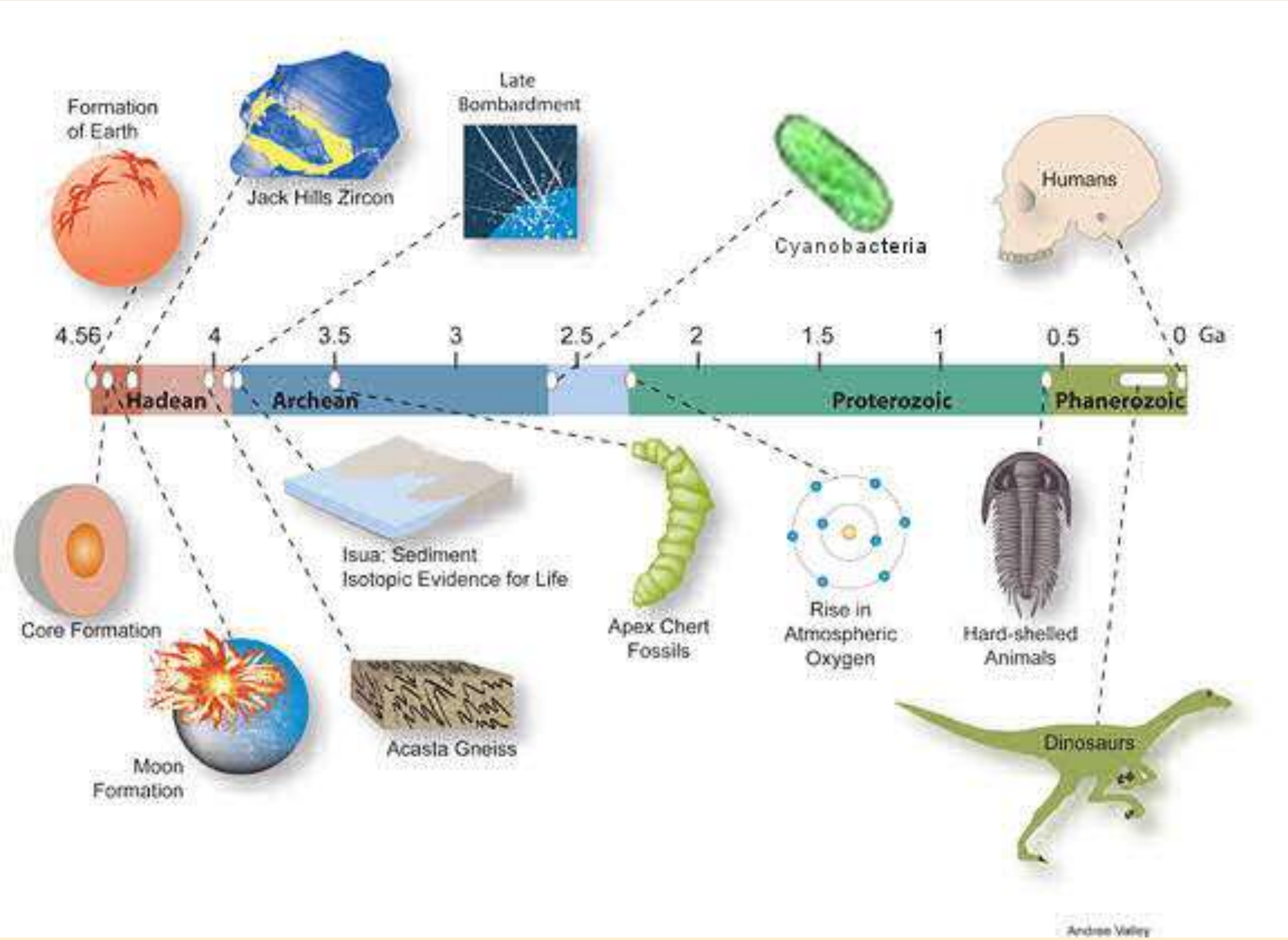
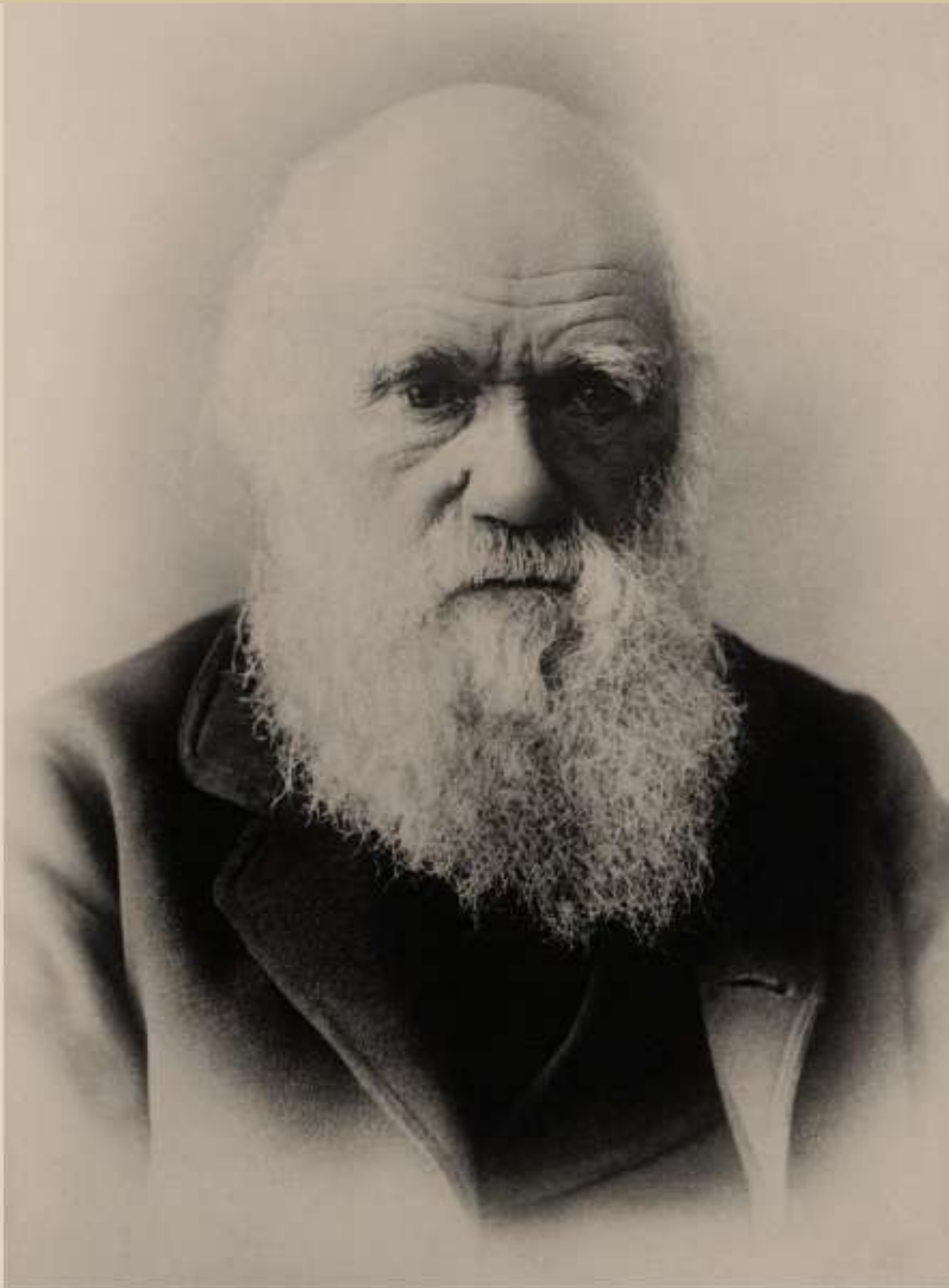
Origin of Life



“Warm little pond…..”

"But if (and oh what a big if) we could conceive in some **warm little pond** with all sort of **ammonia and phosphoric salts,—light, heat, electricity** present, that a **protein** compound was **chemically** formed, ready to undergo still more complex changes … "

- C. Darwin to J. D. Hooker, 1871



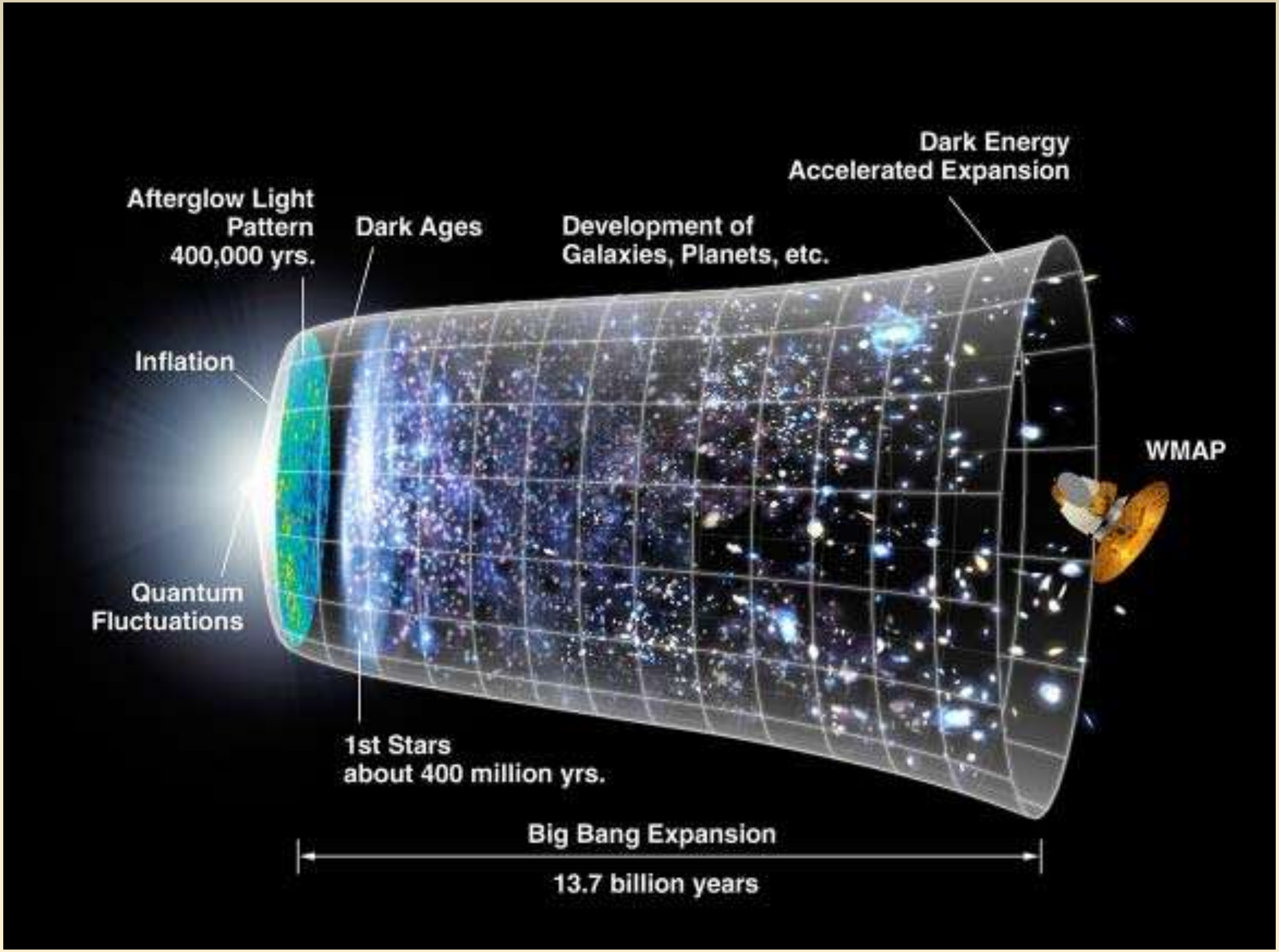
Creation Myths







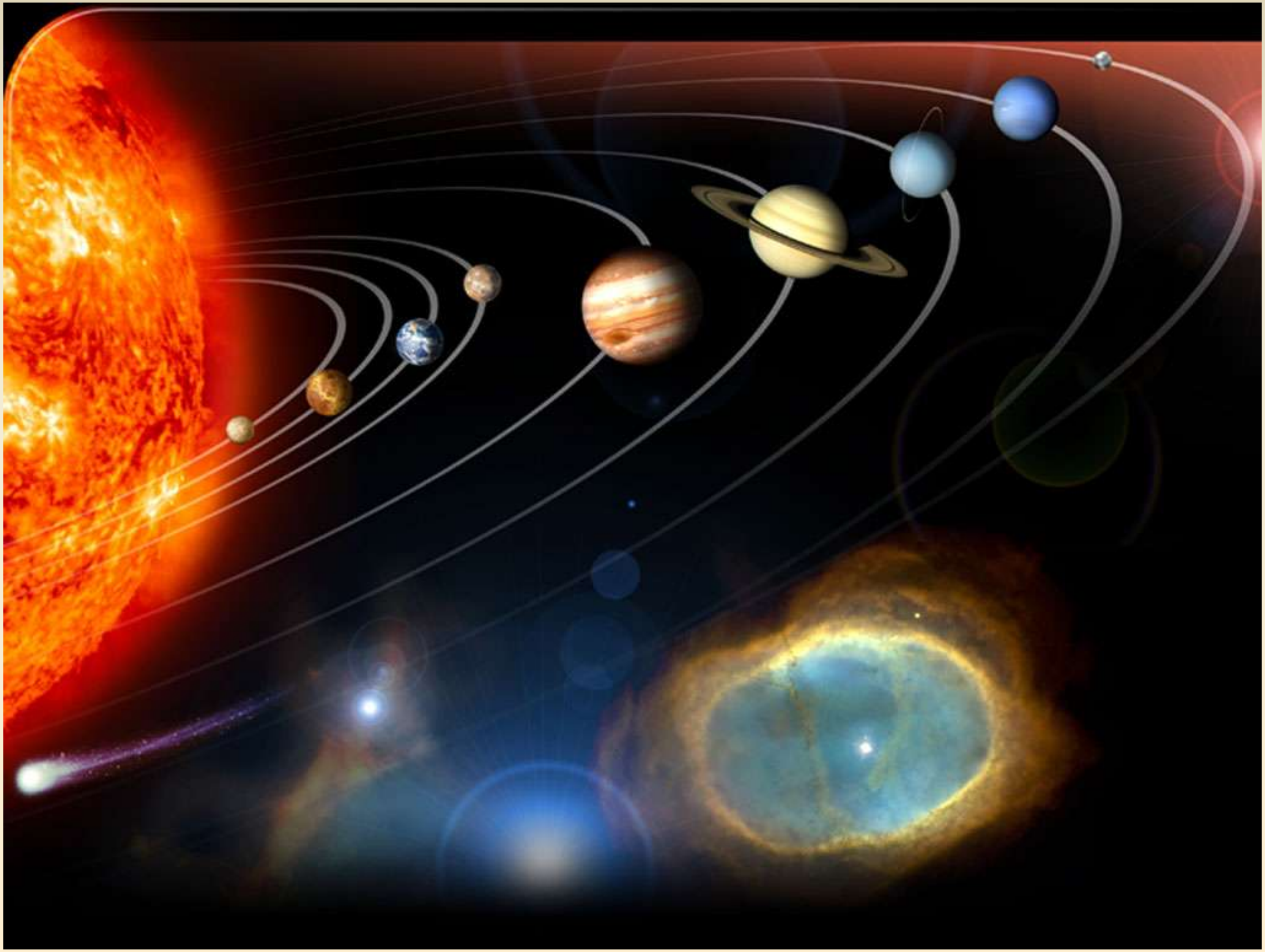
Big Bang Theory



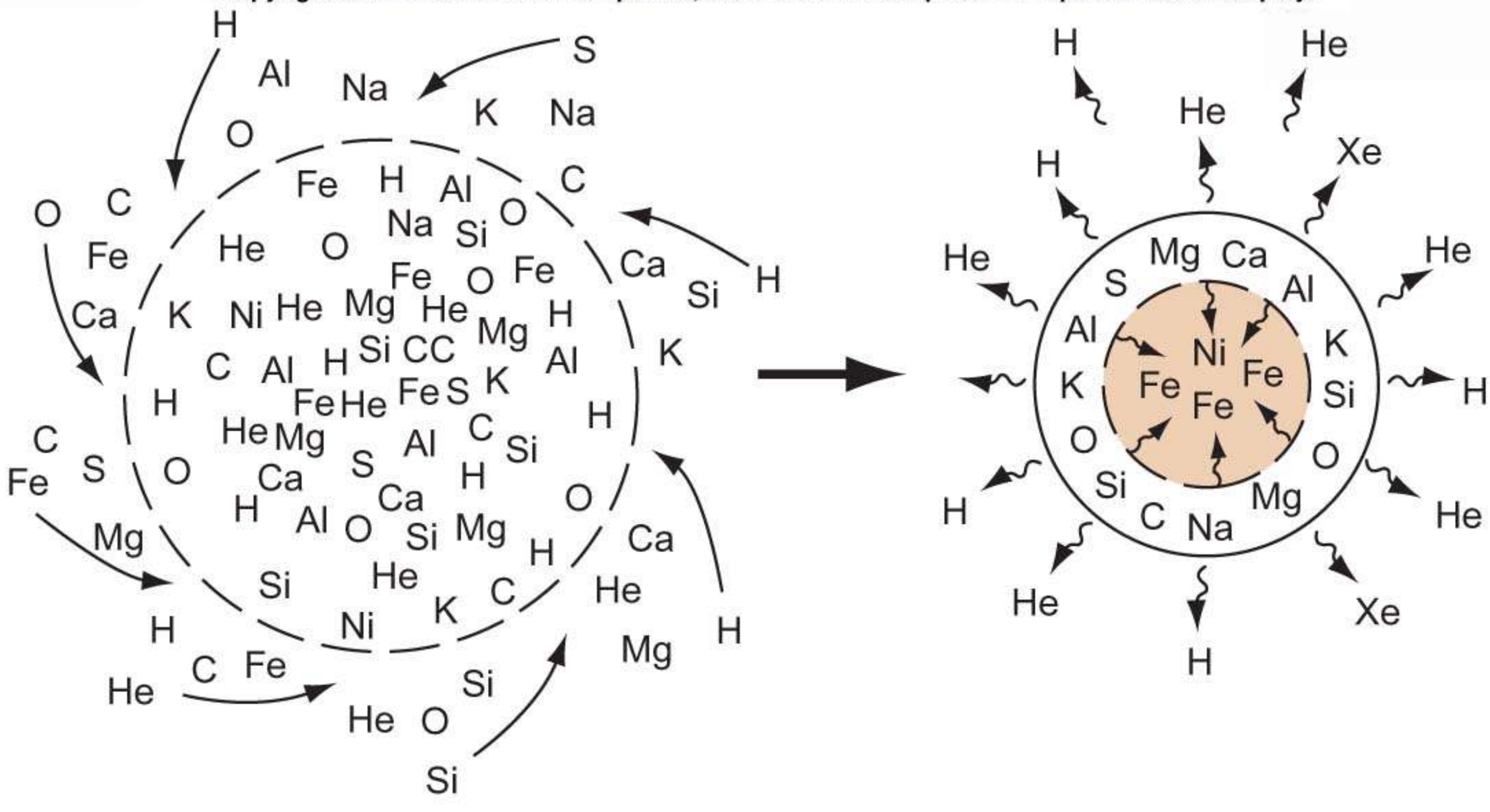
Formation of the Solar System

4.6 billion years ago

Our Solar system forms



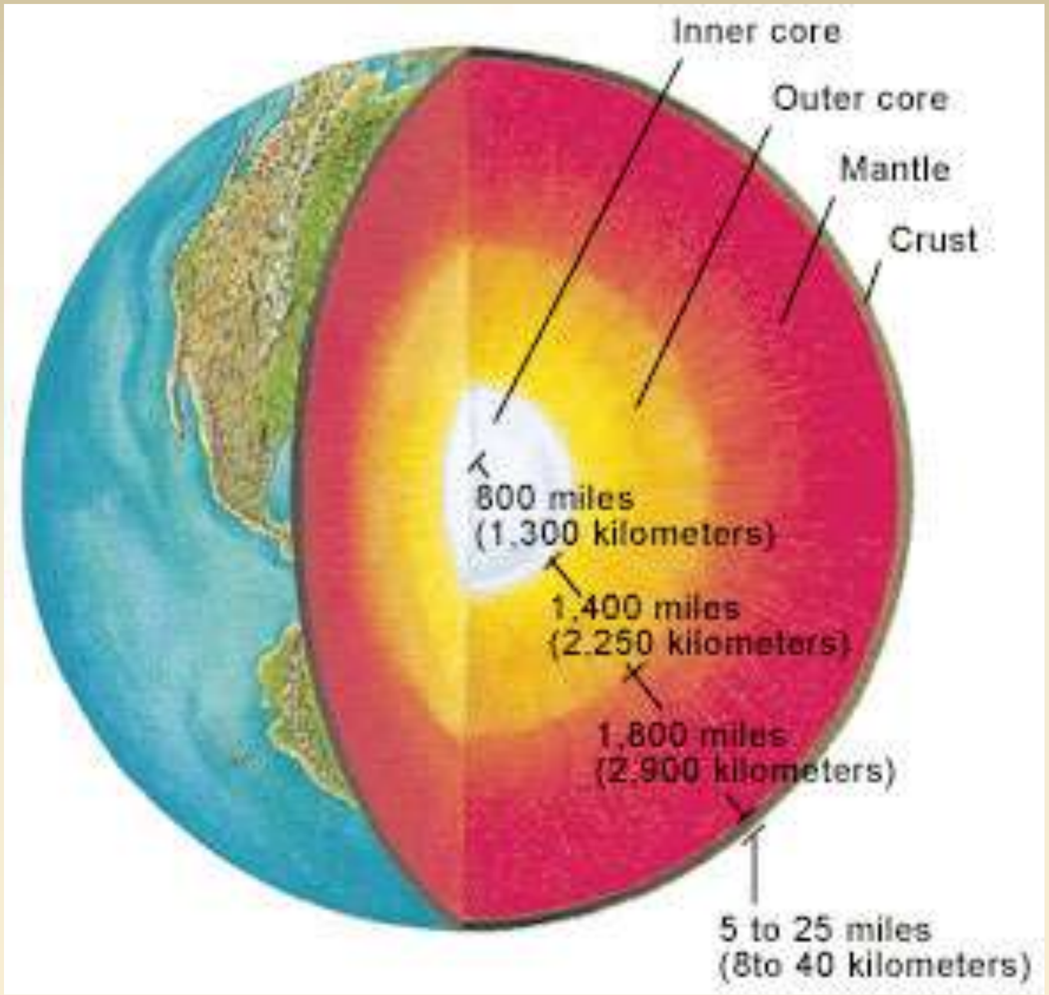
Stages in Formation of Early Earth



A. Initial accretion

B. Contraction and differentiation

. From (A) a homogeneous, low-density protoplanet to (B) a dense, differentiated planet



The Earth is roughly a sphere, with a radius of 6,371 km. In other words, you'd need to dig a tunnel down 6,371 km to reach the center of the Earth; it's hottest place. Geologists believe that the core of the Earth is made up of metals, like iron and nickel, and it's probably in a solid state, surrounded by a shell of liquid metal. The inner core is the hottest part of the Earth, and measures 2,440 km across.

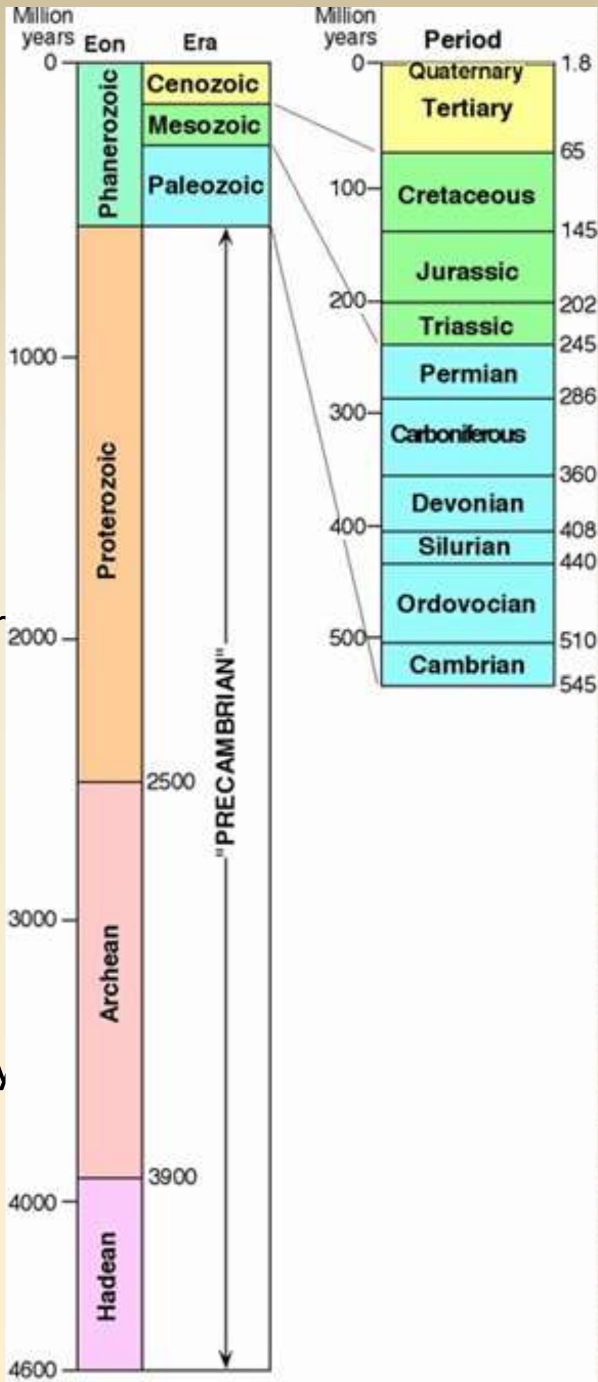
Geological Eras

We can divide the history of life on Earth into six main stages:

1. Hadean Era: from the formation of the Earth about 4.6 billion years ago until about 4 billion years ago. The Earth's surface is constantly bombarded by large objects which repeatedly melt the whole surface, making life impossible.
2. Archean Era: from 4 to 2 billion years ago (very roughly). Origin of life, all life is single celled bacteria. No oxygen in the atmosphere.
3. Proterozoic Era. 2 billion until 550 million years ago. Oxygen appears in the atmosphere and builds to approximately the present level of 21%. Eukaryotes appear. No hard parts: bone, teeth, shells, so very few fossils.

– the first three eras are collectively called the Pre-Cambrian era

4. Paleozoic Era. 550 to 250 million years ago. Fossils appear, complex multicellular organisms, invasion of the land by plants and animals.
5. Mesozoic Era. 250 to 65 million years ago. Appearance of mammals and flowering plants, but the land is dominated by dinosaurs (reptiles).
6. Cenozoic Era. 65 million years ago until present. Land dominated by mammals and flowering plants.



“Pre-Cambrian”

1. **Hadean Era:** from the formation of the Earth about 4.6 billion years ago until about 4 billion years ago. The Earth’s surface is constantly bombarded by large objects which repeatedly melt the whole surface, making life impossible.

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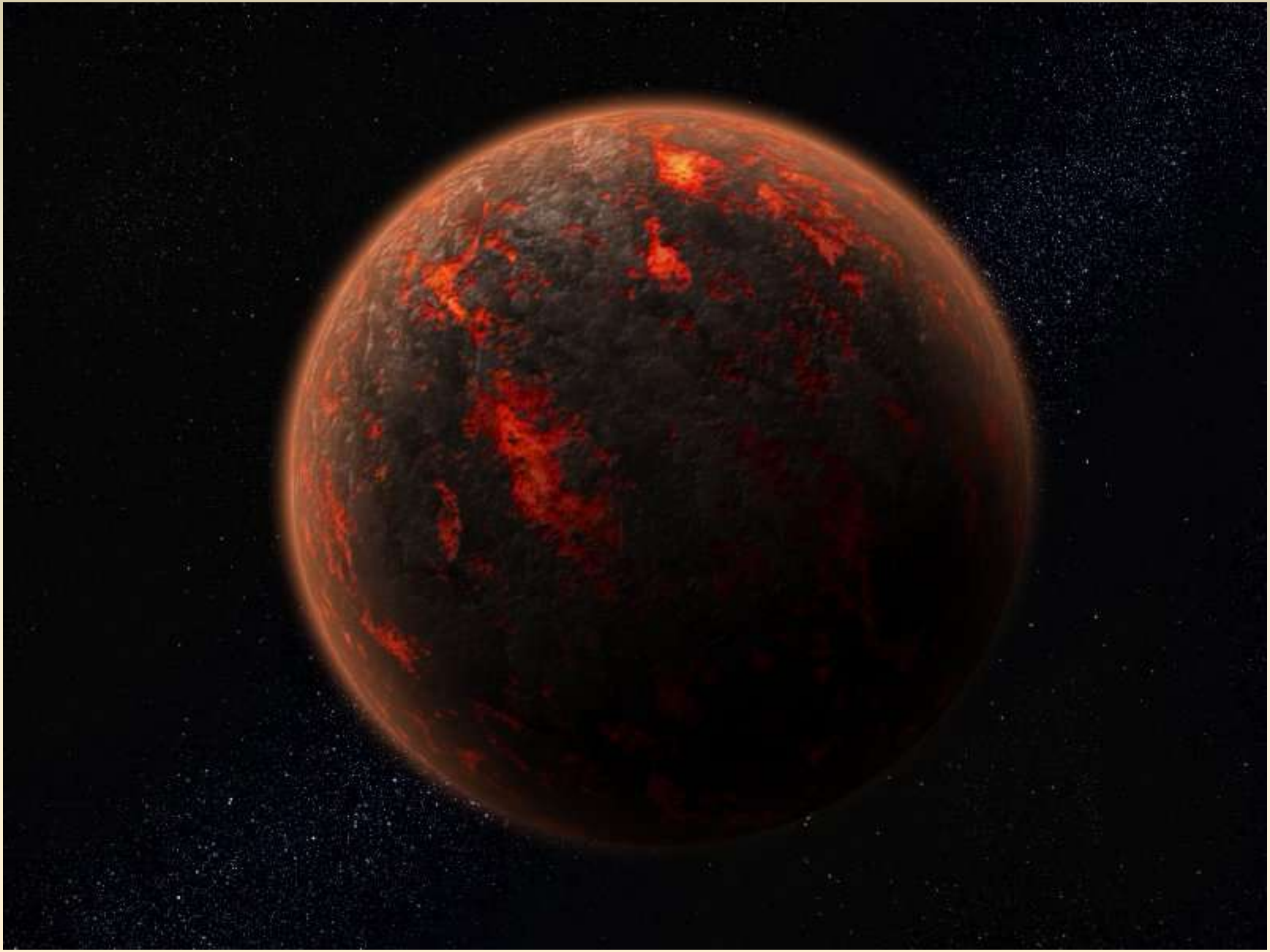
Earth 4.5 BY Ago

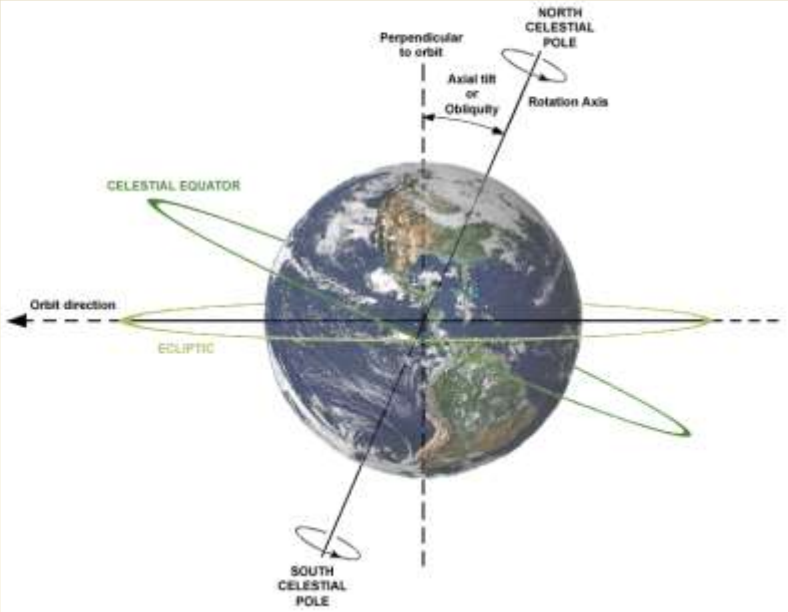


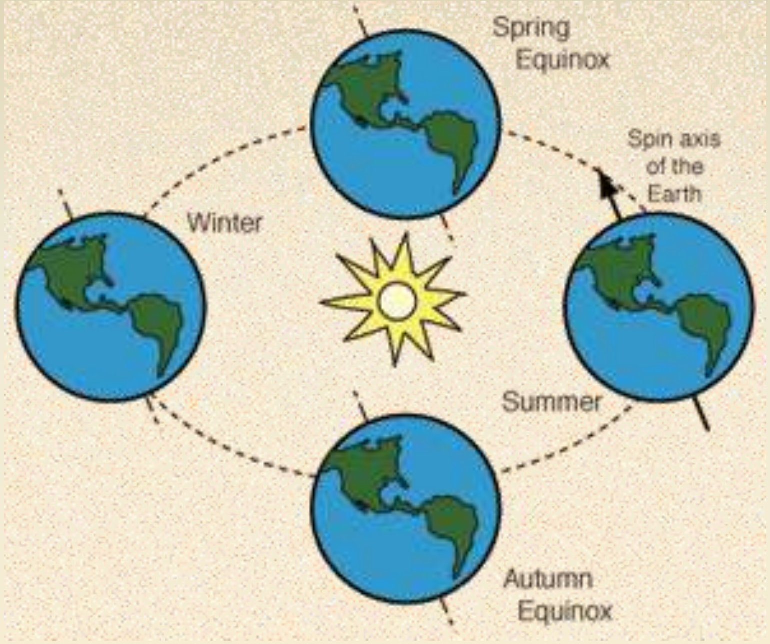
Bombardment

Early Earth

Origin of the Moon

The prevailing hypothesis today is that the Earth–Moon system formed as a result of a giant impact, where a Mars-sized body (named **Theia**) collided with the newly formed proto-Earth, blasting material into orbit around it that accreted to form the Moon

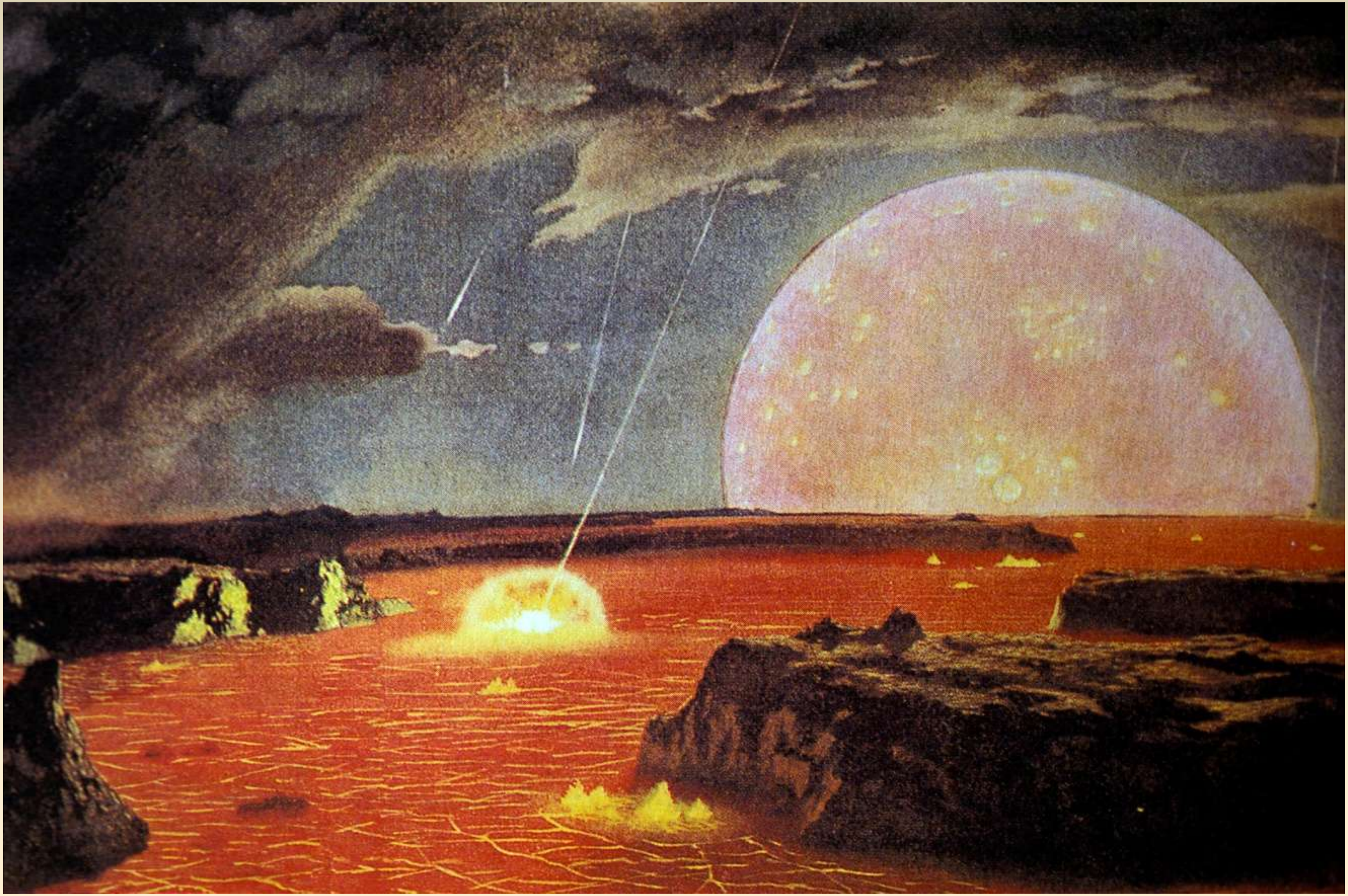


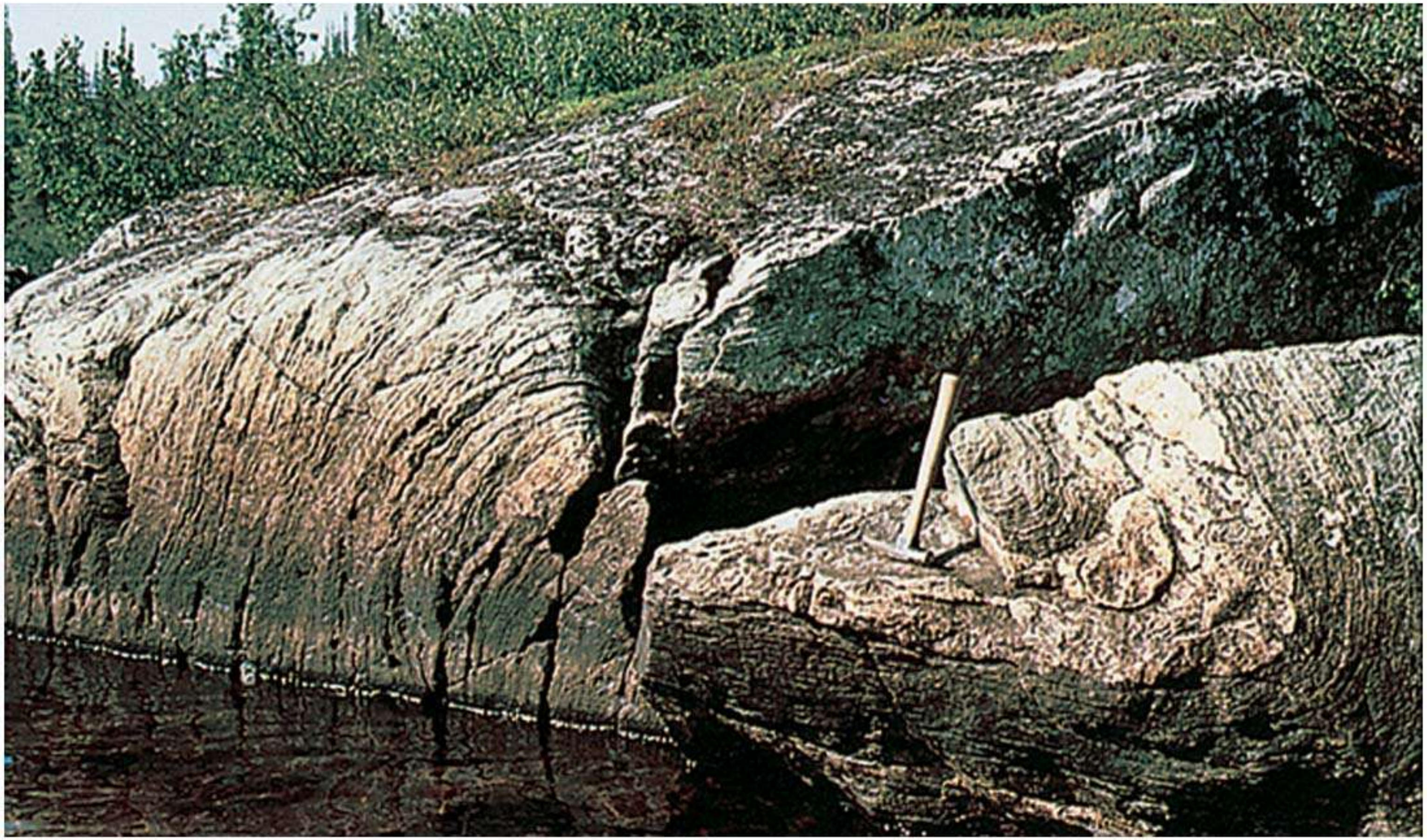


The Earth's spin axis is tilted 23.5° with respect to the ecliptic, giving moderate **seasons** and preventing temperature extremes anywhere on the planet

Molten Earth – 4.5 BY

Hadean - Era of Large Impacts

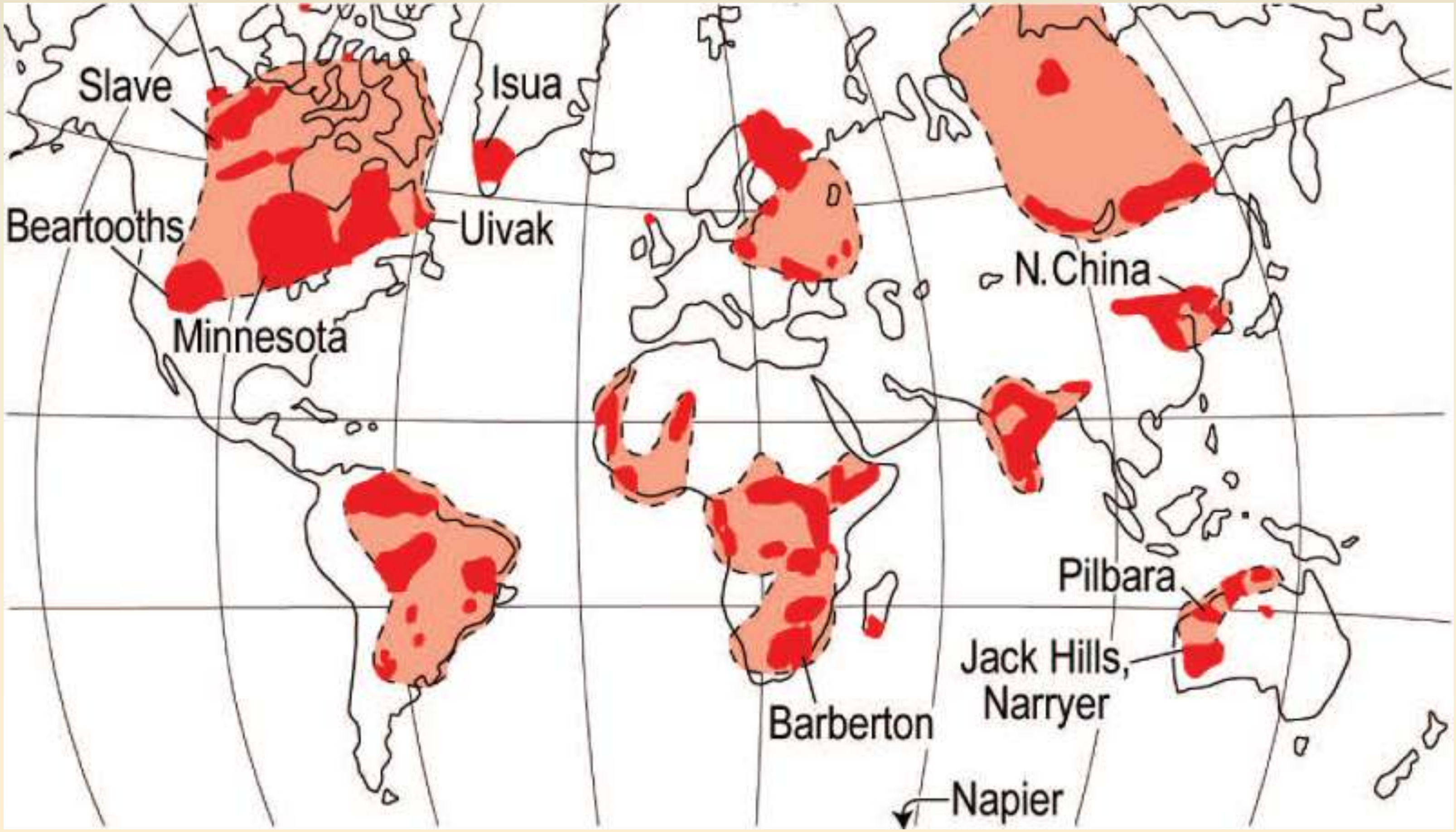




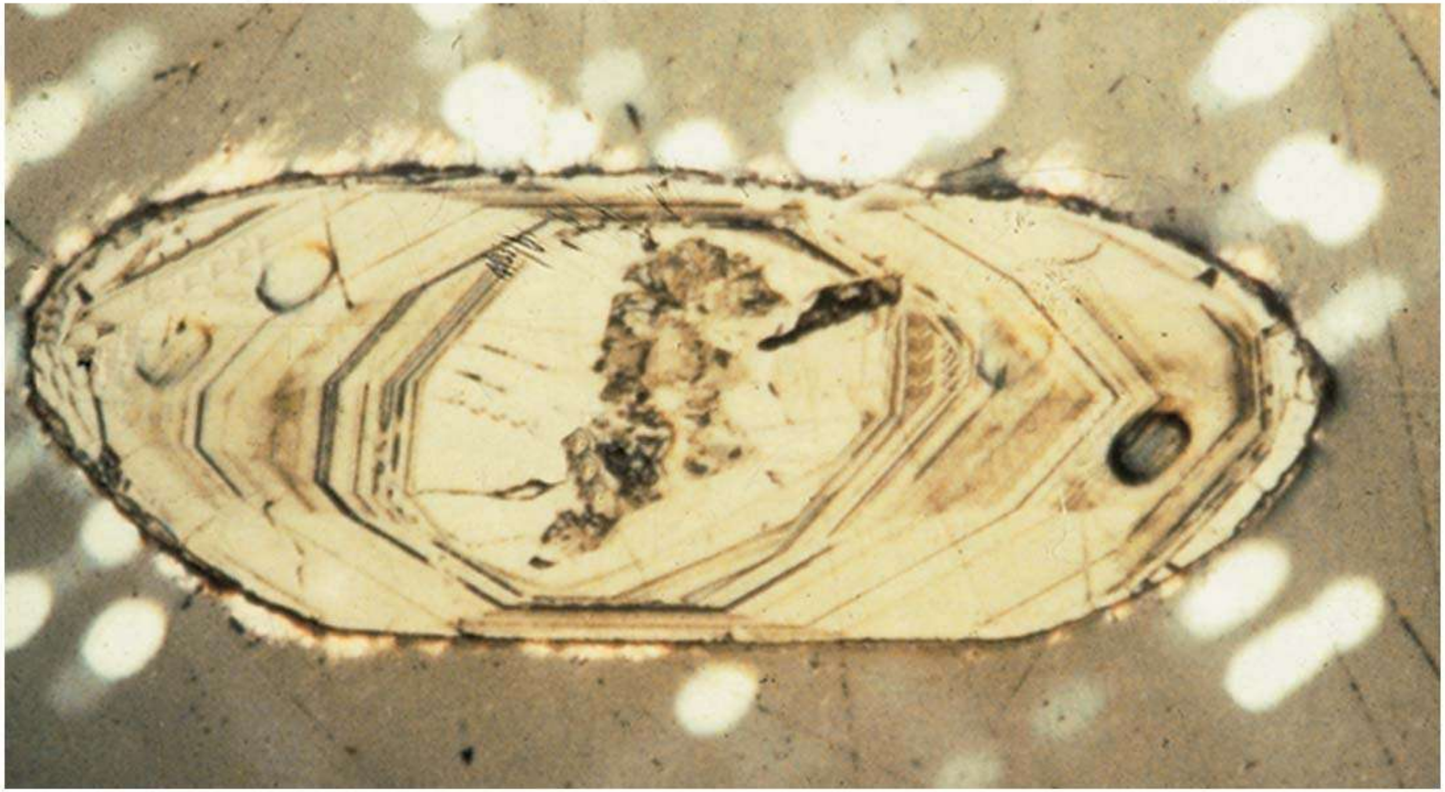
The Acasta Gneiss. Great Slave Province, NW Territories, Canada. One of the oldest (4.03 Bya) dated rocks on Earth. This must have been one of the first crustal rocks to form either at Late Hadean or shortly thereafter.

Acasta River – Gneiss Outcrop

Global distribution of Archean rocks in modern continents. Known (red), suspected (pink). Areas with rocks or zircons older than 3.6 billion years are labeled by name.



Oldest Rocks – Zircon, 4.03 BY



Zircon grain from the Acasta Gneiss, Slave Province, NW Territories, Canada. The crystal has been etched with acid to highlight the growth zones. These zircons have been dated to 4.03 By.

Archean Era, ~4 – 2 BY

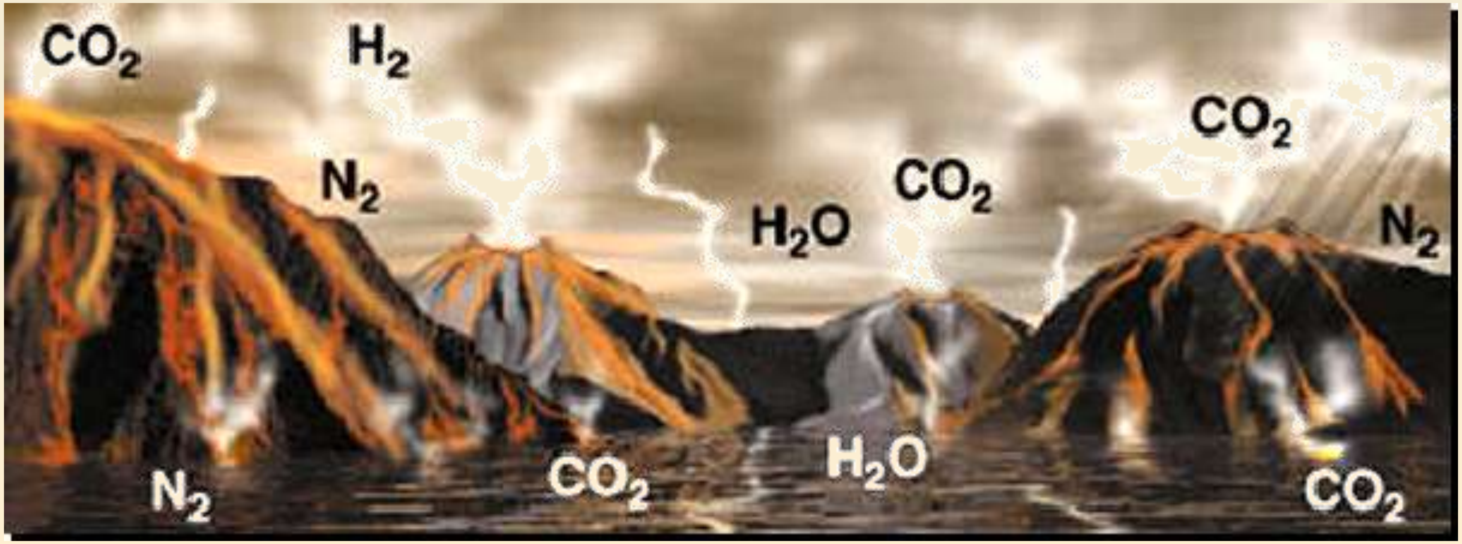
Origin of the Atmosphere

Sun's energy stripped away 1st atmosphere

2nd atmosphere formed from volcanic outgassing

Primitive atmosphere: CO2, water vapor, lesser amts of

CO, N2, H2, HCl, and traces of NH3 and CH4 (3.5 bya)



Early Atmosphere

=

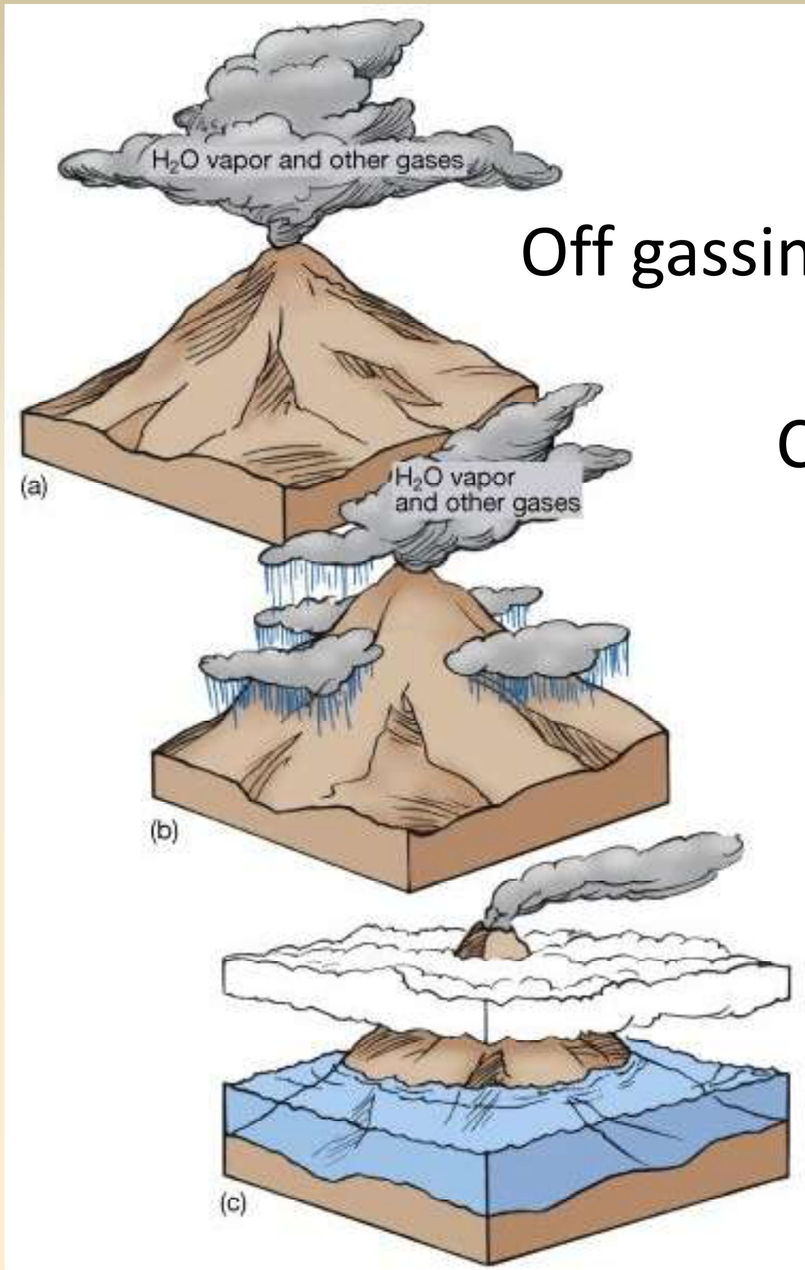
Volcanic gases

Iceland volcano

	%
H_2O	**95 - 97**
CO_2	1.1 - 1.9
SO_2	1.5 - 2.3
H_2S	0.07 - 0.08
HCl	0.004 - 0.006

No free O_2!

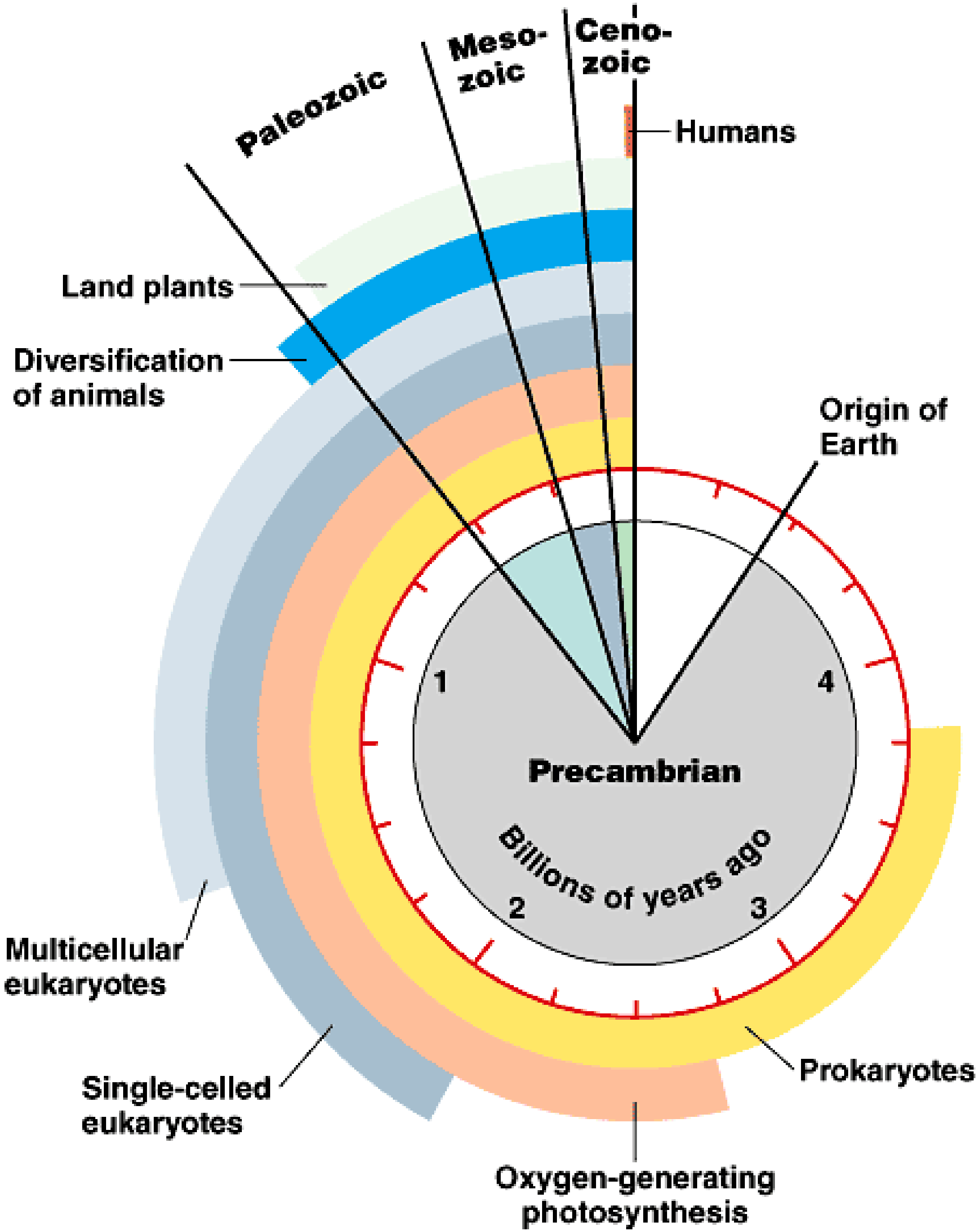
Formation of Earth's Oceans (4 by ago):



Off gassing of water vapor from volcanos

Condensation

Rain



Clock analogy for some key events in evolutionary history

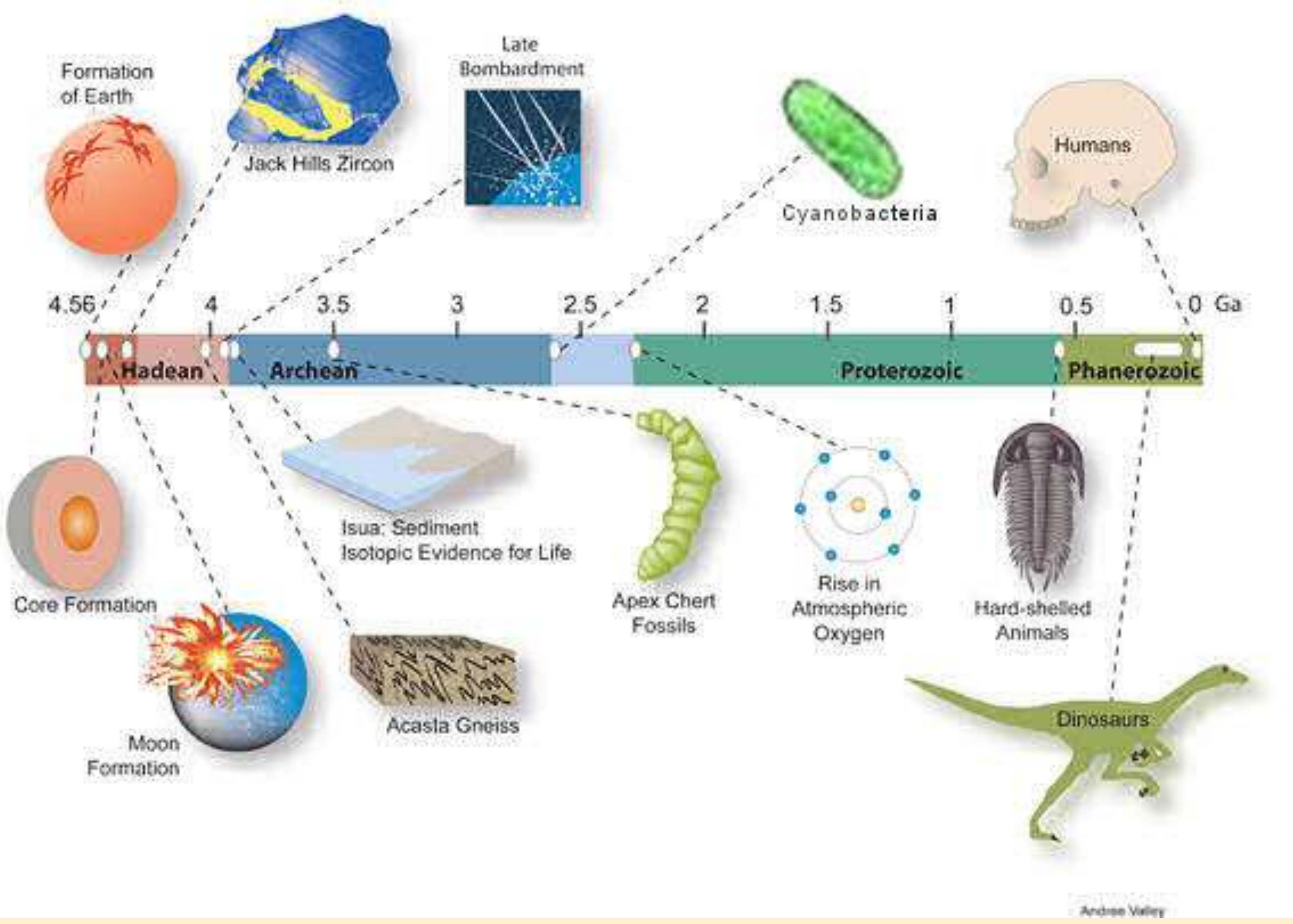
1. The earth was formed ~4.5 billion years ago

2. It took ~500 million years for the crust to solidify.
   End of Hadean, Beginning of Archean

3. The oldest fossils of microorganisms
   - 3.5 billion years old,
   - embedded in rocks in western Australia

   Prokaryotes dominated from 3.5 to 2 billion years ago.
   - During this time, the first divergence occurred:
     Bacteria and Archaea

Oldest known Eukaryote fossils are 1.85 to 2.1 BY



Formation of Earth
Jack Hills Zircon
Late Bombardment
Cyanobacteria
Humans
4.56
4
3.5
3
2.5
2
1.5
1
0.5
0 Ga
Hadean
Archean
Proterozoic
Phanerozoic
Core Formation
Moon Formation
Isua: Sediment Isotopic Evidence for Life
Acasta Gneiss
Apex Chert Fossils
Rise in Atmospheric Oxygen
Hard-shelled Animals
Dinosaurs
Andrea Valley

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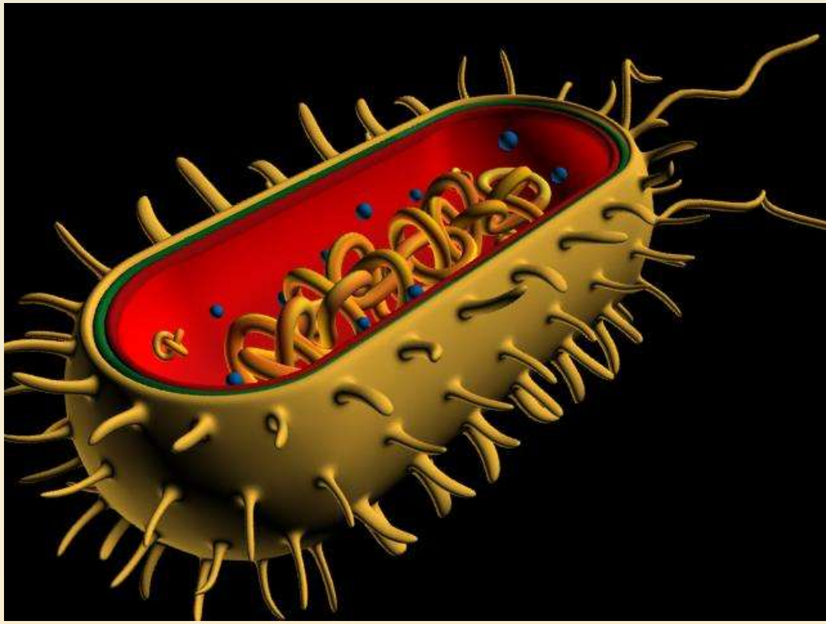
Archean Era: 4-2 BY

Prokaryotes

Characteristics of the first cells:

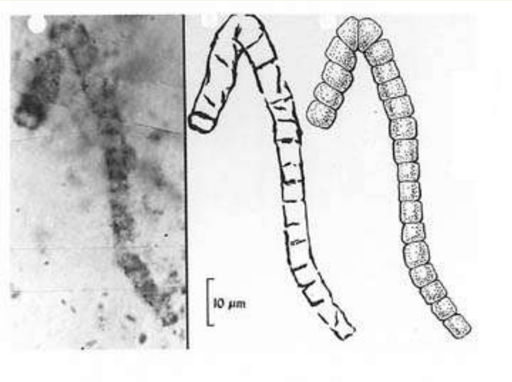
1. Prokaryotes
2. Anaerobic as there was no oxygen in the atmosphere
3. First came the common ancestor, then 3.5 billion years ago the prokaryotes evolved into two groups: Bacteria and Archaea



Age of the Bacteria

Prokaryotes dominated the Earth for most of its history. Multicellular eukaryotes are less than 1 billion years old.

Prokaryotic fossils are very small, and consist mainly of fossilized cell walls. Some structures formed by mats of bacteria are found today and also fossilized from 2 billion years ago. The cyanobacteria (blue-green algae) form cell walls that fossilize nicely.



Traces of organic compounds can also be found, and attributed to living cells because they contain unusual ratios of carbon and sulfur isotopes.

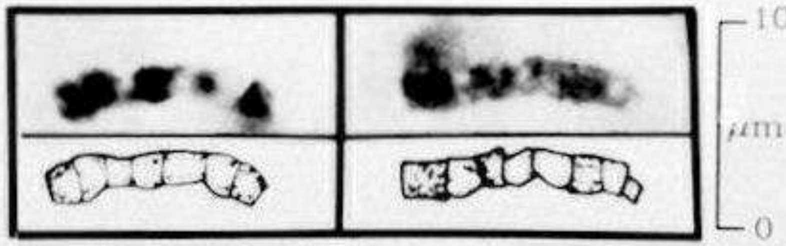
Oldest traces of life: 3.5 – 3.8 billion years old. Very few rocks available of this age or older.

Bacteria can live under a much wider variety of conditions than eukaryotes. They use many different sources of energy and carbon, and they can grew at very high temperatures, high pressures, acidic conditions, etc. Large eukaryotes need much more stable conditions to survive.

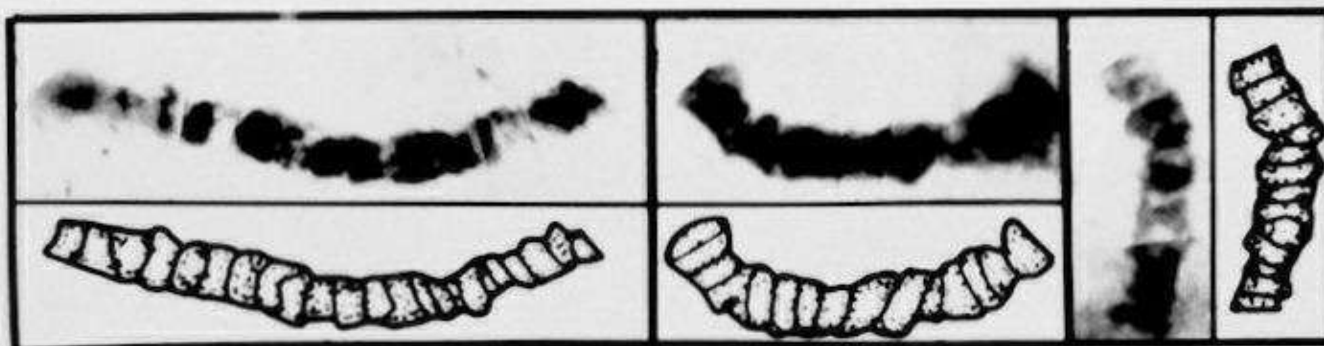
APEX CHERT, 3,465 ± 5 Ma, WESTERN AUSTRALIA

NARROW (1-3μm) CELLULAR FILAMENTS

Outcrop of the Apex Chert near Chinaman Creek, Pilbara in Western Australia.



Primaevifilum minutum

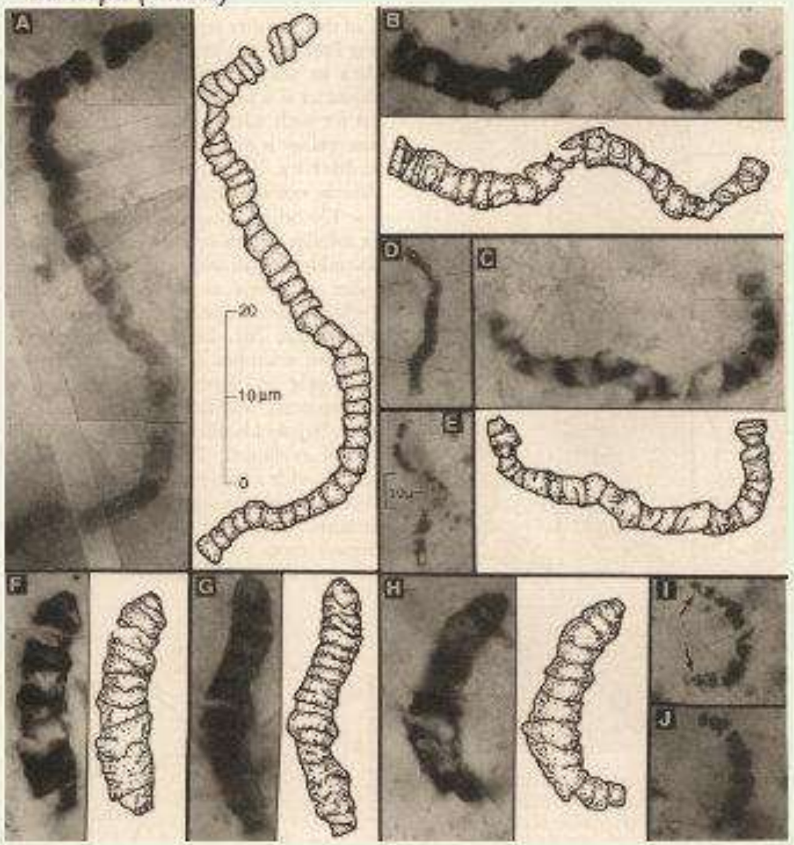


Primaevifilum delicatulum

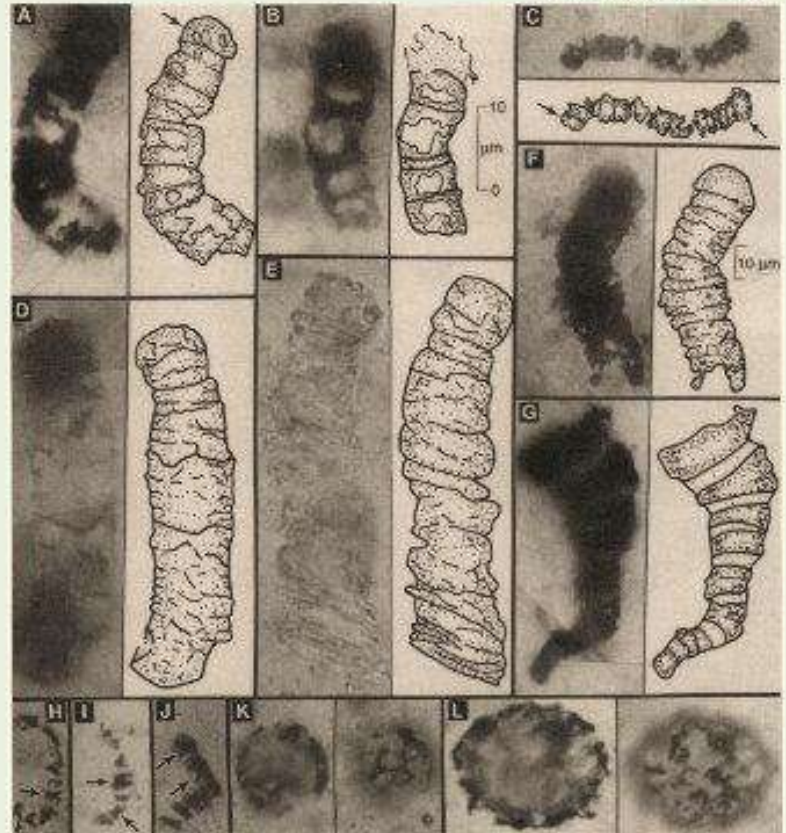
Ma - Million Years Ago

The Apex Chert

Schopf (1993)



Schopf (1993)

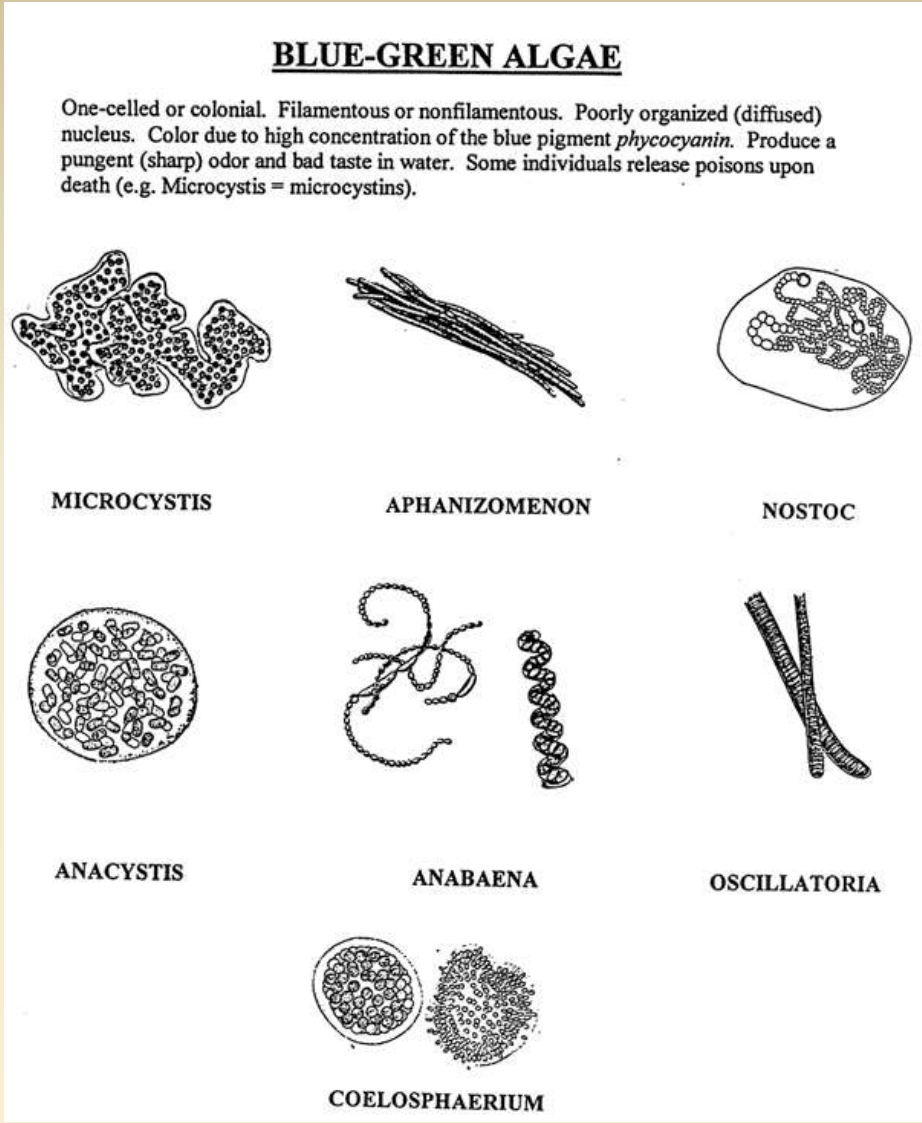


3465 Ma, Western Australia

Real microfossils or overactive imagination?

Oxygen began accumulating in the atmosphere about 2.7 billion years ago.

Cyanobacteria are photosynthetic prokaryotes that are still present today, produced the oxygen.



Stromatolites are fossilized bacterial mats. Many fossils of prokaryotes are found in layers that make up the prokaryotic mats.

Gunflint Formation Stromatolite 1.8 BY

Modern Stromatolites Shark's Bay, Australia

Bacterial mats and stromatolites

Stromatolites achieved their greatest diversity of form about 1,000 MYa. They continued to dominate the fossil record until the late Neoproterozoic, when animals, perhaps grazers or substrate disturbers, began to proliferate

Cuatrocienegas, Mexico – Freshwater Stromatolites

The Onset of Oxygen

The atmosphere of the primitive Earth was probably like that of Mars today: nitrogen, carbon dioxide, water vapor, but no free oxygen.

Oxygen is used up when things burn. In the absence of life, Earth would not retain an oxygen atmosphere.

Oxygen comes from photosynthesis, specifically, an advanced form of photosynthesis where electrons are extracted from water with the aid of sunlight. The electrons take hydrogen with them, leaving oxygen gas. Cyanobacteria created the oxygen in the atmosphere. Today, green plants and the cyanobacteria do this.

Banded iron formations are evidence of the age of oxygenic photosynthesis – approximately 2 BYA in photo

The Onset of Oxygen

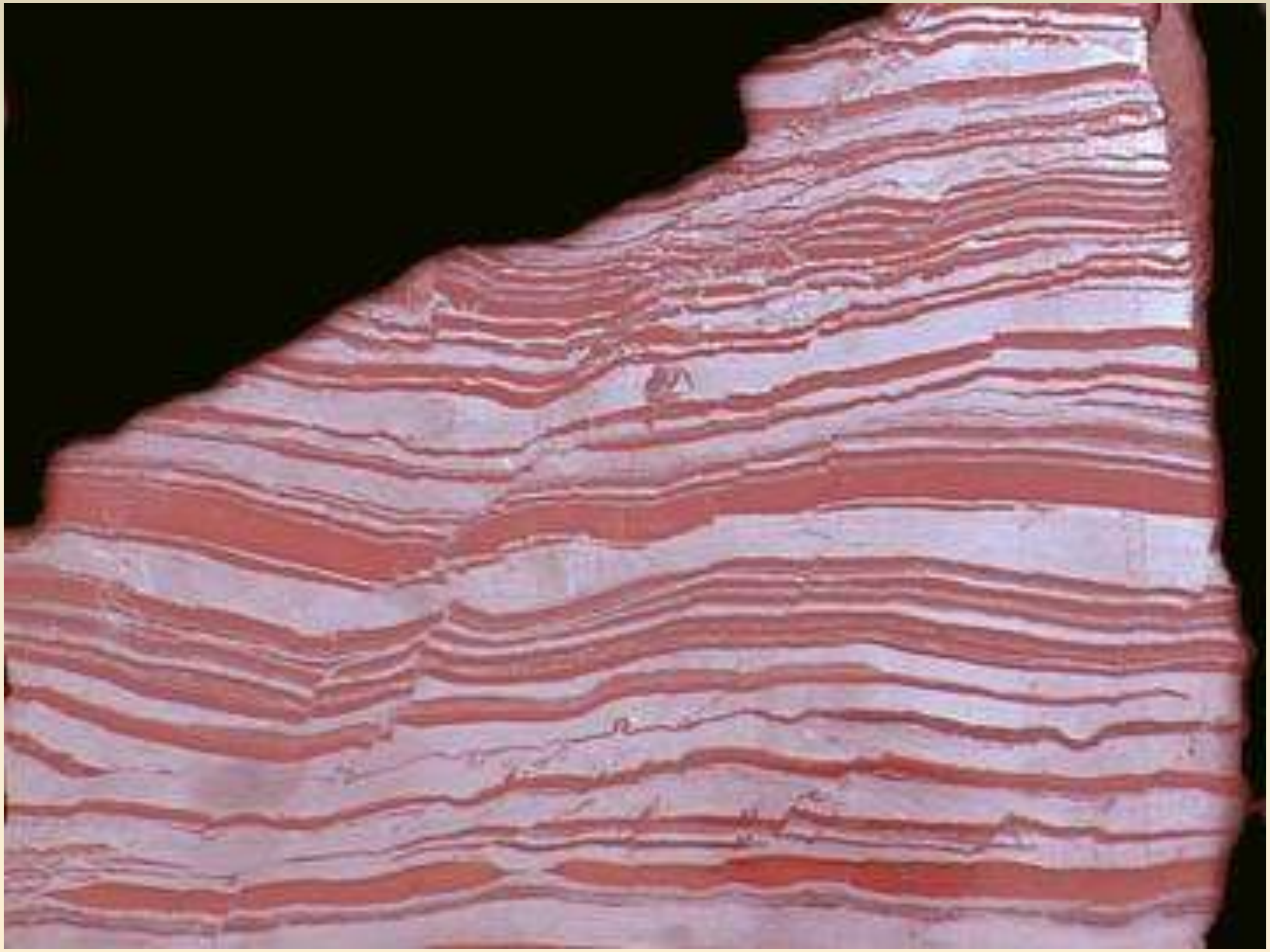
About 2 billion years ago, the oxygen level in the atmosphere started to rise. We can detect this geologically: layers of iron oxide on the bottoms of oceans stopped forming when oxygen appeared.

Many bacteria are poisoned by oxygen. They died out or found anaerobic niches.

Aerobic metabolism, much more efficient than anaerobic, became possible.

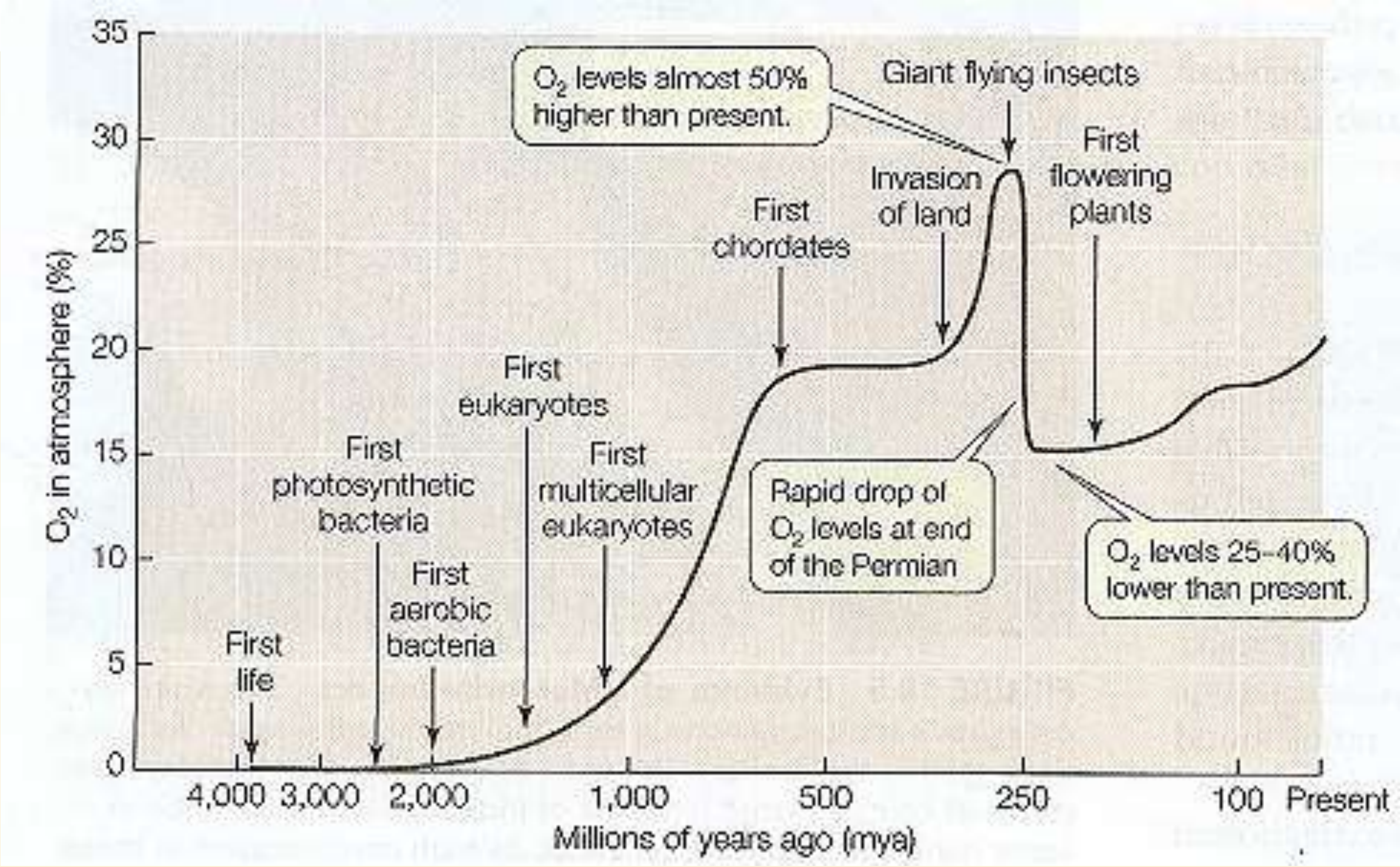
This event marks the onset of the Proterozoic Era and the end of the Archean era.

Banded Iron Formation (Michigan)



Great Oxygen Catastrophe

Increases in oxygen levels led to a mass extinction of obligate anaerobes that could not tolerate oxygen. Maximum oxygen levels were reached 250 million years ago.



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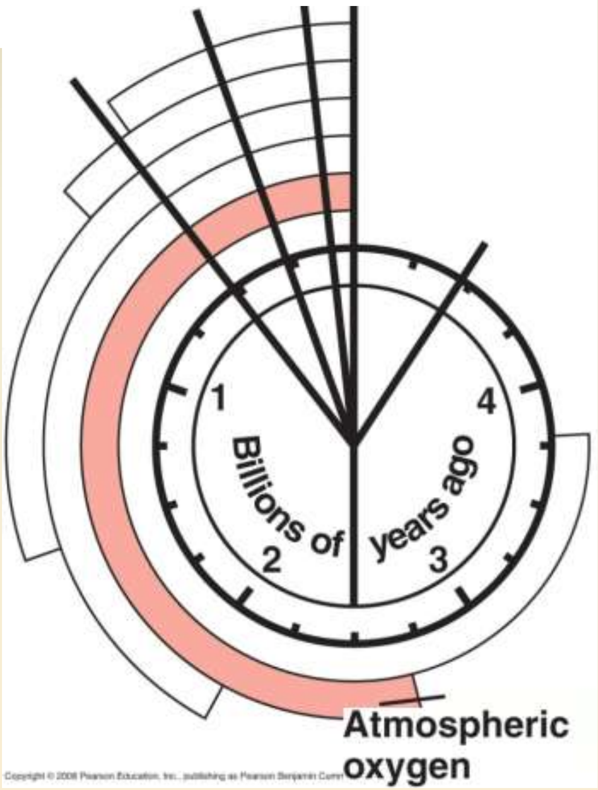
Consequences of Oxygen Production

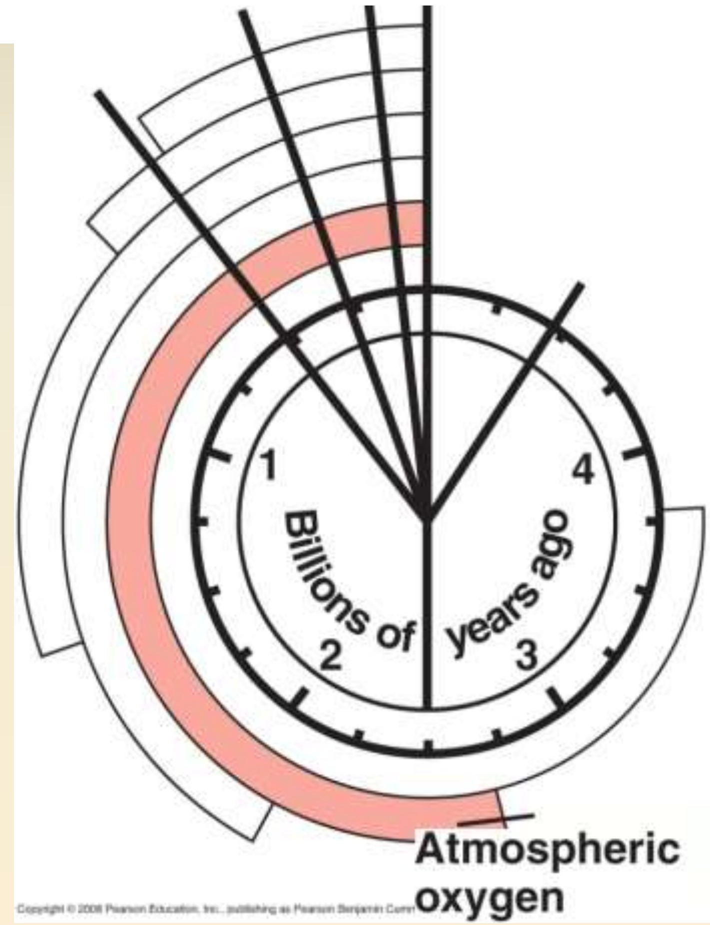
Production of oxygen began 2.7 billion years ago. Consequences?

1. Life can no longer arise from nonliving materials.
2. Organisms that can tolerate oxygen are at an advantage. Obligate anaerobes either became extinct or found anaerobic (without oxygen) environments.
3. Some oxygen formed ozone, O_3 which filtered out UV radiation like the oceans do.

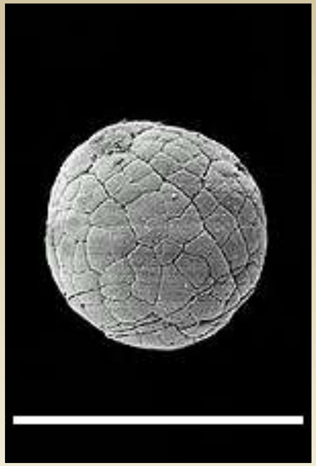


Consequences of Oxygen

4. Organisms that tolerated oxygen survived.
5. The next major biochemical pathway that evolved was aerobic respiration.
6. Aerobic respiration is more efficient at making ATP than anaerobic respiration.



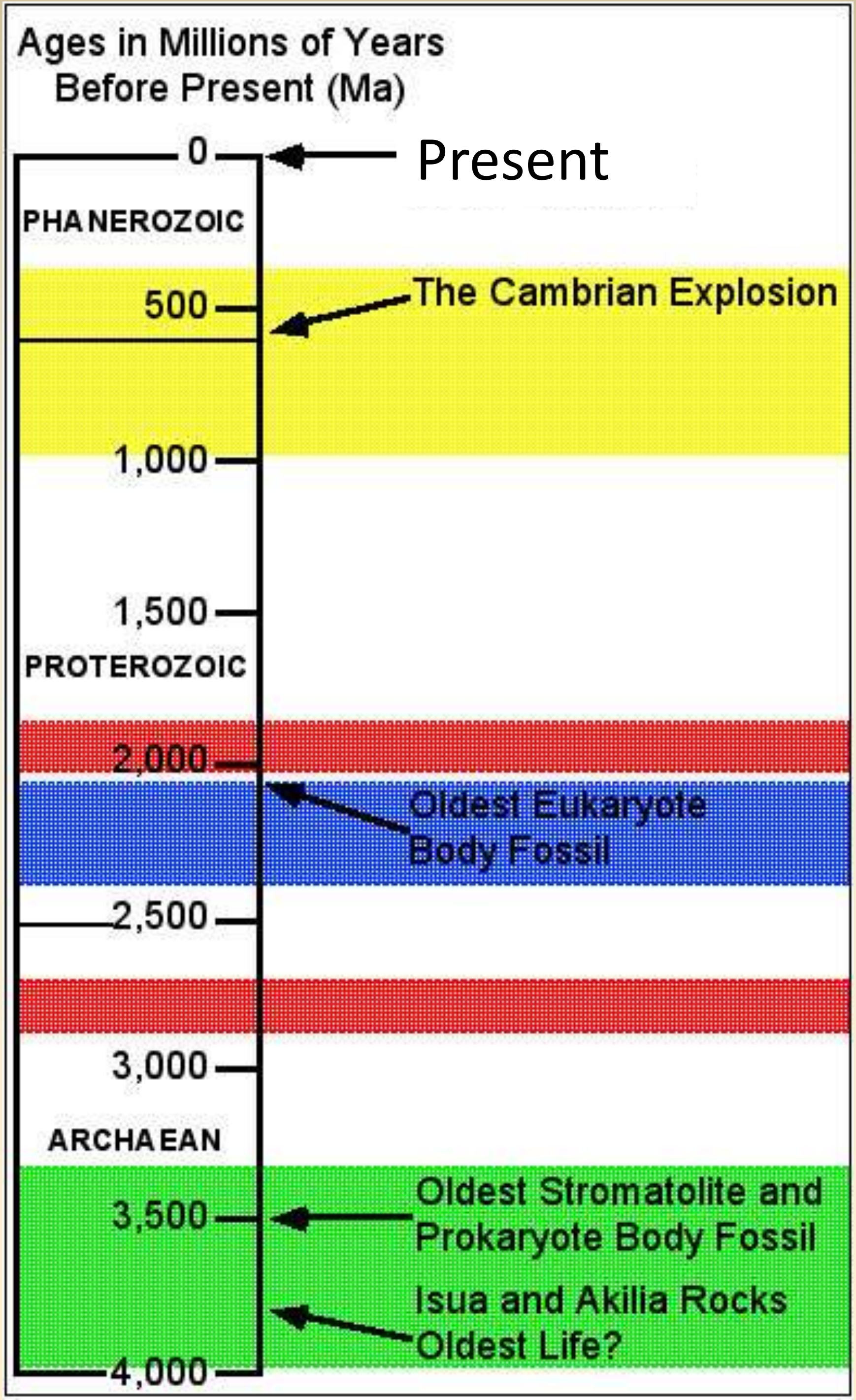
Rise of the Eukaryotes



The Proterozoic era, starting with the appearance of an oxygen atmosphere about 2 billion years ago, and ending with the Cambrian Explosion about 550 million years ago, was dominated by small, soft-bodied eukaryotes. Some were unicellular, others multicellular.

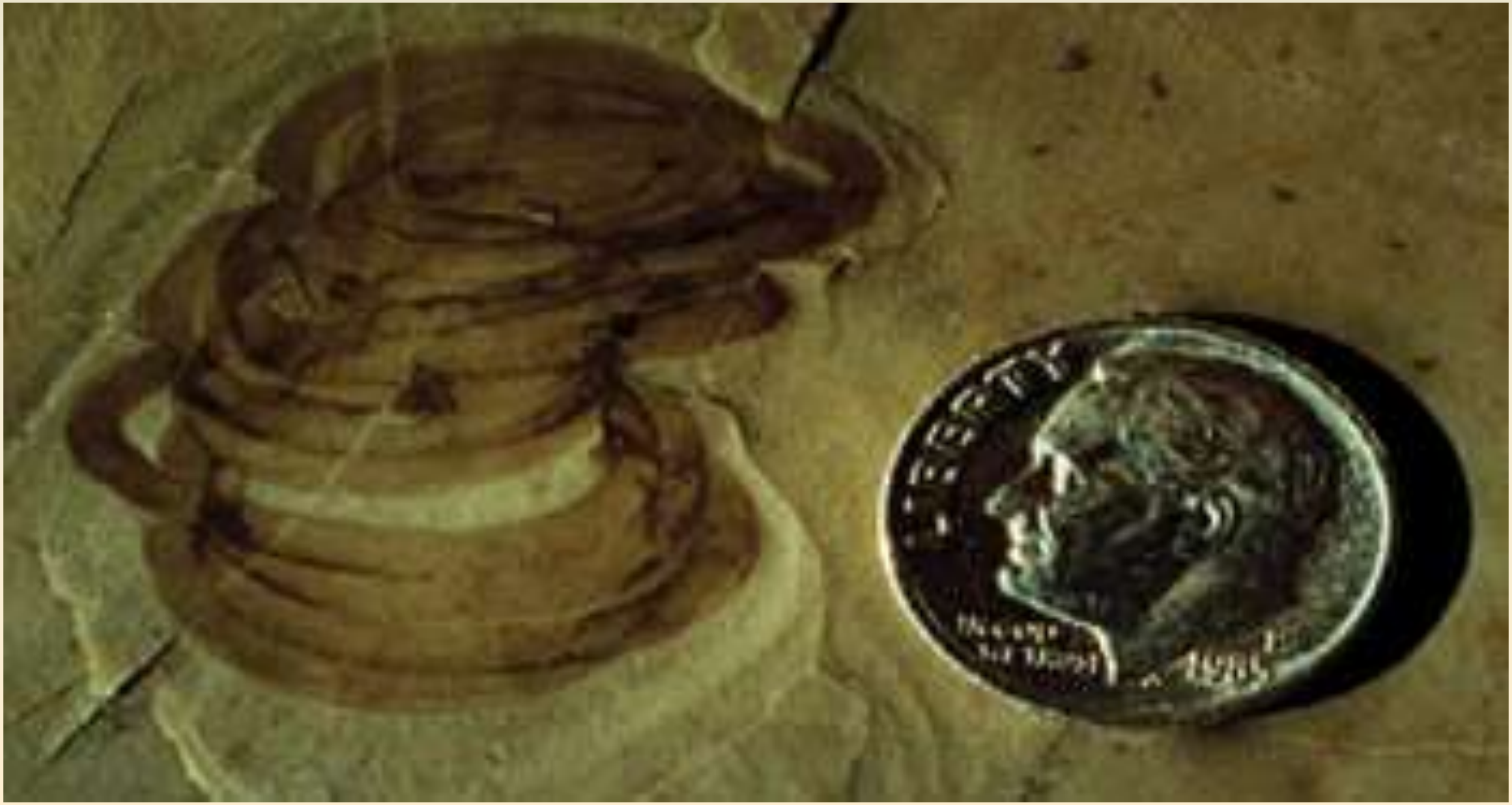
Bacteria were still very common, and continue to the present.

Eukaryotic fossil cells are identified by their size and surface appearance—they look like present day cells. Proterozoic fossils include algae (seaweed), protists (single celled eukaryotes), and simple animals.


Ages in Millions of Years
Before Present (Ma)
0
Present
PHANEROZOIC
500
The Cambrian Explosion
1,000
1,500
PROTEROZOIC
2,000
Oldest Eukaryote
Body Fossil
2,500
3,000
ARCHAEAN
3,500
Oldest Stromatolite and
Prokaryote Body Fossil
Isua and Akilia Rocks
Oldest Life?
4,000

Oldest known Eukaryote

2200 million years old *Grypania spiralis*, coiled thin films of carbon from the Negaunee Iron-Formation in Michigan, USA, provide the first evidence for eukaryotic life on Earth.



Grypania spiralis

Locality: Michigan, USA

Possibly the oldest eukaryotes, ~2 billion years old.

Oldest Animal Embryos

The first direct evidence for sexual reproduction of multicellular organisms comes from microfossils that have been described as animal eggs and embryos from the 570 Ma old Doushantou Formation, located at Weng'an in Guizhou, China

Eukaryotic Origins (from bacteria)

A. Invagination of plasma membrane

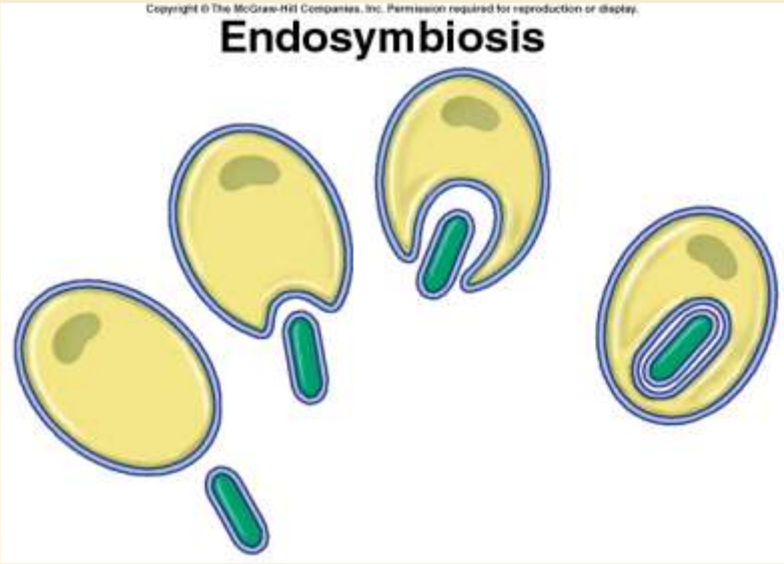
B. Endosymbiosis

- Symbiosis : An ecological relationship between organisms of 2 different species that live together in direct contact.
- How did this get started?
  - prey or parasite

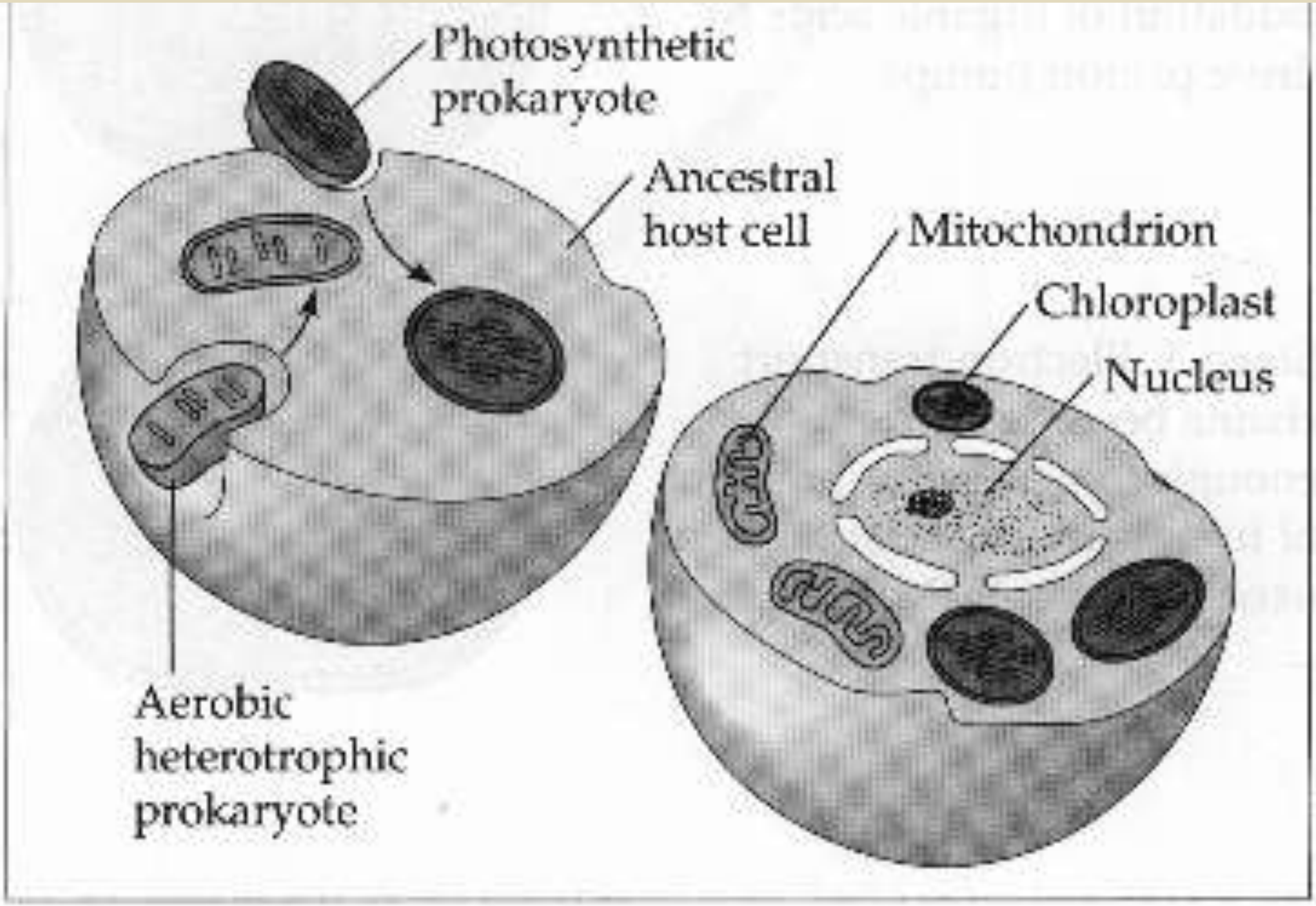
Eukaryotic Origins

Endosymbiont hypothesis: mitochondria were once free-living bacteria that developed an intracellular symbiosis with a primitive eukaryote. Mitochondria generate energy using oxygen. Today all eukaryotes have mitochondria, except a few that had mitochondria once and then lost them.

Chloroplasts: another endosymbiont, of a cyanobacteria. Found in plants and algae.



The “endosymbiont hypothesis” suggests that organelles like mitochondria originated as endosymbiotic bacteria living within the cell membranes of other organisms.



(b) The endosymbiotic model

Evidence

- Modern-day endosymbiotic relationships
  - common among protists
- Similarity between eubacteria & the chloroplasts & mitochondria of eukaryotes
  - size
  - inner membrane systems, enzymes, electron transport systems
  - reproduction resembles binary fission
  - circular DNA
  - DNA sequences (but many genes transferred to nucleus)

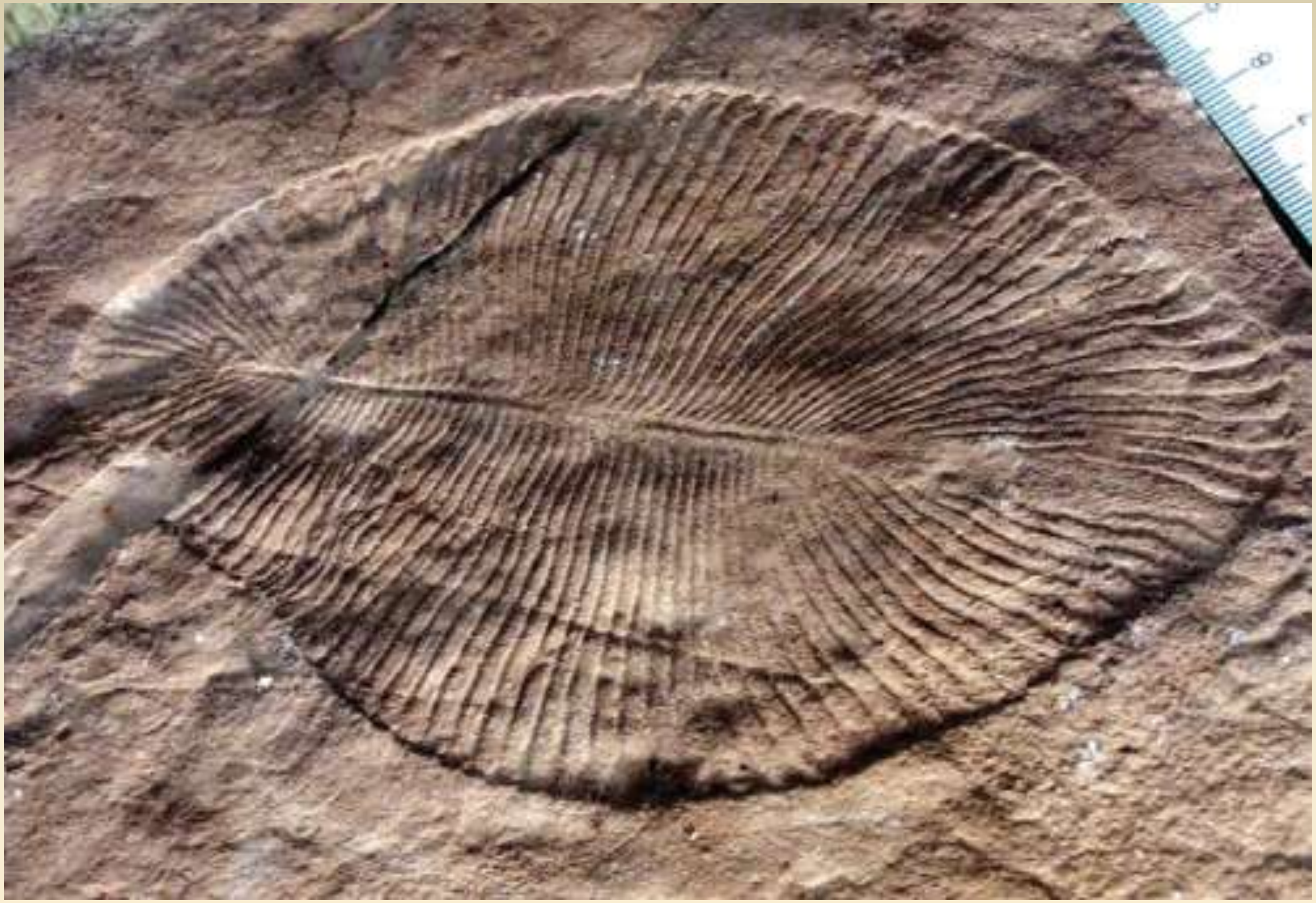
Ediacaran Life

Also known as "Vendian". A period late in the Proterozoic era, just before the Cambrian explosion. A worldwide proliferation of multicellular organisms whose form seems unlike anything alive after this period

Flat, segmented. Maybe ancestral to jellyfish? Or soft-bodied arthropods? Or an extinct kingdom of life?

Few or none survived into the Paleozoic era.

Ediacaran - *Dickinsonia costata* fossil



The earliest known occurrence of a rich diversity of multicellular animals is the 565 million years old Ediacaran fauna from the Ediacaran hills in South Australia. These were soft-bodied organisms which were entirely preserved as impressions, some resembling jellyfish, sponges and segmented worms found in the seas today.

The Origin of Life – How?

19th Century Ideas

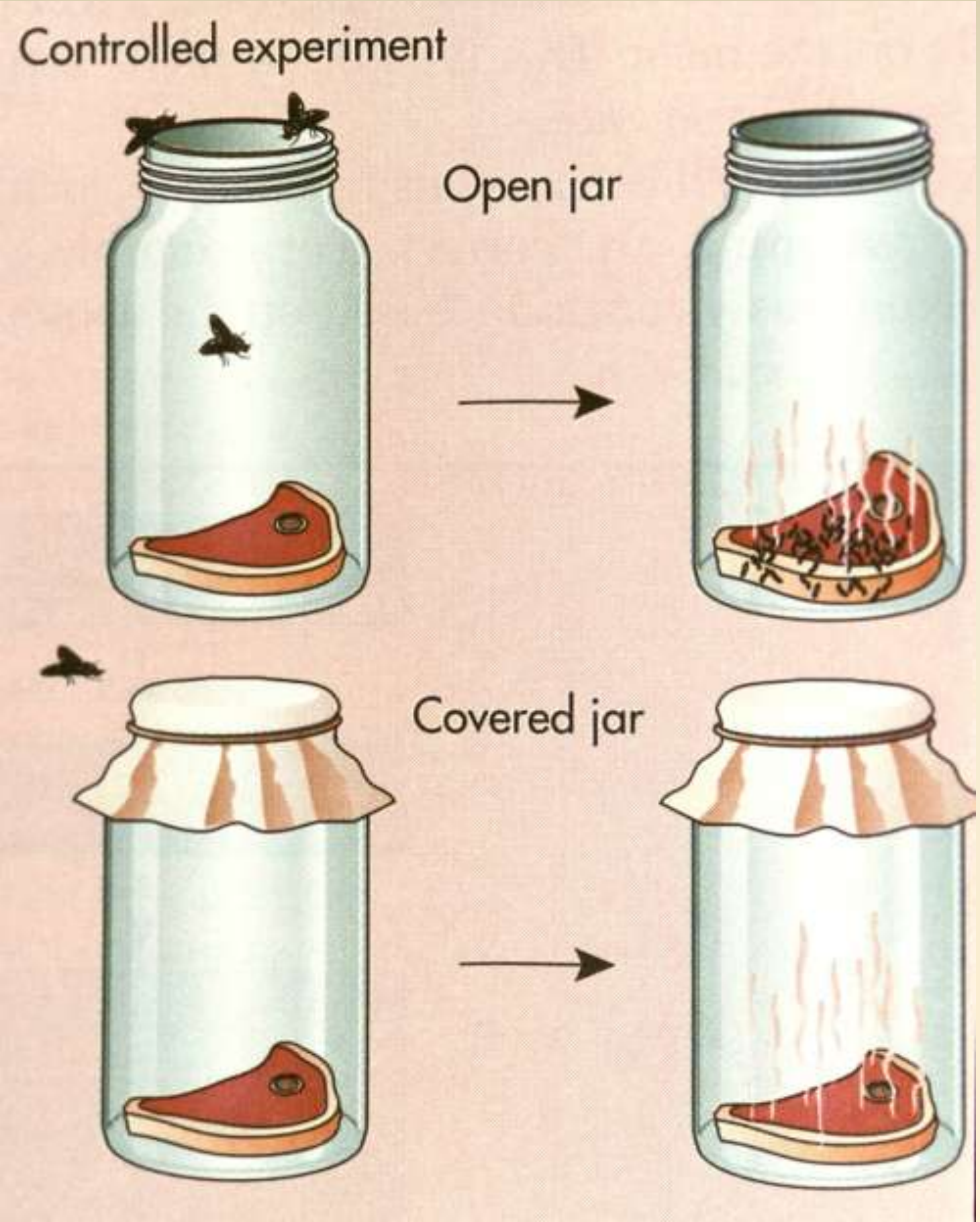
- life created supernaturally
  - cannot be proven scientifically
- continually being formed by spontaneous generation of nonliving matter
  - untenable by numerous experiments

20th Century

- life generated spontaneously and evolved through different steps

Redi's Experiments – Spontaneous Generation

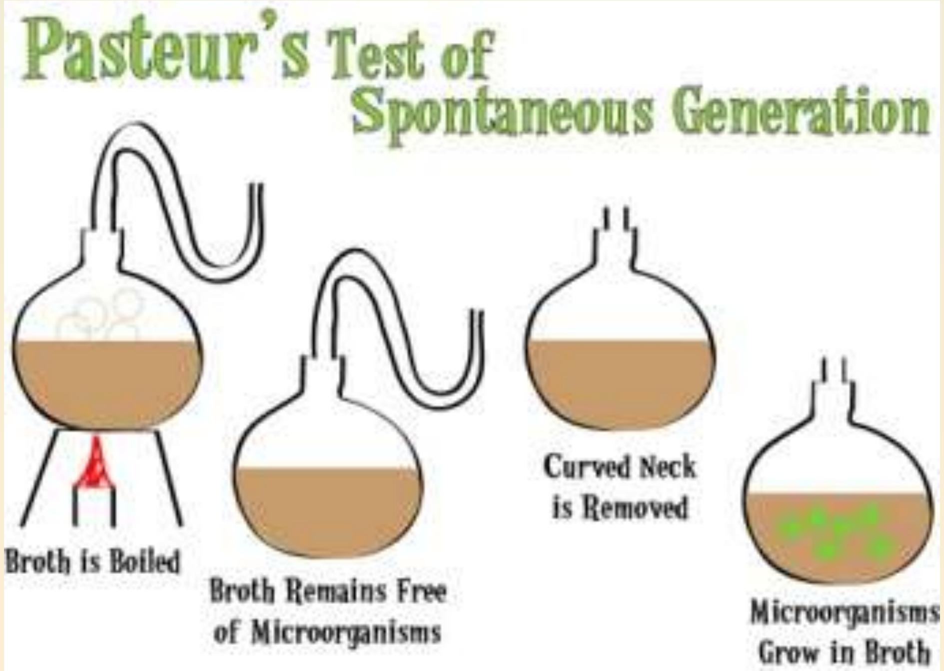
He who experiments increases knowledge. He who merely speculates piles error upon error.
- Arabic epigraph quoted by Redi.



Louis Pasteur in the 1860s

Tested whether microorganisms emerge by spontaneous generation or by reproduction of existing microorganisms.

- Microorganisms grew in open containers of sterilized broth.



What is Life?

"Life is a self-sustained chemical system capable of undergoing **Darwinian evolution."**

Thus, any form of life must be a chemical system.

Life also **grows and sustains** itself by gathering energy and molecules from its surroundings - the essence of **metabolism**.

Finally, living entities must be **self-replicating** and **display variation** (mutation).

All life possesses both **Genotype and Phenotype**, the most important criteria that set life apart from non-life.

Origin of Life

We really don’t know how life originated.

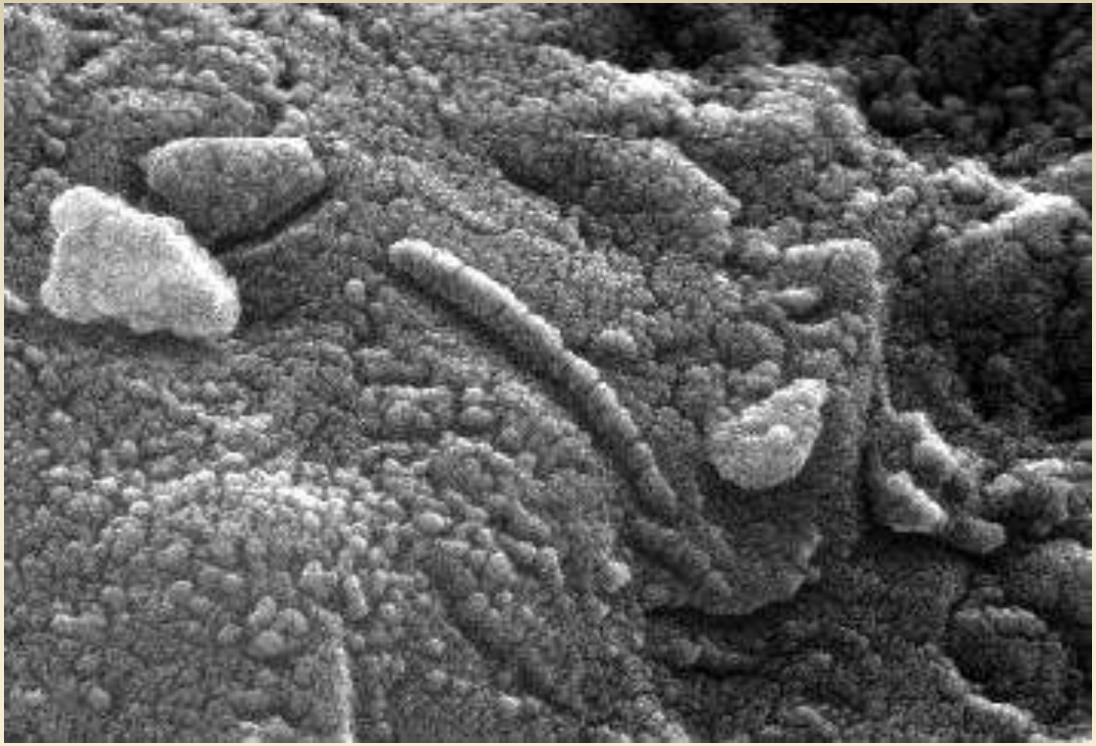
Probably arose on Earth, but an alternate theory suggests it arose elsewhere and drifted through space to seed the Earth (Panspermia). Note that it still had to originate somewhere.

What does life need? A way of harnessing energy to do useful work, a way of storing and reproducing genetic information, a way to keep the inside separated from the outside.

Which of these arose first is a matter of debate. Inheritance first or metabolism first? Or both simultaneously?

However, once a genetic system is in place, natural selection will quickly improve the new life form.

Life Directly from Other Planets?



This 4.5 billion-year-old rock, labeled meteorite ALH84001, is believed to have once been a part of Mars and to contain fossil evidence that primitive life may have existed on Mars more than 3.6 billion years ago. The rock is a portion of a meteorite that was dislodged from Mars by a huge impact about 16 million years ago and that fell to Earth in Antarctica 13,000 years ago.

Can’t really tell from morphology alone!

Chemical Evolution

If life originally arose from non-life, how might this have happened?

Consider the following scenario

- Synthesis and accumulation of small organic molecules
- Joining of these monomers into polymers
- Aggregation of these molecules into droplets to form localized microenvironments
- Origin of heredity

The Origin of Life

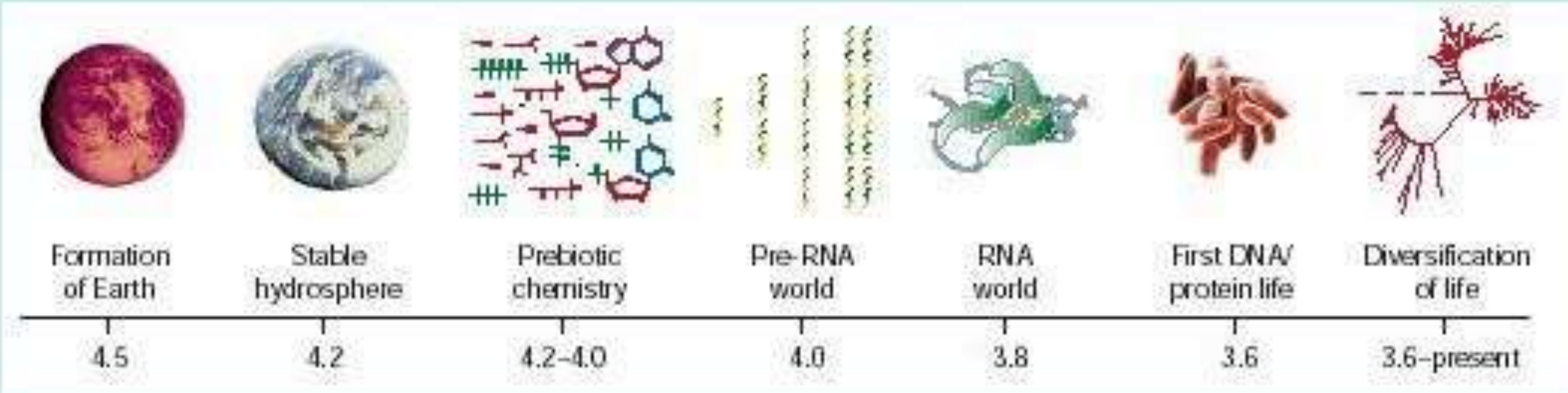
The process of life took many steps over the first 600 my

Probability theory would dictate that at least one random event would have produced a result

This process cannot occur on Earth today because the simple organism would be destroyed by oxidation or predation.

Origin of life is NOT an event

Origin of life is a continuous *process*



Timeline of events pertaining to the early history of life on Earth, with approximate dates in billions of years before the present.

Evolution uses a huge number of incremental steps to go from something simple to something complex. Each step is subjected to natural selection.

Assumptions in the Origin of Life

Anaerobic

- oxygen poisons living cells so early life was anaerobic

Lack of free Oxygen >> No Ozone layer

- UV radiation kills cells so life had to originate at depth
- Water depths of 10m or more

Models

- non-oxidizing secondary atmosphere rich in the constituent chemicals for life--H_2O, CO_2, N
- Energy in the form of UV radiation and Hot springs

Origin of Life – Possible Locations

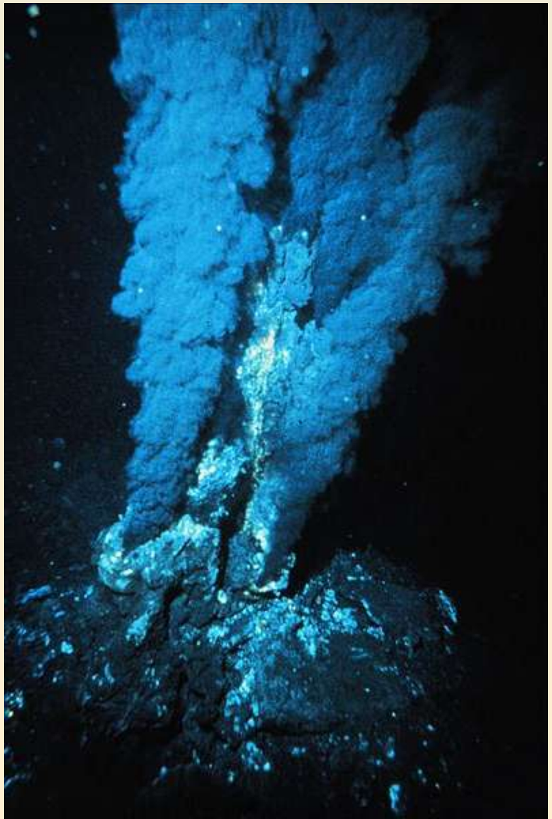
Ocean's edge
- bubble hypotheses

Under frozen seas
- problematic due to necessary conditions

Deep in Earth's crust
- byproduct of volcanic activity

Within clay
- positively-charged clay
- **polymerizing** templates

Deep-sea vents
- conditions suitable for Archaea,
- thermophilic



Synthesis of Small Organic Monomers

Meteorites that fall to Earth today will often contain amino acids, carbohydrates and nucleotide bases.

This suggests that organic molecules could have formed in interstellar clouds and then been transported to Earth on meteorites.

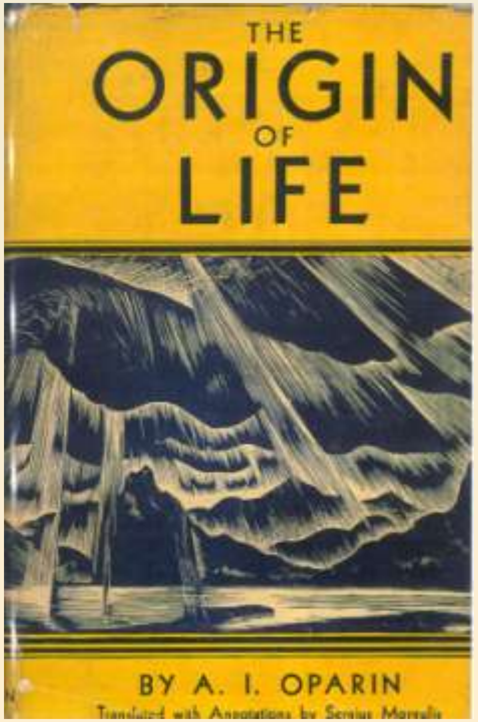
Billions of years ago, there were enormous amounts of meteorites falling to Earth.

Simple Chemicals from Outer Space?

Amino acids of extraterrestrial origin

– Carbonaceous **chondrite meteorites** contain organic compounds, amino acids, fatty acids, etc.
– Murchison Meteorite, Australia (L) and Allende Meteorite (~2 tons), Mexico (R)

The Origin of Life



- This is the cover of the first English edition (1938) of the pioneering work of the biochemist Aleksandr Ivanovich Oparin (1894-1981), published in Russian in 1924 (in English in 1936)
- Oparin elaborated, within the framework of Darwinism, the first successful scientific approach to the problem of the origin of life, modernizing the old spontaneous generation controversy as a new hypothesis of Biogenesis (Abiogenesis)

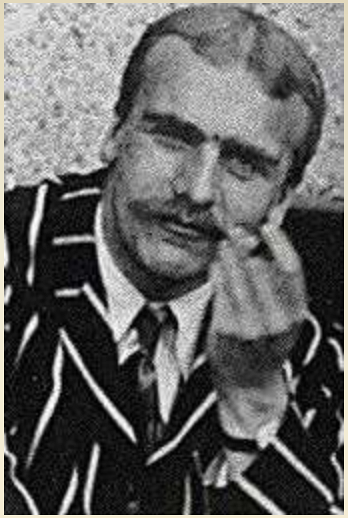
Conditions on Early Earth-Reducing Atmosphere

Life most likely emerged under high-temperature conditions.

- Early atmosphere is often referred to as a reducing atmosphere.
  - exact conditions unknown
    - ample availability of hydrogen atoms
    - very little oxygen

John Burdon Sanderson [J.B.S.] Haldane (1892-1964)

British contemporary of Oparin who independently proposed (1928) a similar hypothesis that conditions on the primitive Earth favored chemical reactions that synthesized organic compounds from inorganic precursors:



Haldane had also suggested that the earth's pre-biotic oceans would have formed a "hot dilute soup" in which organic compounds, the building blocks of life, could have formed – the "**primordial organic soup**" of early oceans, tidal pools or warm ponds

Primordial Soup?

J.B.S. Haldane

"Theories have four stages of acceptance.

i) this is worthless nonsense;

ii) this is an interesting, but perverse, point of view,

iii) this is true, but quite unimportant;

iv) I always said so.“

“J.B.S. Haldane was perhaps the most brilliant science popularizer of his generation.” Arthur C. Clarke

Harold Urey & Stanley Miller

In 1953, Harold C. Urey and his graduate student, Stanley L. Miller, at the University of Chicago conducted experiments that simulated hypothetical conditions present on the early Earth and test for the occurrence of chemical evolution.

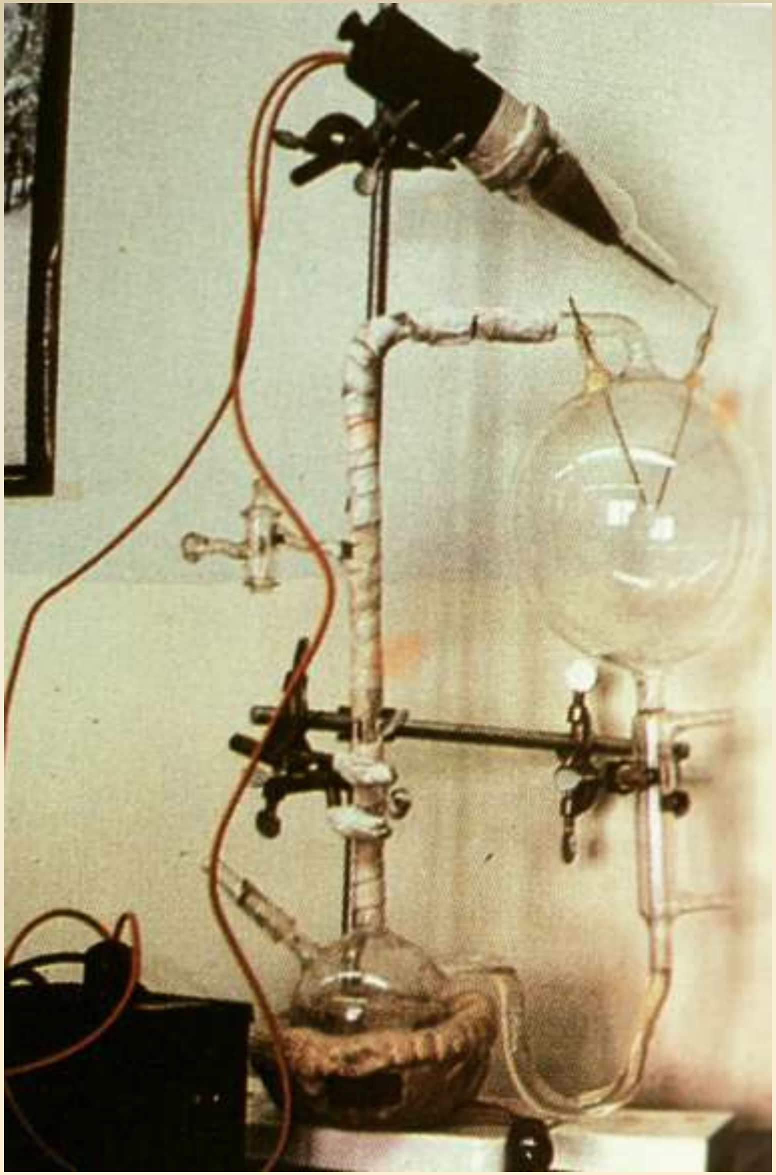


Figure 24.4 Abiotic synthesis of organic molecules in a model system

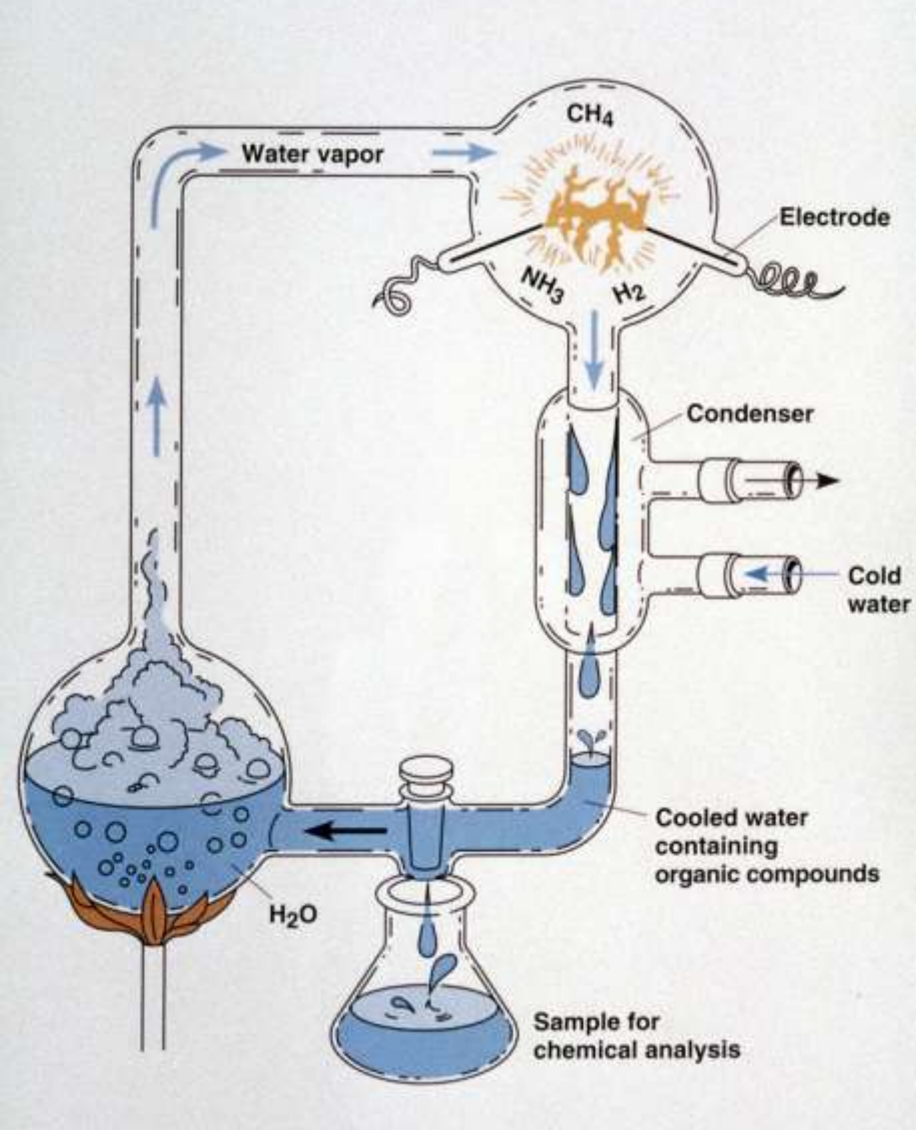
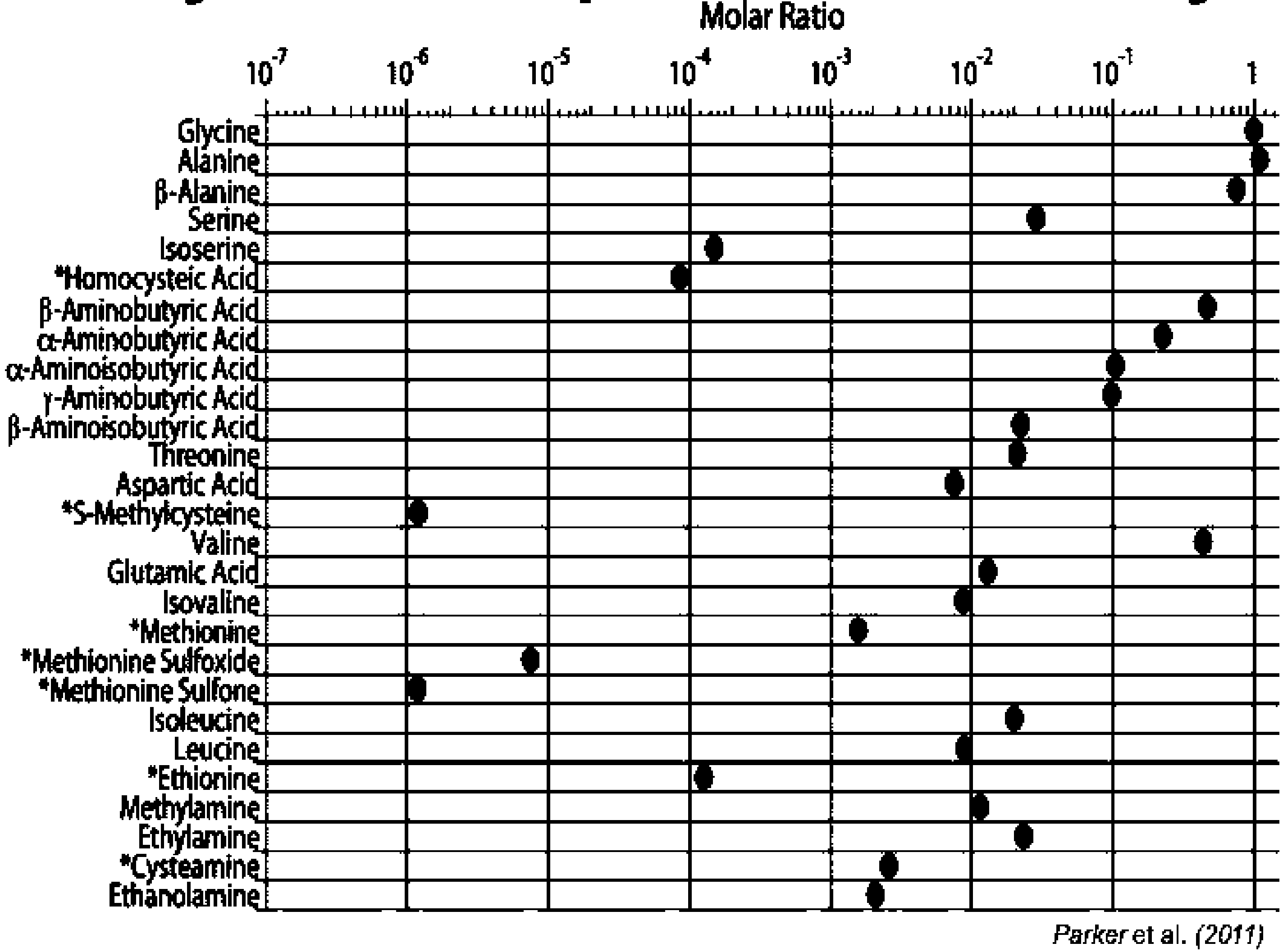


TABLE 23–1 Chemical Products Produced Abiotically in Miller's Experiment

Glycine	Formic acid
Alanine	Lactic acid
Aspartic acid	Urea
Butyric acid	Succinic acid
Glutamic acid	Aldehyde
Acetic acid	Hydrogen cyanide

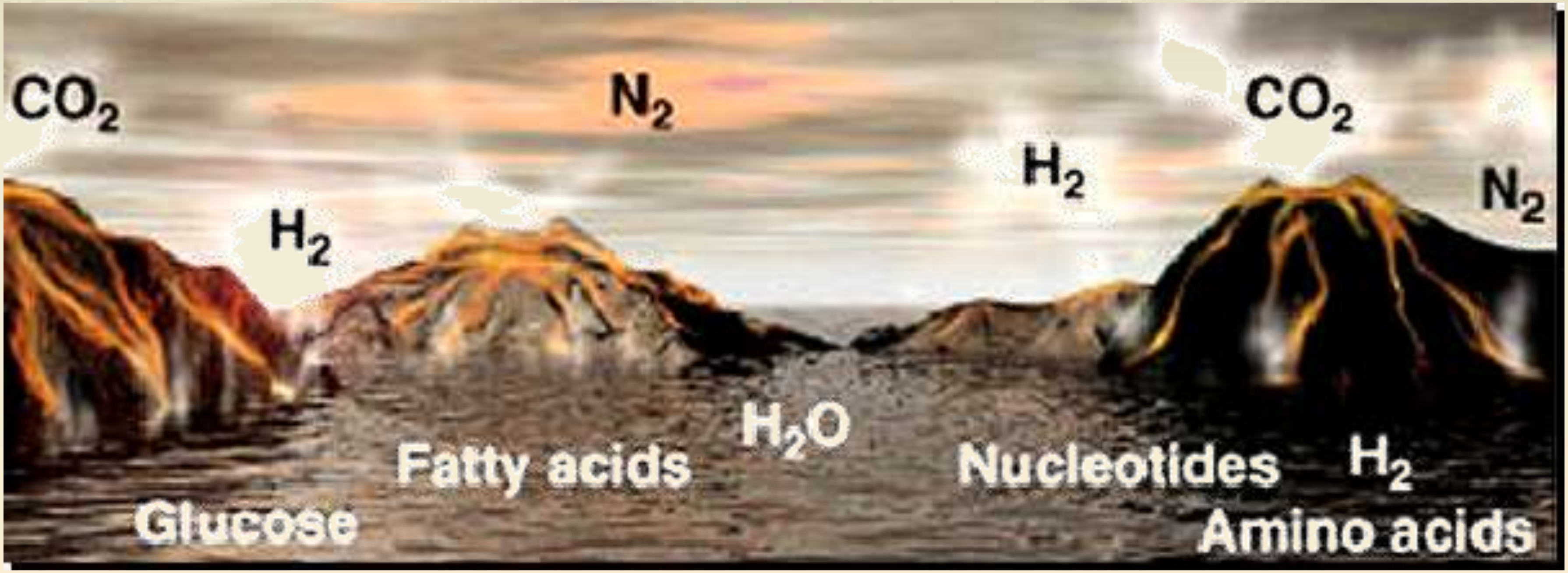
Subsequent follow-up trials, by many other biologists, using various combinations of "primitive atmospheres," produced even more complex organic compounds

Urey-Miller Experiment: Validity



Parker, E. T., Cleaves, H. J., Dworkin, J. P., Glavin, D. P., Callahan, M., Aubrey, A., Lazcano A. & Bada, J. L. **2011**. Primordial synthesis of amines and amino acids in a 1958 Miller H_2S-rich spark discharge experiment. *PNAS* **108**, 5526-5531

Polymer Synthesis - Joining of small molecules (monomers) into large molecules



Polymer Formation - Proteins

Sidney Fox (University of Miami) demonstrated the abiotic polymerization of organic monomers

Polymers were formed when dilute solutions of organic molecules were dripped onto hot sand, clay, or rock

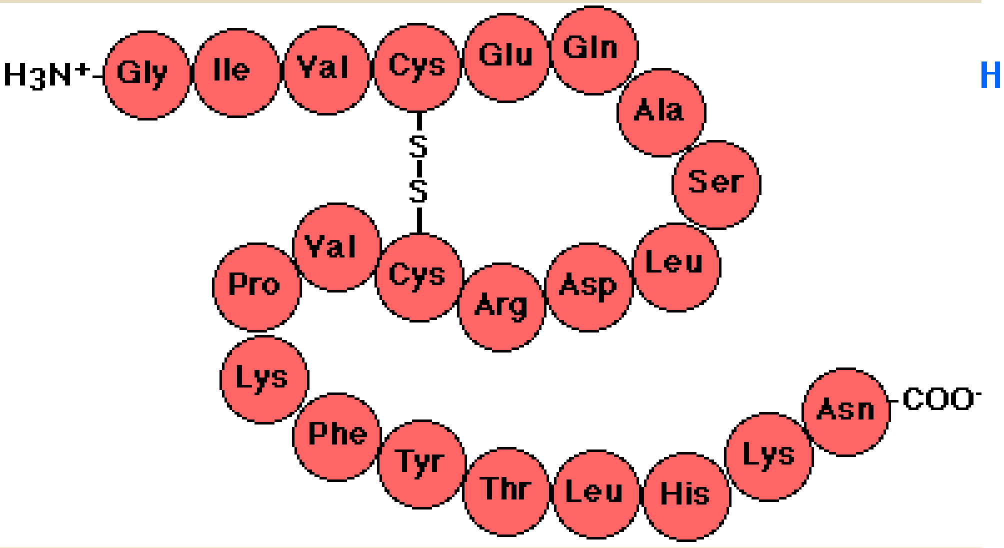
“Proteinoids”

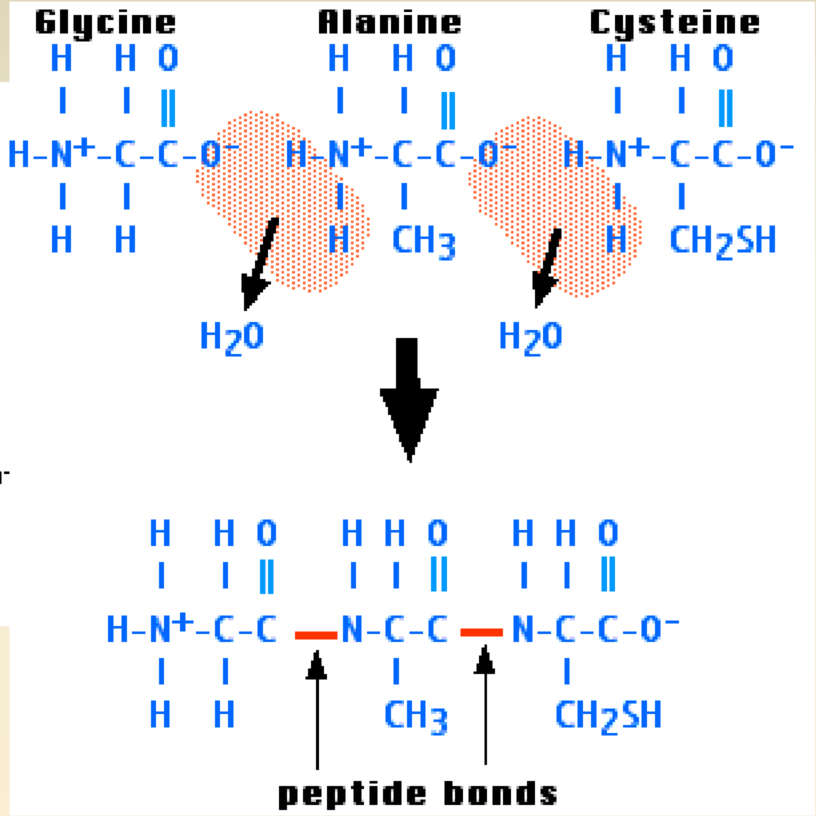
Clay can serve to concentrate these molecules

Monomers bind to charged sites on clay particles

Metal ions in clay have catalytic function

Polymer Synthesis - Proteins





Polymer Synthesis - Proteins

Amino acids are monomers

- Monomers must form peptide bond to form proteins
- This requires an input of energy and removal of water

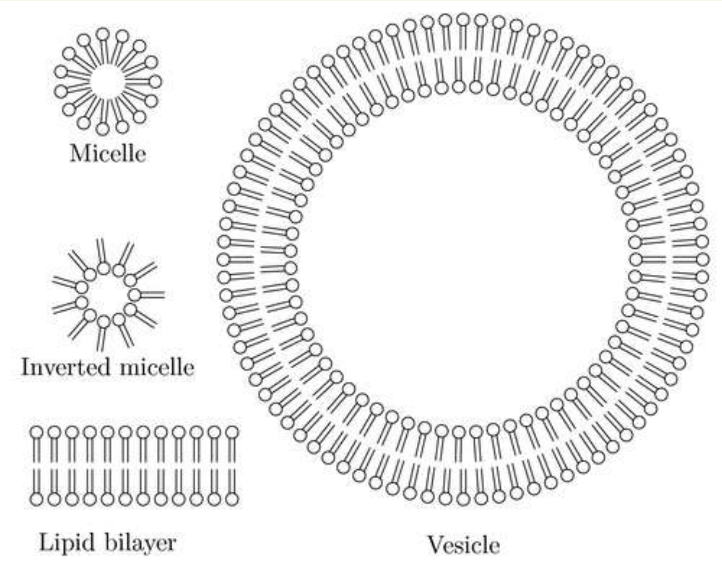
How could this occur?

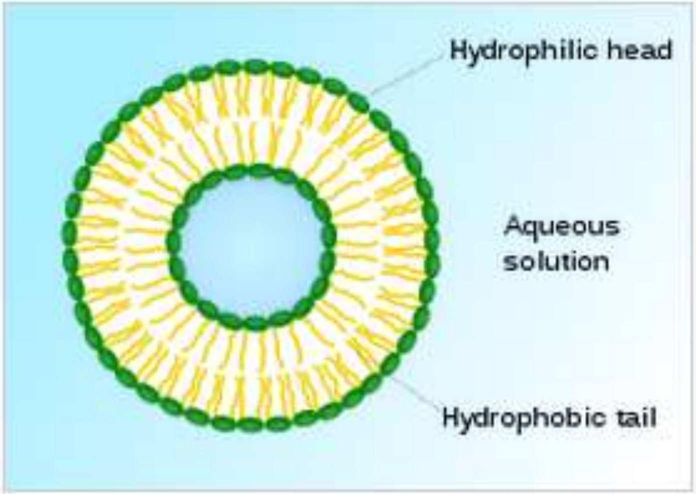
- Evaporation?
  - Tidal pools?
- Freezing?
- Chemical dehydration?
- Bonding to charged mineral surfaces?
  - Clays? Pyrites?

Polymer Synthesis – Lipid Membranes

Lipids will also form organized droplets with bilayer much like that of a plasma membrane.

Liposomes can reproduce as they incorporate more lipids or pinch off smaller droplets. Some liposomes can perform a simple metabolic reaction.



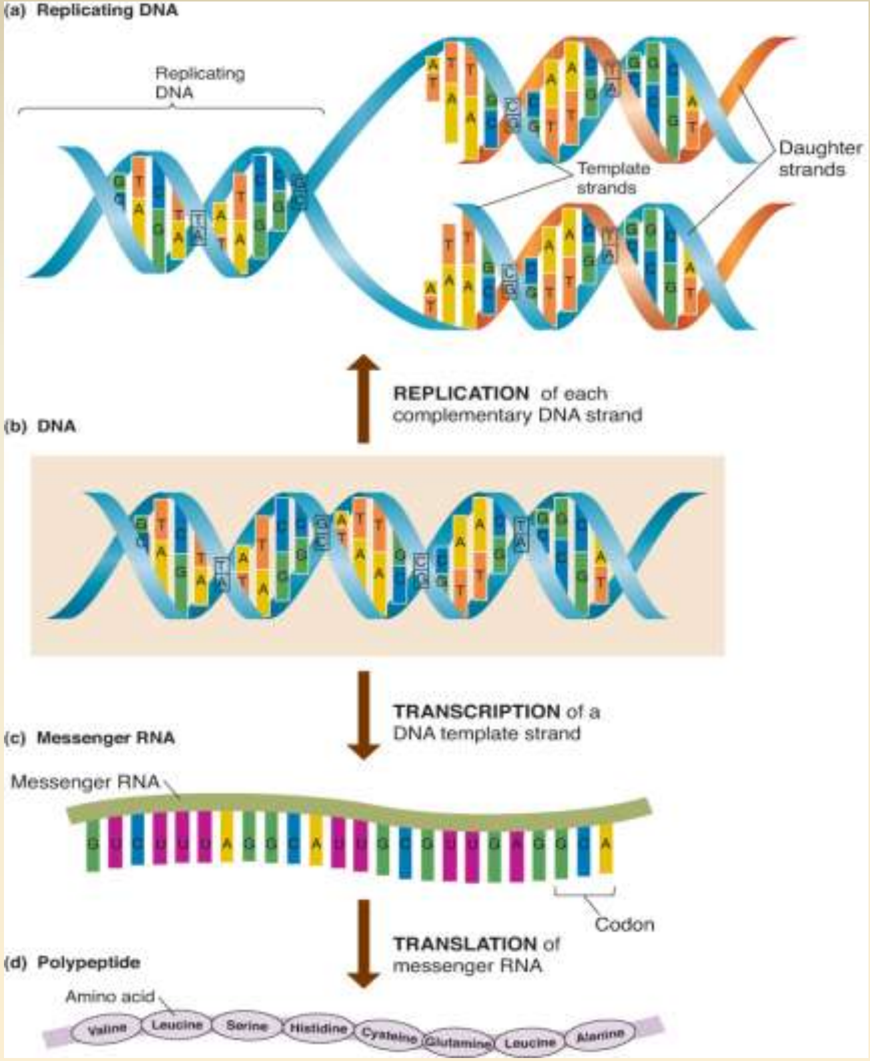


Scheme of a liposome formed by phospholipids in an aqueous solution.

Hereditary - DNA, RNA and Proteins?

Three fundamental classes of molecules are associated with modern life.

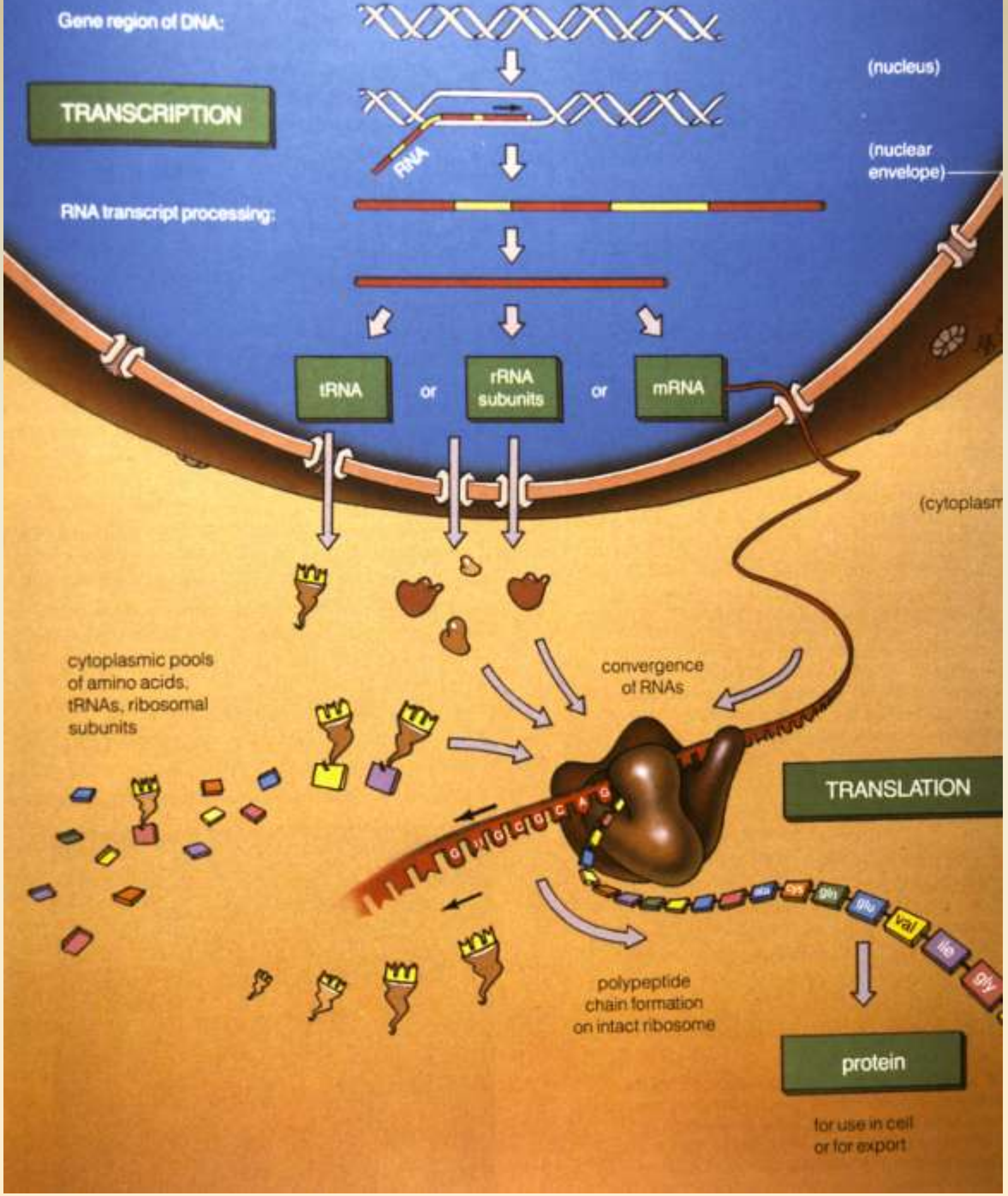
Replication - DNA
Transcription - RNA
Translation - protein



DNA replicates and information is transferred from DNA to RNA to protein

RNA was probably the first hereditary material, more versatile than DNA.

Today, genetic information is usually stored as DNA, but some organisms such as viruses use RNA to store info.



Short polymers of ribonucleotides can be synthesized abiotically in the laboratory.

- If these polymers are added to a solution of ribonucleotide monomers, sequences up to 10 based long are copied from the template according to the base-pairing rules.
- If zinc is added, the copied sequences may reach 40 nucleotides with less than 1% error.

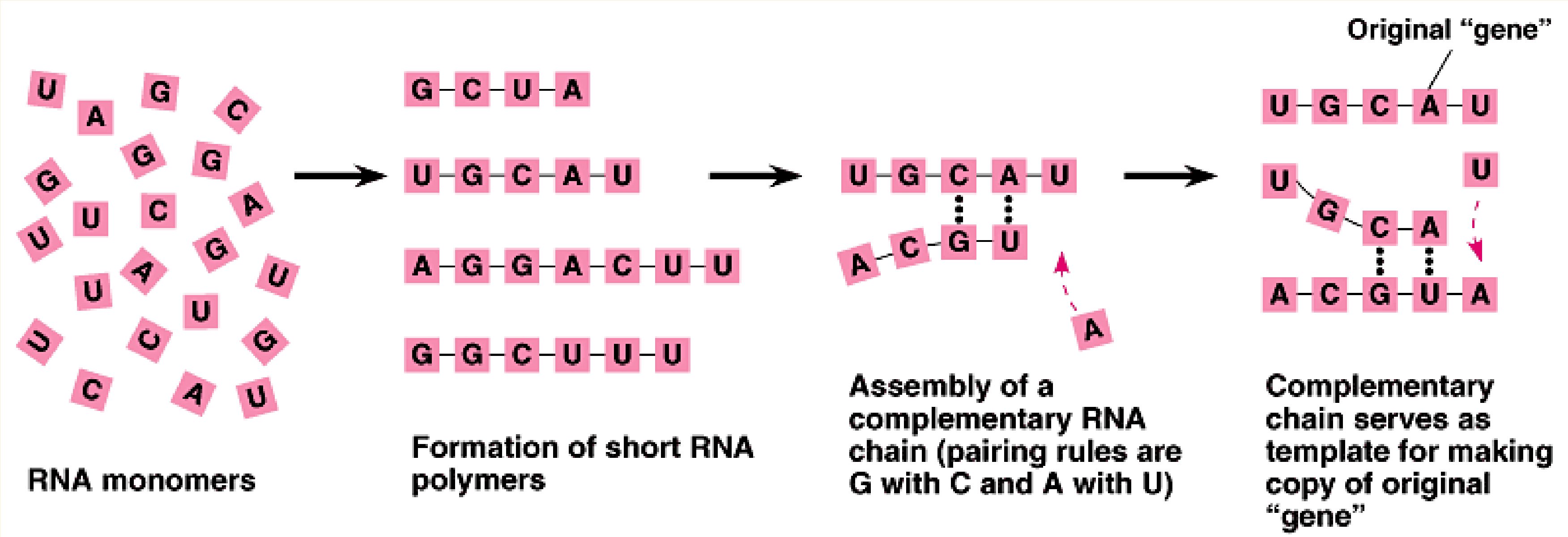
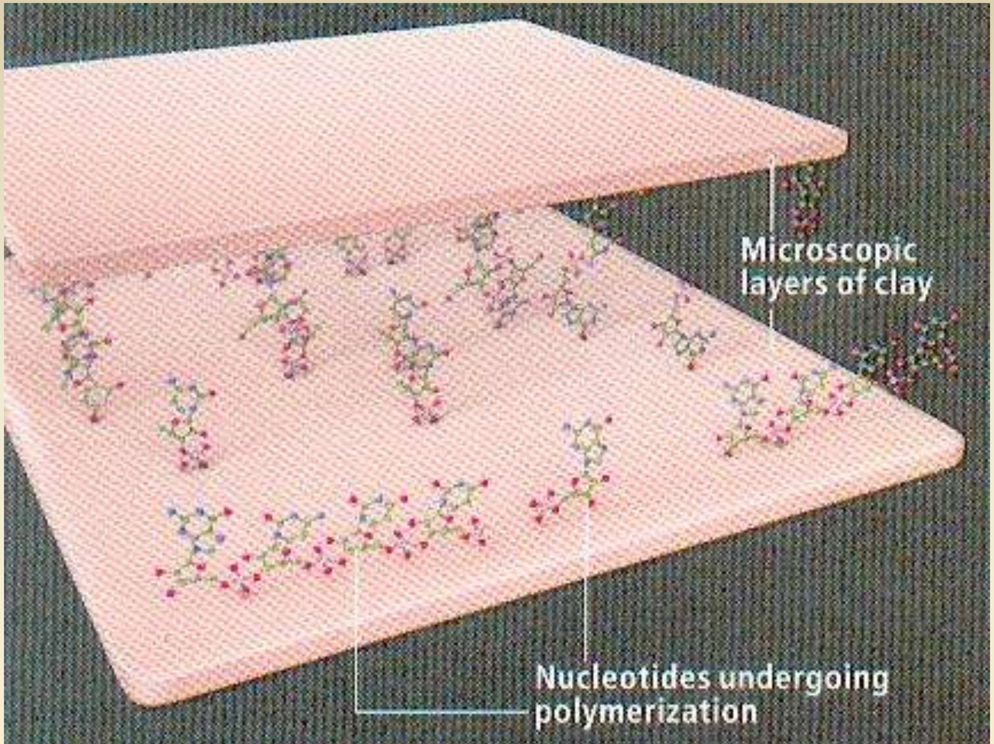


Fig. 26.11

Polymer formation on clay?



RNA BREEDING GROUNDS

In the water solutions in which they formed, nucleotides would have had little chance of combining into long strands able to store genetic information. But under the right conditions—for example, if molecular adhesion forces brought them close together between microscopic layers of clay (*above*)—nucleotides might link up into single strands similar to modern RNA.

In the 1980’s Thomas Cech discovered that RNA molecules are important catalysts in modern cells.

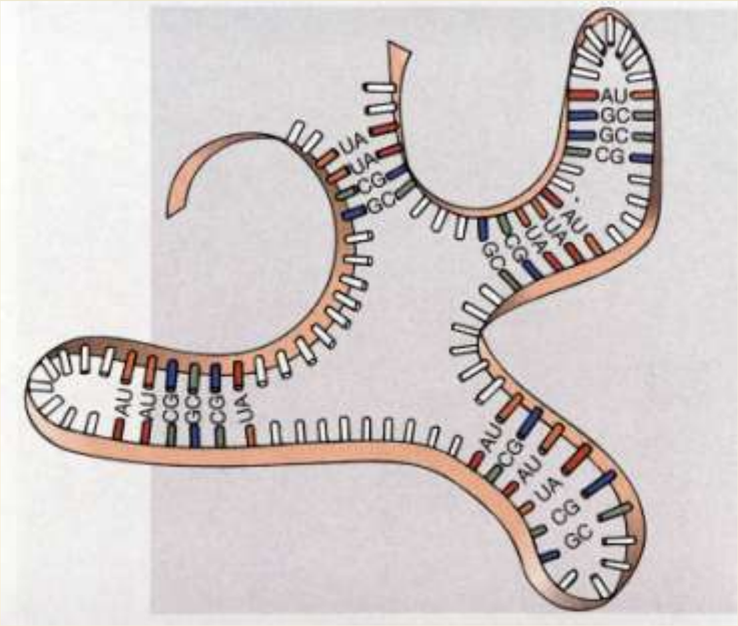
RNA catalysts, called **ribozymes**, remove introns from RNA.

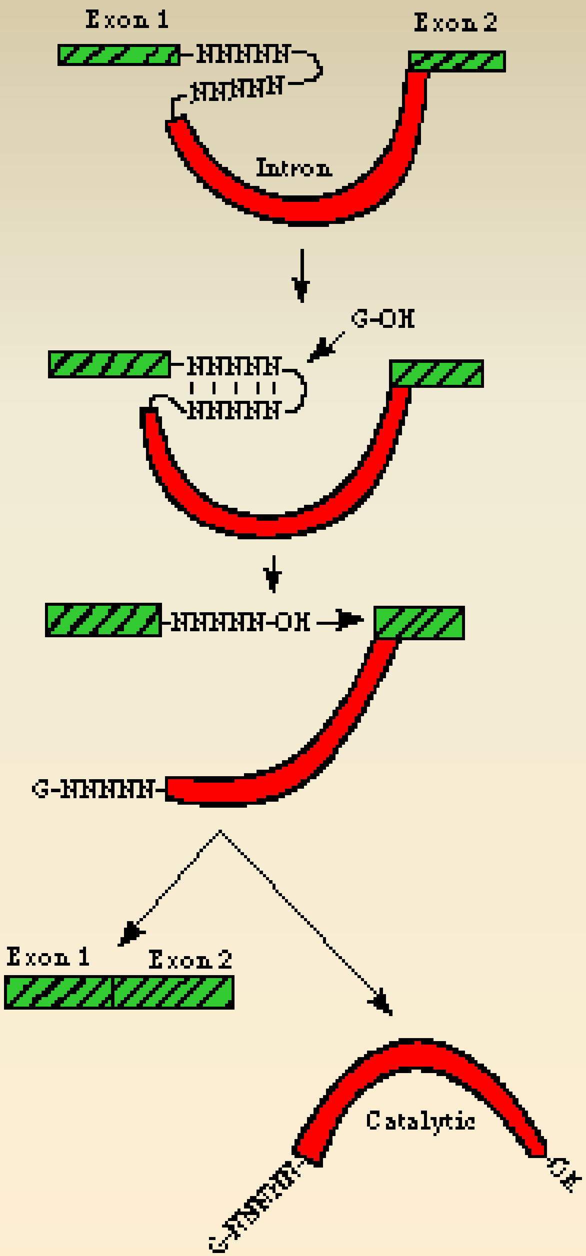
Ribozymes also help catalyze the synthesis of new RNA polymers.

In the pre-biotic world, RNA molecules may have been fully capable of ribozyme-catalyzed replication.

Ribozymes

RNA that catalyzes reactions





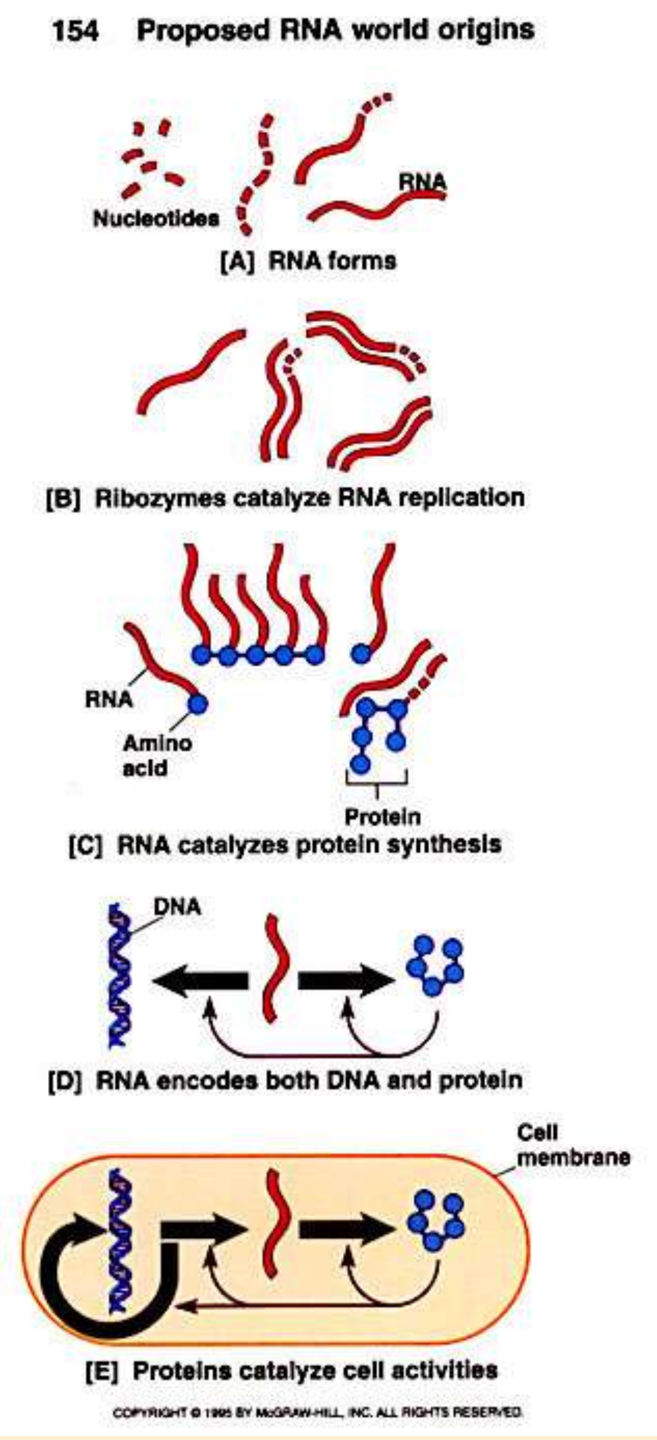
- **Laboratory experiments have demonstrated that RNA sequences can evolve in abiotic conditions**.
- RNA molecules have both a genotype (nucleotide sequence) and a phenotype (three dimensional shape) that interacts with surrounding molecules.
- Under particular conditions, some RNA sequences are more stable and replicate faster and with fewer errors than other sequences.
  - Occasional copying errors create mutations and selection screens these mutations for the most stable or best at self-replication.

The RNA World

During the time of the RNA World, proteins were not yet engaged in biochemical reactions

RNA carried out both the information storage task of genetic information and the full range of catalytic roles necessary in a very primitive self-replicating system

Later RNA catalyzed the formation of **DNA, more stable and mutations can be fixed**.



Proto-Cells

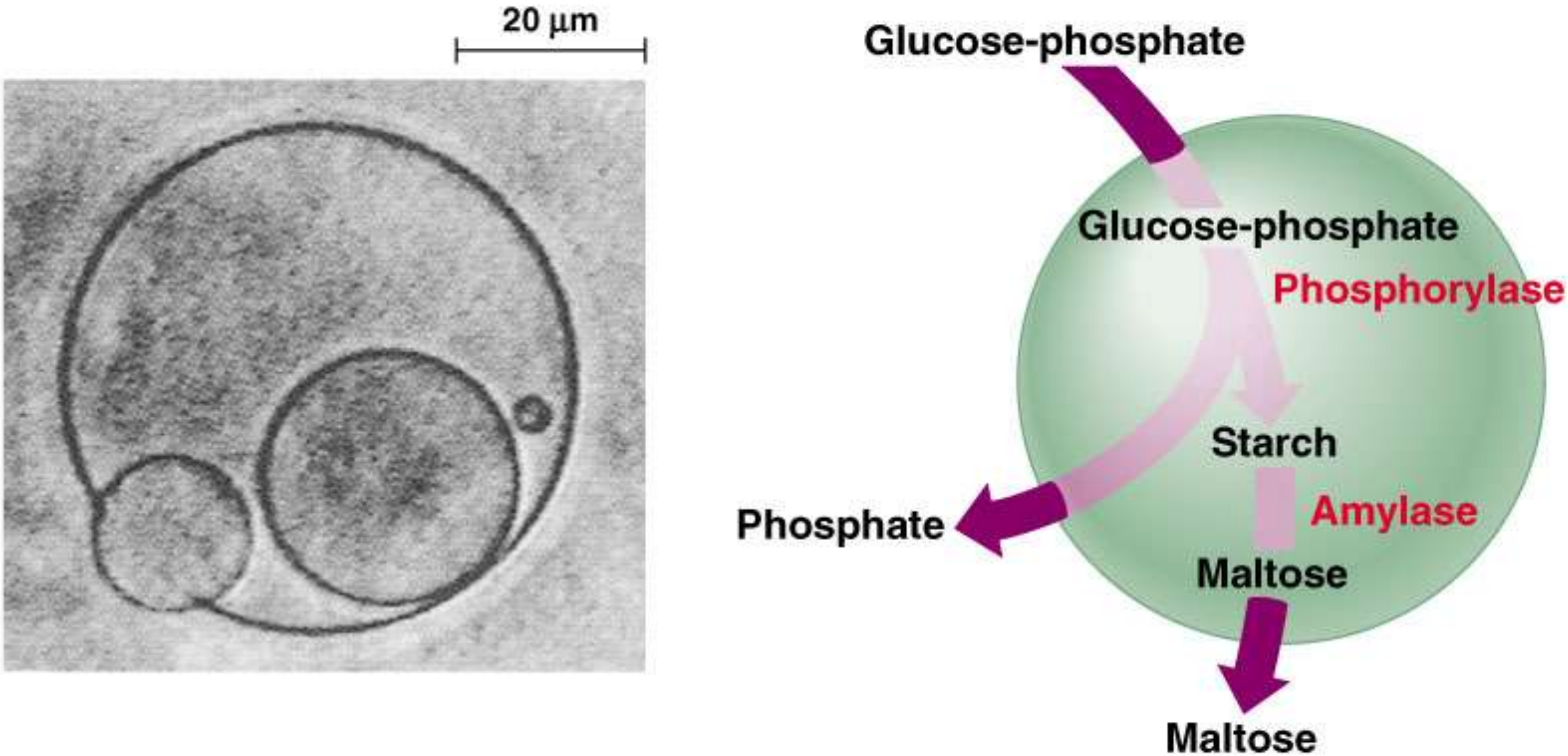
Chemical evolution ultimately led to the formation of proto-cells

Membrane-surrounded sacs containing genetic material and metabolically-active molecules

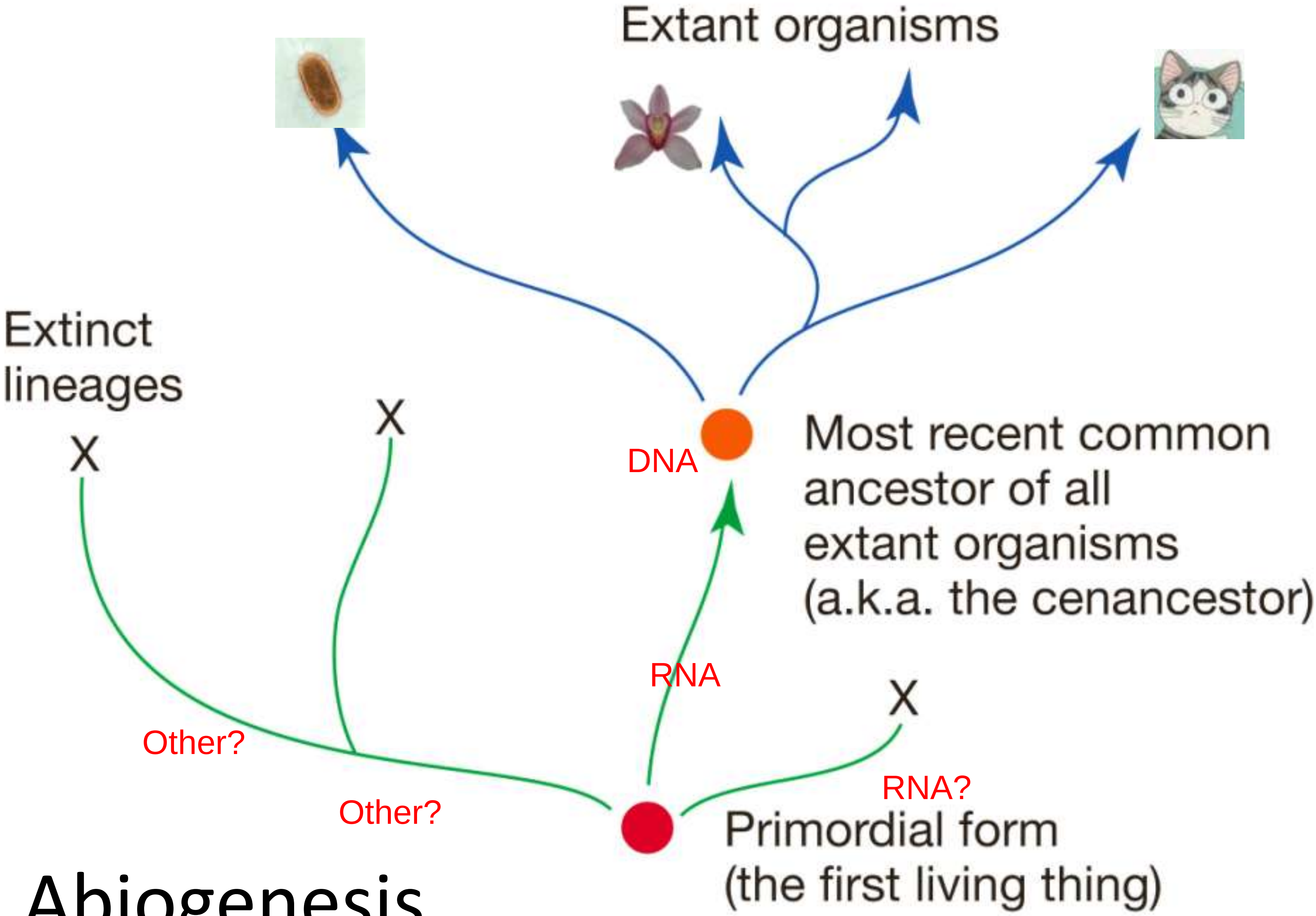
Such structures have been experimentally produced (**but not a living cell yet**).

From these proto-cells, cells ultimately arose.

It would only take the creation and evolution of one (1) proto-cell to give rise to the all the different organisms we see today.



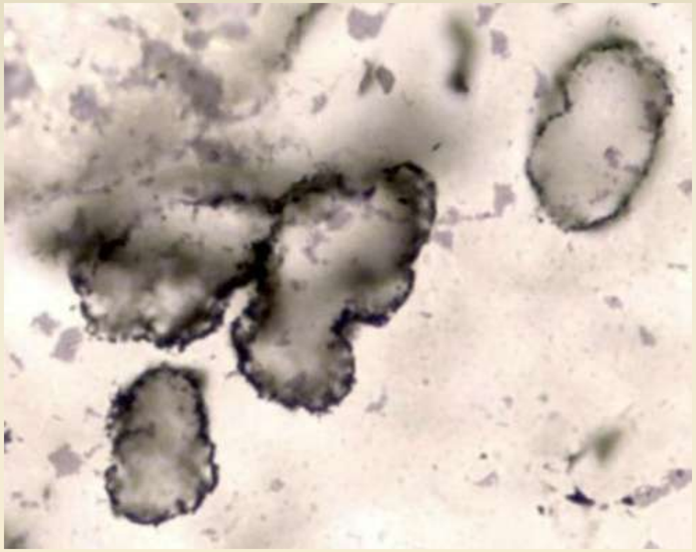
(a) Simple reproduction (b) Simple metabolism

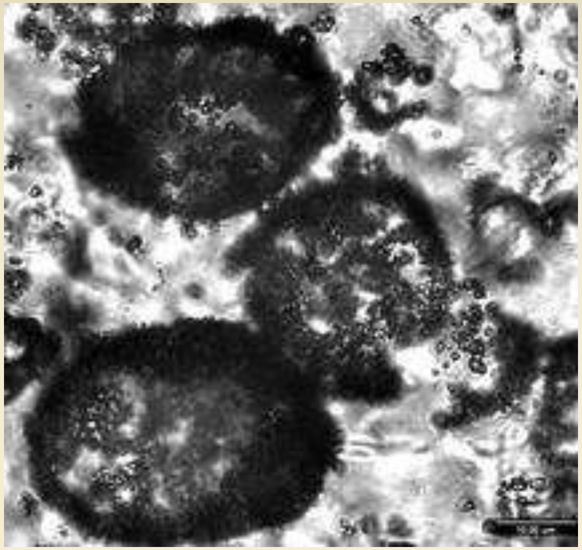


Abiogenesis

Oldest fossils 3.4 BY

Older fossil evidence questionable





The microfossils were found in a remote part of Western Australia called Strelley Pool. They are very well preserved between the quartz sand grains of the oldest beach or shoreline known on Earth, in some of the oldest sedimentary rocks that can be found anywhere

Stromatolites 3.5 BY, lipid biomarker evidence (isotopic evidence of biological activity at 3.9 BY)

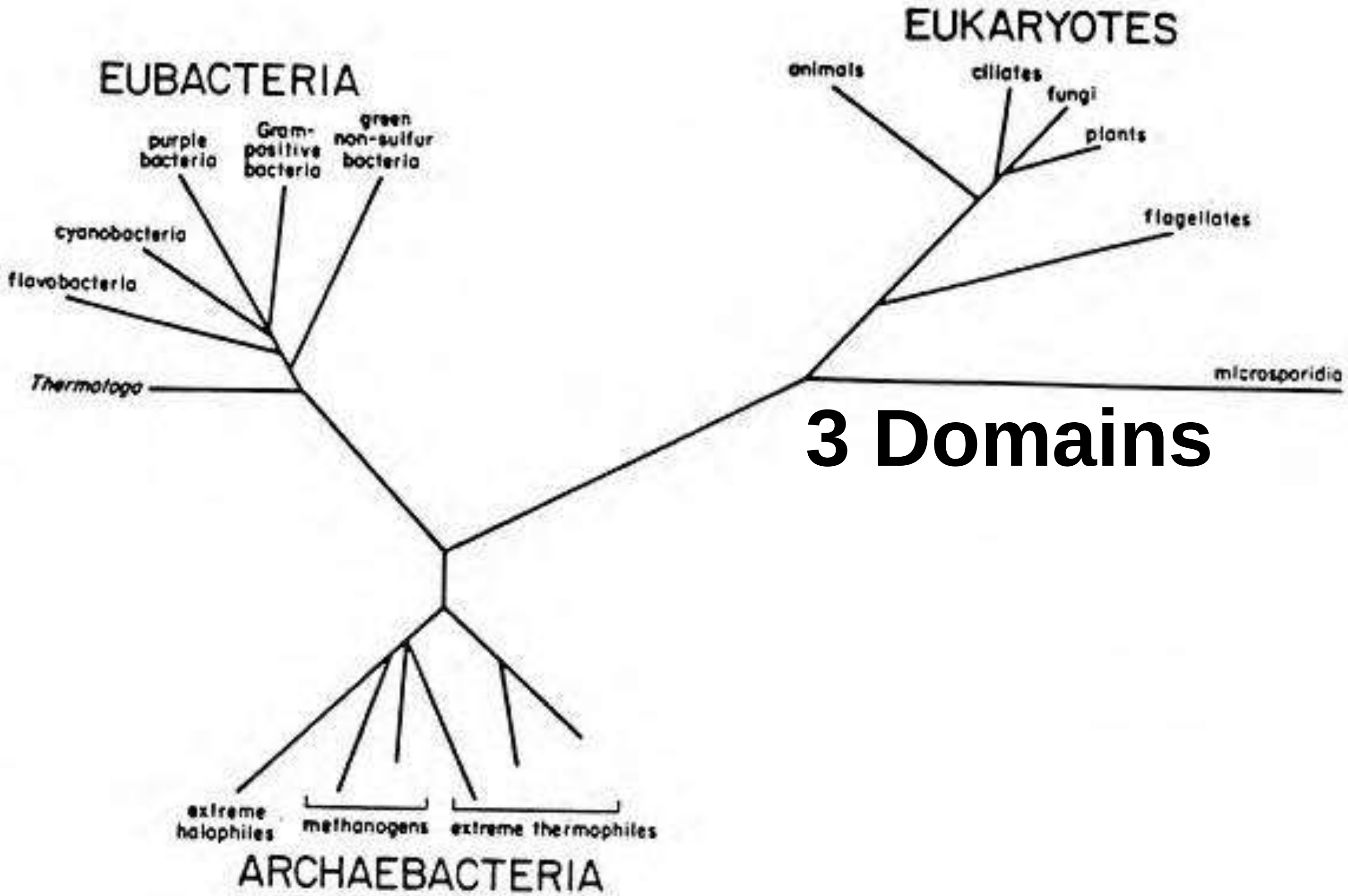
The earliest cell fossils 3.5 BY, were prokaryotic

- Lack a membrane-bound nucleus

Early in the history of life, populations diverged into two major lineages

- → bacteria
- → archaea & eukaryotes (1.5 BY?)

Carl Woese and the rRNA Tree of Life



3 Domains

Carl Woese
1980s
ssRNA
Sequences

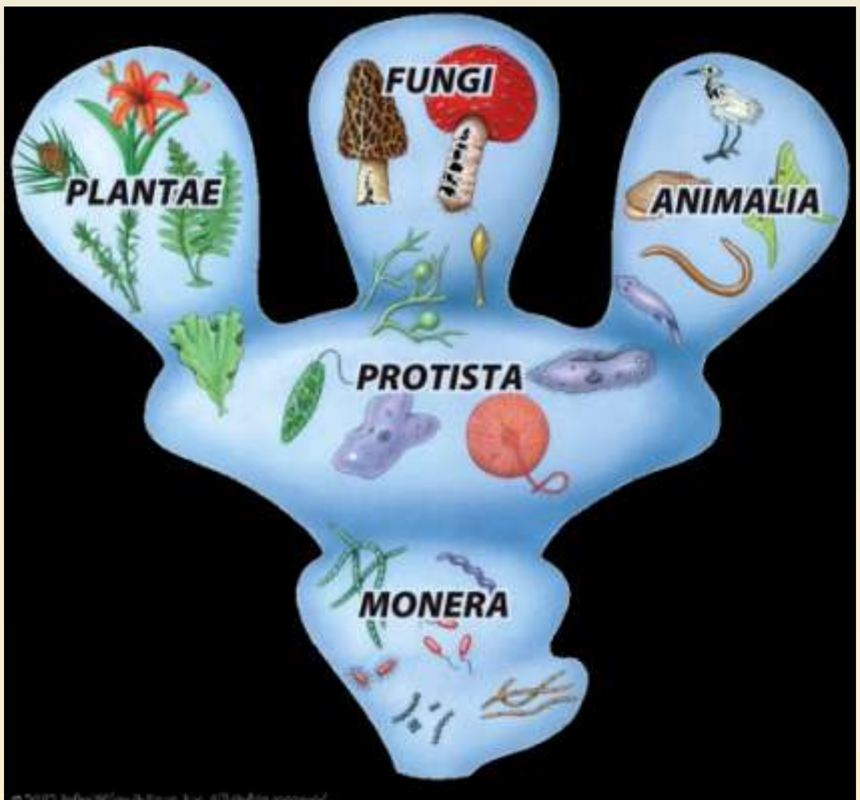
Four Kingdom Sysytem - 1950s

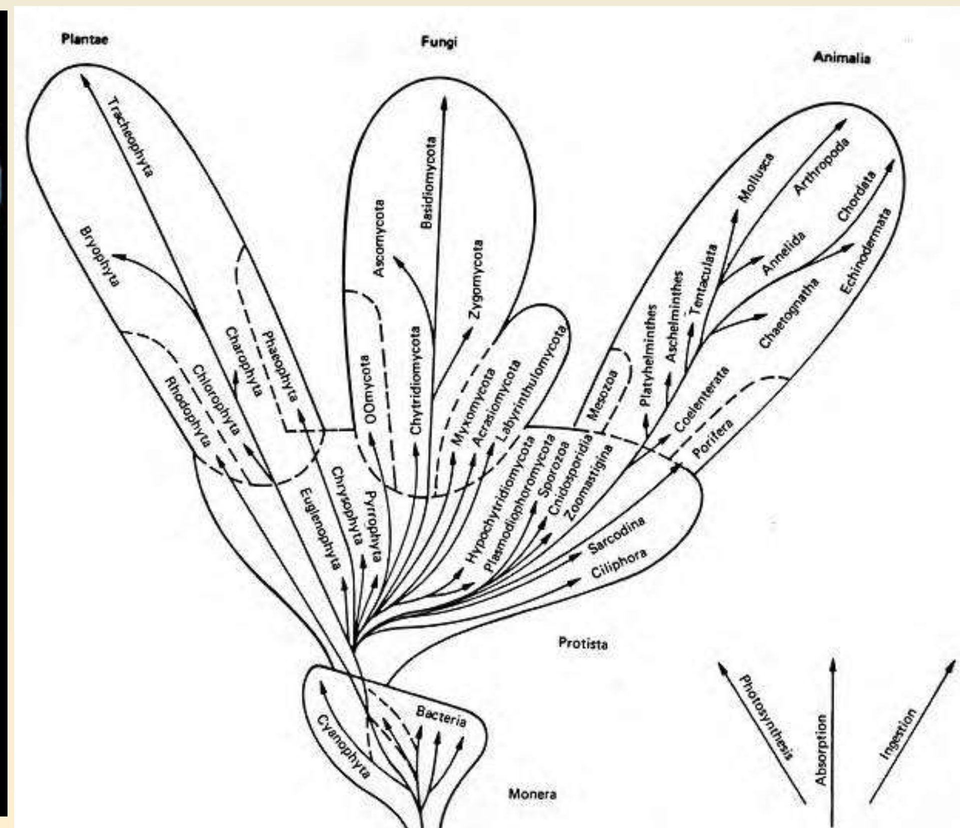
Protista lacking nuclei placed in separate kingdom, the Monera (bacteria)

Five Kingdom System - Whittaker's Tree of Life, 1967

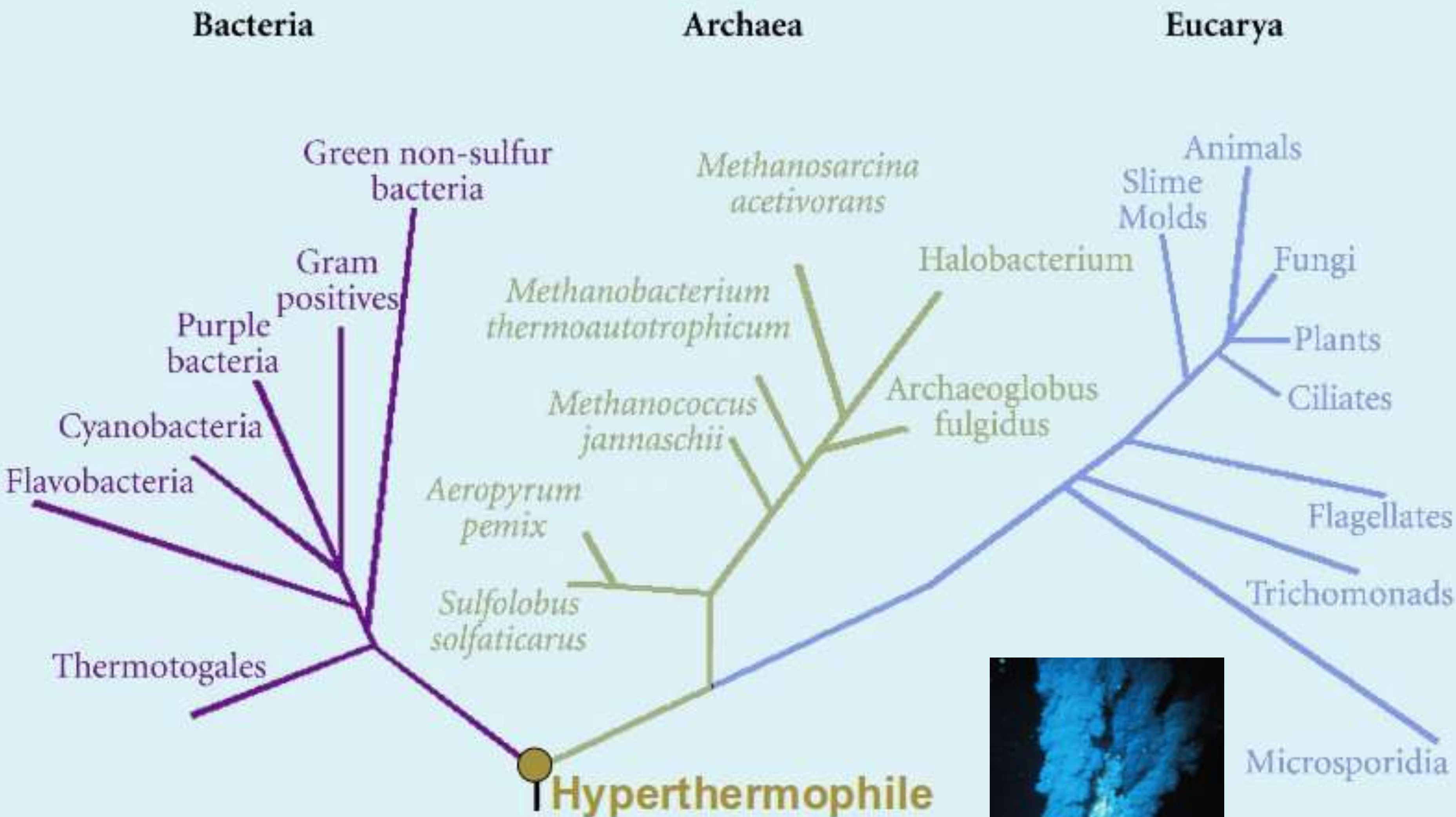
Stresses mode of nutrition (

Fungi recognized as separate kingdom, separate from plants

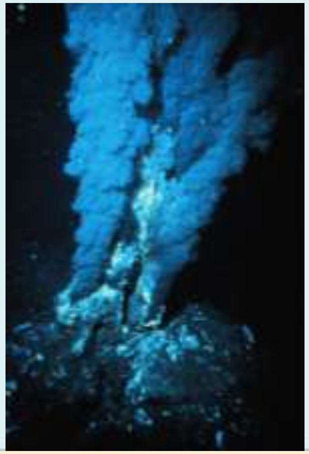




LUCA



→ Hydrothermal vents!



Bacteria (Eubacteria)

Major group of prokaryotes

- strong cell walls (peptidoglycan)
- simple gene structure
- contains most modern prokaryotes
  - includes photosynthetic bacteria
    - cyanobacteria

Archaea (Archaebacteria)

Ribosomal RNA different

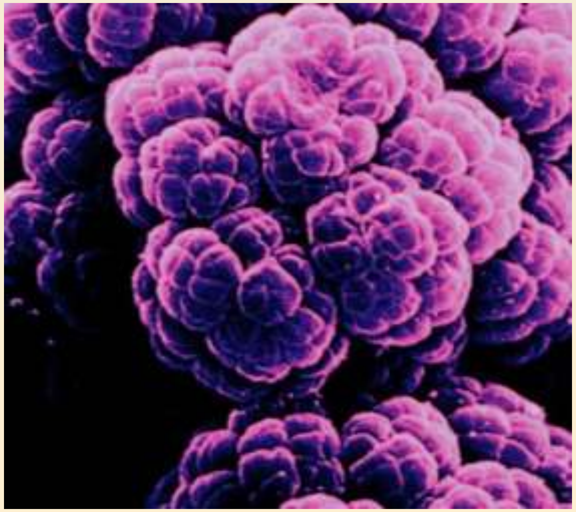
Cell walls lack peptidoglycan which Bacteria cell walls have

Membrane lipids with branched hydrocarbons which Bacteria do not have

Archaea has more in common with Eukarya than with Bacteria

Some live in extreme conditions

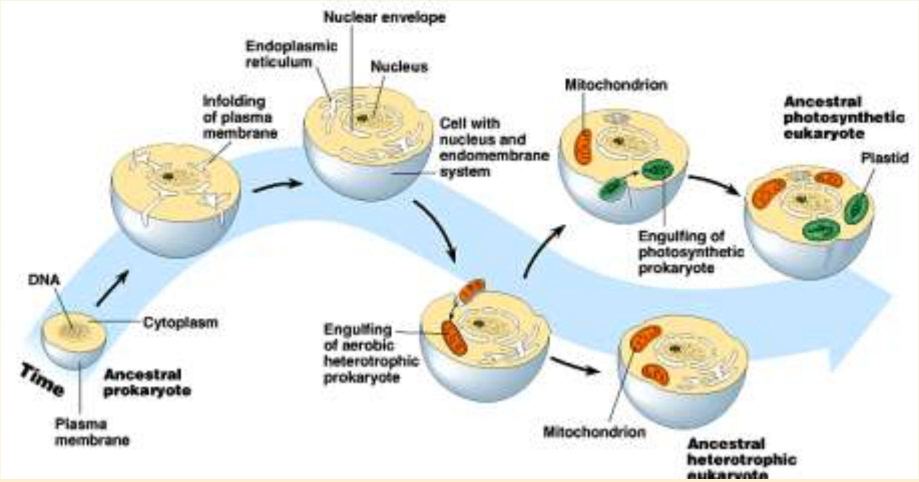
- methanogens
- extreme halophiles
- extreme thermophiles



Eukarya

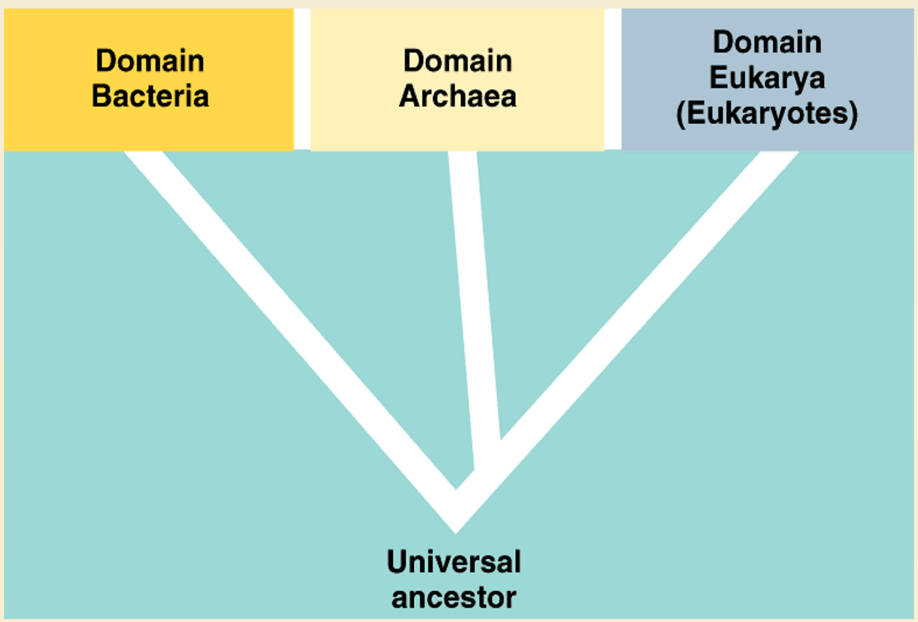
Probably arose about 1.5 bya.

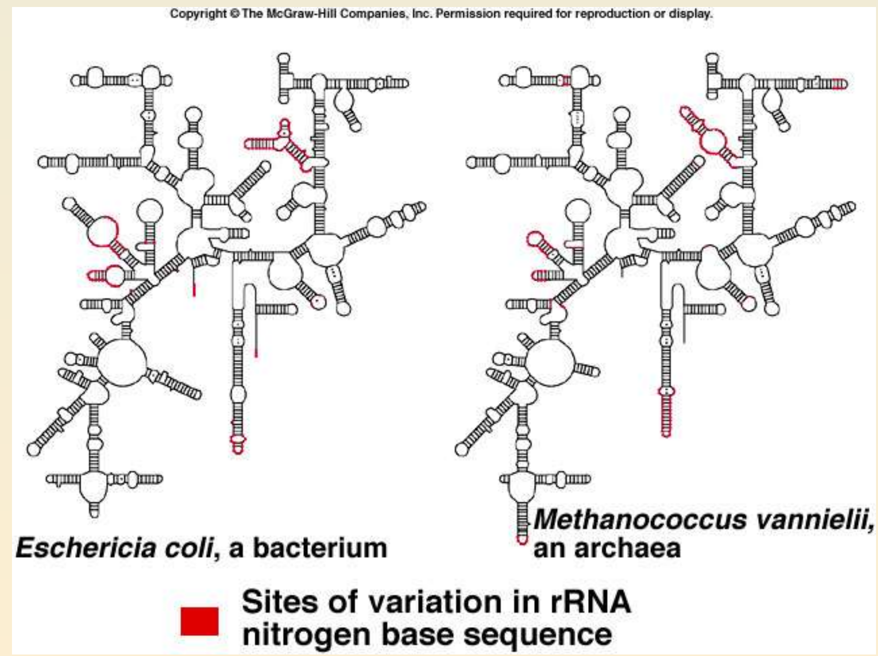
- Internal membrane-bound structures such as mitochondria and chloroplasts are thought to have evolved via endosymbiosis. Nucleus?
  - Energy-producing bacteria were engulfed by larger bacteria.
    - beneficial symbiotic relationship

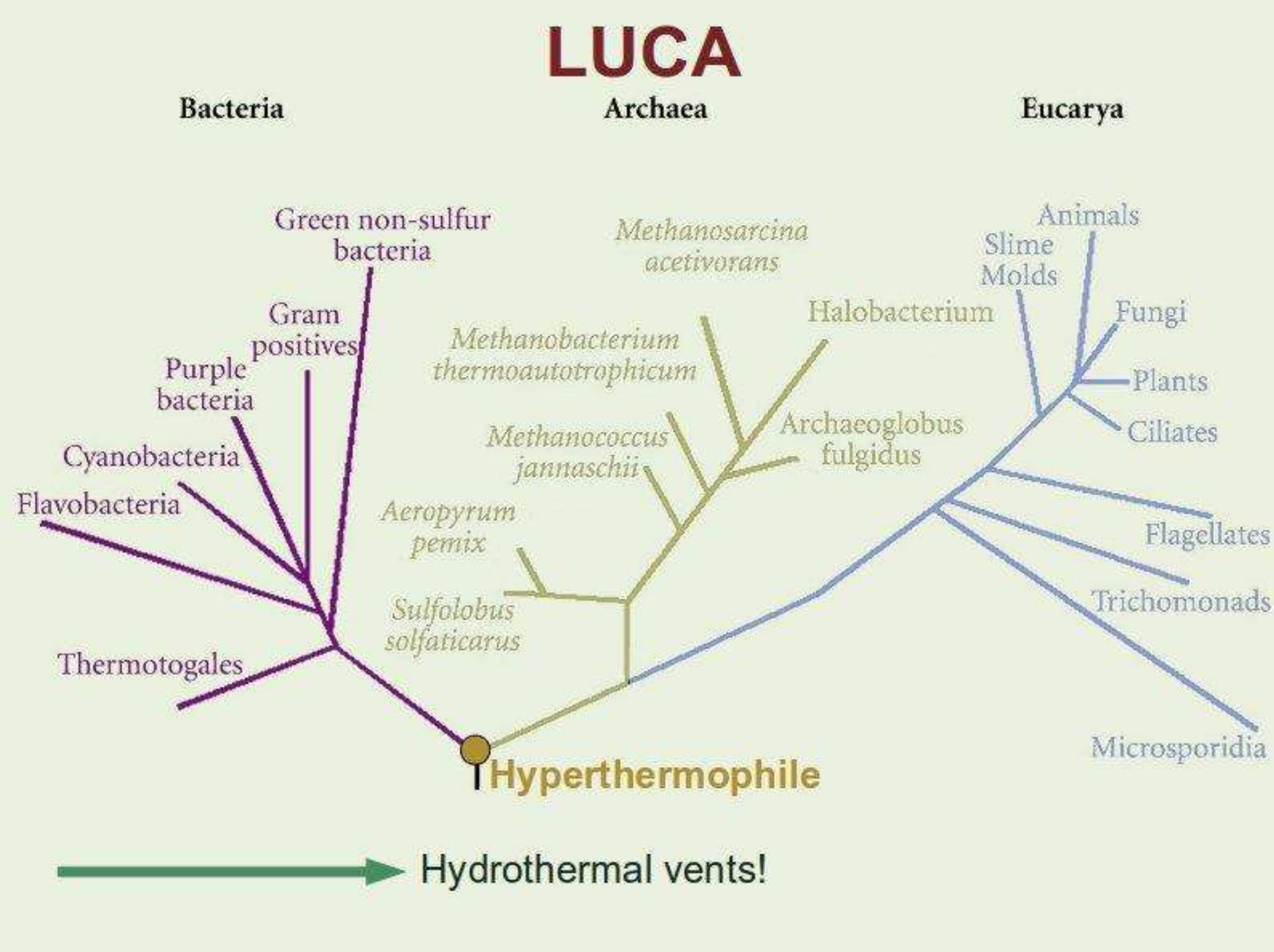


Eukarya is more closely related to domain Archaea than to domain Bacteria

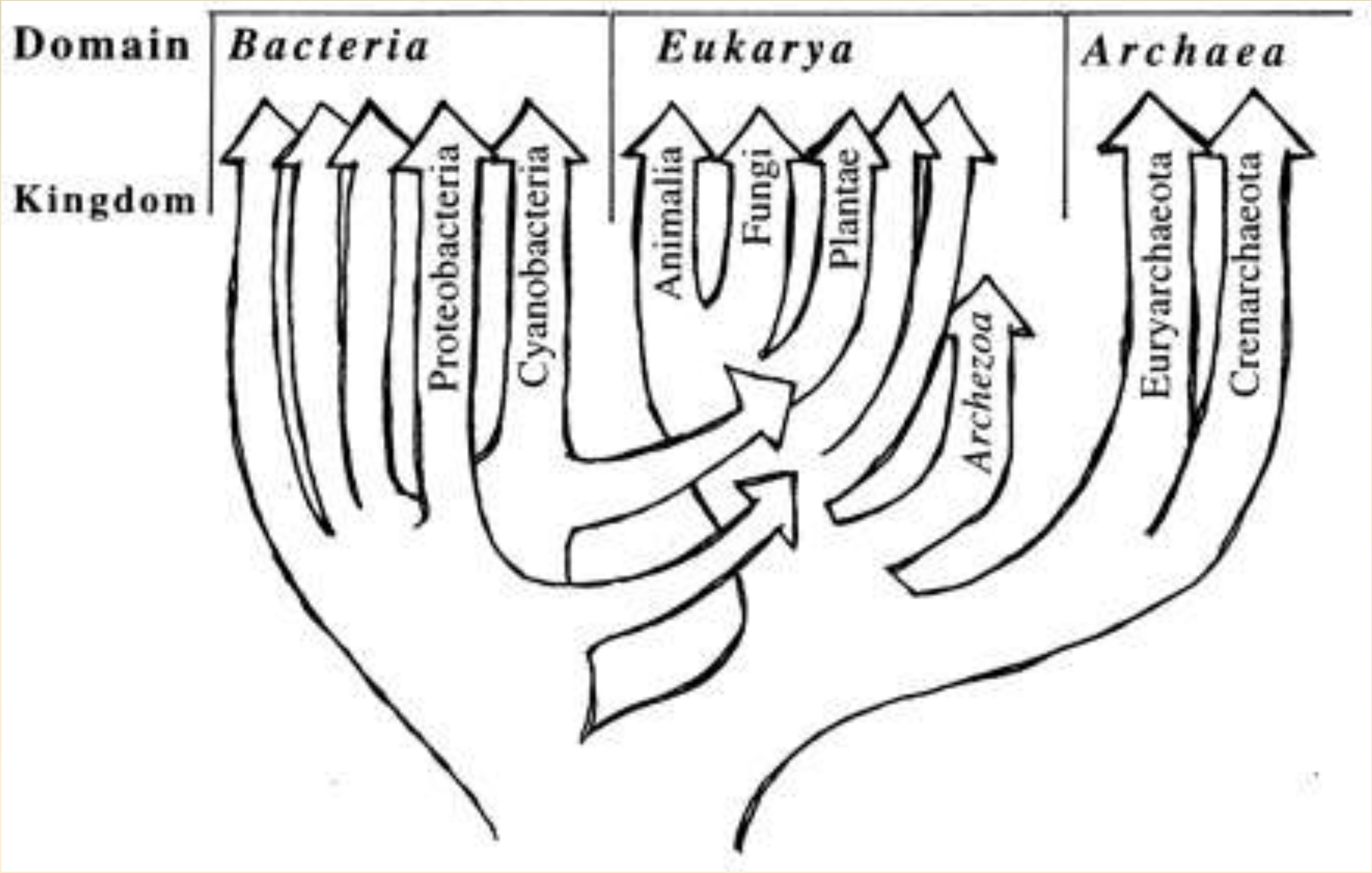
- Analysis of rRNAs and other highly conserved genes and proteins provide the strongest evidence



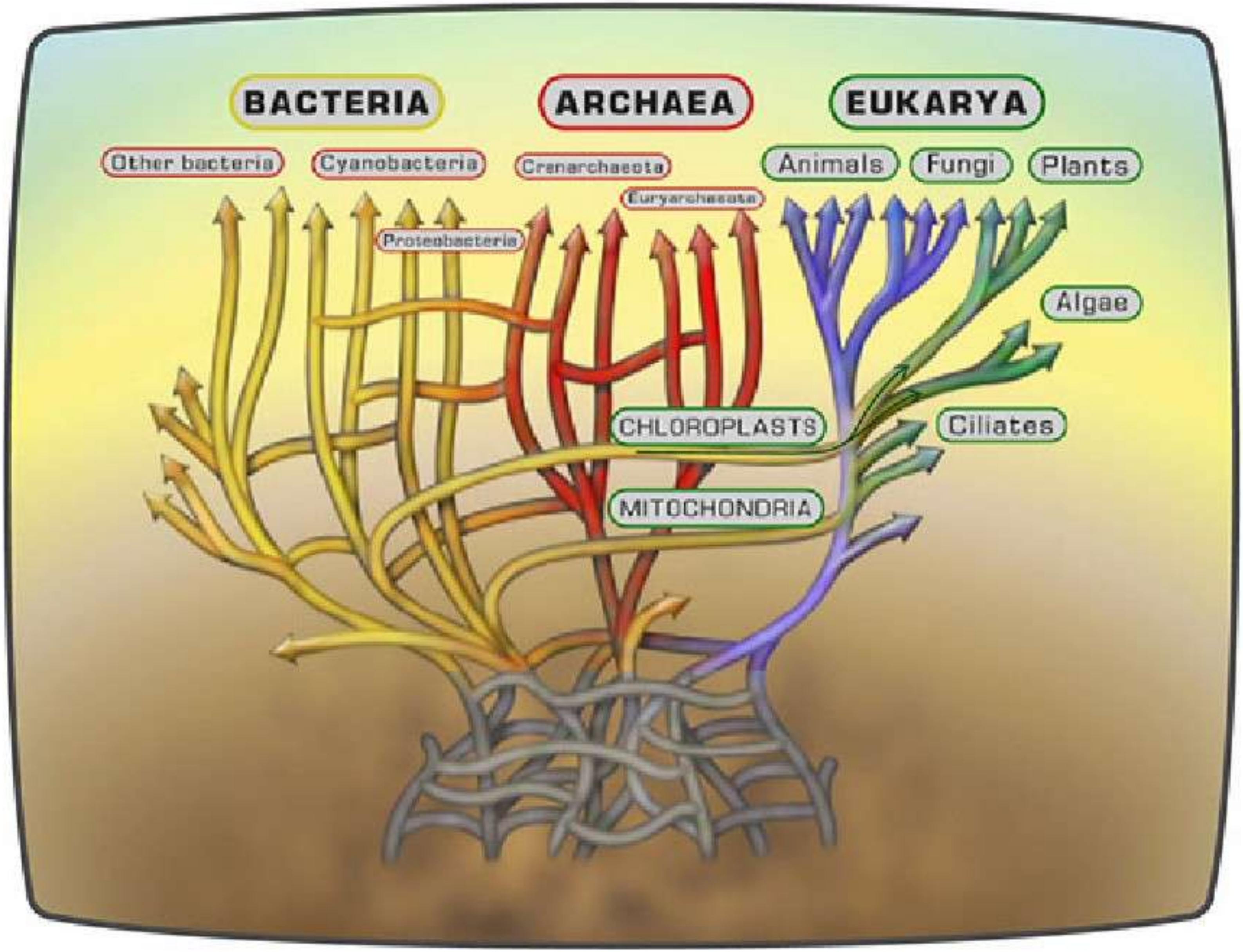



LUCA
Bacteria
Archaea
Eucarya
Green non-sulfur bacteria
Gram positives
Purple bacteria
Cyanobacteria
Flavobacteria
Thermotogales
Methanosarcina acetivorans
Methanobacterium thermoautotrophicum
Methanococcus jannaschii
Aeropyrum pernix
Sulfolobus solfaticarus
Halobacterium
Archaeoglobus fulgidus
Animals
Slime Molds
Fungi
Plants
Ciliates
Flagellates
Trichomonads
Microsporidia
Hyperthermophile
Hydrothermal vents!

Mitochondria and Chloroplast



Horizontal Gene Transfer



Our Story So Far

We have come 5/6 of the way through the history of the Earth.

Earth forms 4.6 billion years ago

Solid surface forms 4 billion years ago

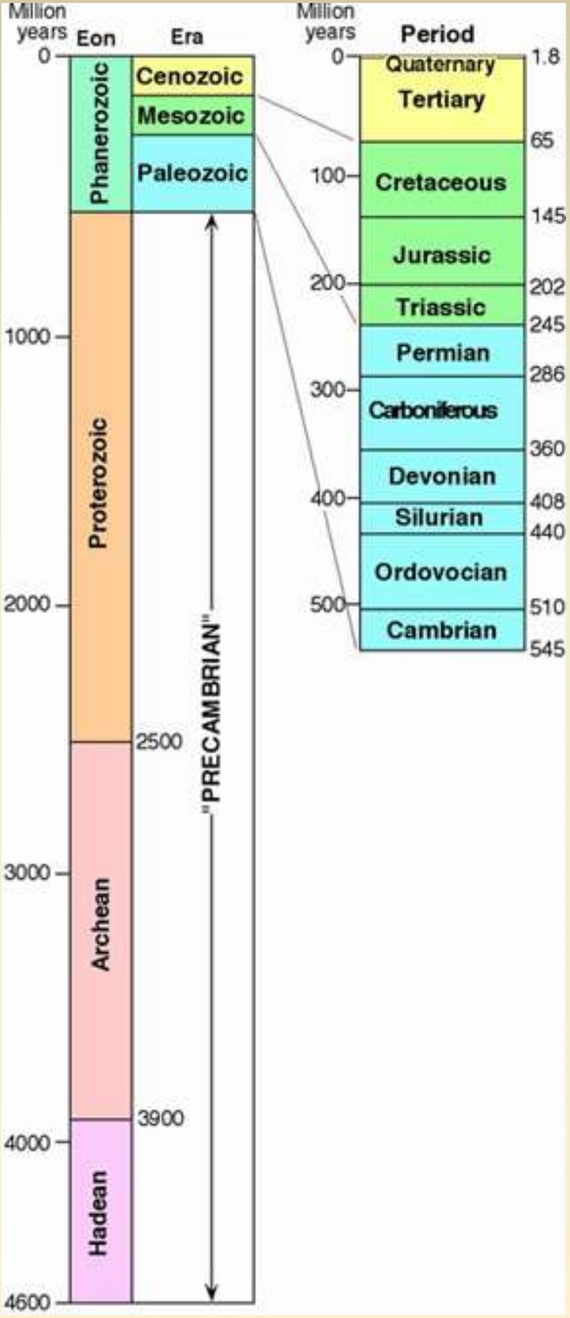
Life starts (?) 3.8 billion years ago

Age of Bacteria

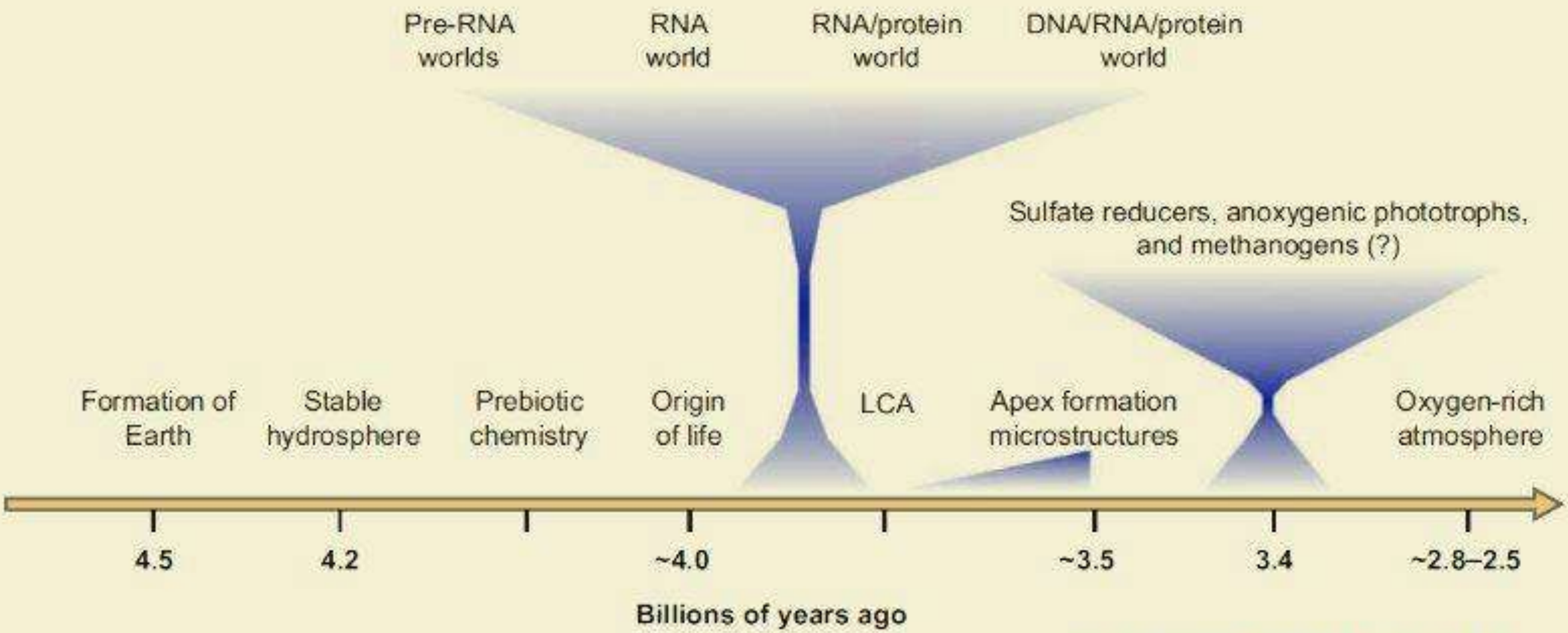
Oxygen atmosphere develops 2 billion years ago.

Eukaryotes develop.

Edicarian life: 650 million years ago. First multicellular life, forms unknown today



Timeline



Modified from Becerra et al. *(2007)*

End