Origins of Life

Preface

- Origin of life happened once a long time ago.
- The question of Life's origin is difficult to answer but not impossible.
- Remember the rules of science predicate a "natural" explanation, this might not always seem the most reasonable or probable but slides that follow represent the best plausible natural explanation.
- Although some explanations are speculative they still lead to testable predictions in the lab.

Themes

- The theme to look for throughout this powerpoint is CHANGE.
- The earth has changed, it is changing today and will continue to change into the future.
  - This change includes both the abiotic and biotic.
  - Look for examples of abiotic factors effecting biotic change but also look for examples throughout earth's history where the biota effect the earth's abiotic characteristics.
- The changes in earth and its living organisms are episodic, significant events followed by stasis, repeated over and over again through time.

What did early earth look like?

- **The easy answer...nothing like it does today!**
- **The early earth was a barren, inhospitable place devoid of any life.**
  - **There were no oceans, no oxygen.**
  - **Earth was under continual bombardment of rock and ice from the formation of the solar system.**
  - **Latest evidence suggests that the atmosphere was primarily nitrogen and carbon dioxide.**
  - **Volcanoes were large and numerous, the earth as hot.**
  - **UV radiation was great with no atmosphere to filter it**
  - **Lightning was widespread**

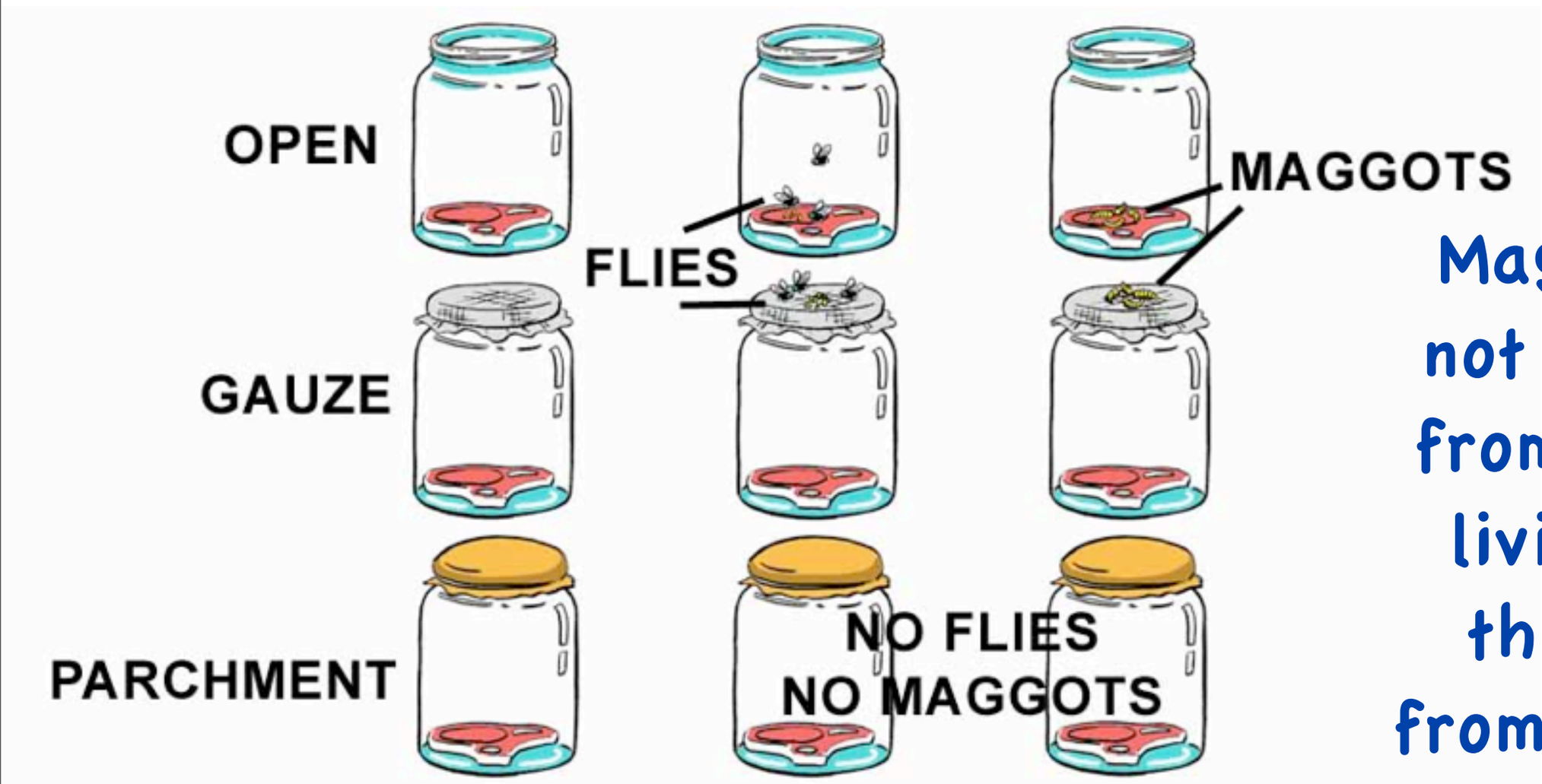
How did life begin? Spontaneous Generation

- Dating back at least to Aristotle was the thought that life originated from a "life force".
  - This idea ***spontaneous generation*** or abiogenesis held that living organisms could arise from non-living material.

- This idea has been dispelled and today we know that cells come from cells, life from life.
- Ironically we support the idea of abiogenesis, however, its meaning is more limited and specific.
  - Modern abiogenesis refers only to the origin of the first living organism(s), some 3.5+ billion years ago!

Classical Spontaneous Generation Dispelled

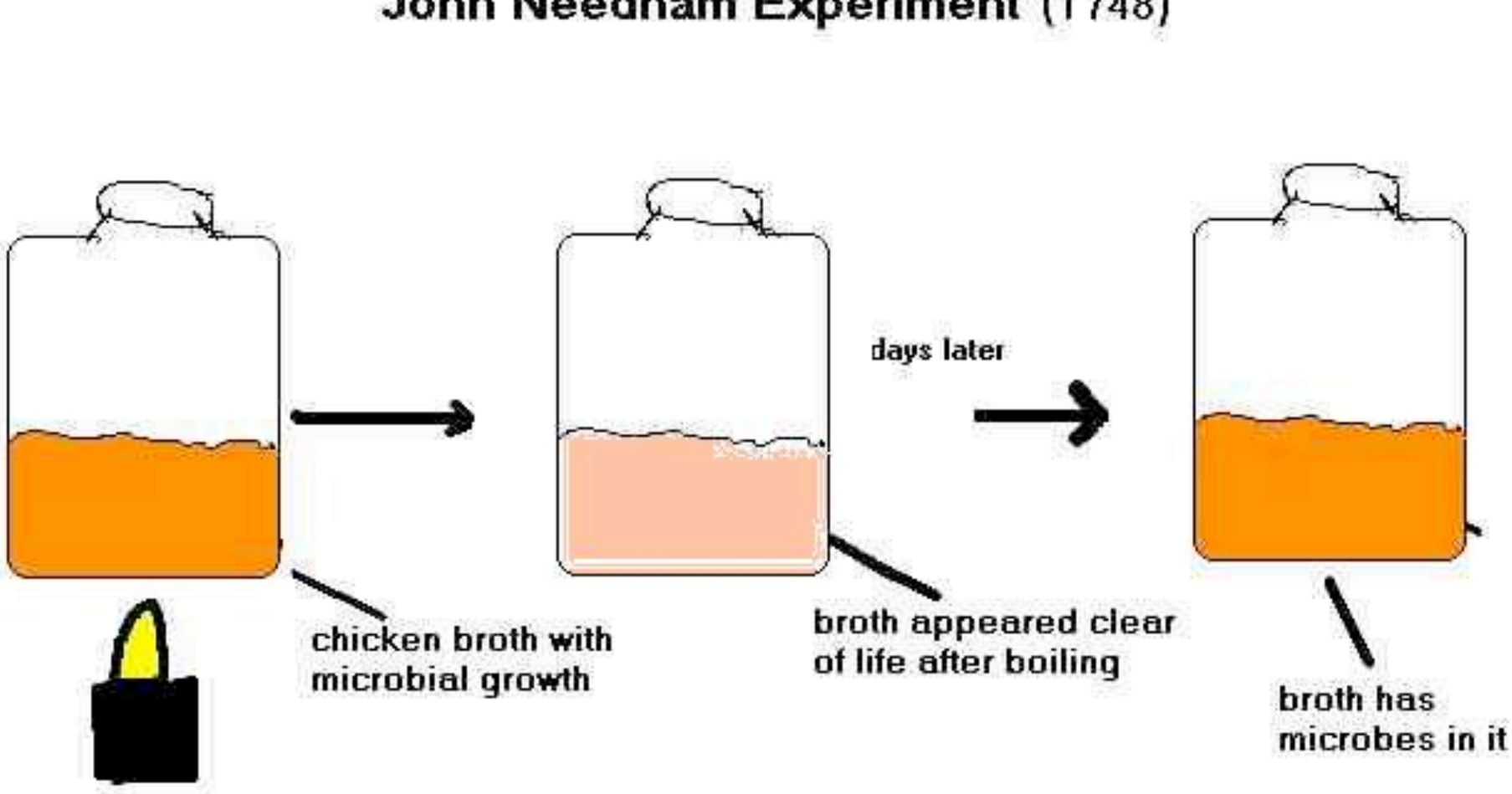
- The first evidence against this idea dates back to 17th century.
- Francesco Redi carried out a simple experiment that did not support the idea of spontaneously generation.



Maggots did not originate from the non living beef, they came from fly eggs.

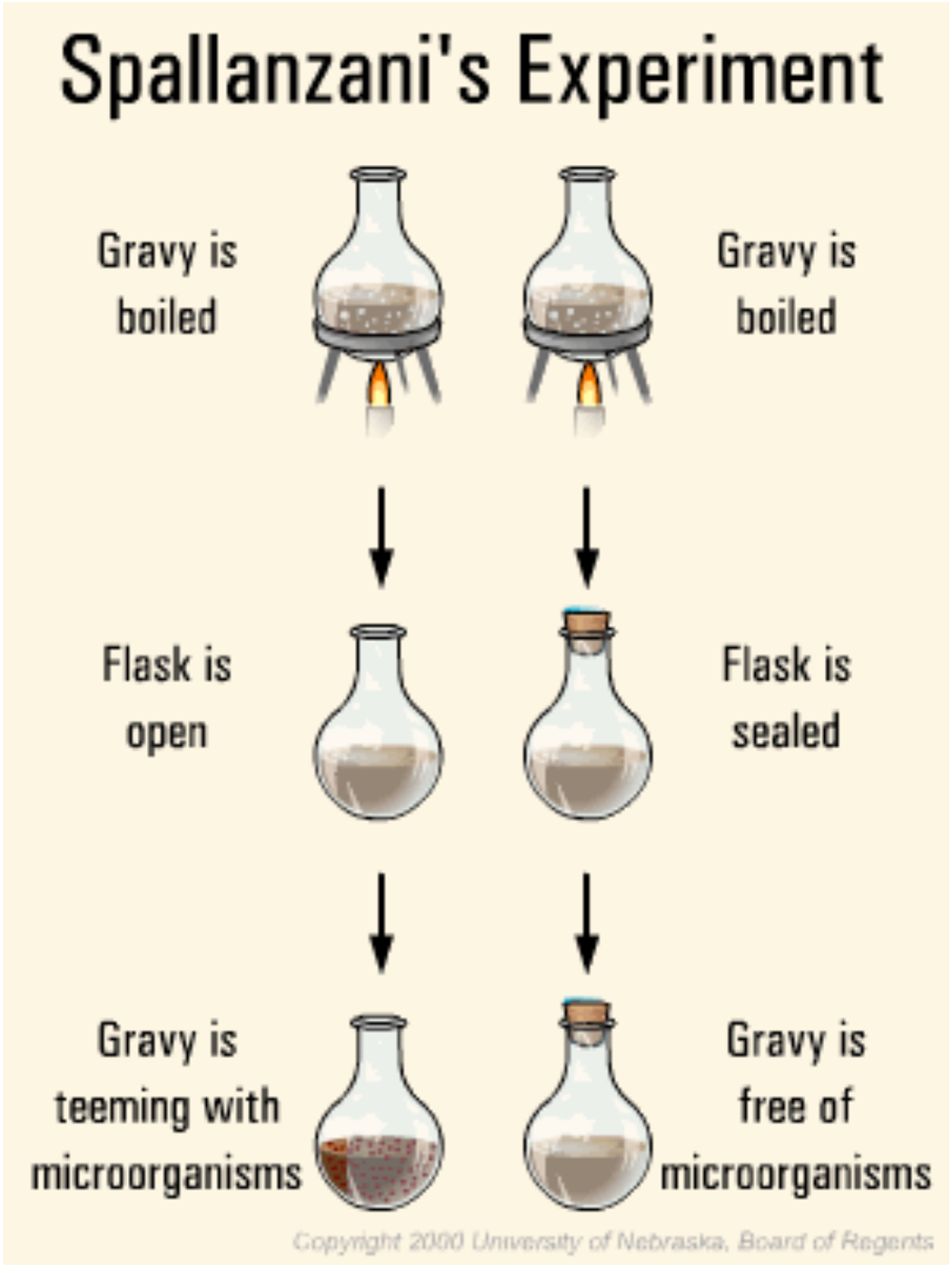
Classical Spontaneous Generation Dispelled

- In the 1748 John Needham, rekindles the debate.
- Knowing that heat killed organisms Needham boiled his nutrient broth and left it out on the table, only to find microbes growing days later.



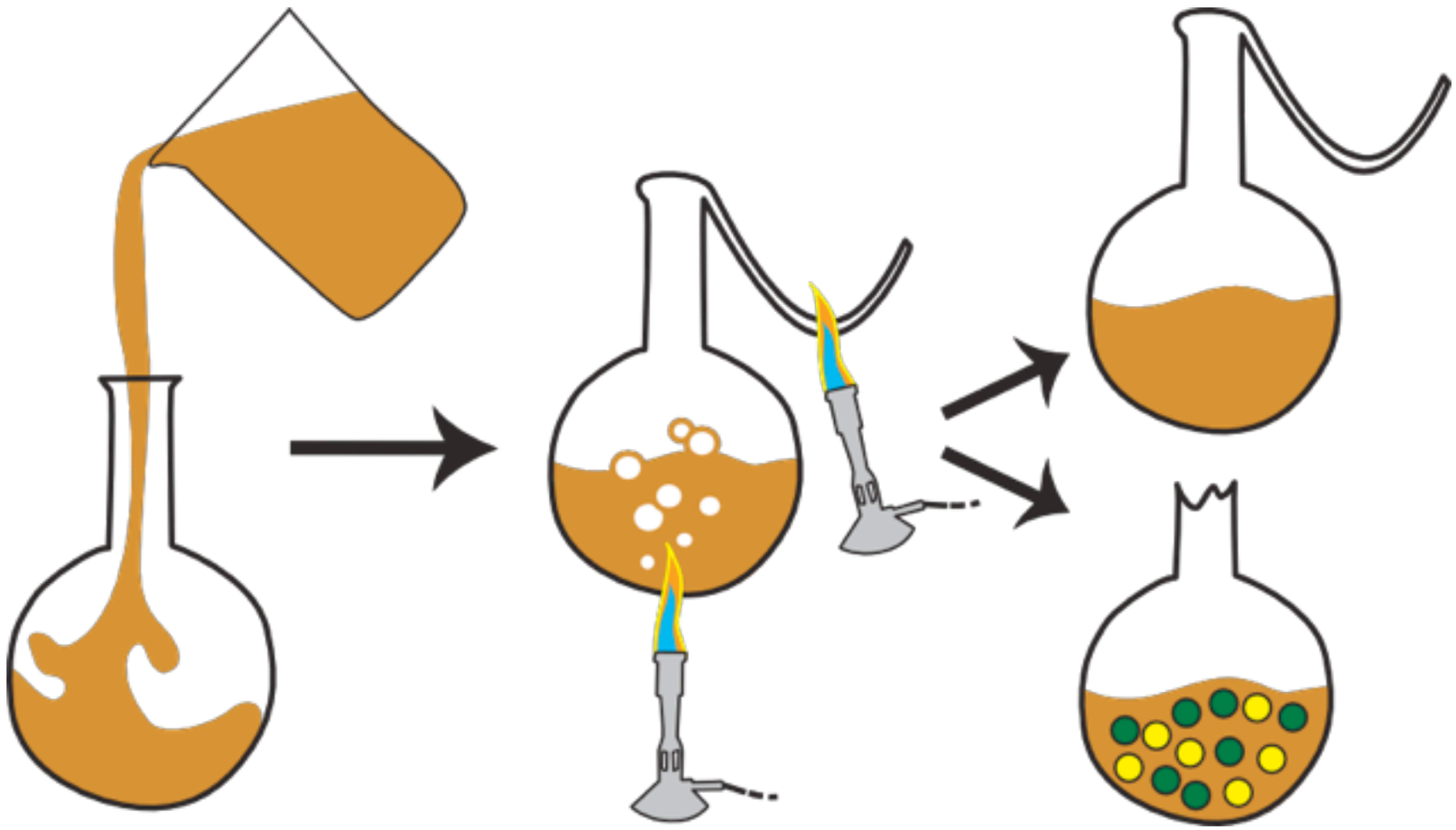
Classical Spontaneous Generation Dispelled

- Lazzaro Spallanzani answers Needham later that century with yet another definitive experiment.
- Spallanzani carried out yet another simple experiment that showed microbes could travel in the air.
- Some were still not convinced they said that removing the air was unfair because it contained the “life force”.



Classical Spontaneous Generation Dispelled

- Enter Louis Pasteur.
- Pasteur puts the debate to rest with the experiment below.



Its amazing just how many scientific discoveries involved a little "luck". For example both Spallanzani and Pasteur were lucky to show no growth in their respective bottles because neither of them sterilized their glassware at that time.

Spontaneous Generation… A Footnote

- It was the work of these scientists who paved the way for scientists after them.
- From their work our knowledge of microbes grew including of course the knowledge of pathogens and ultimately the development of vaccines.

How did life begin? **Modern Abiogenesis**

- The current explanation involves 4 general steps.
  - 1. The synthesis of small organic molecules.
    - *monomers*
  - 2. The synthesis of large organic molecules.
    - *polymers*
  - 3. The synthesis of vesicles.
    - *protocells*
  - 4. The synthesis of self-replicating RNA
    - *ribozymes*

Synthesis of Small Organic Molecules

- As the earth formed and cooled there was an abundance of certain chemicals.
  - *nitrogen oxides, carbon dioxides, methane, ammonia, hydrogen, hydrogen sulfide, water vapor*
  - Recent evidence confirms that meteorites carry carbon compounds, 1-2% of their mass.
    - *meteorite fragments have been analyzed and found to contain, some amino acids, simple sugars, lipids and nitrogenous bases.*
- Under favorable conditions these compounds may have formed simple organic compounds, monomers.

Synthesis of Small Organic Molecules

- The favorable conditions are as follows:
  - Time *billions of years available*
  - Energy *earth was very hot and its slowly cooled*
  - Building Blocks *by-products of earth's formation*
  - A reducing (or even neutral) atmosphere
    - *the presence of oxygen would have would have created a degradative environment where the breakdown of compounds would have been favored over the synthesis of compounds*
  - In the 1920's two chemists Oparin and Haldane hypothesized that a reducing atmosphere would favor the production of organic molecules

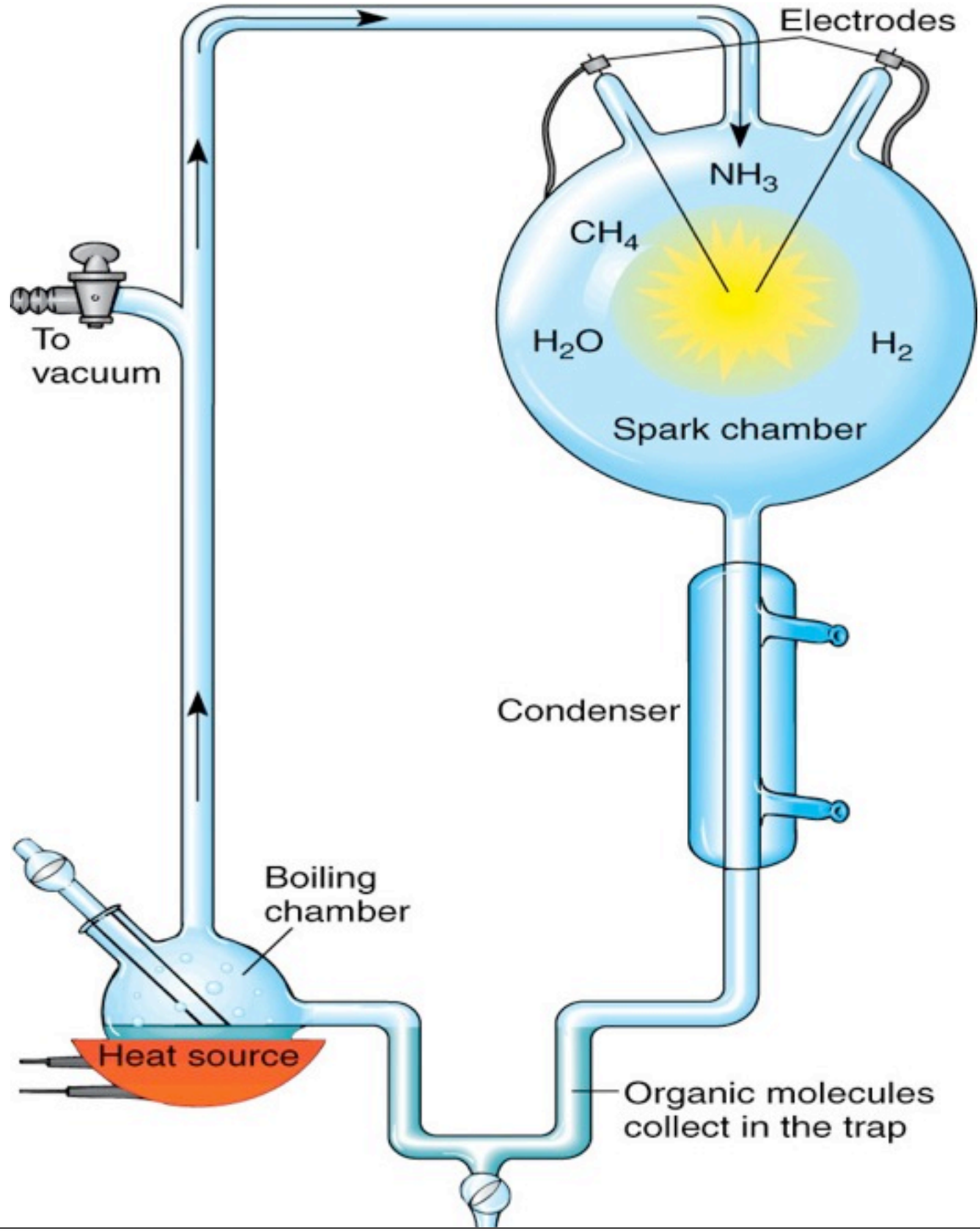
Stanley Miller & Harold Urey Experiment

- These scientists set out to test Oparin & Haldane's hypothesis.
- They tried to recreate the conditions of early life in the laboratory to see if they could in fact create organic compounds from inorganic precursors:
  - They were able to create some organic compounds (amino acids for instance)
  - *Latest evidence suggests that the atmosphere was not the reducing atmosphere that this experiment assumed but instead a neutral atmosphere made of primarily nitrogen and carbon dioxide. New experiments like Miller & Urey's have confirmed that a neutral atmosphere also produces organic compounds.*

Stanley Miller & Harold Urey Experiment

Experiment

Miller and Urey set up a closed system in their laboratory to simulate conditions thought to have existed on early Earth. A warmed flask of water simulated the primeval sea. The strongly reducing "atmosphere" in the system consisted of H_2, methane (CH_4), ammonia (NH_3), and water vapor. Sparks were discharged in the synthetic atmosphere to mimic lightning. A condenser cooled the atmosphere, raining water and any dissolved compounds into the miniature sea.



Results

As material circulated through the apparatus, Miller and Urey periodically collected samples for analysis. They identified a variety of organic molecules, including amino acids such as alanine and glutamic acid that are common in the proteins of organisms. They also found many other amino acids and complex,oily hydrocarbons.

Conclusion

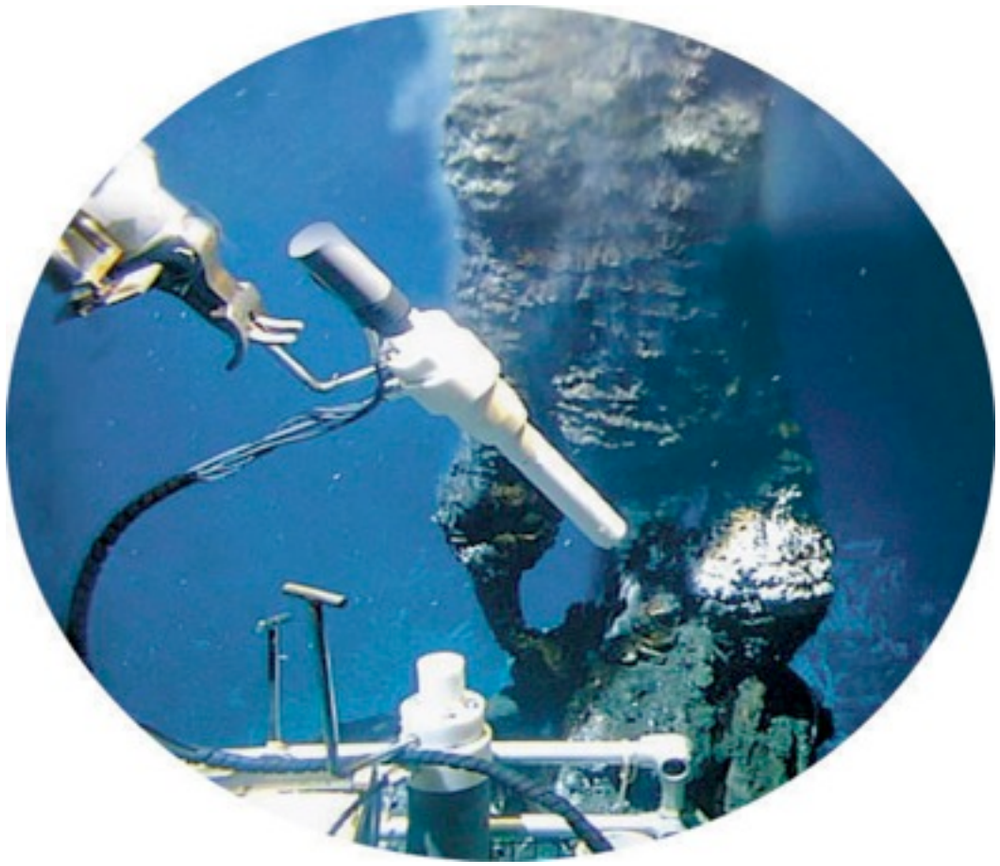
Organic molecules, a first step in the origin of life, can form in a strongly reducing atmosphere.

Stanley Miller & Harold Urey Experiment

- Latest evidence suggests that the atmosphere was not the reducing atmosphere that this experiment assumed but instead a neutral atmosphere made of primarily nitrogen and carbon dioxide. New experiments like Miller & Urey's have confirmed that a neutral atmosphere also produces organic compounds.

- Also even with neutral atmosphere some suggest that local areas around hydrothermal vents and volcanoes may have had reducing characteristics

Iron-Sulfur World Hypothesis



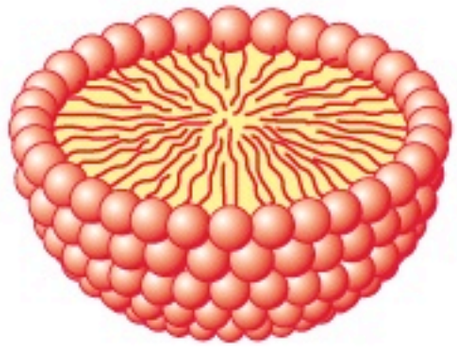
Synthesis of Large Organic Molecules

- All cells have a vast collection of large macromolecules.
  - Some research has shown that a solution of amino acids and nucleotides have formed spontaneously when dripped onto hot sand, clay or rock.
    - *the clay etc acts as a catalyst*
    - *the results are not overwhelming as the proteins that did form were are mix of linked and cross-linked amino acids unlike the our proteins*

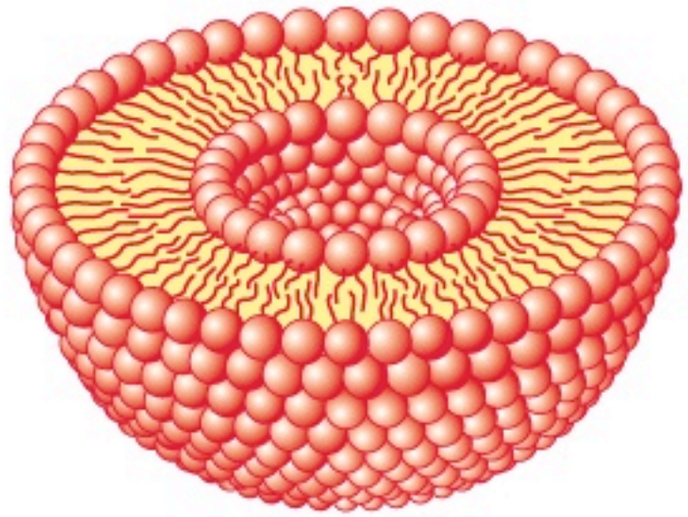
The Synthesis of Vesicles

- The synthesis of vesicles.
  - *vesicles form spontaneously when lipids and other organics are added to water*
  - *these vesicles could have trapped organics inside during their formation or small organics may have diffused through the membrane later*
  - *vesicles have been shown to grow and reproduce on their own*

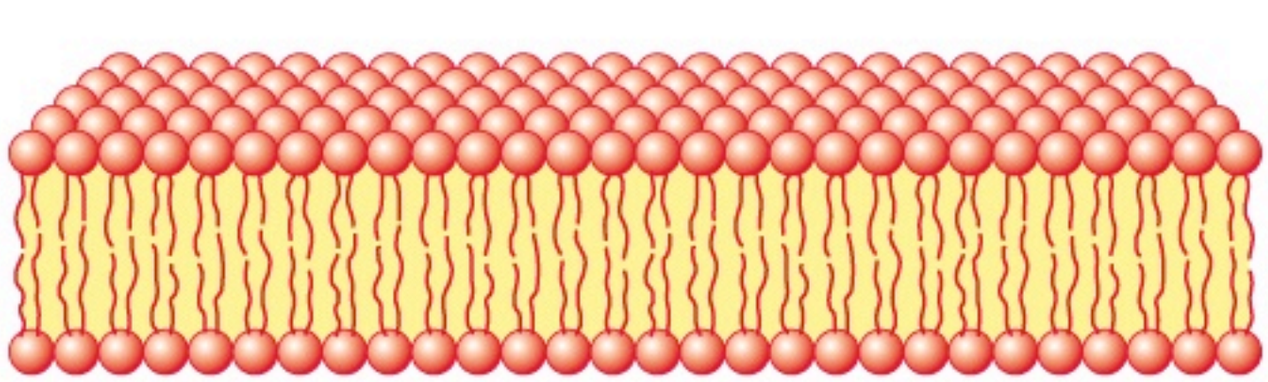
The Synthesis of Vesicles



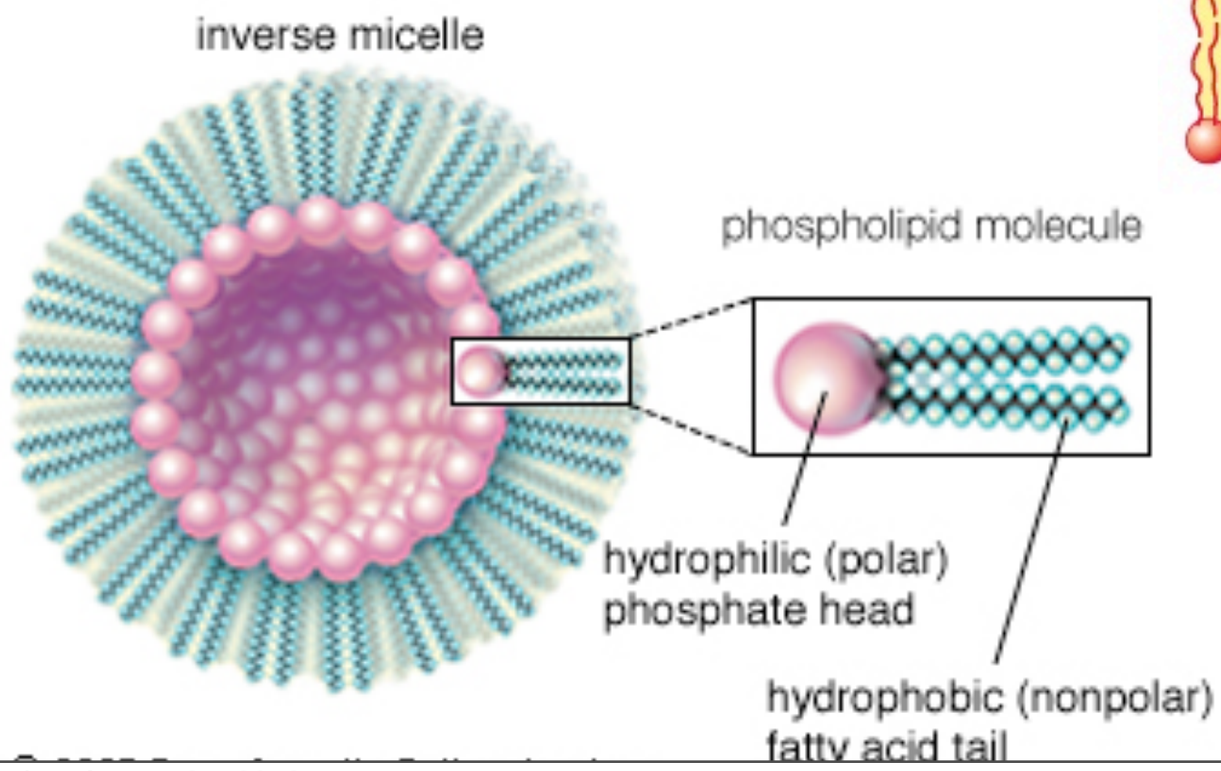
Micelle



Liposome



Bilayer sheet



The Synthesis of Self-Replicating RNA

Until recently biology had a "chicken or the egg" problem. DNA synthesis requires proteins, protein synthesis requires DNA

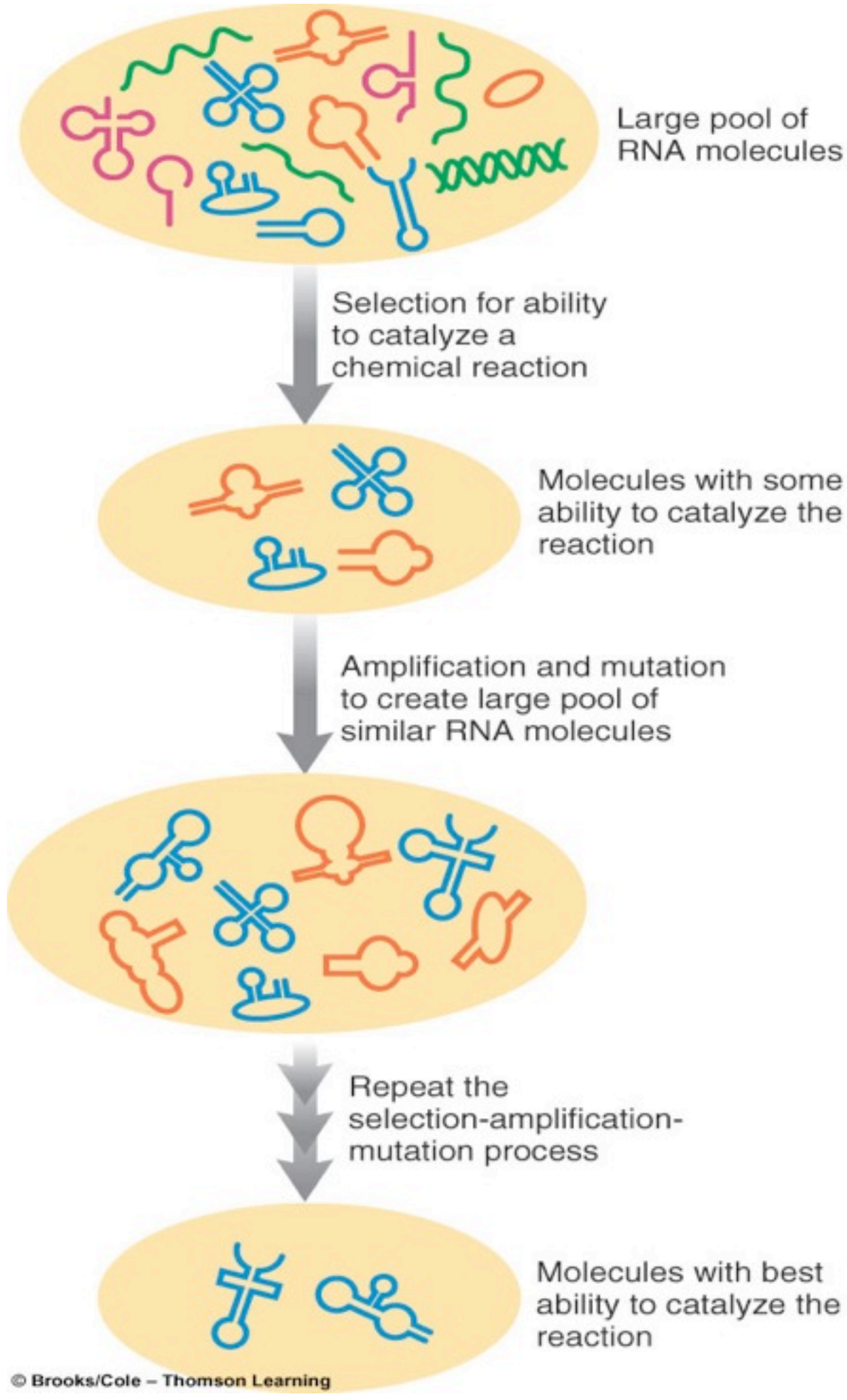
- Then came the discovery of **ribozymes,** an RNA molecule that contains genetic instructions and has catalytic properties.
  - *Up to this discovery it was believed that proteins were the only organic molecule that had catalytic properties, now we realize that organic catalysts include certain proteins and certain nucleic acids.*
- Single stranded RNA is thought be the first genetic molecule.
- In fact because single stranded RNA could fold into different shapes (phenotype) and contained genetic instructions (genotype), natural selection could have driven its evolution.

The Synthesis of Self-Replicating RNA

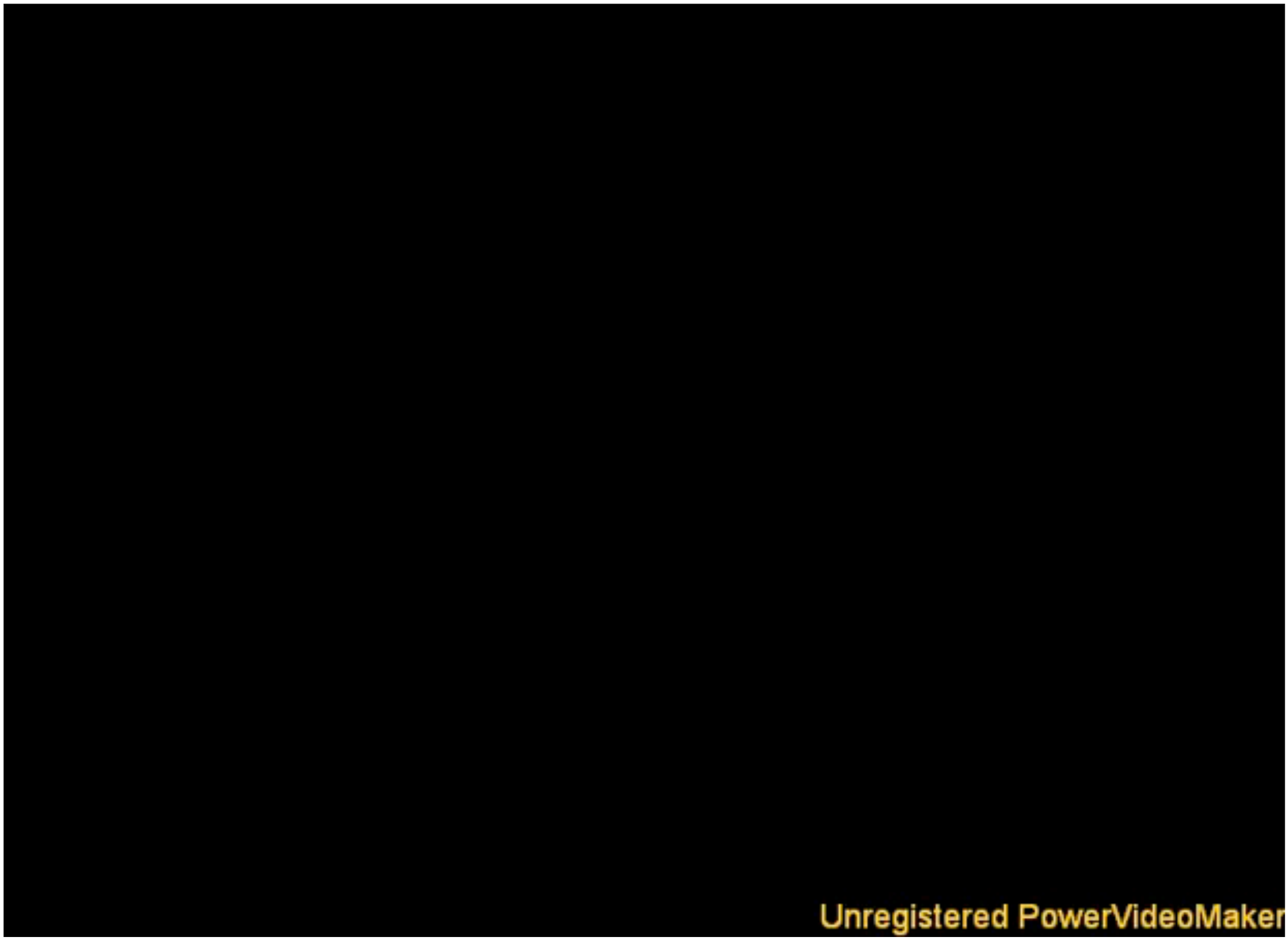
- RNA self replicates, vesicles grow and split (reproduce) passing on some the self replicating RNA
- Protocells would have limited amounts of genetic instructions, traits and metabolism.
- Those that best able to exploit resources would have been selected for
- RNA could serve as a template for DNA synthesis
- DNA may have been selected for because its double stranded structure is far more stable.

The Evolution of RNA Molecules

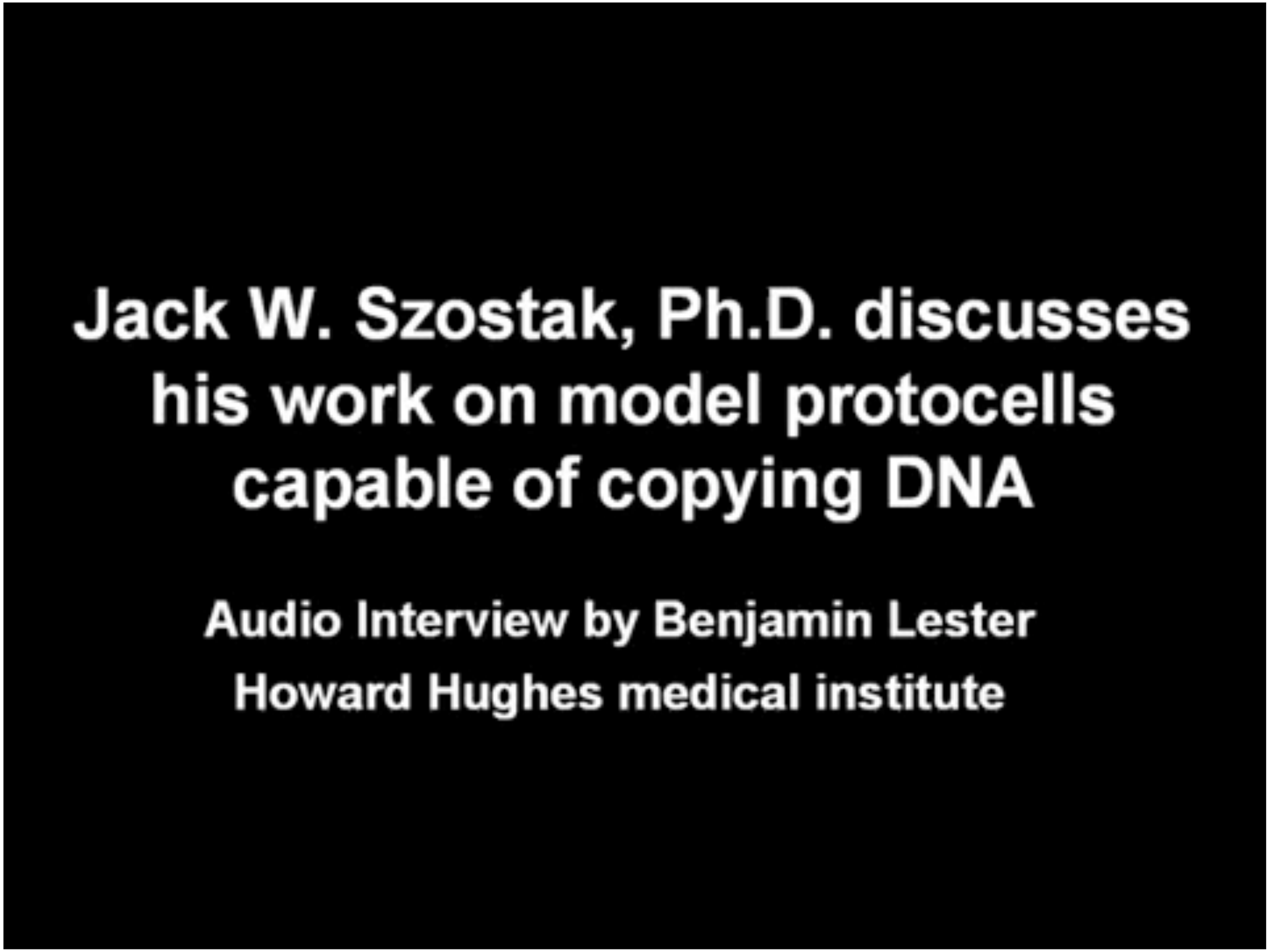
- *some RNA's would be more stable and replicate faster than others and would be therefore more fit*



Origin of Life Summary

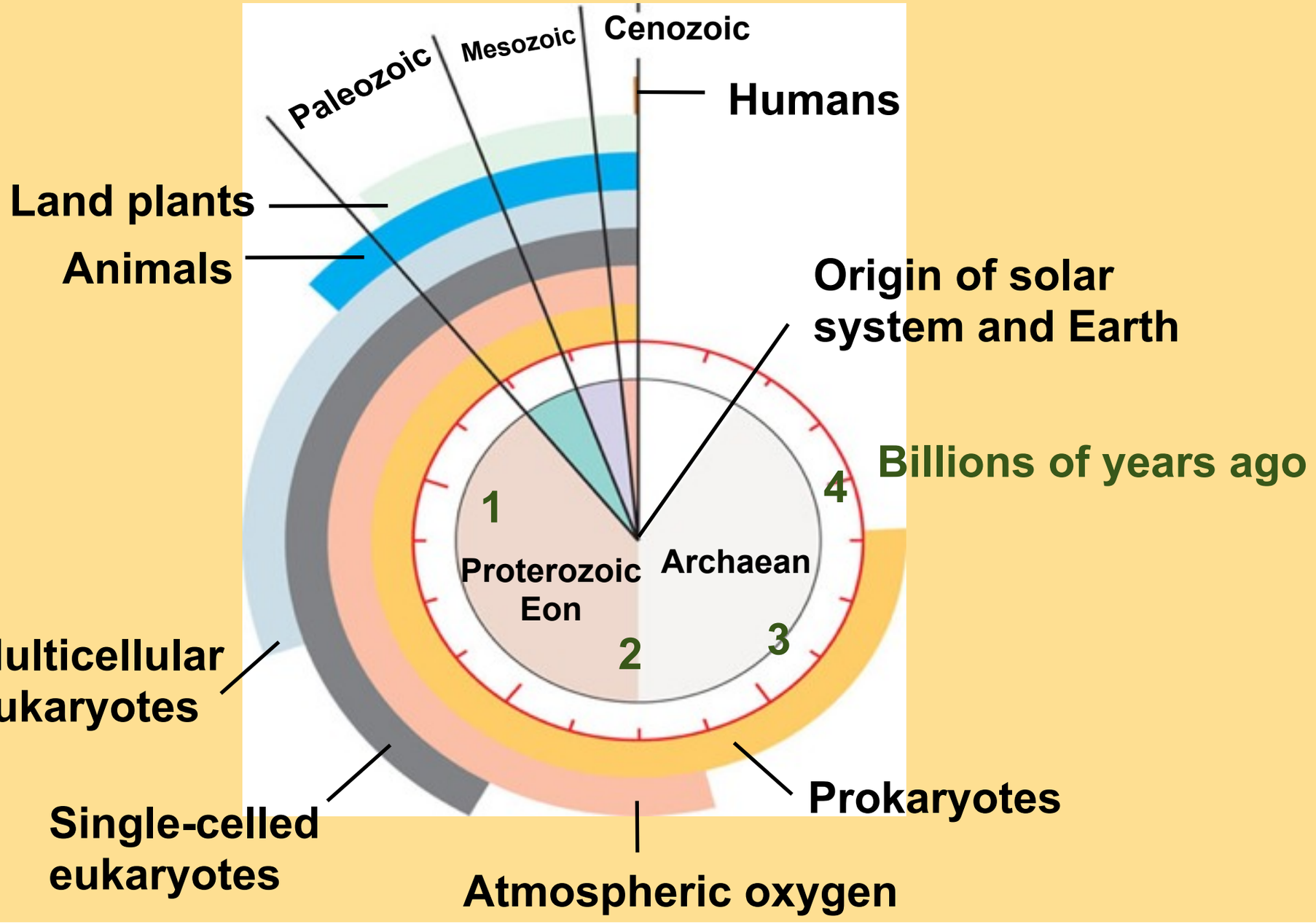


Origin of Life Interview



Major Events in Earth History

- **Formation of earth and abiogenesis 3.8 bya**



What did the first cells look like?

- Nobody can say for sure. (I have found conflicting information but here is what I can say)
- Science agrees the first cell was a very simple prokaryotic.

Most Likely:

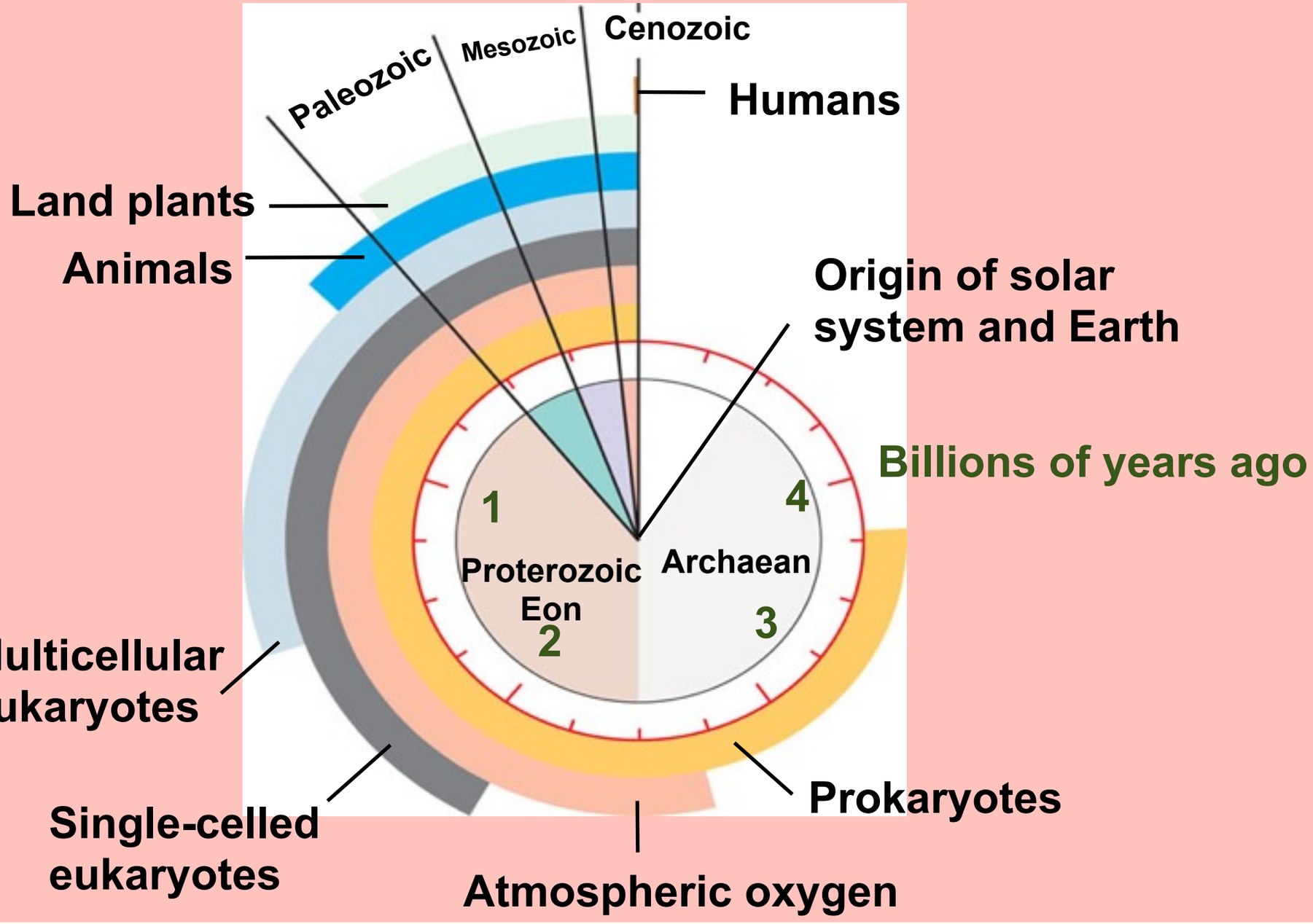
Anaerobic Chemoheterotrophic Bacteria

What did the earliest fossils look like?

- The earliest known fossils date back to 3.5 billion years ago.
  - **Stromatolites** are rock like structures composed of layers of bacteria and sediment.

Major Events in Earth History

- **Atmospheric Oxygen ~2.5 bya**



Major Events in Earth History

- **The earliest metabolism likely produced ATP via glycolysis.**

↓

- **The earliest form of photosynthesis likely used the electrons from hydrogen sulfide (used up quickly).**

↓ Life's First Major Crisis

- **The earliest form of photosynthesis likely used the electrons from water. (cyanobacteria)**

$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$$

→ Produces atmospheric oxygen

Major Events in Earth History

- **The production of oxygen accumulates on earth around 2.3 - 2.7 billion years ago.**
  - *theme...biotic effecting the abiotic*
- **The oxygen rich atmosphere has a significant effect on the evolution of living organisms**
  - *theme...abiotic effecting the biotic*

Major Events in Earth History

- **The oxidative (degradative) atmosphere posed a challenge to living organisms.**

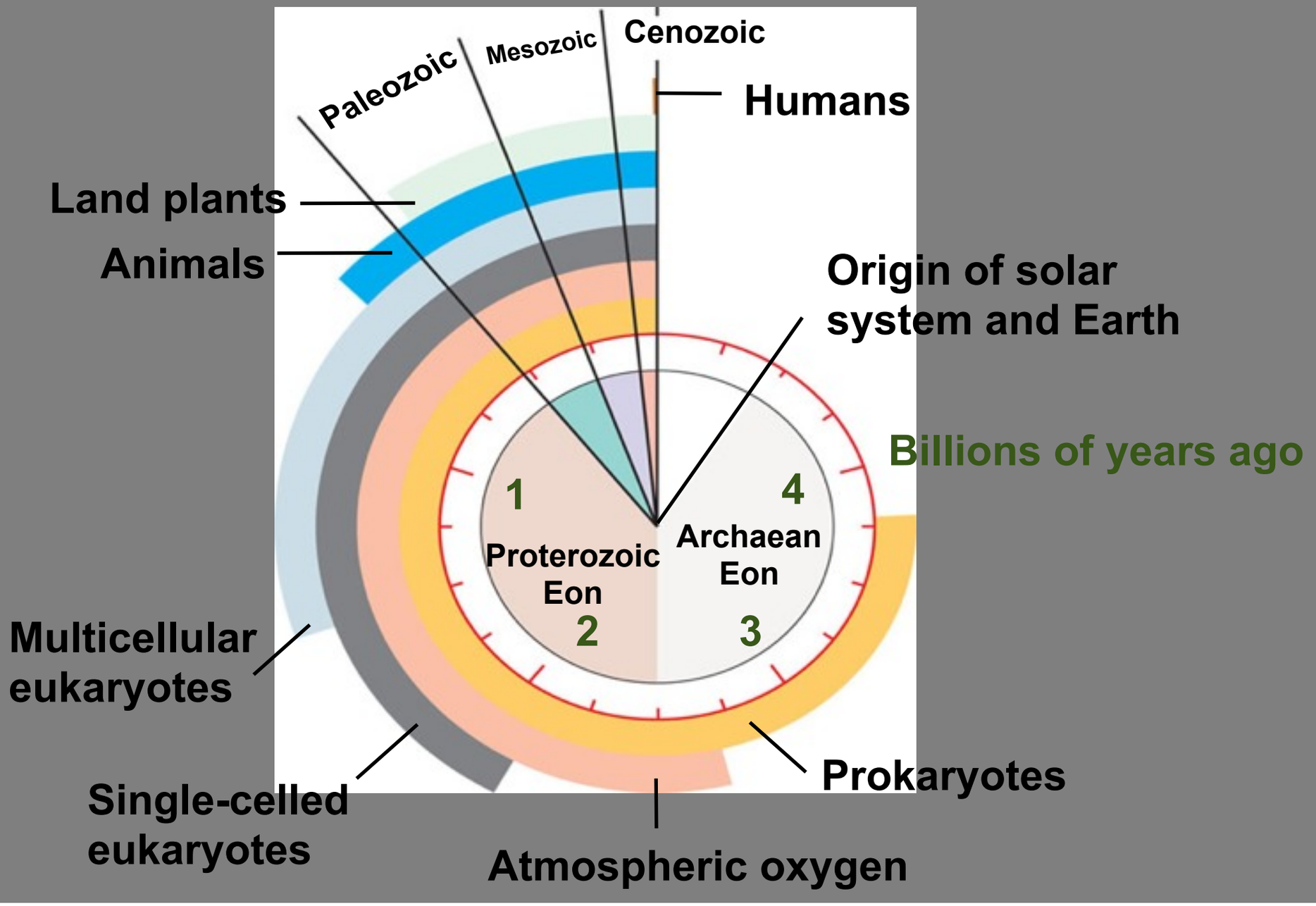
  Second Major Crisis

- **The oxidative atmosphere also provided an opportunity for living organisms to gain energy.**

  Aerobic Respiration- A Major Innovation

Major Events in Earth History

- **Evolution of Eukaryotes 2.1 bya**

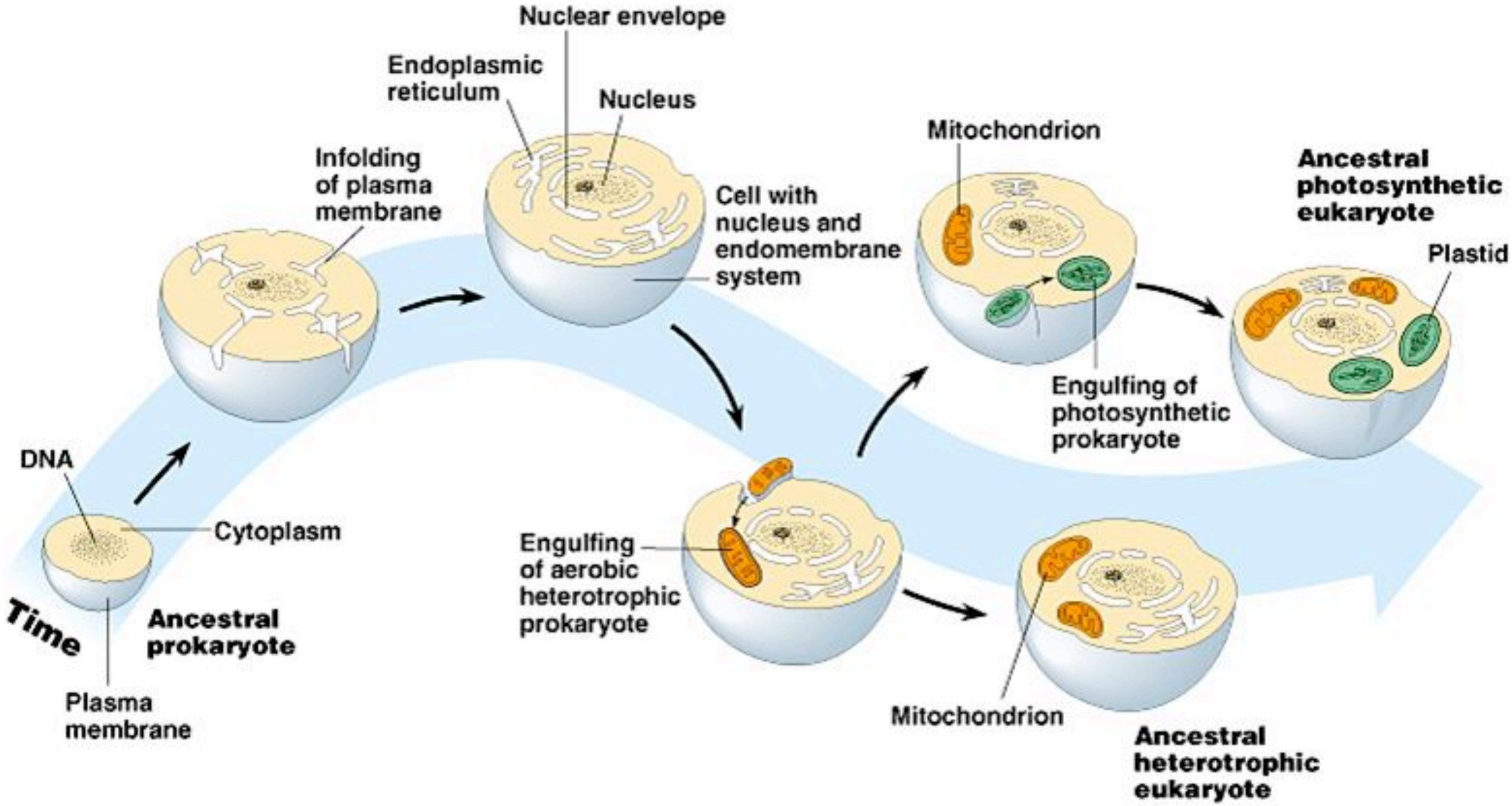


Major Events in Earth History

- **Evolution of Eukaryotes dates back to 2.1 BYA**
- **It is possible that the oxygen revolution provided the selective pressure for eukaryotic evolution.**
- **These cells are more complex than prokaryotes**
  - **They possess membrane organelles**
    - ***nucleus, mitochondria, chloroplasts, etc***
  - **They possess a cytoskeleton**

Endosymbiont Theory

...could have been undigested prey or a parasite



Major Events in Earth History

- **The endosymbiont lives within the host cell.**
- **The prey/parasite form a mutualistic relationship.**
- **At some point the host and the prey/parasite become dependent on one another.**
- **It is likely that the heterotroph/mitochondria came first.**
- **Then later the autotrophic bacteria/chloroplast came second.**

There is an overwhelming amount of evidence to support this theory and and these ideas.

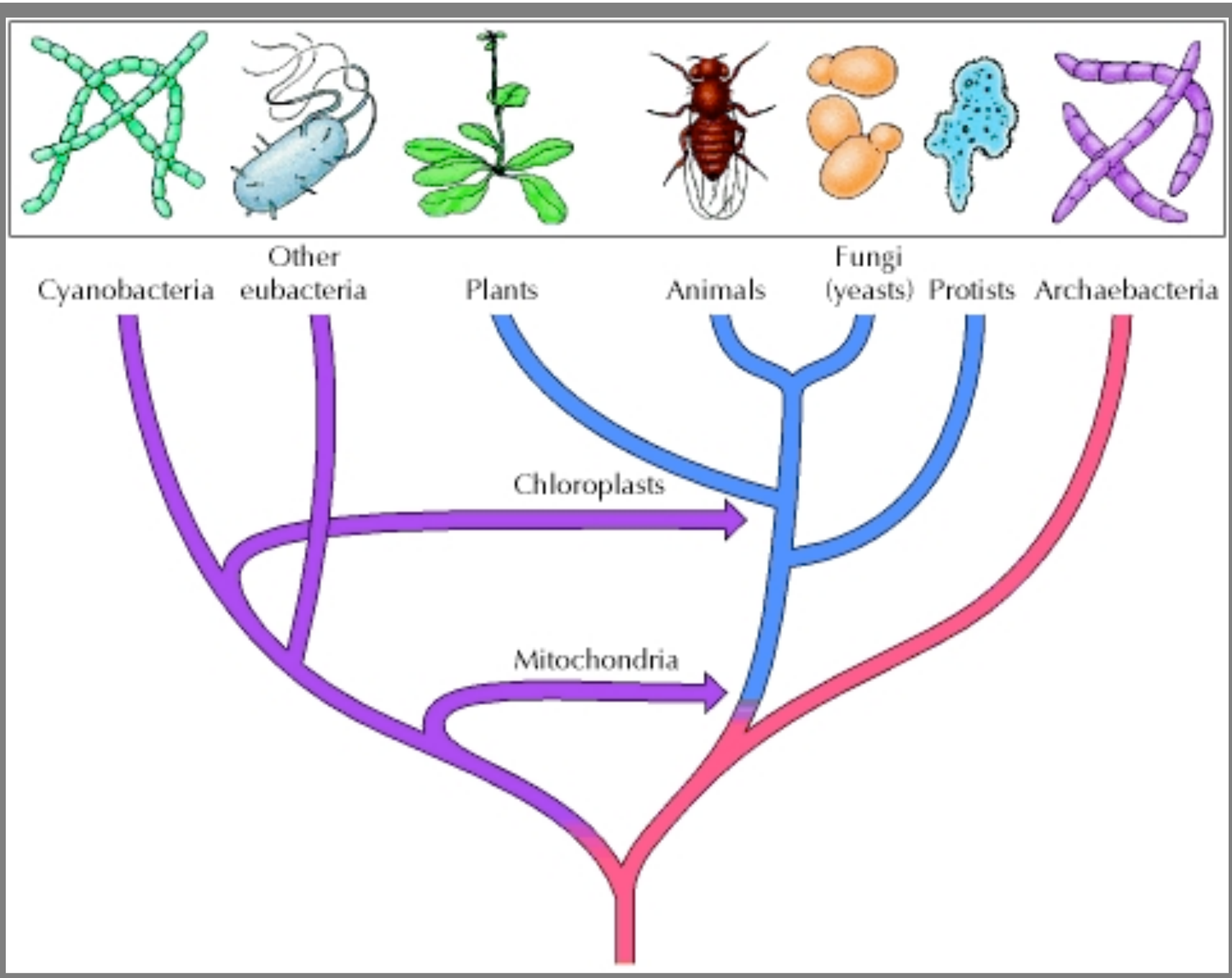
Evidence for Endosymbiosis

Prokaryotes	Mitochondria & Chloroplasts
• plasma membrane enzymes	• membrane enzymes homologous to prokaryotic plasma membrane
• plasma membrane transport systems	• membrane transport proteins homologous to prokaryotic plasma membrane
• replicate via binary fission	• replicate similar to binary fission
• single, circular chromosome with no histones	• organelles both posses their own single circular chromosome also with no histones even though eukaryotic chromosomes have histones
• ribosomes have unique size and sequence	• organelles posses their own ribosomes, which are equal in size to the prokaryotes and their RNA sequences are nearly identical

What are the advantages of membrane bound organelles?

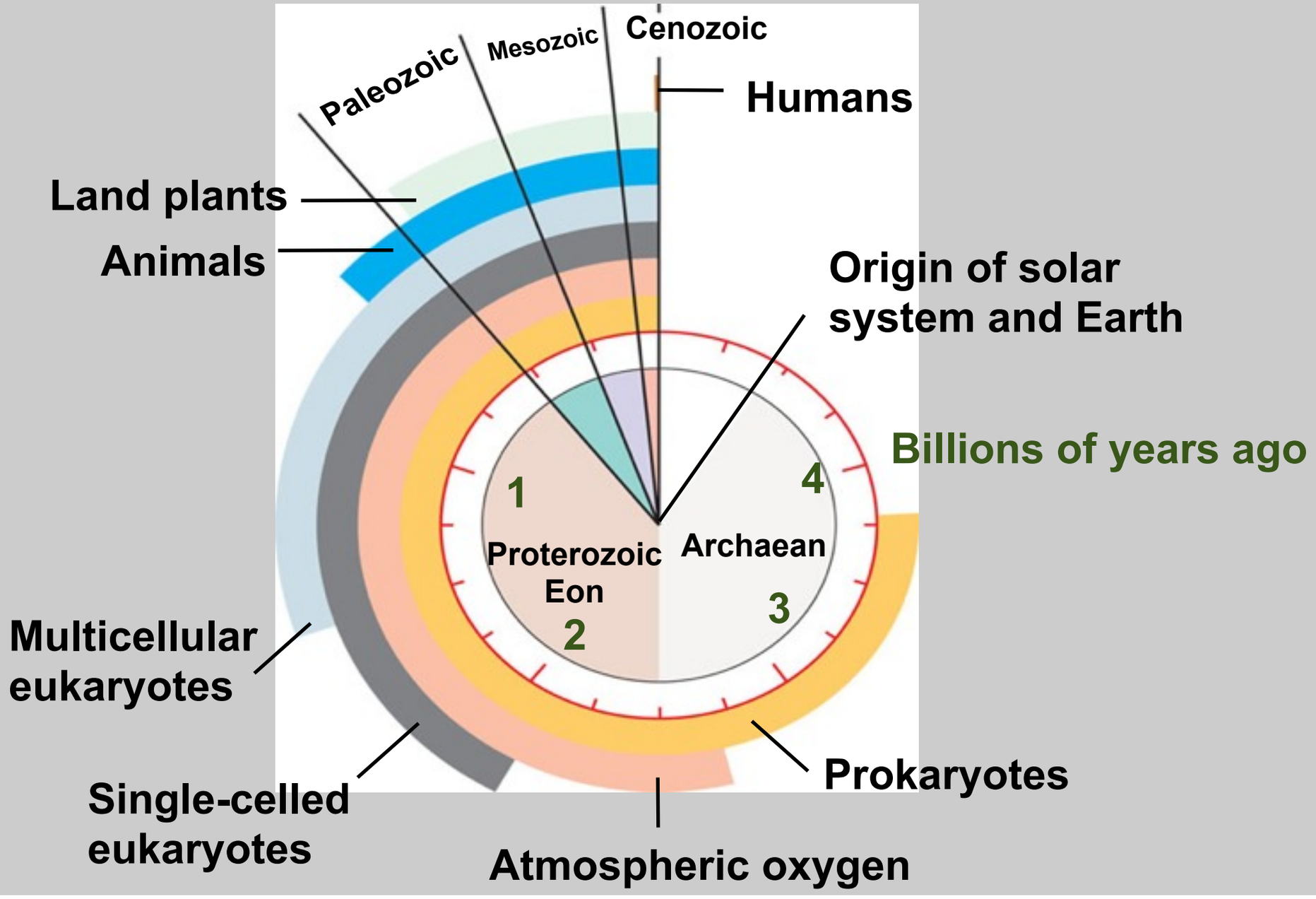
- **Protection**
  - *DNA has an added layer of protection*
- **Specialization**
  - *each organelle can do something different*
- **Efficiency**
  - *digestion, energy production gets better*
- **Diversity**
  - *gain new metabolic pathways*

Evolution of Cells



Major Events in Earth History

- **Evolution of Multicellular Organisms 1.7 bya**



How did multicellularity evolve?

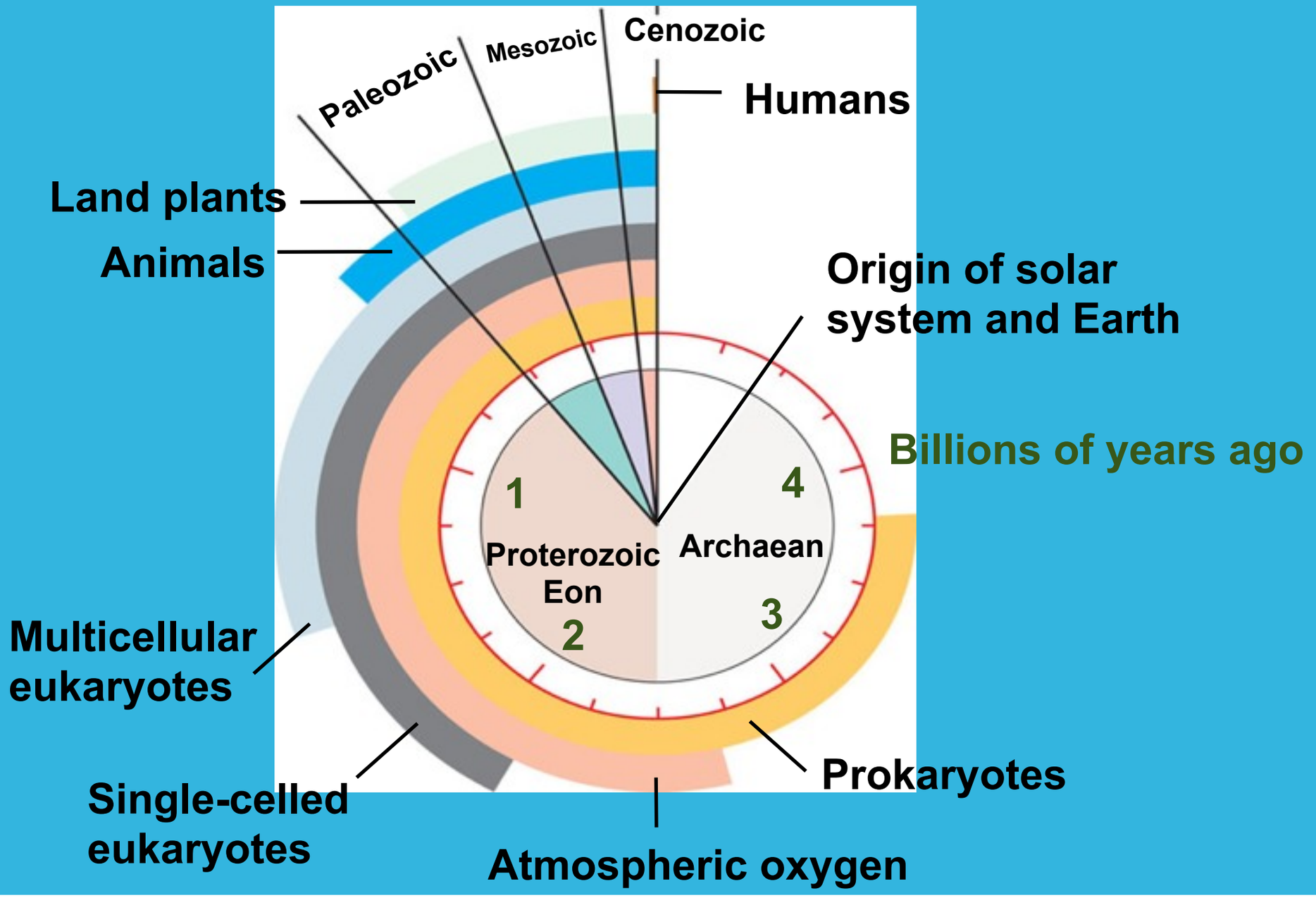
- Around 1.7 BYA multicellularity evolves.
- Unicellular eukaryotes form aggregates.
- These aggregates form multicellular colonies.
- The cells in the colony become specialized.
- Division of labor becomes pronounced.
- The colony cells become dependent on each others survival and you now a precursor for multicellular organism.

How did multicellularity evolve?

A collection of autonomously replicating cells form a colony

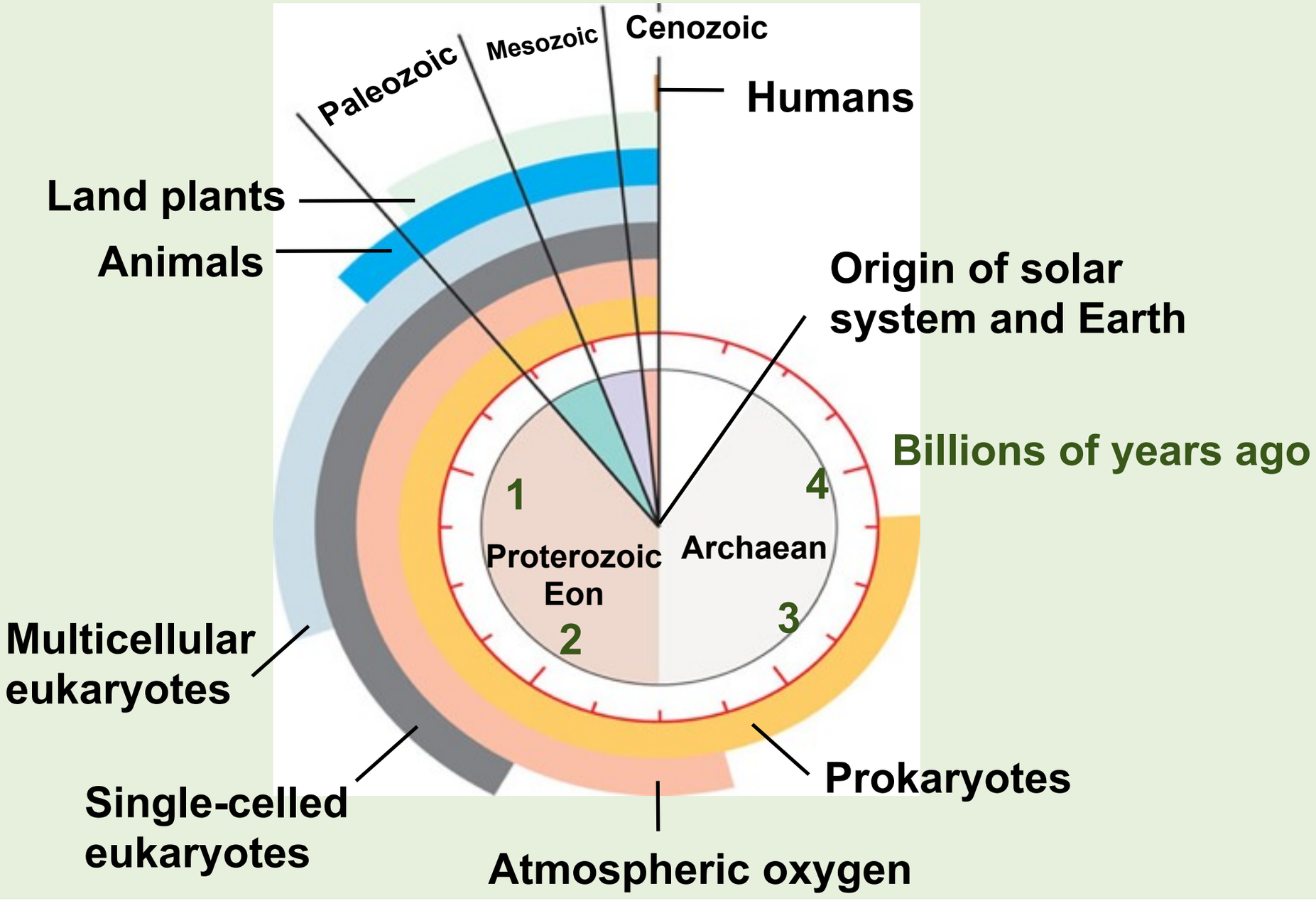
Major Events in Earth History

- **Evolution of Animals- (700-630 MYA)**
  - **Cambrian Explosion (530 MYA)**



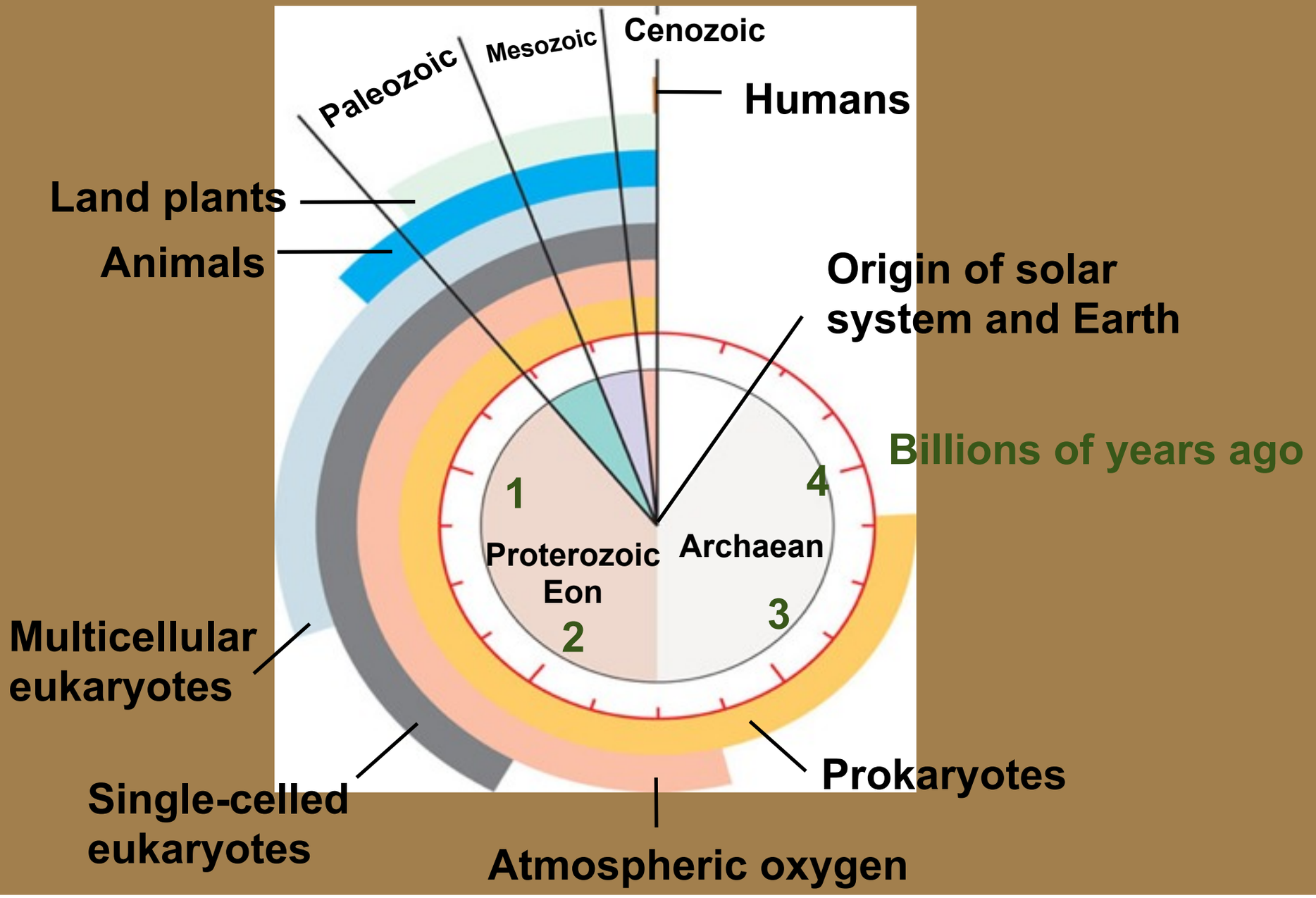
Major Events in Earth History

- **Colonization of Land- 500 - 420 MYA**
  - **plants, fungi and animals**



Major Events in Earth History

- **Evolution of Humans- 6-7 MYA**



The Fossil Record

- Fossils provide a window into the past.
- The fossil record reveals...
  - organisms have changed over time
  - many past organisms are unlike today's organisms
  - many organisms have gone extinct
  - relationships between organisms
  - emergence of new traits and the loss of others
  - age of the organisms

The Fossil Record

- Keep in mind the fossil record is an incomplete picture into the past.
- Fossils are by nature rare...
  - organisms must die in the right place and the right time to be preserved
  - even if the preservation occurred, geological changes destroyed many of them
  - fossils are biased remains, environmental biases and structural biases
    - *for example most remains are limited to hard shells, bone and teeth*

The Fossil Record

- None the less the fossil record still reveals a wealth of information about our past.

Fossil Formation Review

❶ Rivers bring sediment to the ocean. Sedimentary rocks containing fossils form on the ocean floor.

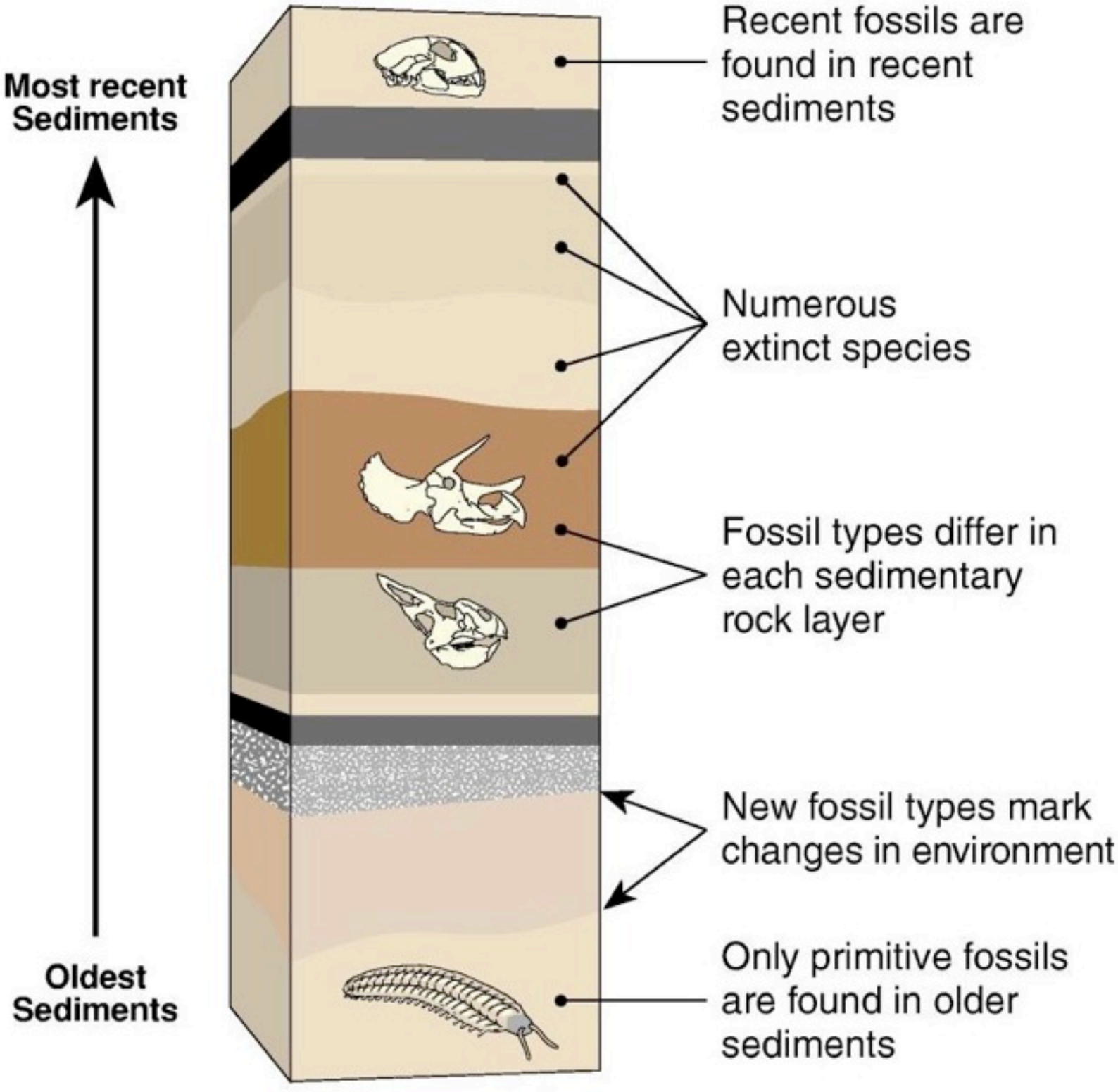
❷ Over time, additional strata are added, containing fossils from each time period.

❸ As sea levels change and the seafloor is pushed upward, sedimentary rocks are exposed. Erosion by rivers reveals strata; older strata contain older fossils.

Younger stratum with more recent fossils

Older stratum with older fossils

Fossil Trends Review



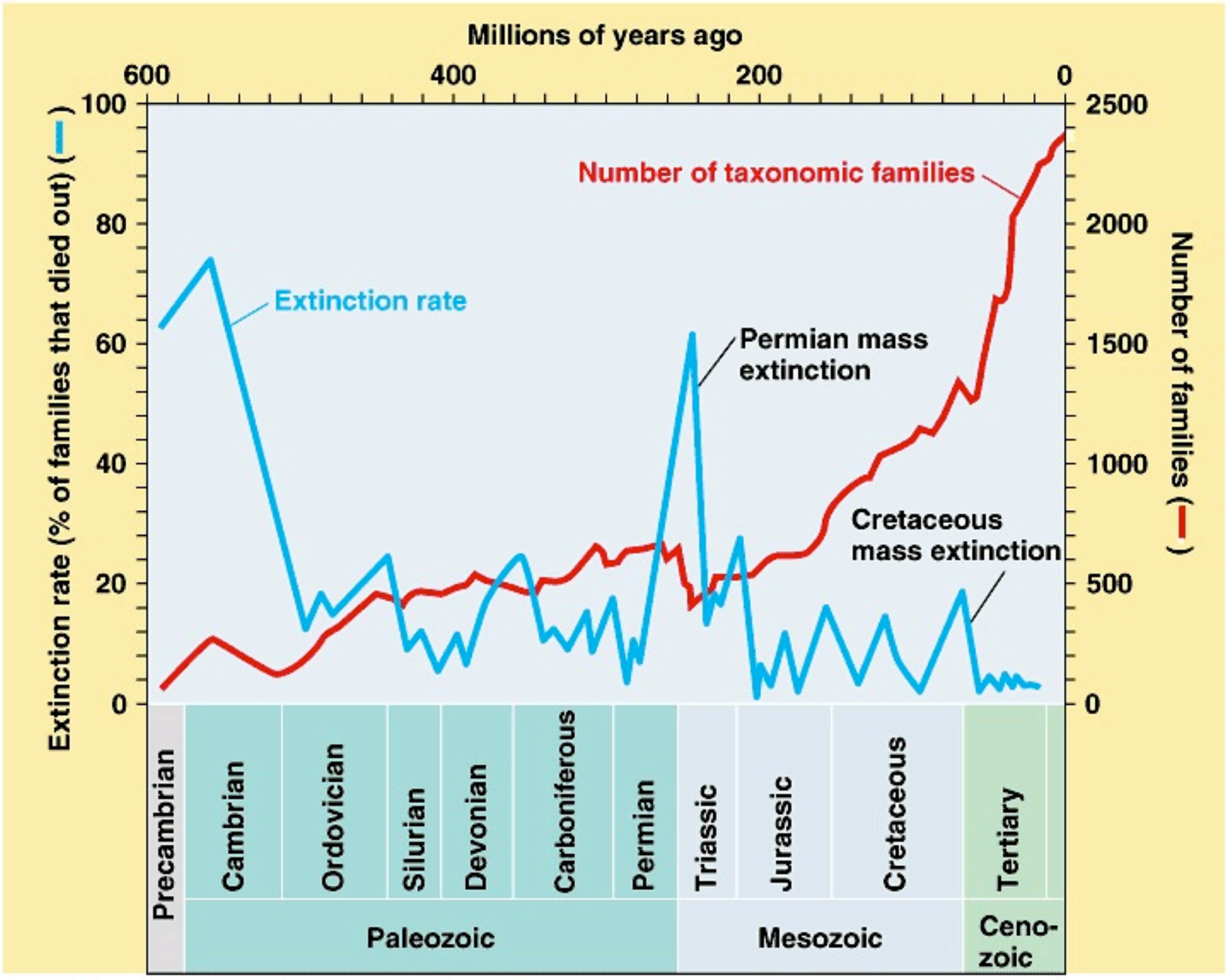
A Rise, A Fall and Something New

- The the theme of this presentation...Change!
  - The earth has witnessed episodic explosions of life, remarkable speciation events and widespread adaptive radiations.
    - *cambrian explosion, colonization of land, time of dinosaurs, the rise of mammals*
  - The earth has also witnessed episodic mass extinctions.
    - *5 in total, including the Permian extinctions and the Cretaceous extinctions*

Life is on a very long roller coaster ride!

A Rise, A Fall and Something New

Life is on a very long roller coaster ride! **BUT WHY?**



A Rise, A Fall and Something New

- **Change!**
  - The earth is forever changing, episodic large scale geological events have played a big part
    - *production of oxygen, meteor impacts, ice ages, climate change, volcanic eruptions, methane release,*

A Rise, A Fall and Something New

Mass Extinctions Past—and Present?

TIMELINE OF EXTINCTION marks the five most widespread die-offs in the fossil history of life on Earth.

END ORDOVICIAN
DURATION: **10 million years (my)**
MARINE GENERA OBSERVED EXTINGUISHED: **60%**
CALCULATED MARINE SPECIES EXTINCT: **85%**
SUSPECTED CAUSE: Dramatic fluctuations in sea level

Trilobite

Placoderm

LATE DEVONIAN
DURATION: **<3 my**
MARINE GENERA OBSERVED EXTINGUISHED: **57%**
CALCULATED MARINE SPECIES EXTINCT: **83%**
SUSPECTED CAUSES: Impact, global cooling, loss of oxygen in oceans

END PERMIAN
DURATION: **Unknown**
MARINE GENERA OBSERVED EXTINGUISHED: **82%**
CALCULATED MARINE SPECIES EXTINCT: **95%**
SUSPECTED CAUSES: Dramatic fluctuations in climate or sea level; asteroid or comet impacts; severe volcanic activity

Rugose coral

Phytosaur teeth

END TRIASSIC
DURATION: **3 to 4 my**
MARINE GENERA OBSERVED EXTINGUISHED: **53%**
CALCULATED MARINE SPECIES EXTINCT: **80%**
SUSPECTED CAUSES: Severe volcanism; global warming

END CRETACEOUS
DURATION: **<1 my**
MARINE GENERA OBSERVED EXTINGUISHED: **47%**
CALCULATED MARINE SPECIES EXTINCT: **76%**
SUSPECTED CAUSES: Impact; severe volcanism

Mosasaur

Millions of years ago

570 510 439 409 363 290 248 210 146 65 1.64

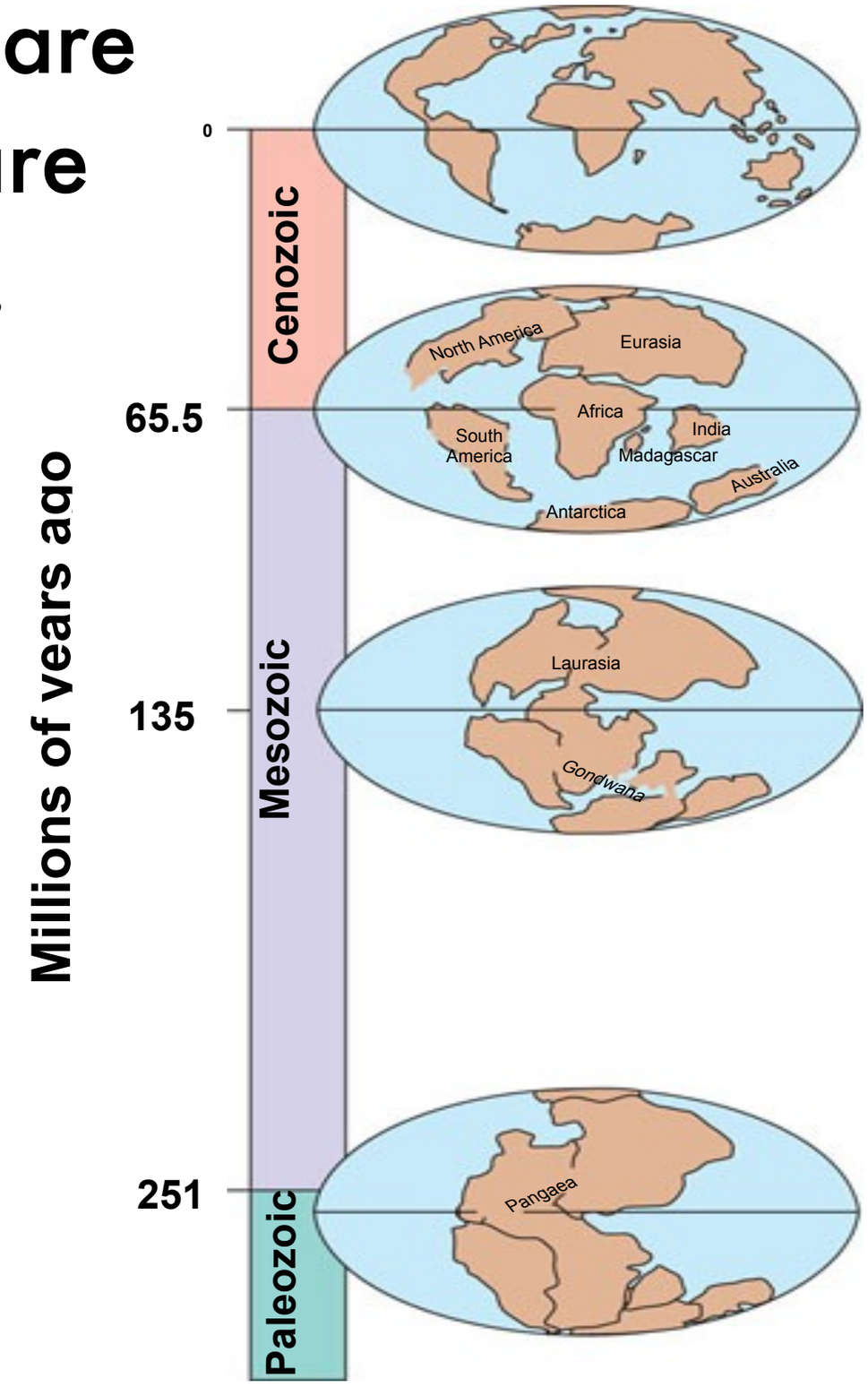
Cambrian Ordovician Silurian Devonian Carboniferous Permian Triassic Jurassic Cretaceous Tertiary Quaternary

A Rise, A Fall and Something New

- **Change!**
  - Even on a slower acting or smaller scale the earth is dynamic.
    - *plate tectonics move land masses, mountains are formed, lakes created, seas disappear, rain patterns shift,etc,*

A Rise, A Fall and Something New

The earth's continents are not stationary, they are continually moving.



India collided with Eurasia just 10 million years ago, forming the Himalayas, the tallest and youngest of Earth's major mountain ranges. The continents continue to drift.

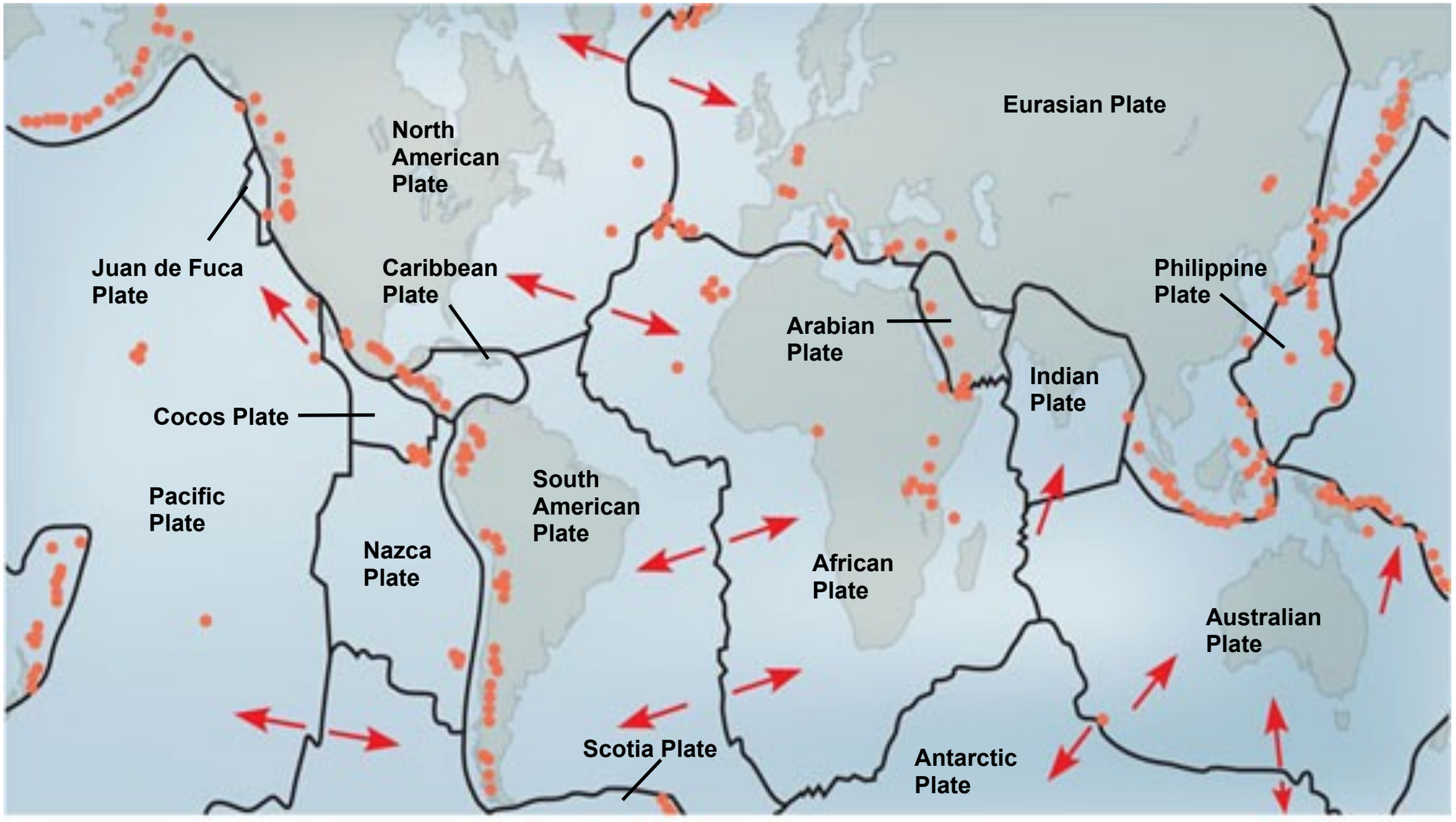
By the end of the Mesozoic, Laurasia and Gondwana separated into the present-day continents.

By the mid-Mesozoic, Pangaea split into northern (Laurasia) and southern (Gondwana) landmasses.

At the end of the Paleozoic, all of Earth's landmasses were joined in the supercontinent Pangaea.

A Rise, A Fall and Something New

The earth's plates either pull apart or crash into one another. The boundaries of these plates are highly active (earth quakes/volcanoes).

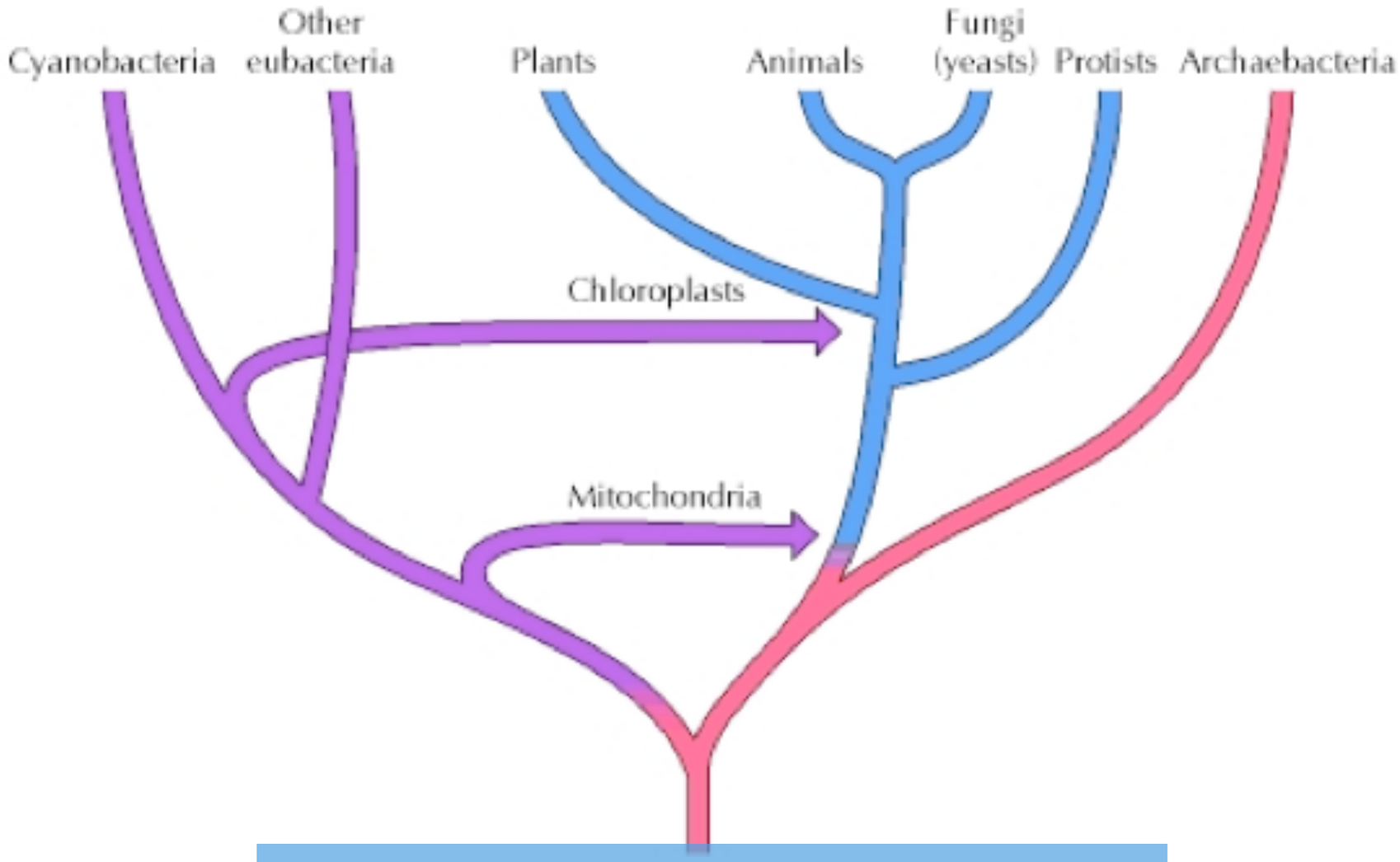


A Rise, A Fall and Something New

- **The "Two": the Earth and its Organisms are extricably tied together!**
  - The change of one effects the other
    - Are we now on the verge of a 6th major extinction?
  - Will human impact on on planet be added to the list of causes for mass extinction?
    - *4 of the 5 mass extinctions did occur when earth's temperature were abnormally high*

The Tree of Life

- Evidence suggests that all life shares a universal common ancestor.



The Tree of Life

- Traits of the...

Universal Common Ancestor

prokaryotic
-no membrane bound organelles

simple metabolism

cell membrane
-made of lipids

cytosol
-different from outside solution

makes simple proteins

simple genetic material
-RNA

prokaryotic

Unicellular
-self contained functions

reproduced
-asexually

small
-high SA:V ratio

ability to mutate and adapt

anaerobic or aerobic depending on site of evolution

chemotrophic
-likely heterotrophic may have been autotrophic

aquatic