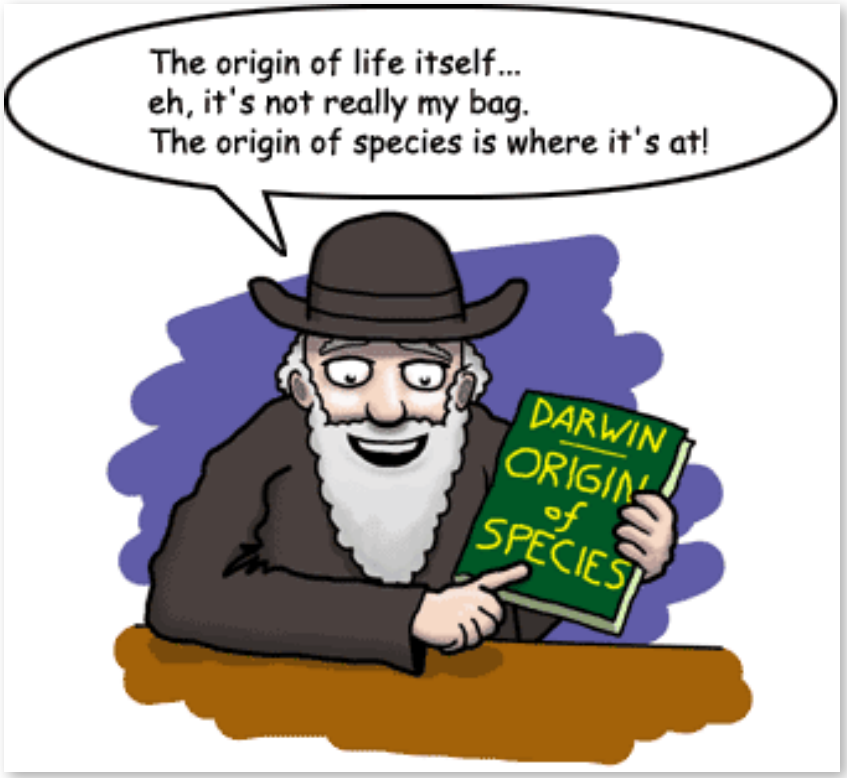


- Past organisms were very different from those now alive
- The fossil record shows macroevolutionary changes over large time scales including
  1. The emergence of terrestrial vertebrates
  2. The origin of photosynthesis
  3. Long-term impacts of mass extinctions

Biogenesis, the Origin of Life, is another story…

What is Life?

- First we have to define LIFE…
  - organized as cells
  - respond to stimuli
  - regulate internal processes
    - Maintain homeostasis
  - use energy to grow
    - metabolism
  - develop
    - change & mature within lifetime
  - reproduce
    - heredity
      - DNA / RNA
    - adaptation & evolution



The Origin of Life is Hypothesis

- **Special Creation**
  - ***Was life created by a supernatural or divine force?***
  - **not testable**
- **Extraterrestrial Origin**
  - ***Was the original source of organic (carbon) materials comets & meteorites striking early Earth?***
  - **Testable** ***(amino acids have been found in meteorites)***
- **Spontaneous Abiotic Origin**
  - ***Did life evolve spontaneously from inorganic molecules?***
  - **testable**

Origin of Life hypothesis

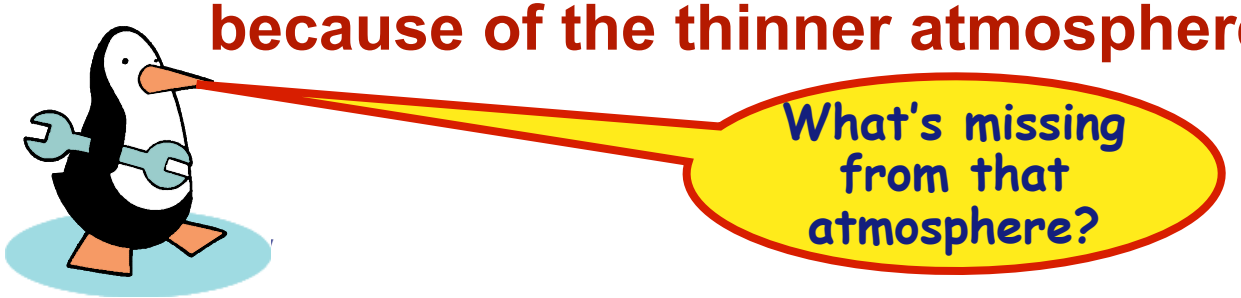
- **Chemical and physical processes on early Earth may have produced very simple cells through a sequence of 4 stages:**
  1. **Abiotic synthesis of organic molecules**
     - amino acids & nucleotides
  2. **Building polymers**
     - joining molecules into polymers *(small organic molecules do polymerize when they are concentratedon hot sand, clay, or rock)*
     - proteins & nucleic acids
  3. **Packaging of molecules into protobionts *(precells)***
     - packaging polymers into membrane-bound droplets
     - maintain internal chemistry distinct from surroundings
  4. **Origin of self-replicating molecules**
     - makes inheritance possible

Conditions on early Earth -

The primordial atmosphere

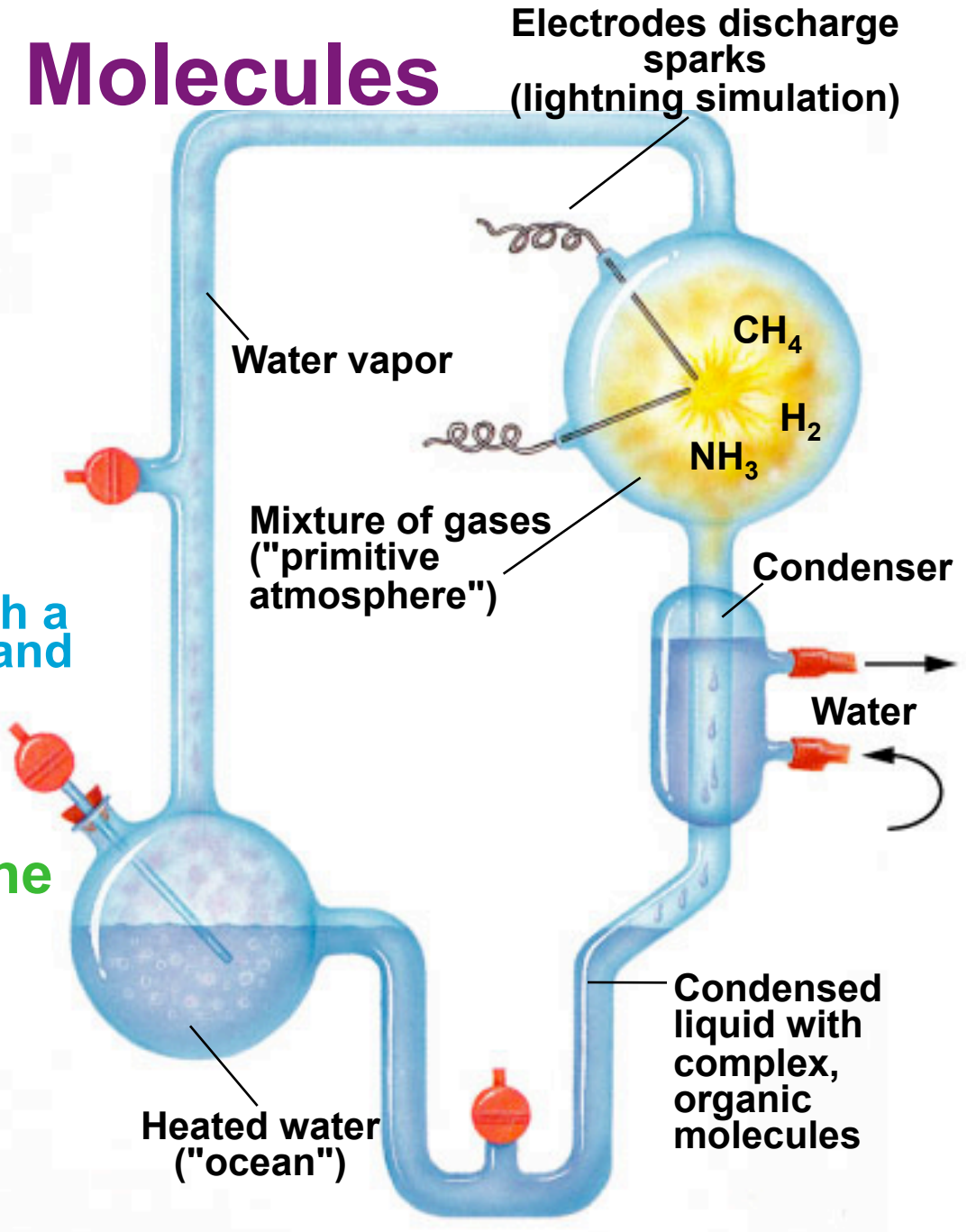
- Earth formed about 4.6 billion years ago, along with the rest of the solar system
- Earth's early atmosphere likely contained water vapor and chemicals released by volcanic eruptions
  - <u>May have been a Reducing Atmosphere</u> *(oxidation is prevented due to little oxygen)*
    - water vapor (H_2O), CO_2, N_2, NO_x, H_2, NH_3, CH_4, H_2S
    - Lots of available H & its electron
    - <u>NO</u> free oxygen (O2)!!!!!!!!!!
- Energy source
  - lightning, lots of UV radiation because of the thinner atmosphere

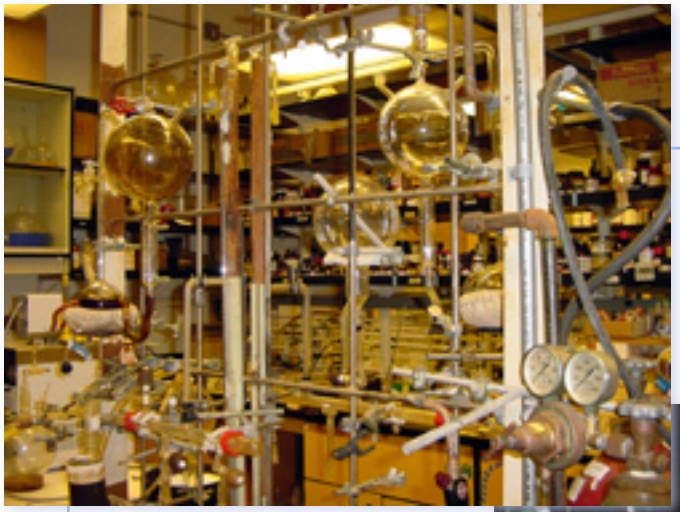
low O_2 = organic molecules do not breakdown as quickly



Origin of Organic Molecules

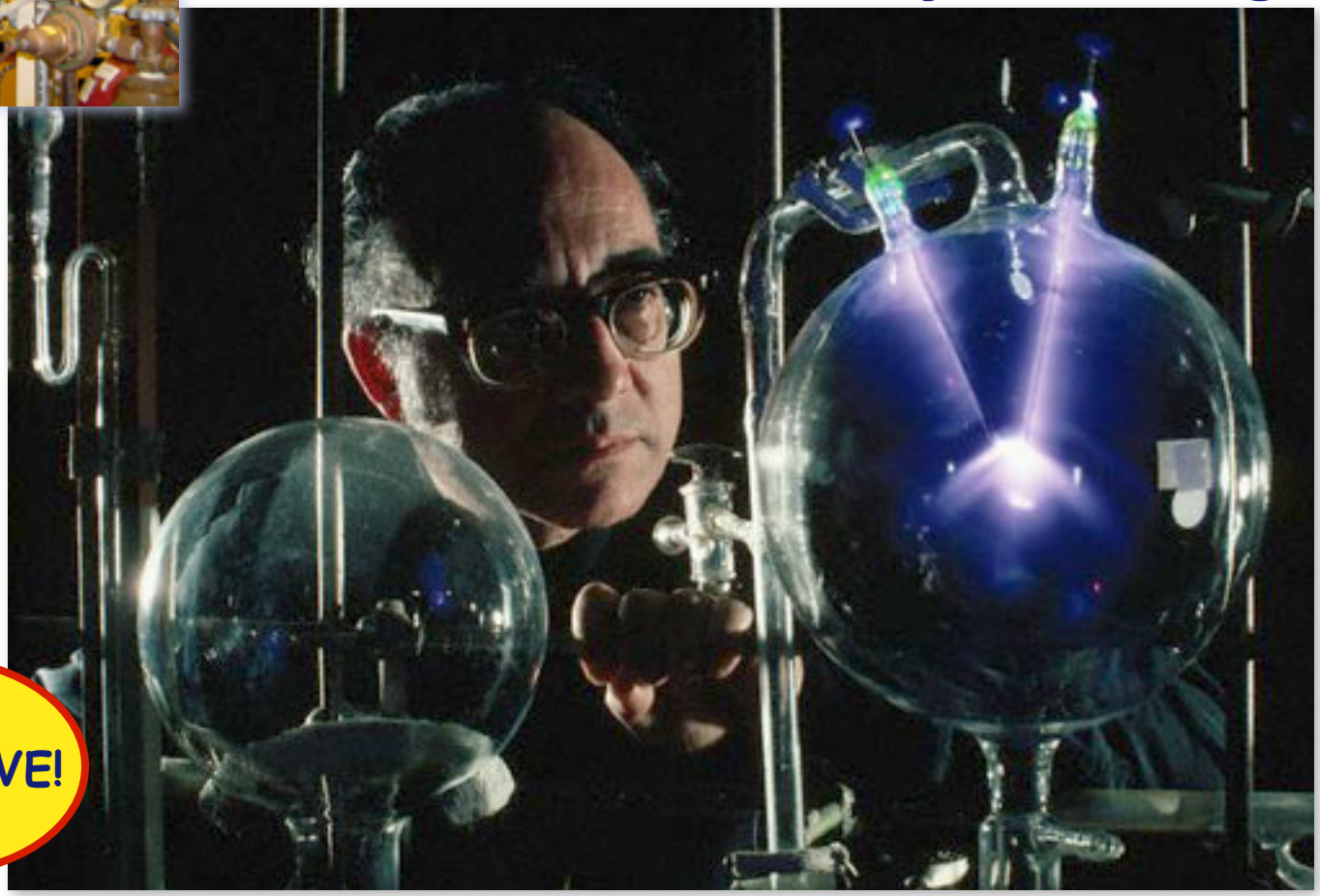
- **Abiotic synthesis**
  - **1920**
    Oparin & Haldane
    propose reducing (electron-adding) atmosphere hypothesis
    - **Atmosphere filled with a lot of methane (CH_4) and ammonia (NH_3)**
  - **1953**
    Miller & Urey
    tested Oparin-Haldane hypothesis
    - **formed organic compounds from abiotic compounds**
      - **amino acids**
      - **adenine**





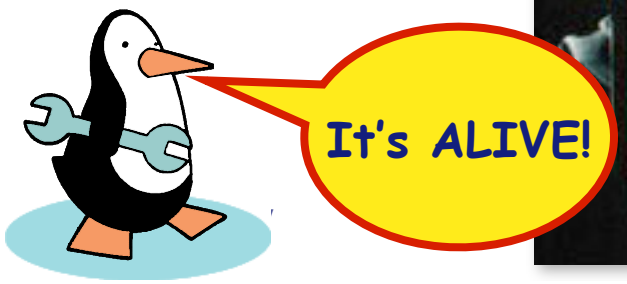
Stanley Miller

University of Chicago



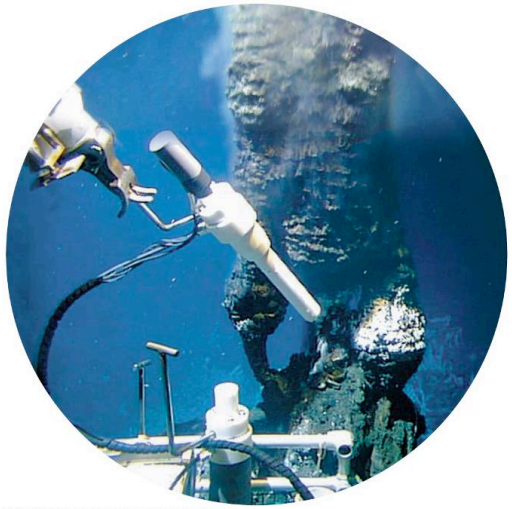
produced

- amino acids
- hydrocarbons
- nitrogen bases
- other organics



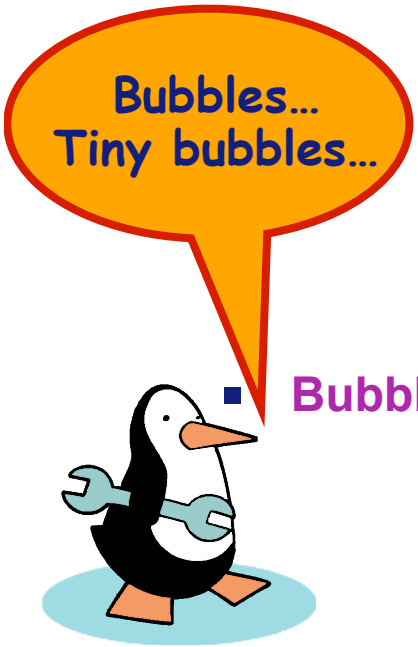
Abiotic synthesis of macromolecules

- The evidence is not yet convincing that the early atmosphere contained enough ammonia and methane to be completely reducing.
  - The first organic compounds may have been synthesized near submerged volcanoes and deep-sea vents instead
- Growing evidence suggests that the early atmosphere was made up primarily of nitrogen and carbon dioxide and was neither reducing nor oxidizing (electron–removing).
  - Miller–Urey–type experiments using such atmospheres have not produced organic molecules.
    - Still, it is likely that small "pockets" of the atmosphere where hot water and into oceans—perhaps near volcanic openings—were reducing.

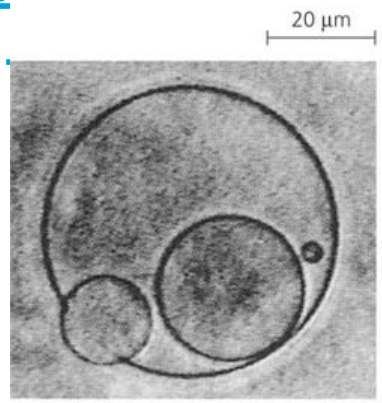


Origin of Cells (Protobionts)

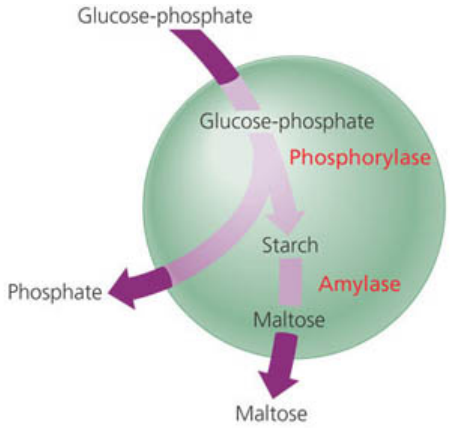
- **Life is defined partly by two properties:**
  - **1. accurate replication and 2. metabolism.**
    - **Neither property can exist without the other.**
  - **Conditions for life may have been met by protobionts, *aggregates of abiotically produced molecules surrounded by a membrane or membrane–like structure.***
    - **Protobionts exhibit some of the properties associated with life, including simple reproduction and metabolism, as well as the maintenance of an internal chemical environment different from that of their surroundings.**



- **Bubbles → separate inside from outside → metabolism & reproduction**



(a) Simple reproduction. This liposome is "giving birth" to smaller liposomes (LM).

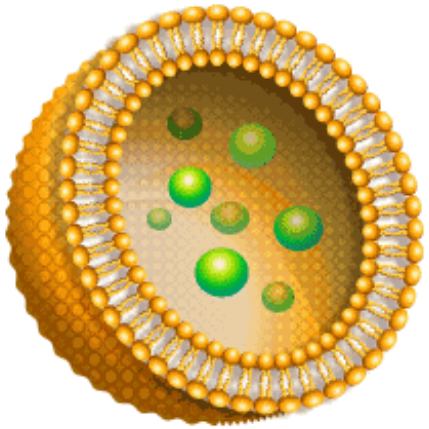


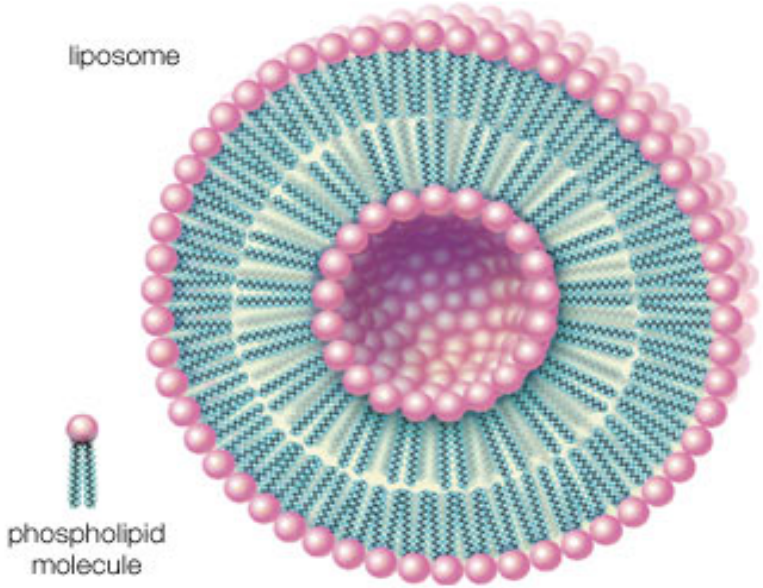
(b) Simple metabolism. If enzymes—in this case, phosphorylase and amylase—are included in the solution from which the droplets self-assemble, some liposomes can carry out simple metabolic reactions and export the products.

Origin of Cells (Protobionts)

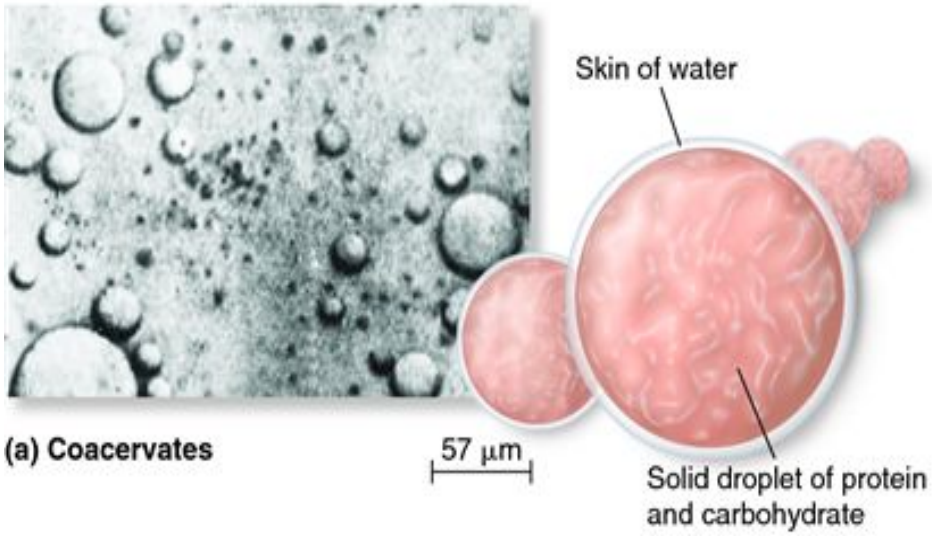
- **Lab experiments show protobionts can form spontaneously**
  - **Ex: membrane bound droplets called liposomes can form when lipids are added to water**
    - **Liposomes can reproduce.**
    - **They can undergo osmotic swelling and shrinking**
    - **Some can perform simple metabolic reactions.**

- **Bubbles → separate inside from outside → metabolism & reproduction**

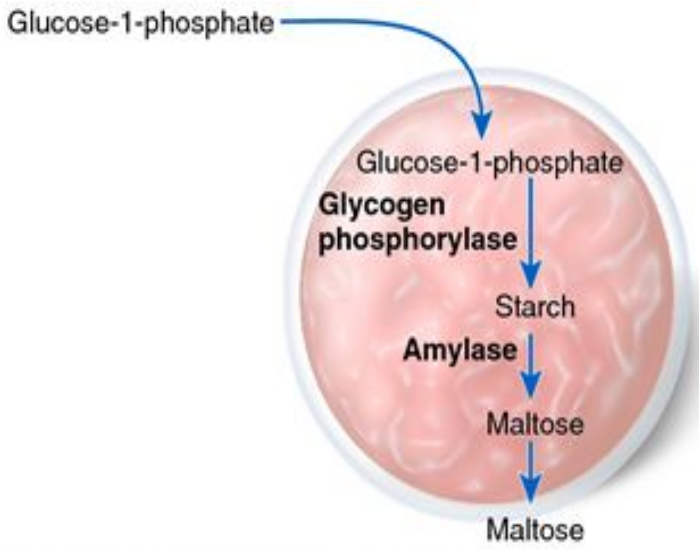

Liposome



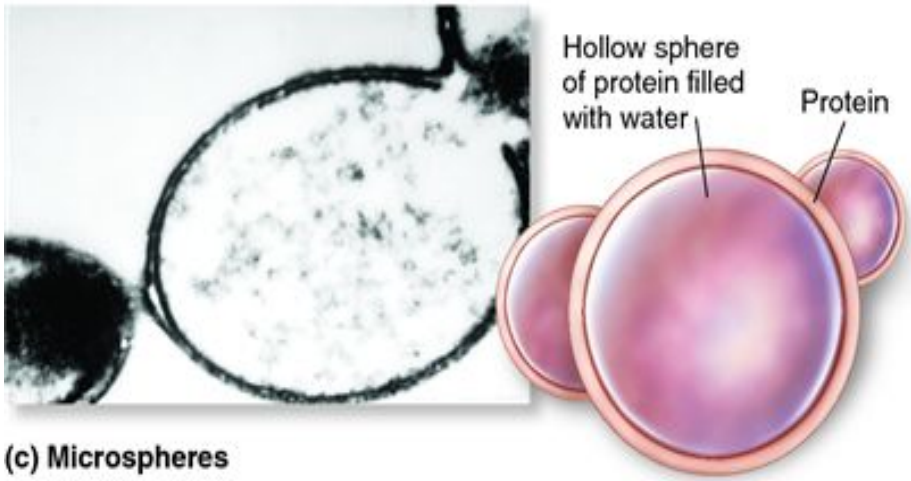
Origin of Cells (Protobionts)



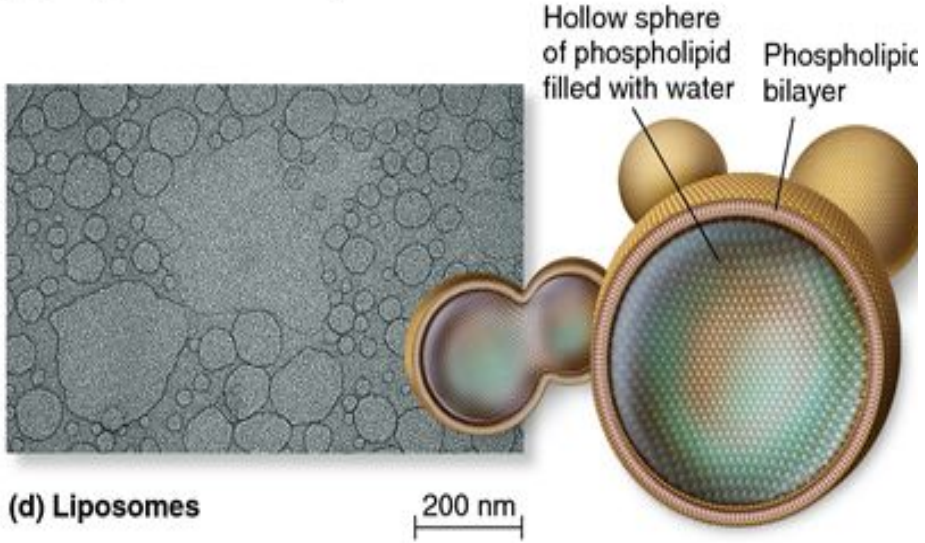
(a) Coacervates



(b) Simple metabolism by a coacervate



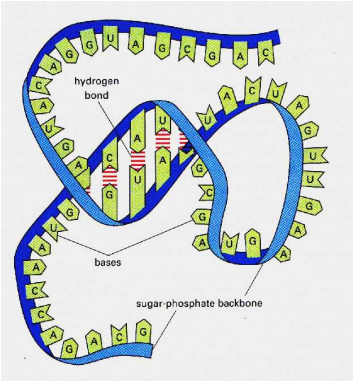
(c) Microspheres

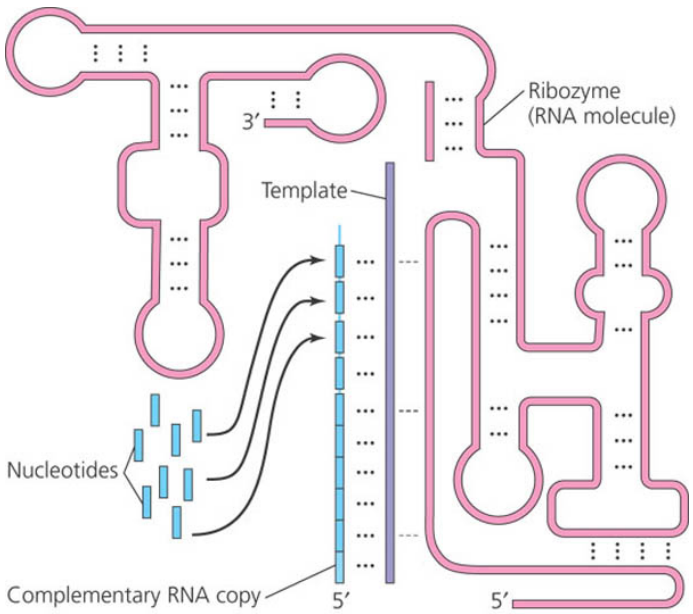


(d) Liposomes

Origin of Genetics - At the start it was an "RNA WORLD"

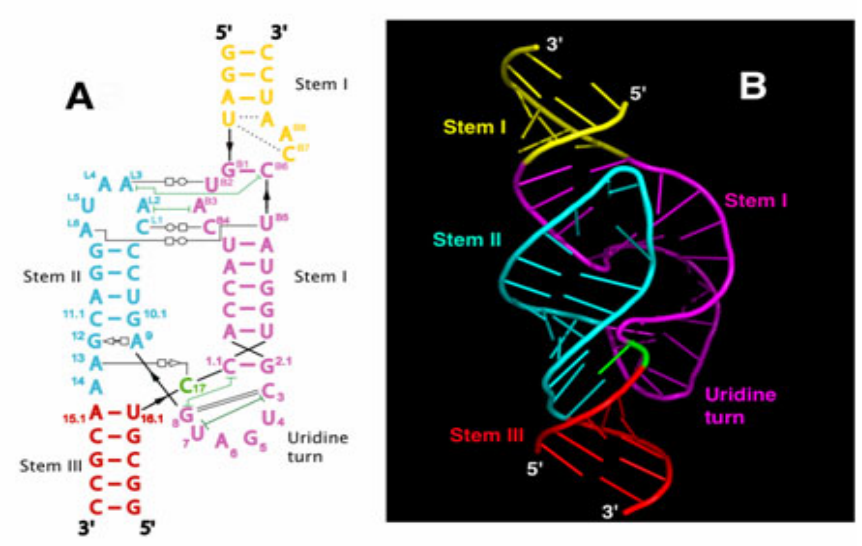
- **RNA is likely the first genetic material** (not DNA)
  - It is multi-functional
  - It codes information
    - self-replicating molecule
    - makes inheritance possible
      - natural selection would favor protobionts more effective at using resources
  - It is a regulatory molecule
  - It is a transport molecule
    - tRNA & mRNA





Origin of Genetics - At the start it was an "RNA WORLD"

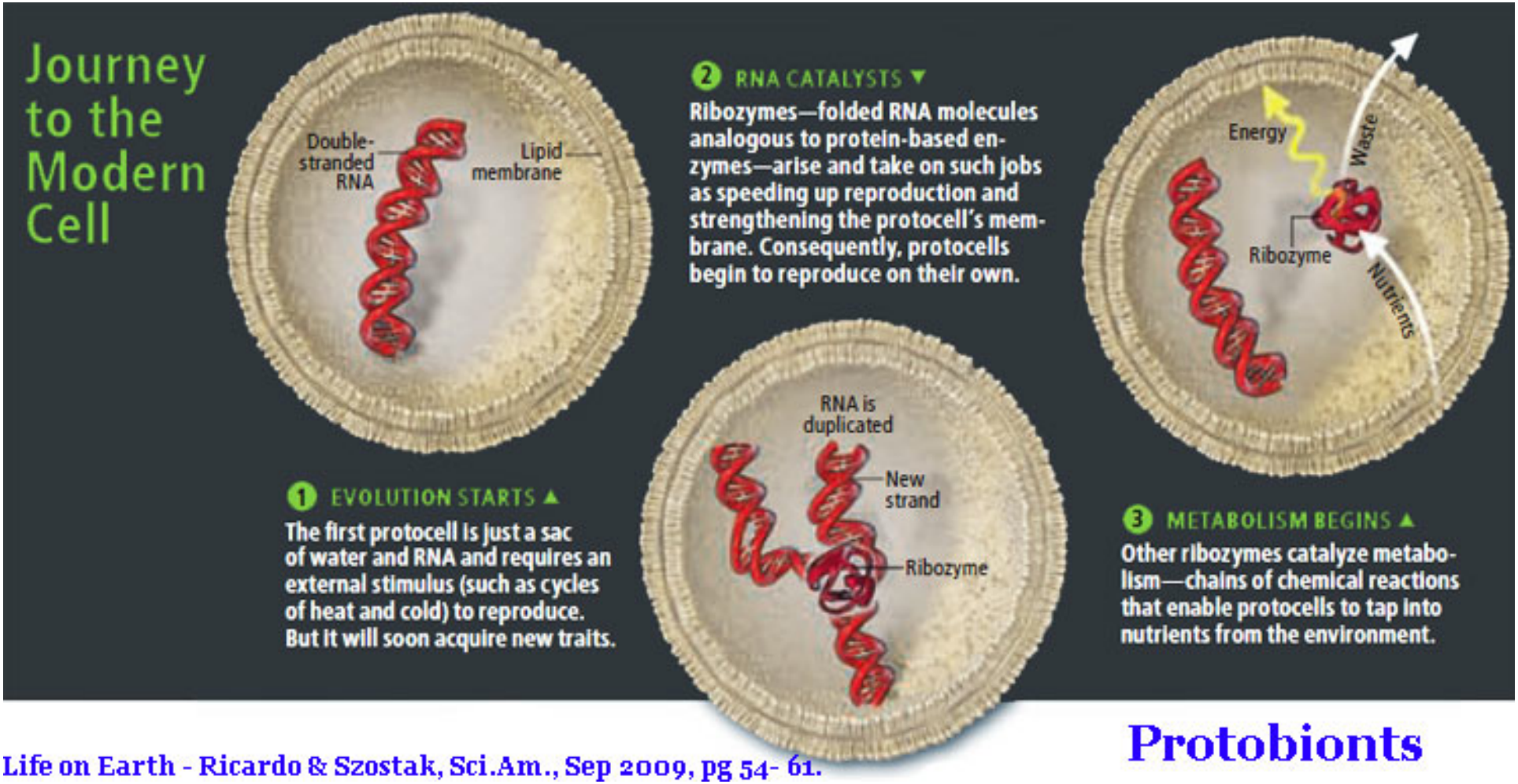
- ***RNA can have enzyme-like functions
  - call these ribozymes (not enzymes which are proteins)
    - For example, it is the rRNA that catalyzes the construction of polypeptides in ribosomes not the ribosomal proteinl
    - It's the snRNA in snRNPs of Spliceasomes that catalyze the hydrolysis of intron to exon borders and the dehydration synthesis reactions to splice exons together during RNA processing in Eukaryotes.
  - RNA can be autocatalytic - *ribozymes can make complementary copies of short stretches of their own sequence or other short pieces of RNA*
    - RNA may have been involved in ribozyme-catalyzed replication of RNA genetic material when there were still no DNA or protein enzymes



"RNA WORLD"

Dawn of natural selection

- A protobiont with self-replicating, catalytic RNA would differ from its neighbors that did not carry RNA or noncatalytic RNA
  - The protobiont that could grow split, and pass its RNA to daughters would grow in numbers.

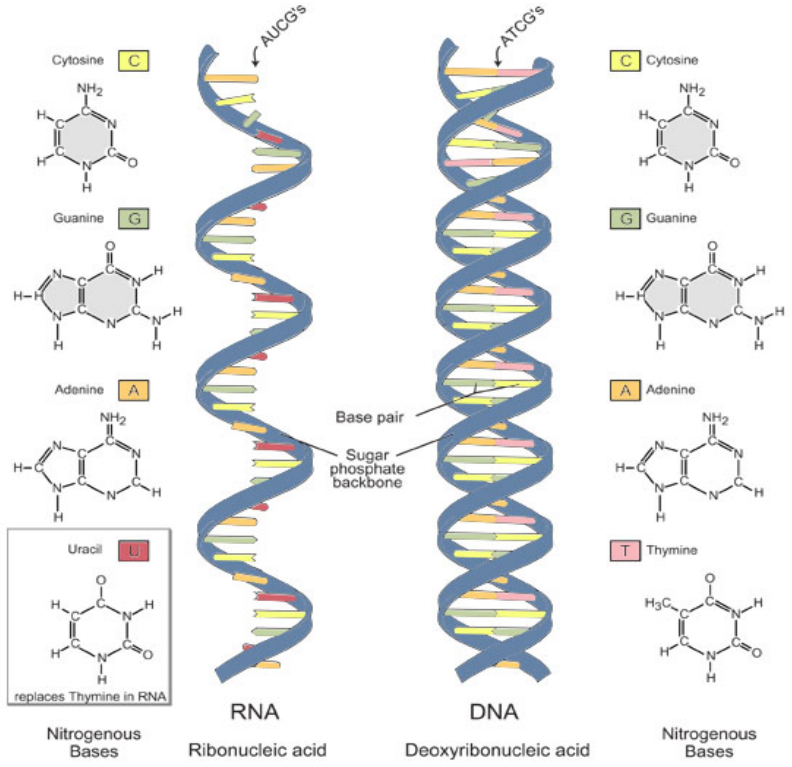


Life on Earth - Ricardo & Szostak, Sci.Am., Sep 2009, pg 54- 61.

Protobionts

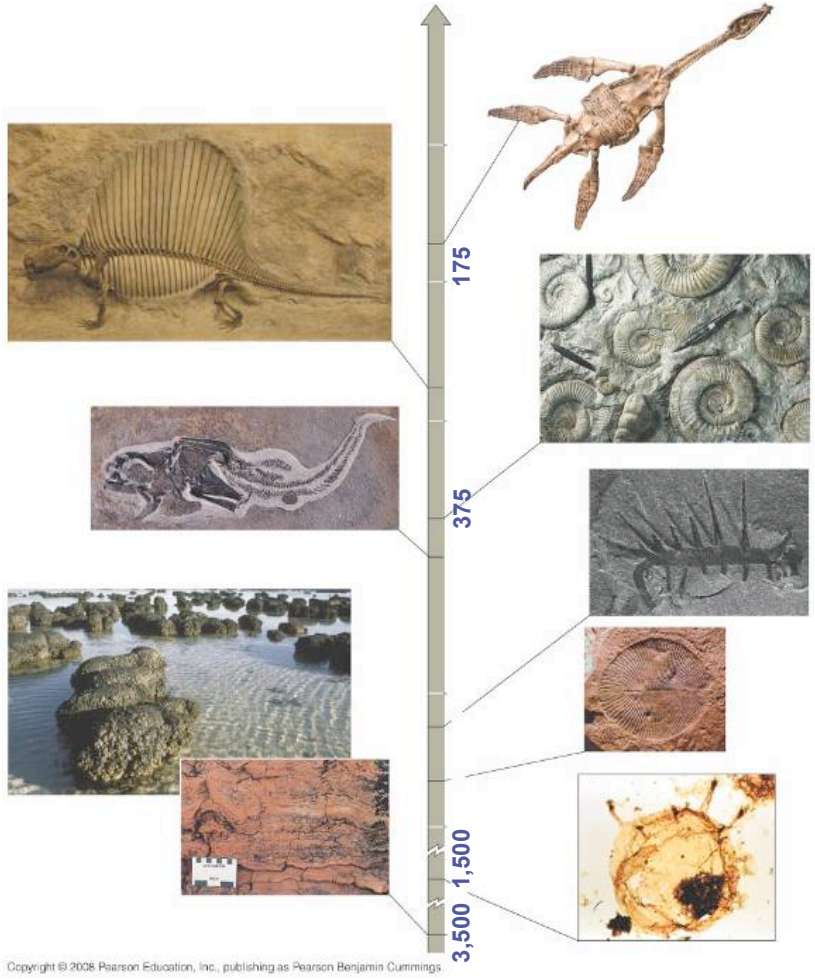
The dawn of the modern "DNA WORLD"

- RNA could have been then the template on which DNA nucleotides were assembled.
  - Double-stranded DNA is more stable and better for storing and accurately replicating genetic information
- Genomes grew through gene duplications errors etc..
  - RNA molecules took on intermediate roles in this new DNA world.



The fossil record documents the history of life

- **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**
- **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 wide-spread**
  - **Had hard parts**



***Tappania*, a unicellular eukaryote**

Fig. 25-5

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
    - 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

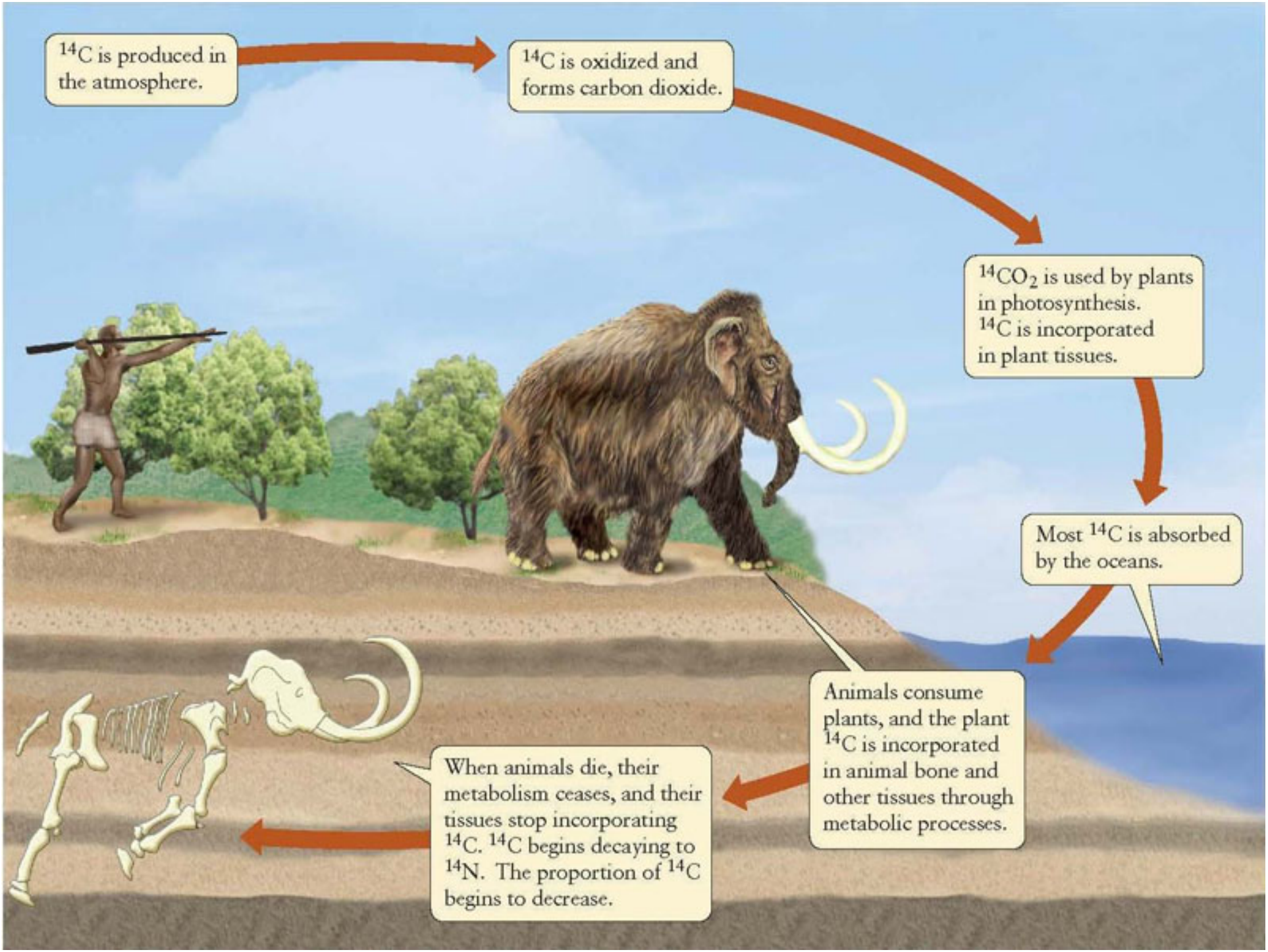
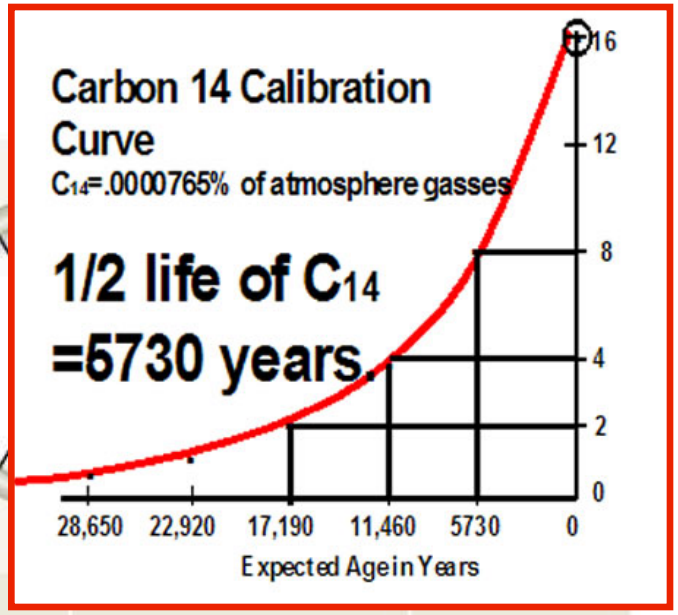
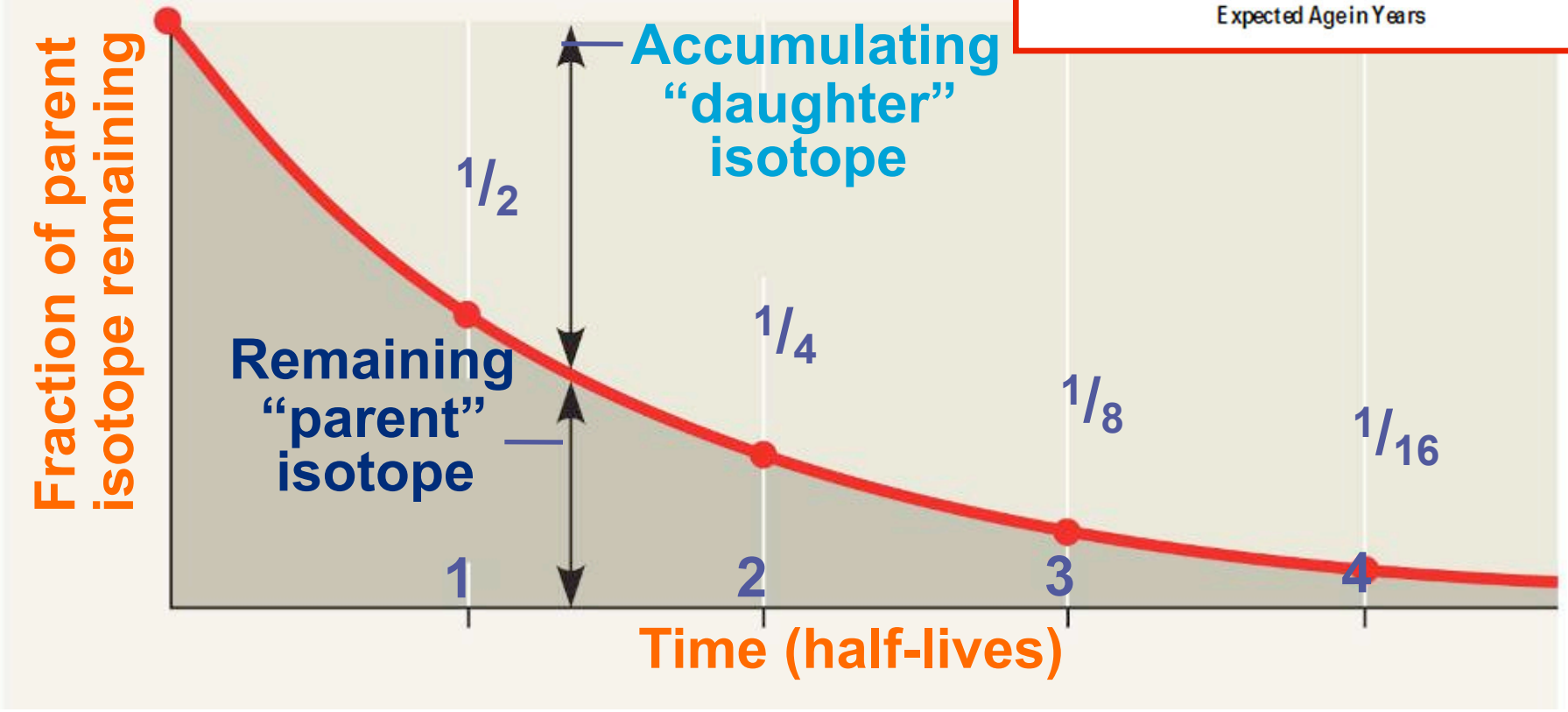

^{14}C is produced in the atmosphere.
^{14}C is oxidized and forms carbon dioxide.
$^{14}CO_2$ is used by plants in photosynthesis. ^{14}C is incorporated in plant tissues.
Most ^{14}C is absorbed by the oceans.
Animals consume plants, and the plant ^{14}C is incorporated in animal bone and other tissues through metabolic processes.
When animals die, their metabolism ceases, and their tissues stop incorporating ^{14}C. ^{14}C begins decaying to ^{14}N. The proportion of ^{14}C begins to decrease.

Fig. 25-5

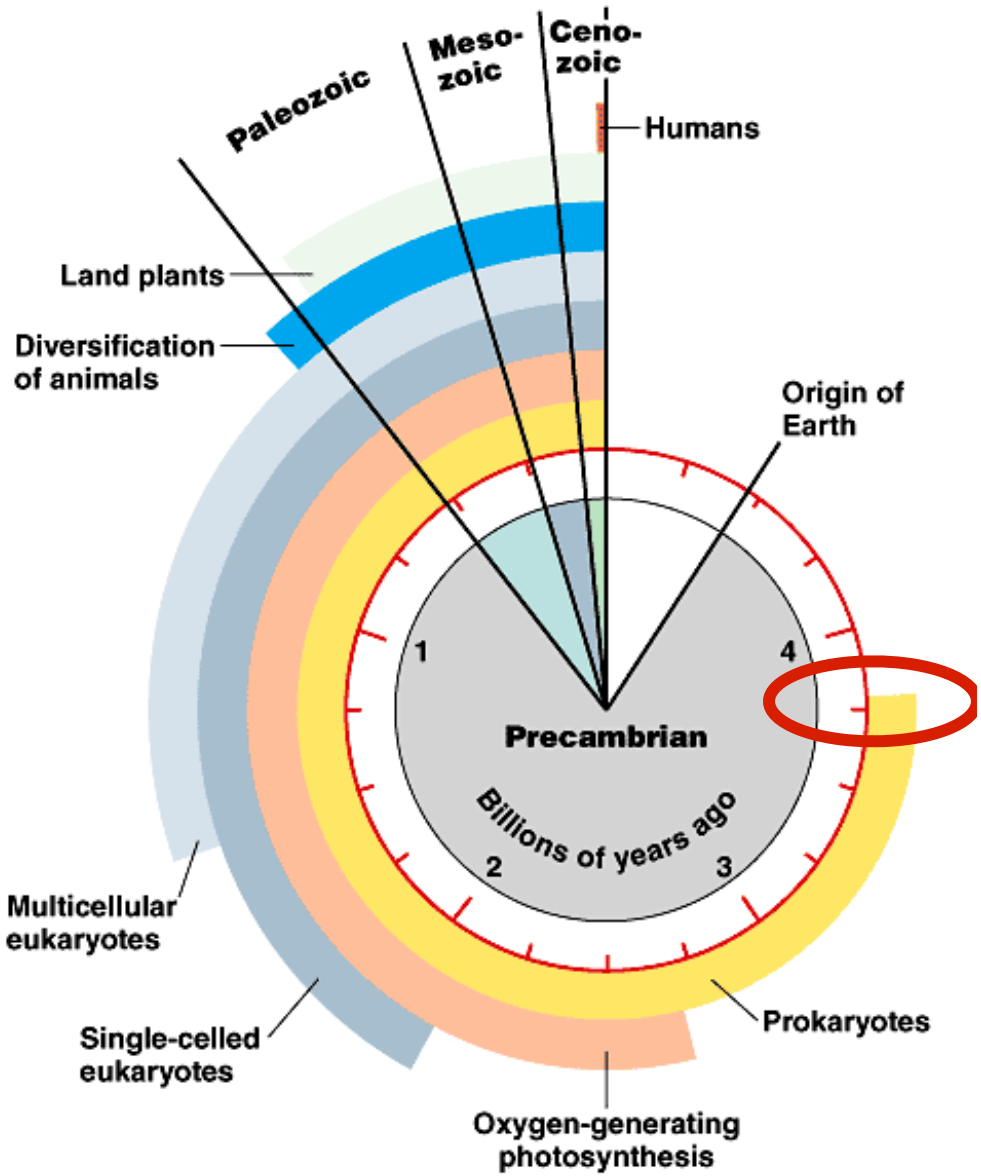
How Rocks and Fossils





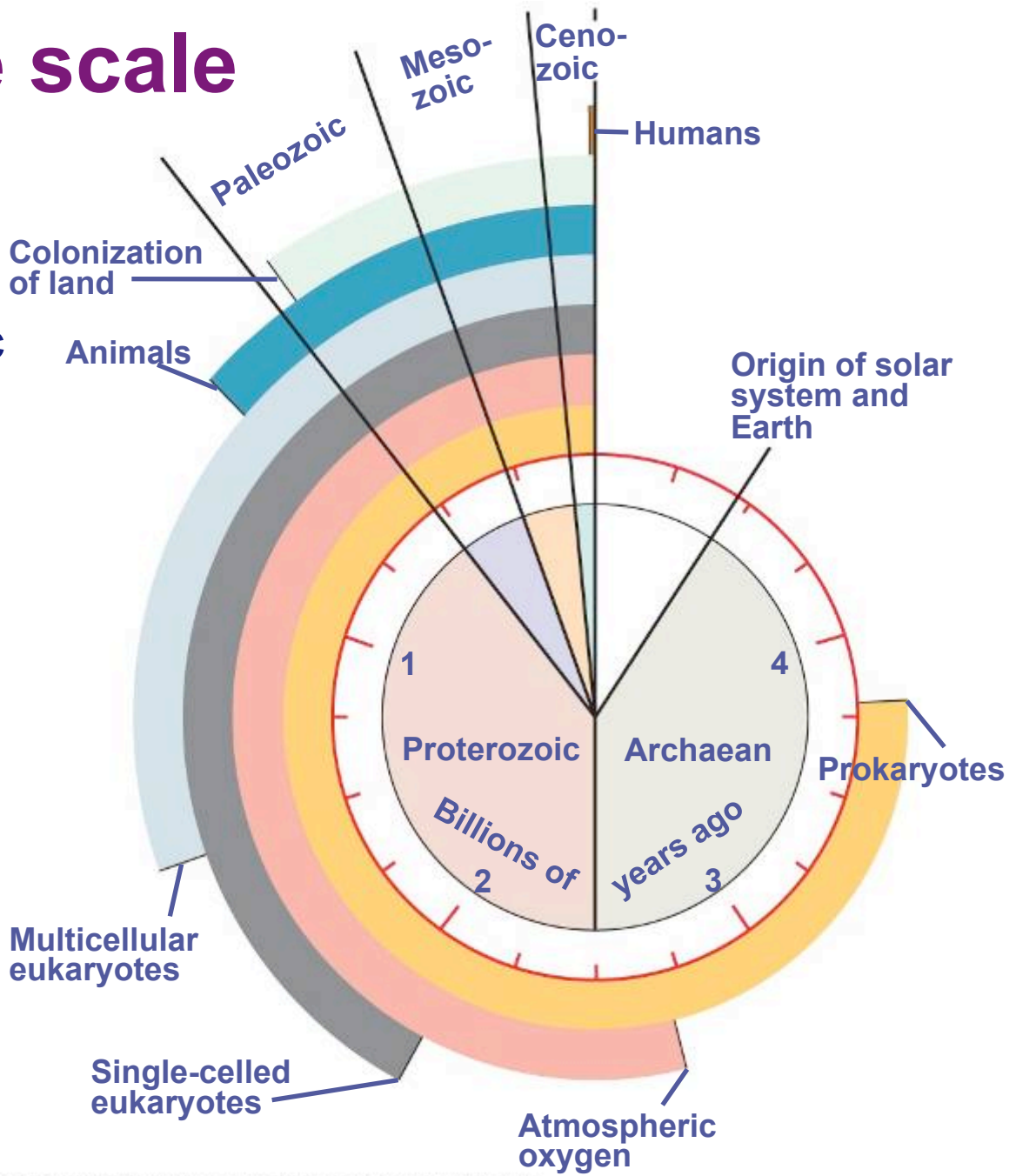
Key Events in the Origin of Life

- Life is divided into three eons the first two of which lasted 4 billion years!
  - Evidence suggests life originated 3.5–4.0 bya
    - The first prokaryotes transformed life on Earth



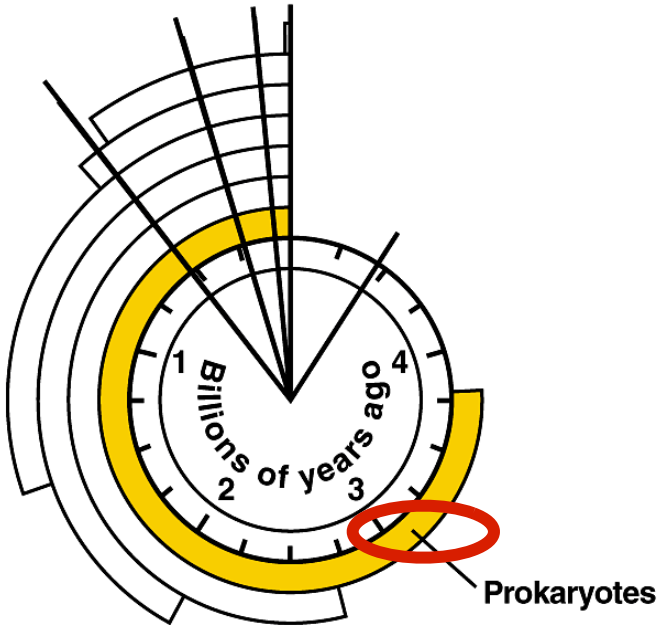
Geological time scale

- The Phanerozoic eon 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

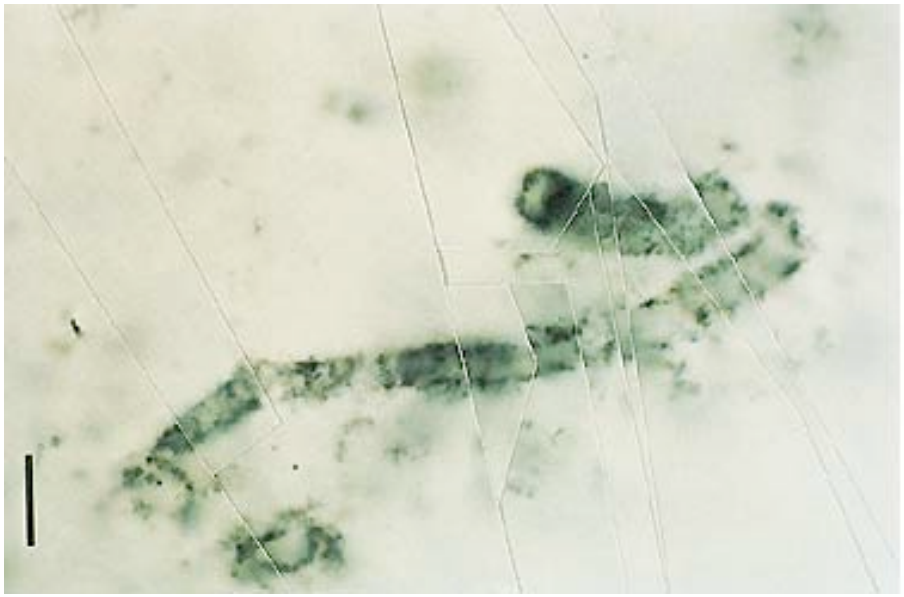


Prokaryotes

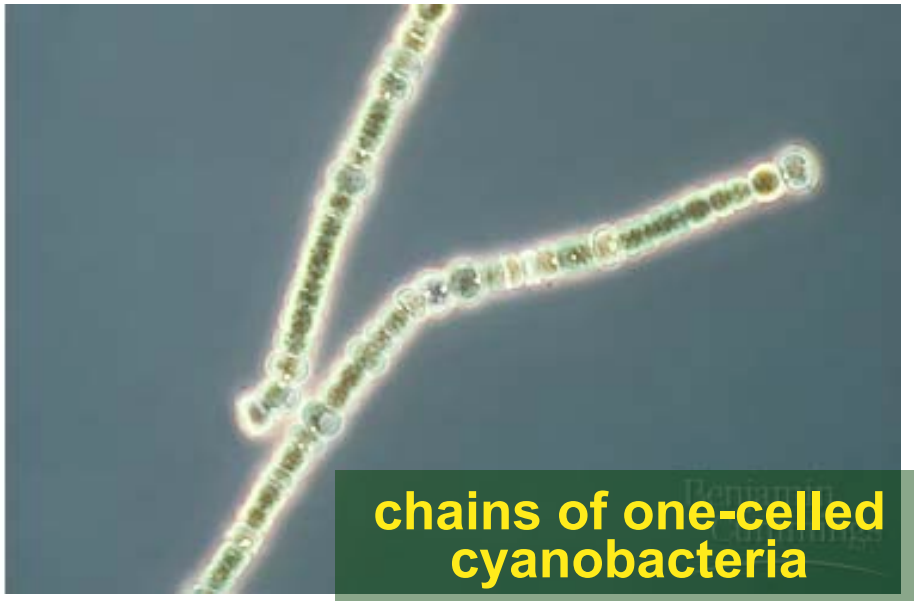
- Prokaryotes dominated life on Earth from 3.5–2.0 bya



3.5 billion year old fossil of bacteria



modern bacteria



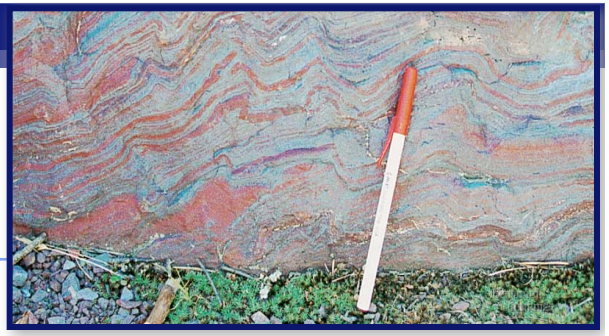
Stromatolites = the oldest fossils

Fossilized rock-like mats of prokaryotes resemble modern microbial colonies

- Stromatolites date back 3.5 billion years ago

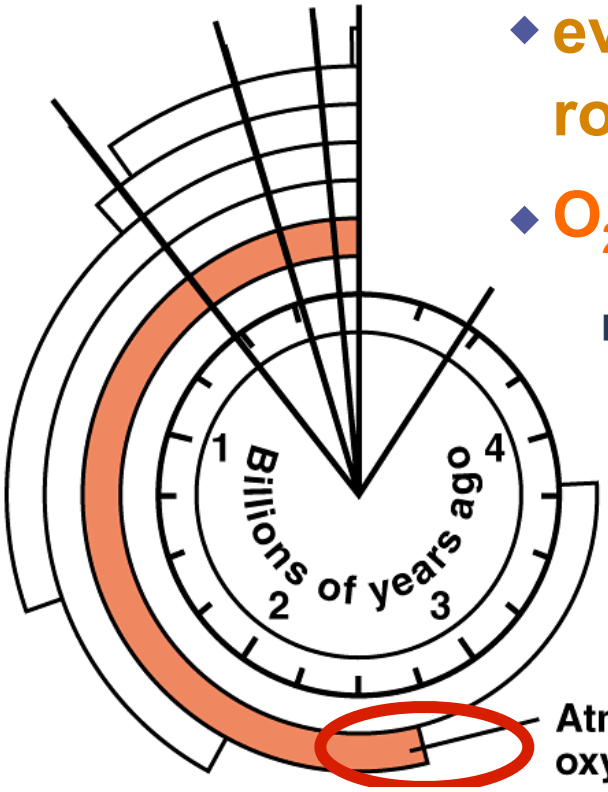
Prokaryotes were Earth's sole inhabitants from 3.5 to about 2.1 billion years ago

The rise of an "oxygen-rich" atmosphere



- Oxygen begins to accumulate 2.7 bya

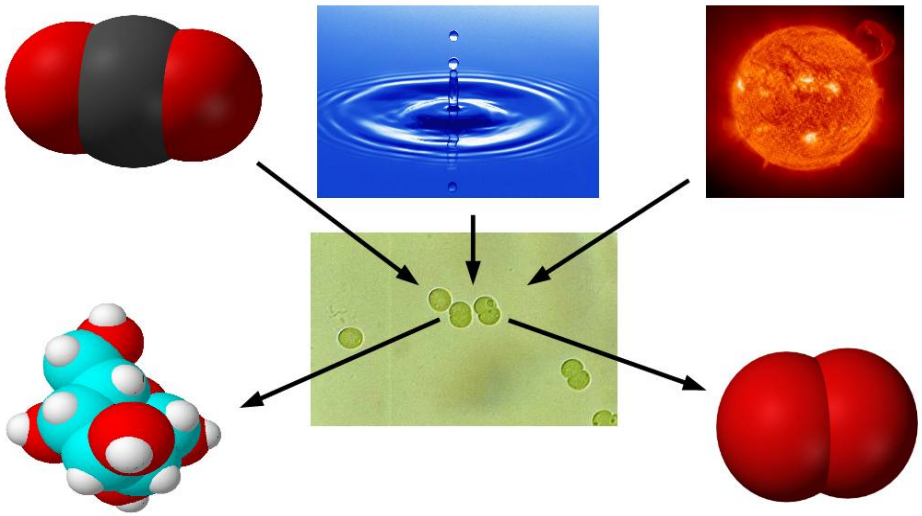
  - Atmosphere changes from reducing to <u>oxidizing</u>
    - evidence is in the banded iron oxide in rocks = rusting *(O_2 reacting with Fe)*
    - O_2 makes aerobic respiration possible!!!!!
      - photosynthetic bacteria (blue-green algae also known as cyanobacteria) were the gradual <u>source</u> of new atmospheric O_2



The Oxygen Revolution

- **Though levels started rising gradually, after a few billion years the levels of oxygen SHOT UP to more than 10% of what it is today.**
  - **This "oxygen revolution" ~ 2.1 billion years.**
  - **CAUSE? EVOLUTION OF EUKARYOTIC CELLS WITH CHLOROPLASTS**
    - **Posed challenge for life**
      - **Oxygen attacks chemical bonds and doomed many prokaryotes alive then**
    - **Provided opportunity to gain energy from light**
    - **Allowed organisms to exploit new ecosystems**

Photosynthesising prokaryotic autotrophs

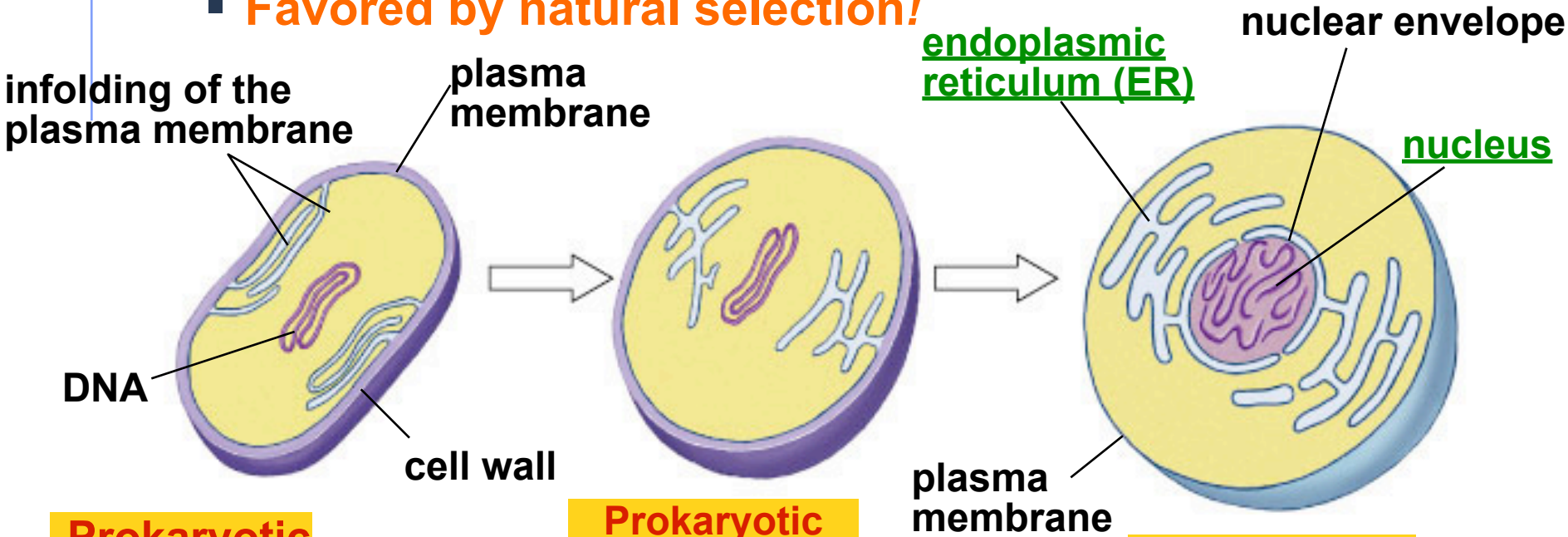


$CO_2 + H_2O + light \rightarrow (CH_2O) + O_2$

First Eukaryotes

~2 bya

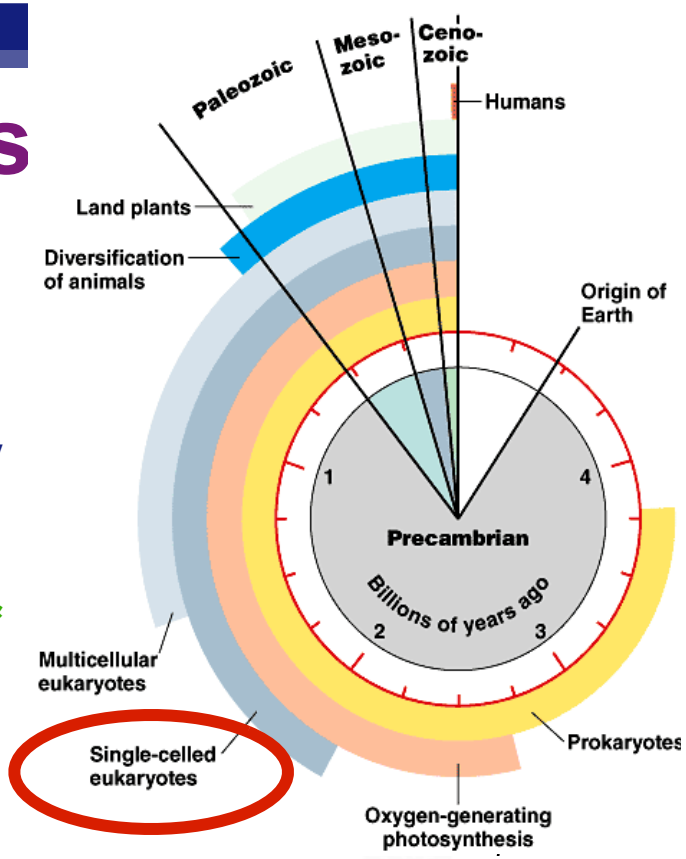
- **Development of internal membranes**
  - create internal micro-environments
  - **advantage**: specialization of activity = increase efficiency of chemistry since reactants are concentrated in one location
    - Favored by natural selection!

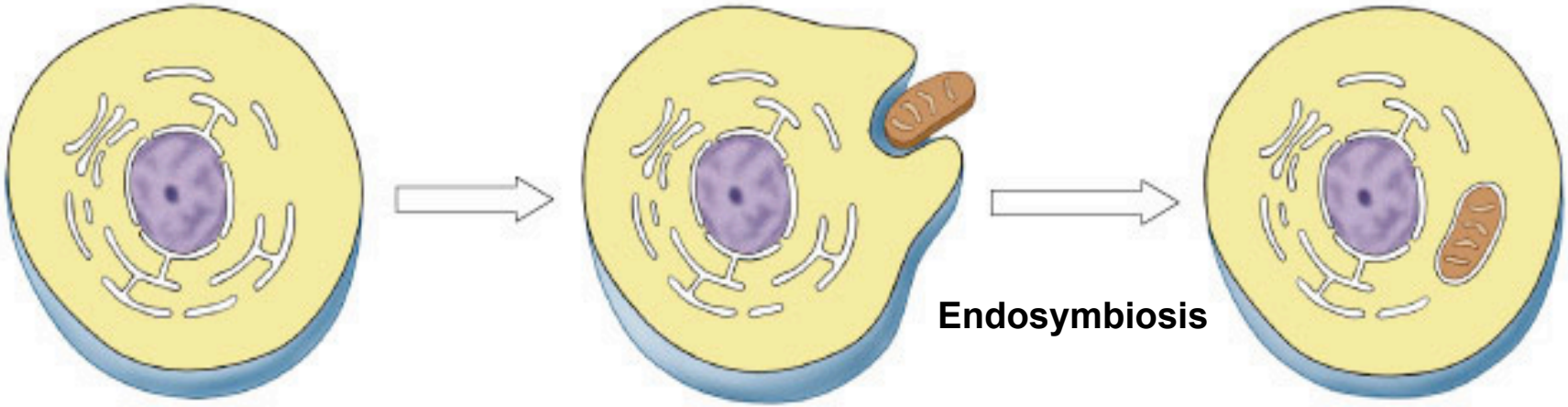


First endomembrane system

Endosymbiosis Hypothesis

- **Evolution of eukaryotes**
  - origin of **mitochondria**
    - engulfed aerobic bacteria, undigested prey or internal parasites that were not digested
    - mutually beneficial relationship evolved - *host (does glycolysis) provides pyruvate & high energy electrons, engulfed cell (does aerobic respiration steps like Krebs/ETC/ ATP Synthase), providing extra ATP*
      - Favored by natural selection*!*





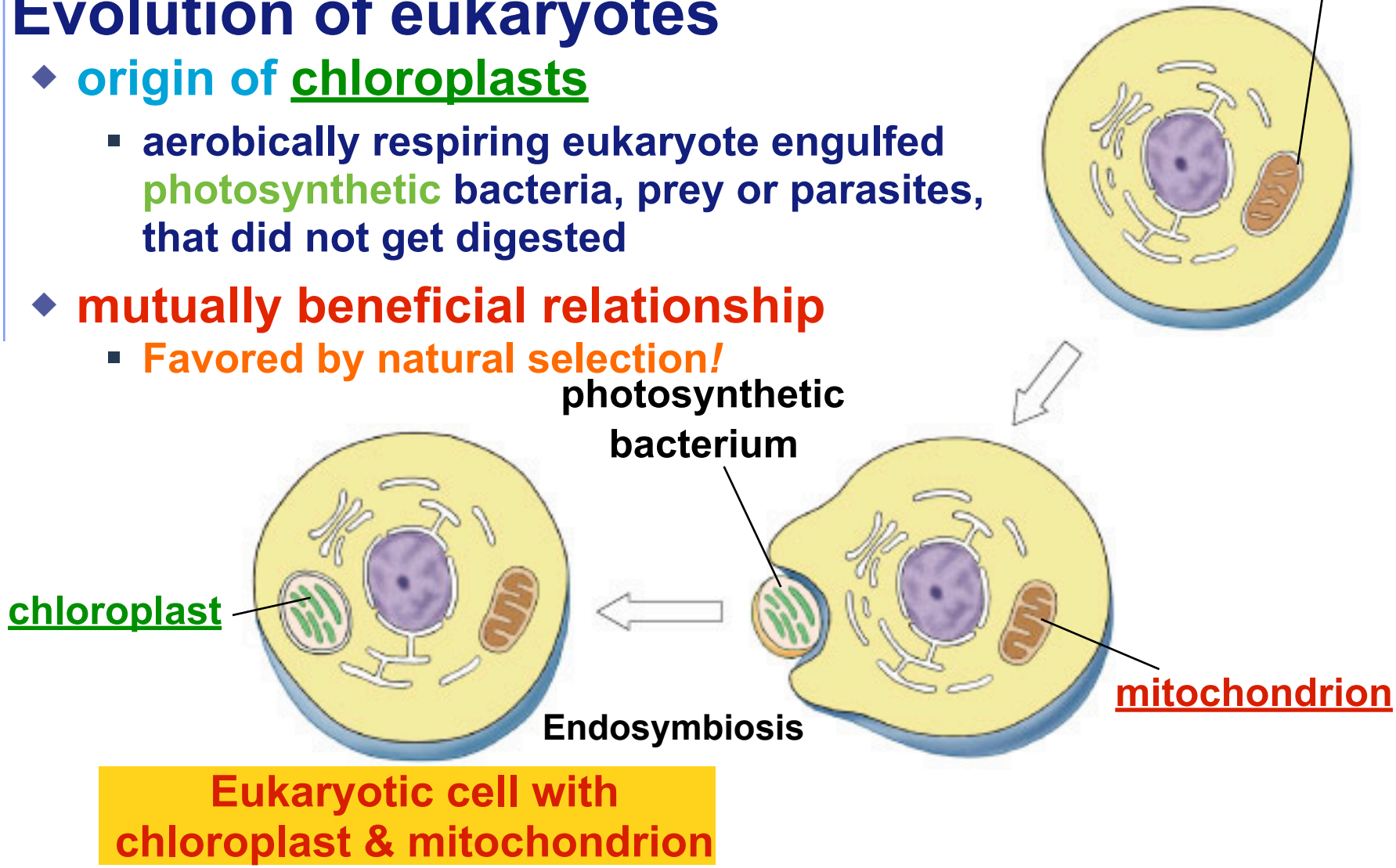
Endosymbiosis

Ancestral eukaryotic cell

Eukaryotic cell with mitochondrion

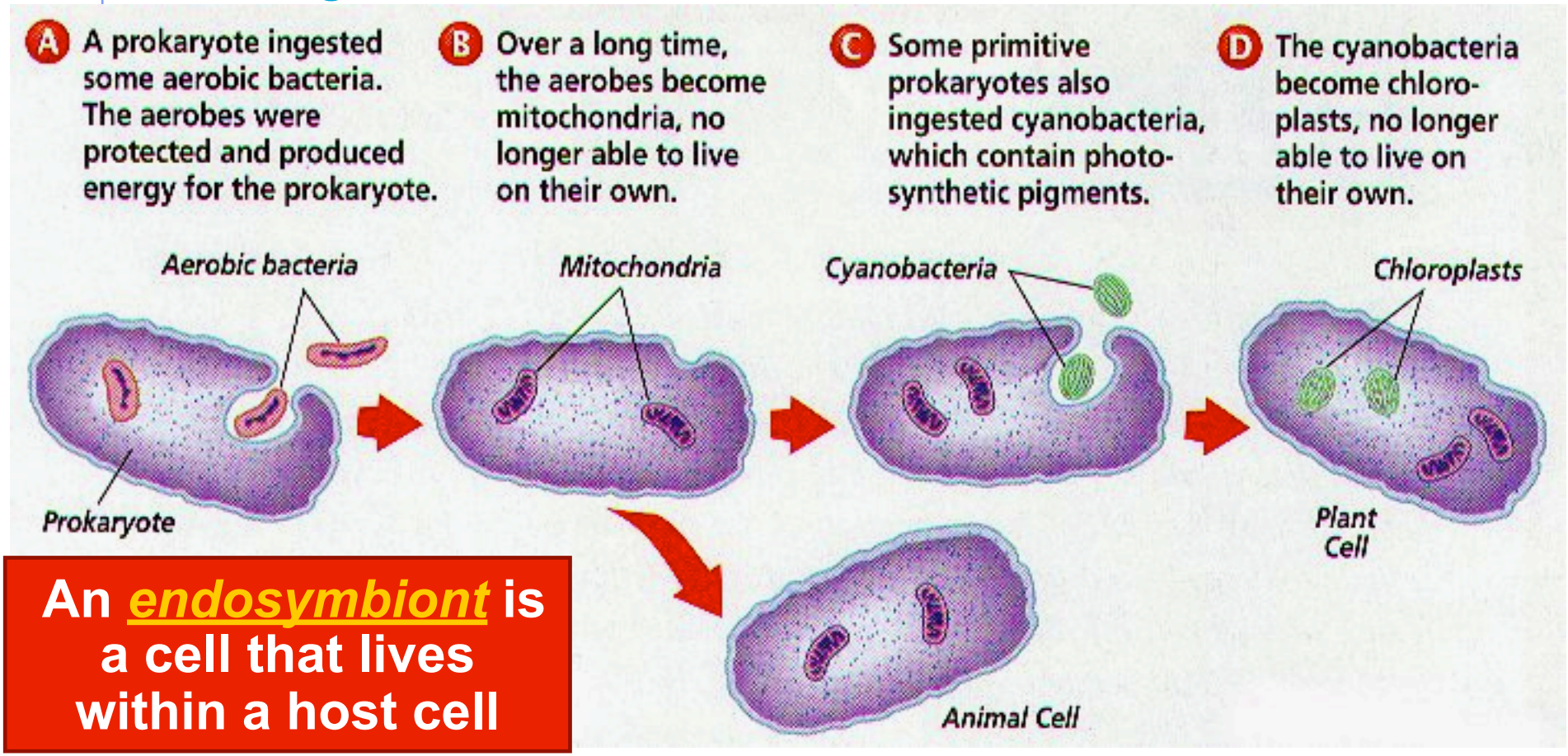
Serial Endosymbiosis - mitochondria evolved before plastids

- **Evolution of eukaryotes**
  - origin of chloroplasts
    - aerobically respiring eukaryote engulfed photosynthetic bacteria, prey or parasites, that did not get digested
  - mutually beneficial relationship
    - Favored by natural selection!



Evolution of eukaryotes

- membrane bound organelles = 2.1 bya
  - The hypothesis of endosymbiosis proposes that mitochondria and plastids (chloroplasts and related organelles) were formerly small prokaryotes living within larger host cells



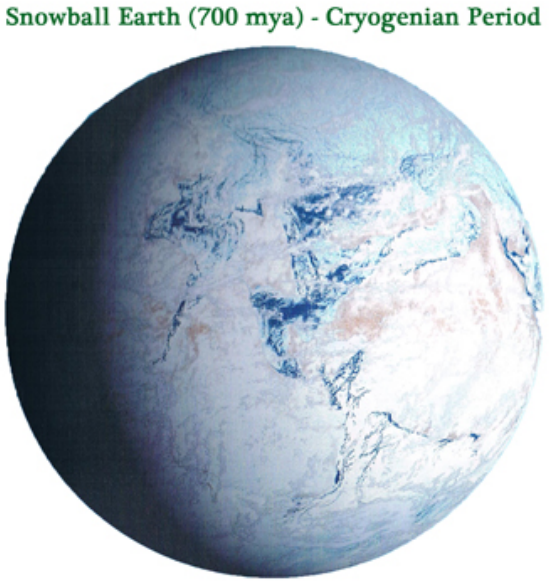
An *endosymbiont* is a cell that lives within a host cell

Theory of Endosymbiosis

Lynn Margulis

- Evidence
  - structural
    - mitochondria & chloroplasts resemble bacterial structure
    - Their ribosomes are more similar to prokaryotic than eukaryotic ribosomes
  - genetic
    - mitochondria & chloroplasts have their own circular DNA, like bacteria
    - DNA gets transcribed and translated on their own ribosomes
  - functional
    - mitochondria & chloroplasts move freely within the cell
    - mitochondria & chloroplasts reproduce independently from the cell

Cambrian explosion

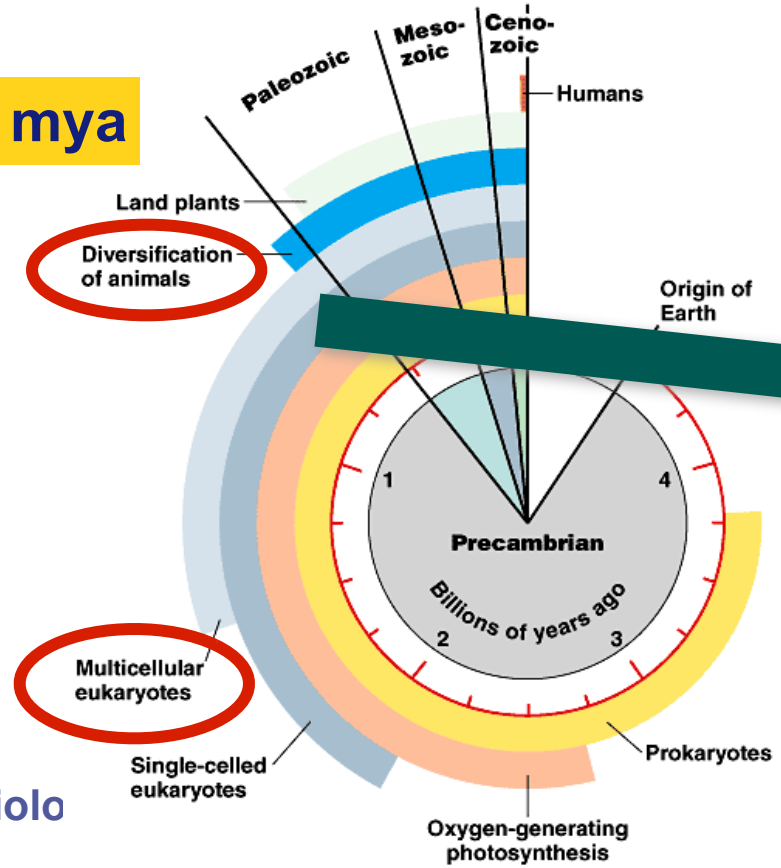


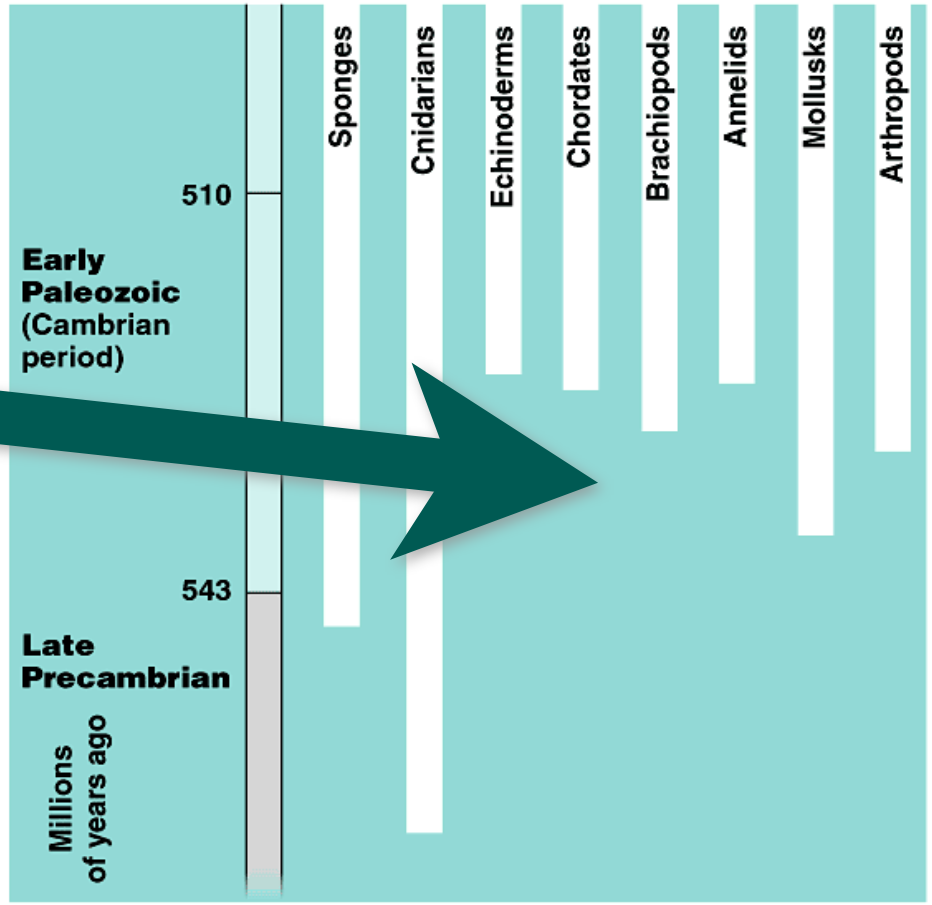
- The oldest known fossils of multicellular eukaryotes are of small algae that lived about 1.2 billion years ago
- The "snowball Earth" hypothesis suggests that periods of extreme glaciation confined life to the equatorial region or deep-sea vents from 750 to 580 million years ago
  - Then when the ice receded, the Cambrian explosion occurred and we see an explosion of new multicellular life forms
    - Refers to the sudden appearance of a large number of fossils resembling modern multicellular phyla in the Cambrian period (535 to 525 million years ago)

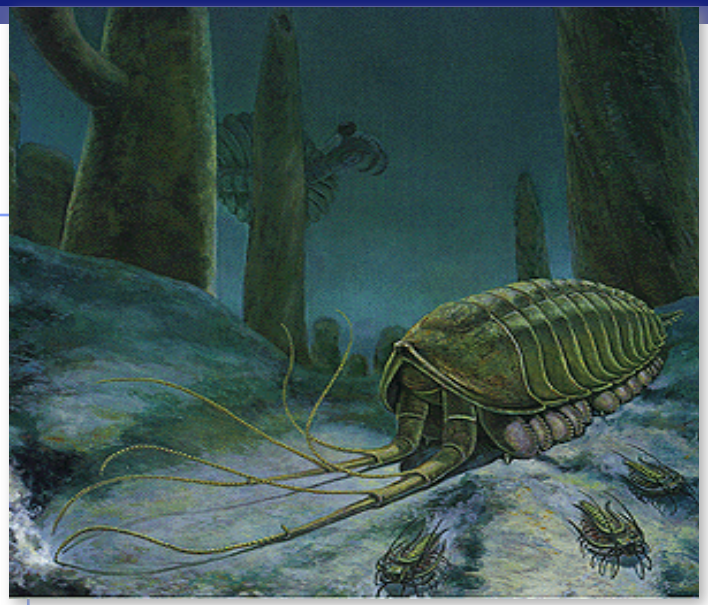
Cambrian explosion

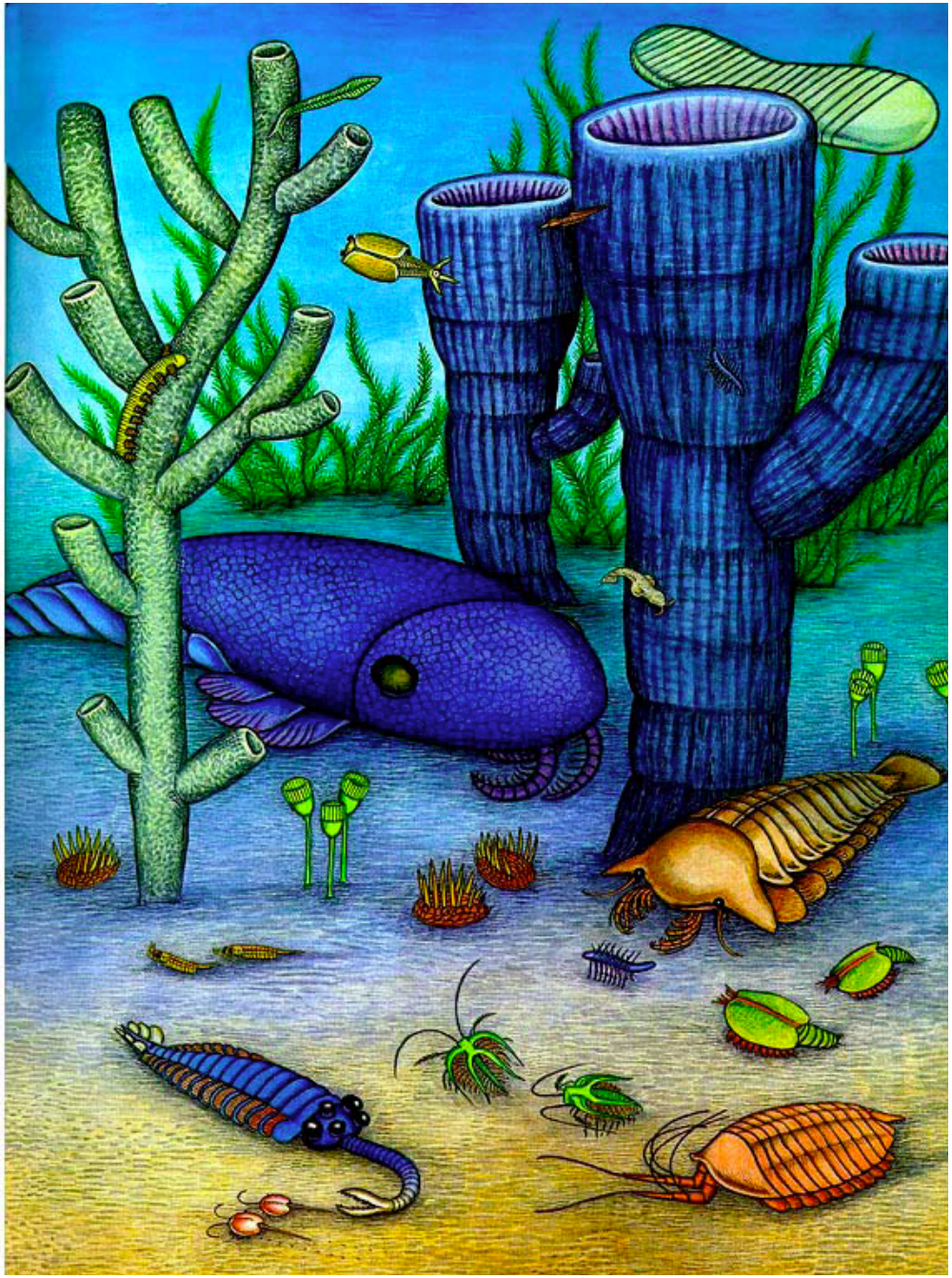
- **Huge Diversification of Animals seen around 550 mya**
  - **within 10–20 million years most of the major phyla of animals appear in fossil record**
    - **The Cambrian explosion provides the first evidence of predator-prey interactions**

543 mya

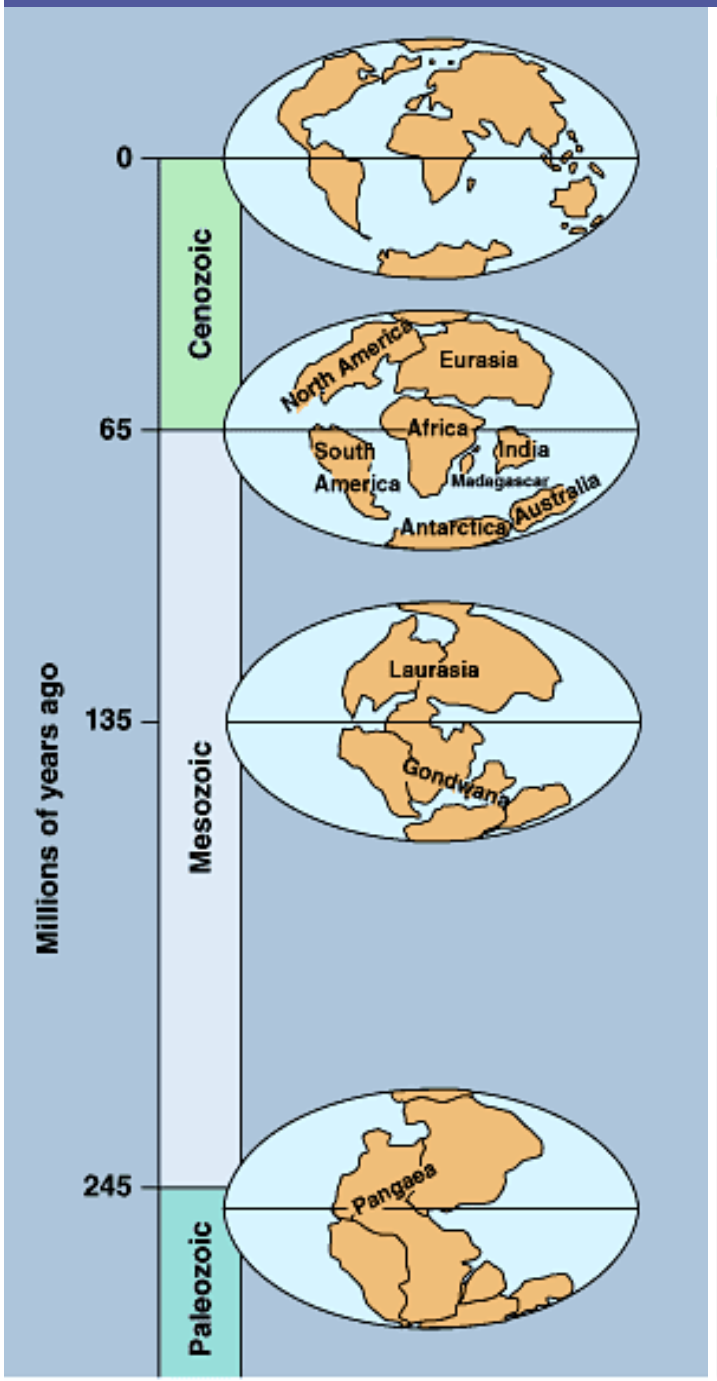








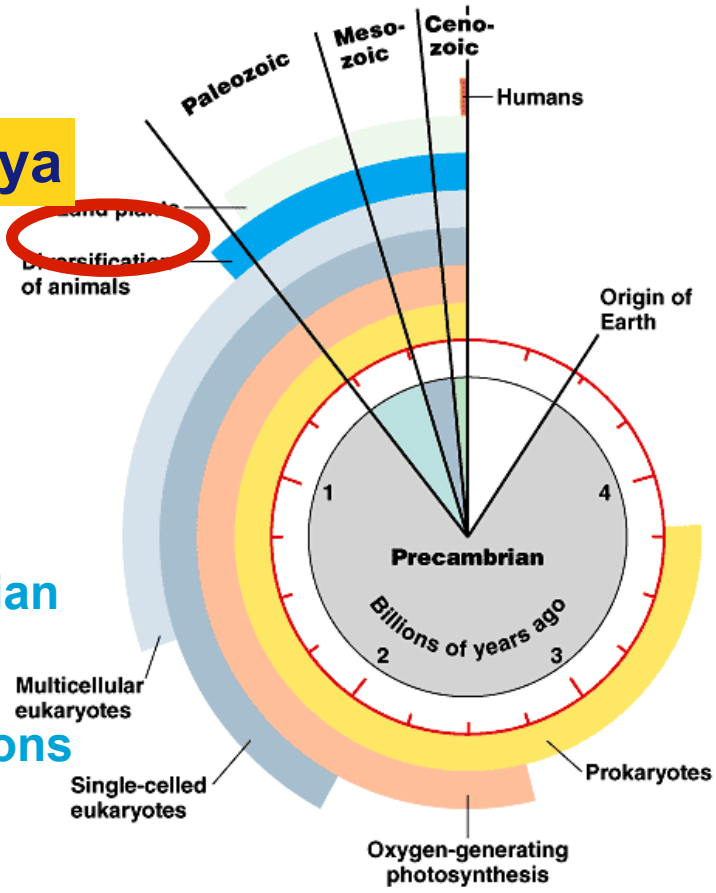
CAMBRIAN EXPLOSION was characterized by the sudden and roughly simultaneous appearance of many diverse animal forms almost 600 million years ago. No other period in the history of animal life can match this remarkable burst of evolutionary creativity. Most of the Cambrian creatures shown here were reconstructed from fossils by Simon Conway Morris and Harry Whittington of the University of Cambridge.



Relative Time Span of Eras	Era	Period	Epoch	Age (Millions of Years Ago)	Some Important Events in the History of Life
Cenozoic	Cenozoic	Quaternary	Recent	0.01	Historical time
			Pleistocene	1.8	Ice ages; humans appear
Mesozoic		Tertiary	Pliocene	5	Apelike ancestors of humans appear
			Miocene	23	Continued radiation of mammals and angiosperms
			Oligocene	35	Origins of many primate groups, including apes
			Eocene	57	Angiosperm dominance increases; continued radiation of most modern mammalian orders
Paleozoic			Paleocene	65	Major radiation of mammals, birds, and pollinating insects
	Mesozoic	Cretaceous		144	Flowering plants (angiosperms) appear; many groups of organisms, including dinosaurs, become extinct at end of period (Cretaceous extinctions)
		Jurassic		206	Gymnosperms continue as dominant plants; dinosaurs abundant and diverse
		Triassic		245	Cone-bearing plants (gymnosperms) dominate landscape; radiation of dinosaurs
Pre-cambrian	Paleozoic	Permian		290	Extinction of many marine and terrestrial organisms (Permian mass extinction); radiation of reptiles; origins of mammal-like reptiles and most modern orders of insects
		Carboniferous		363	Extensive forests of vascular plants; first seed plants; origin of reptiles; amphibians dominant
		Devonian		409	Diversification of bony fishes; first amphibians and insects
		Silurian		439	Diversity of jawless fishes; first jawed fishes; diversification of early vascular plants
		Ordovician		510	Marine algae abundant; colonization of land by plants and arthropods
		Cambrian		543	Radiation of most modern animal phyla (Cambrian explosion)
	Precambrian			600	Diverse soft-bodied invertebrate animals; diverse algae
				2,200	Oldest fossils of eukaryotic cells
				2,700	Atmospheric oxygen begins to increase
				3,500	Oldest fossils of cells (prokaryotes)
				3,800	Earliest traces of life
				4,600	Approximate time of origin of Earth

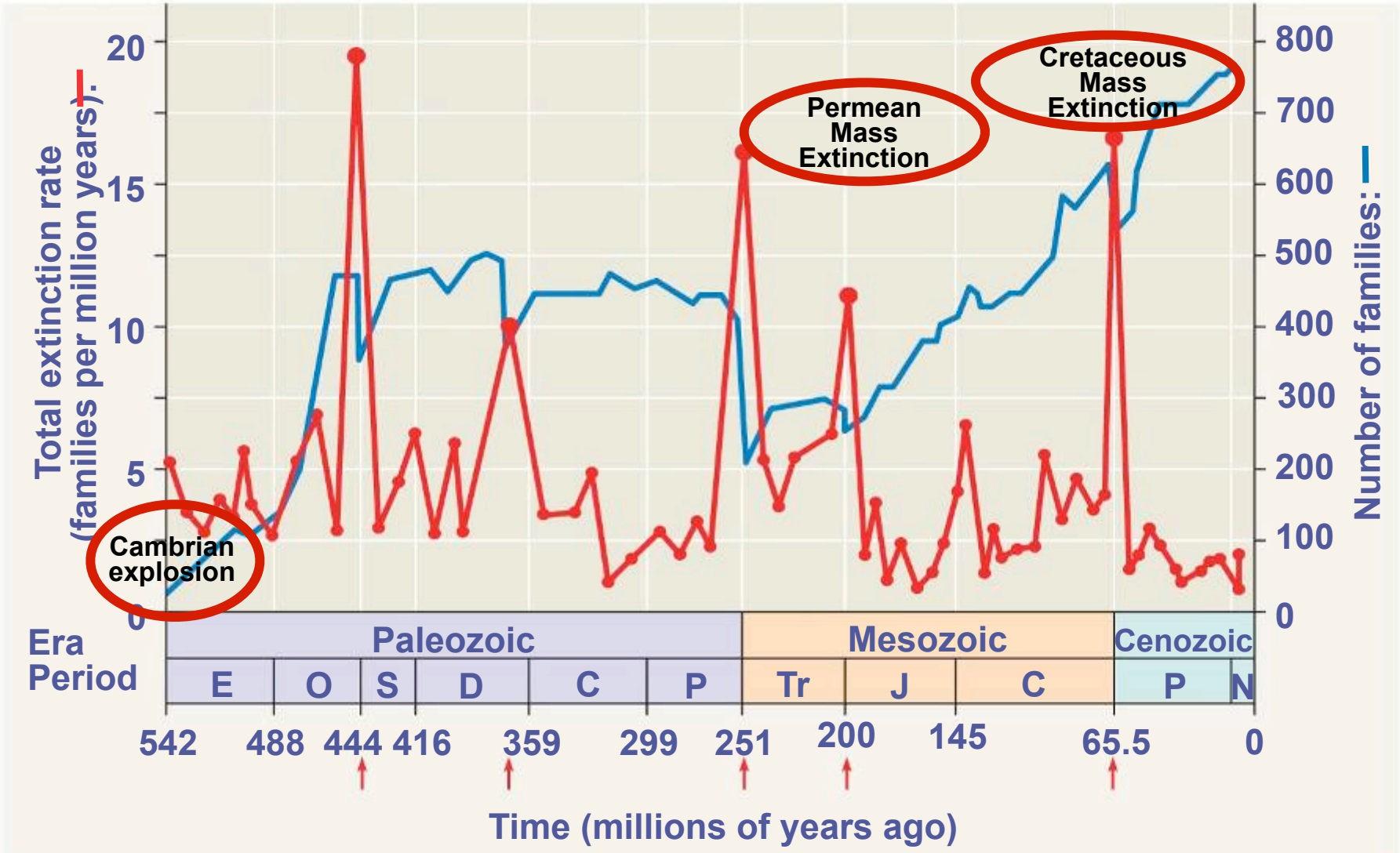
Colonization of Land

- Fungi, plants, and animals began to colonize land about 500 million years ago
- Plants and fungi likely colonized land together by 420 million years ago
  - Arthropods and tetrapods are the most widespread and diverse land animals
    - Tetrapods evolved from lobe-finned fishes around 365 million years ago
      - First arthropods date to the Cambrian period, and included trilobites, horseshoe crabs, and crustaceans. Centipedes, millipedes, and scorpions were among the first arthropods to reach dry land.



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

Diversity of life & periods of mass extinction



The Permian mass extinction, which defines the boundary between the Paleozoic and Mesozoic eras, claimed about 96% of marine animal species. Terrestrial life was also affected.

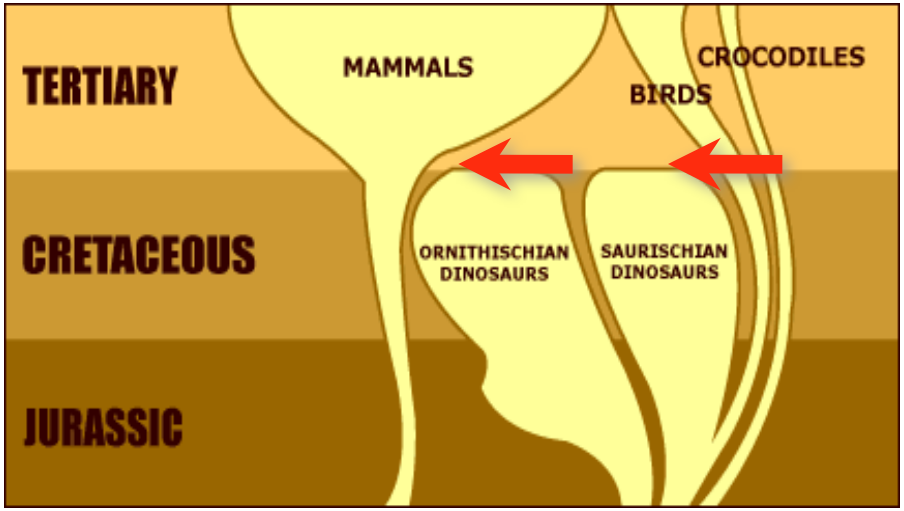
Cretaceous extinction

The Chicxulub impact crater in the Caribbean Sea near the Yucatan Peninsula of Mexico indicates an asteroid or comet struck the earth and changed conditions 65 million years ago

The Cretaceous mass extinction of 65 million years ago, which marks the boundary between the Mesozoic and Cenozoic eras, doomed more than half of all marine species and exterminated many families of terrestrial plants and animals, including most of the dinosaurs.

Early mammal evolution

- **Mass extinction can alter ecological communities and the niches available to organisms**
  - **Mass extinction can pave the way for adaptive radiations**
- **125 mya mammals began to radiate out & fill niches**
  - **<u>Adaptive radiation</u> is the evolution of diversely adapted species from a common ancestor upon introduction to new environmental opportunities**
    - **The disappearance of dinosaurs (except birds) allowed for the expansion of mammals in diversity and size**



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