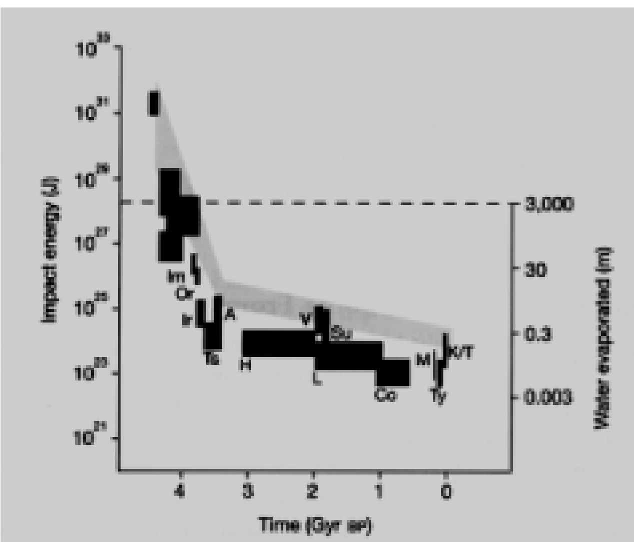
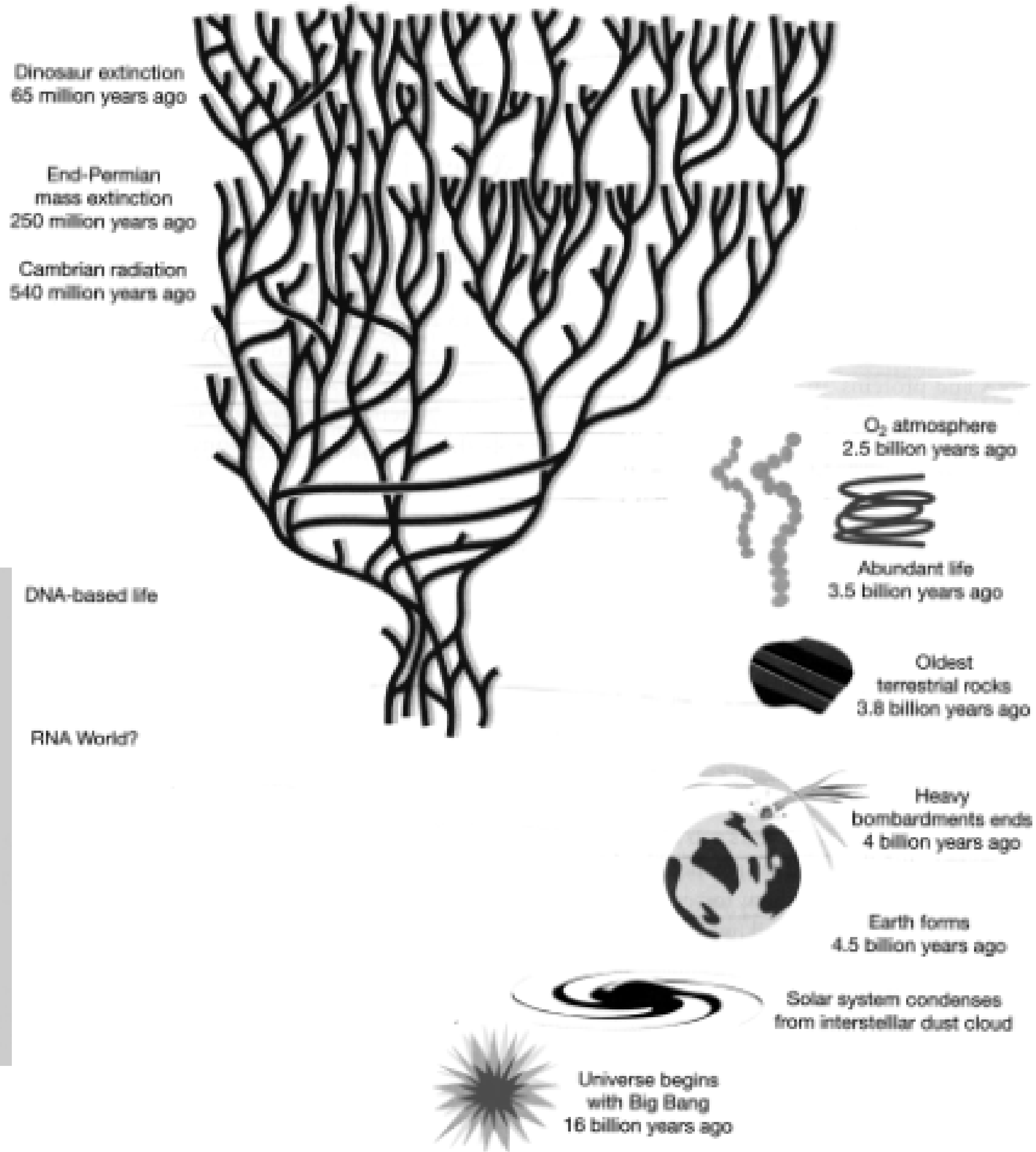
Origin of Life, Precambrian Evolution

History of Everything



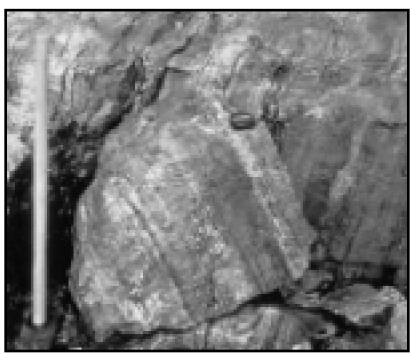


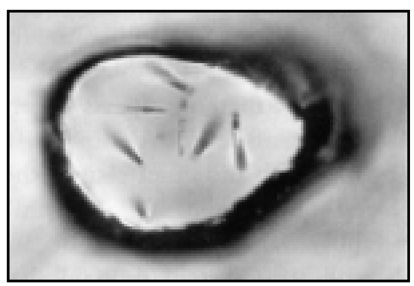
Timeframe

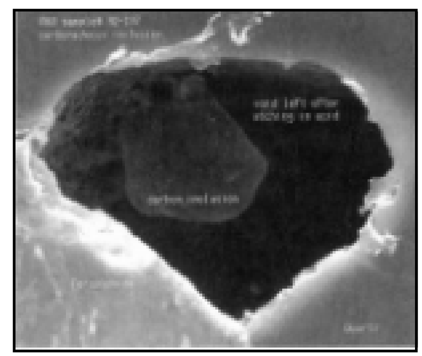
- Life existed at least 3.85 billion years ago
- Oldest known sedimentary rocks contain oldest known life
  - Perhaps if older rock are found, older life will be found
- How do we know?
- Stable carbon isotopes C12 and C13
  - Organisms preferentially use C12

Oldest rocks, Akilia Island, Greenland

- Rock dated by radio-dating methods
- Inside rock layers are apatite crystals
  - Apatite calcium phosphate
- Carbon specks embedded within the apatite crystals measured for C12 and C13
  - Show C12:C13 ratio typical of life







Start of Life

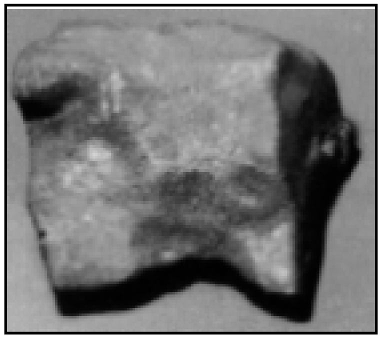
- Extra-terrestrial origin hypothesis
  - Building block of life arrived from somewhere else
- Life arose on Earth hypothesis
  - Oparin-Haldane model

- Both required basic building blocks made of simpler chemical somewhere somehow

Basic building blocks

- Biologically active molecules synthesized
  - 1953 Stanley Miller boiled methane, ammonia, and hydrogen with spark of electricity
  - Inorganic synthesis of
    - Amino acids glycine, alpha-alanine, Beta-alanine
  - Since 1953 chemists have inorganically synthesized wide range of organic molecules
    - Amino acids, nucleotides, sugars
- Could have happened on earth in highly reducing atmosphere
  - Chemically less likely in oxidizing atmosphere

Extra-terrestrial origin of basic building blocks



- Idea is that life did not have to originate on earth
  - Perhaps carried in by comets, asteroids, or dust
- Murchison meteorite hit earth in 1969
  - Collected and analyzed without contamination
  - Amino acids glycine, alanine, glutamic acid, valine, proline fairly abundant *within* the meteorite

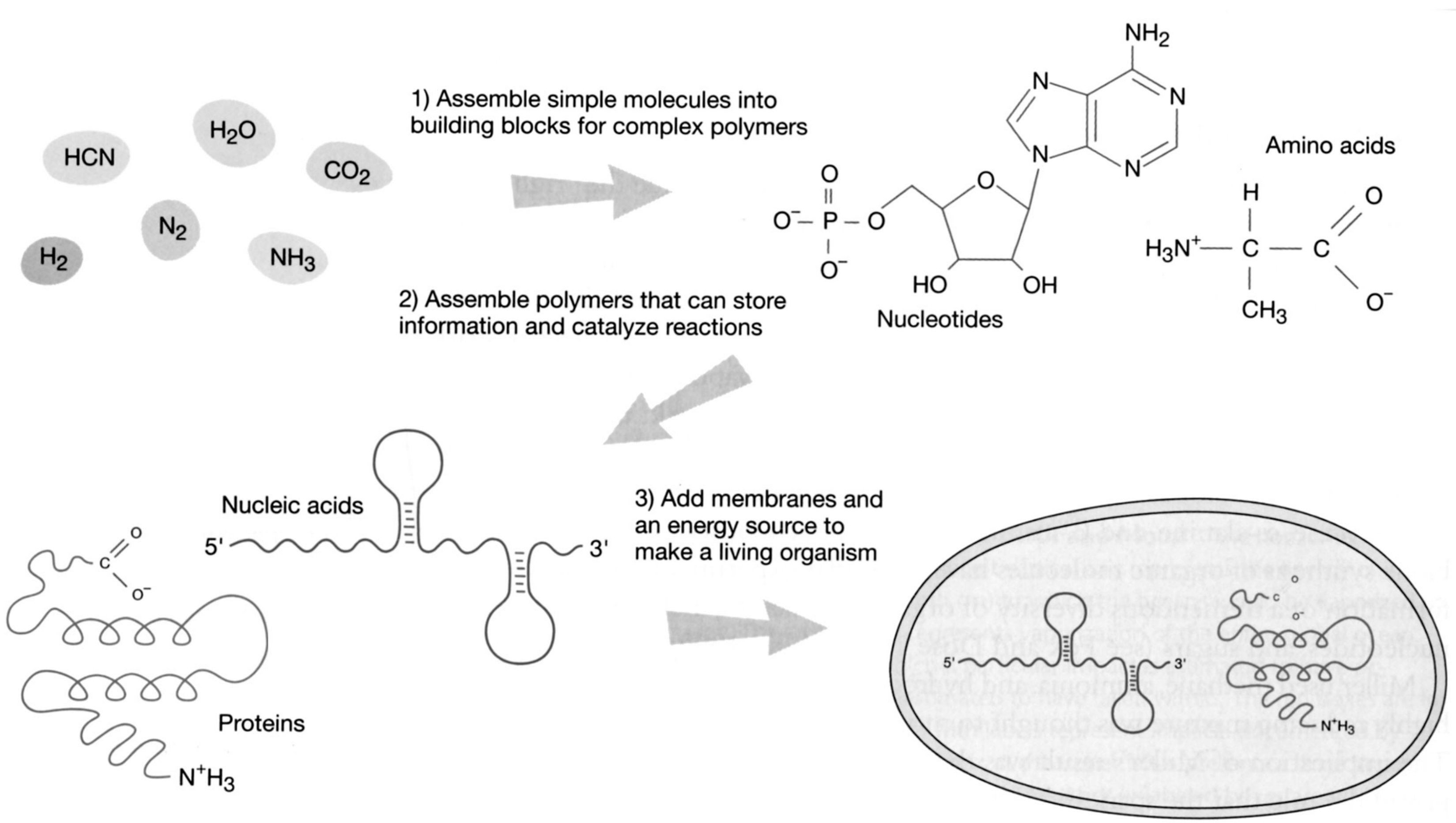
Importance of extra-terrestrial evidence

- Extra-terrestrial organic molecules show
  - Possibility of extra-terrestrial origin of basic molecules
  - Some molecules *could have* made it to earth intact
  - Larger pieces of life almost certainly could not
    - UV radiation, cold, and vacuum could be overcome
    - Impact with earth likely could not (pre-atmosphere)

Oparin-Haldane model

- Life arose on earth
  - Simple inorganic synthesis
  - Assembly to large more complex molecules
  - Polymers that can
    - Store information (genotype)
    - Catalyze reactions (phenotype)
  - Add membranes and energy source -> life

Oparin-Haldane diagram



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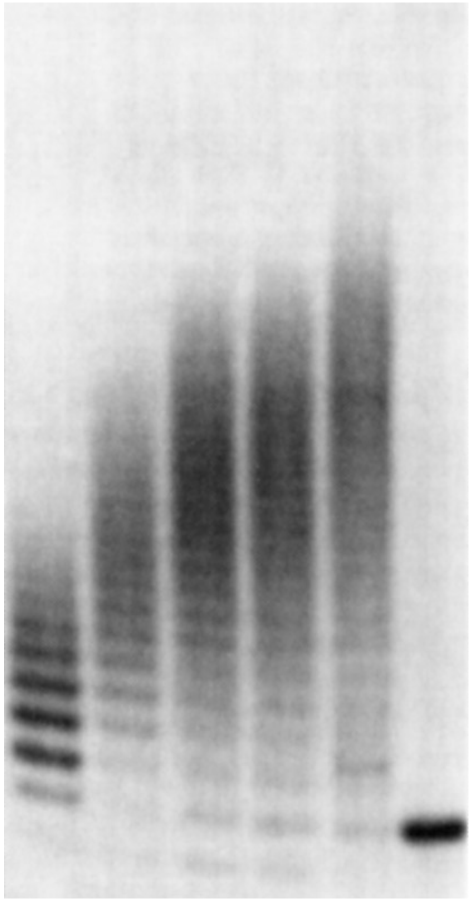
Complex molecules

- Problem: large molecules can be built in water, but also broken down
- Assembly of larger polymers may have been assisted by inorganic substrates such as clay
- Long nucleotide chains assembled by Ferris with clay mineral montmorillonite
  - Acts as catalyst to join molecules into polymers
  - Experimental addition of new nucleotides daily to the solution
    - 40+ nucleotide chains produced



Extension to amino acids

- Ferris and Orgel continuation
- Using minerals illite and hydroxylapatite
  - Created amino acid chains up to 55 amino acids long

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Polymer qualities

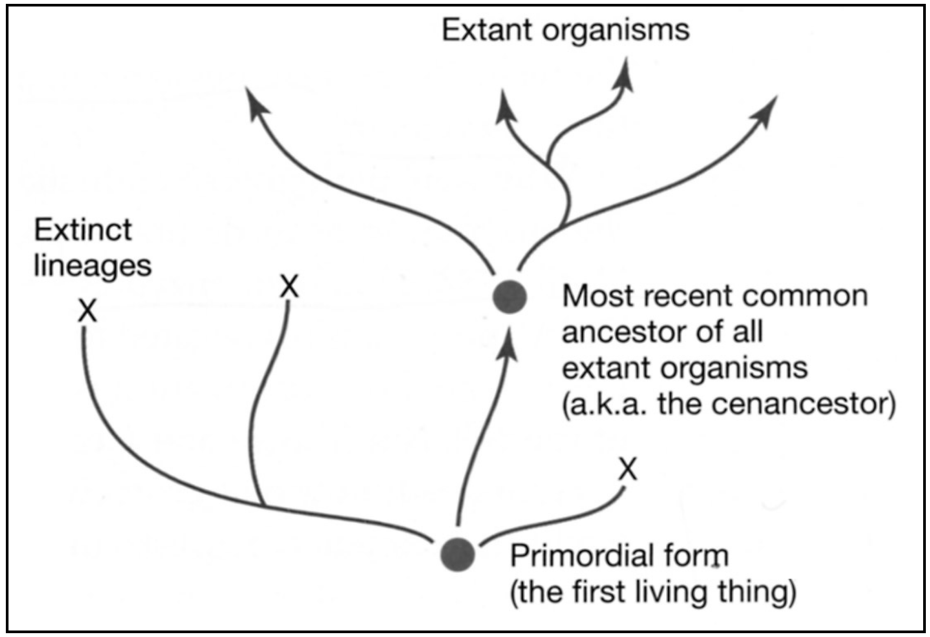
- Store information
  - Like modern DNA and RNA do
- Catalyze reaction
  - Like modern proteins do
- So what came first, DNA or protein?
  - DNA can’t do anything
  - Proteins can’t transmit heritable information

Can RNA catalyze reactions?

- Early 1980’s Altman and Cech independently discovered RNA that can catalyze nucleic acid bonds
  - Can break bonds
  - Can reform bonds
- Called ribozymes for “RNA-Enzymes”

RNA world hypothesis

- RNA preceded DNA as information molecule
- Cenancestor
  - Most common recent ancestor of all extant living things
  - not necessarily closely similar to first living things



Could be that cenancestor was DNA based but first living things were RNA based

Evidence consistent with RNA world

- Ribozyme RNA can have both phenotype (do something) and a genotype (transmit information)

Ribozyme functions discovered to date

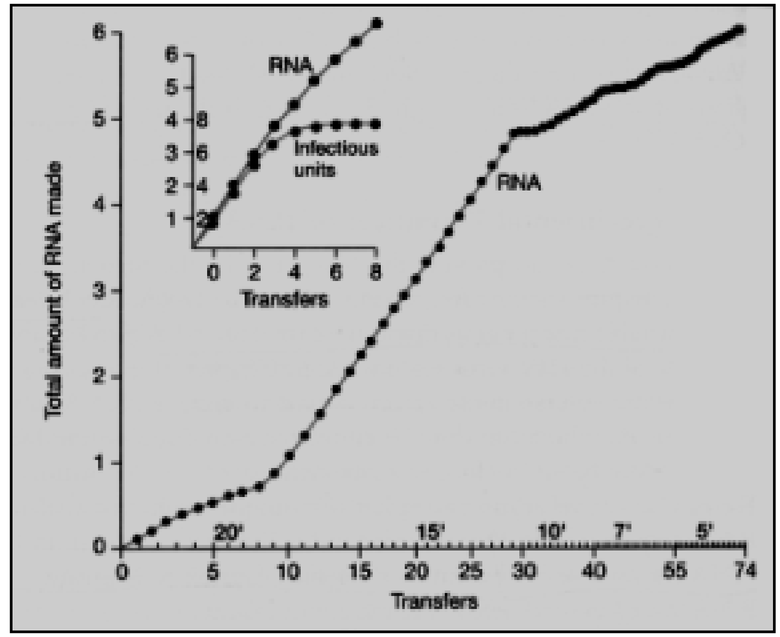
- Now known to catalyze reaction such as
  - Phosphorylation
  - Aminoacyl trasfer
  - Peptide bond formation
  - Carbon-carbon bond formation
  - Can bind specifically to substrates
- But could a ribozyme *evolve* ?

Ribozyme evolution

- RNA sequences store information needed for complementary base pairing
  - Store information that could be propagated
    - E.g. RNA viruses
- Can catalytic RNA (ribozymes) sequences change to improve their own transmission?
  - I.e. show adaptive evolution

Spiegelman Q-beta replicase

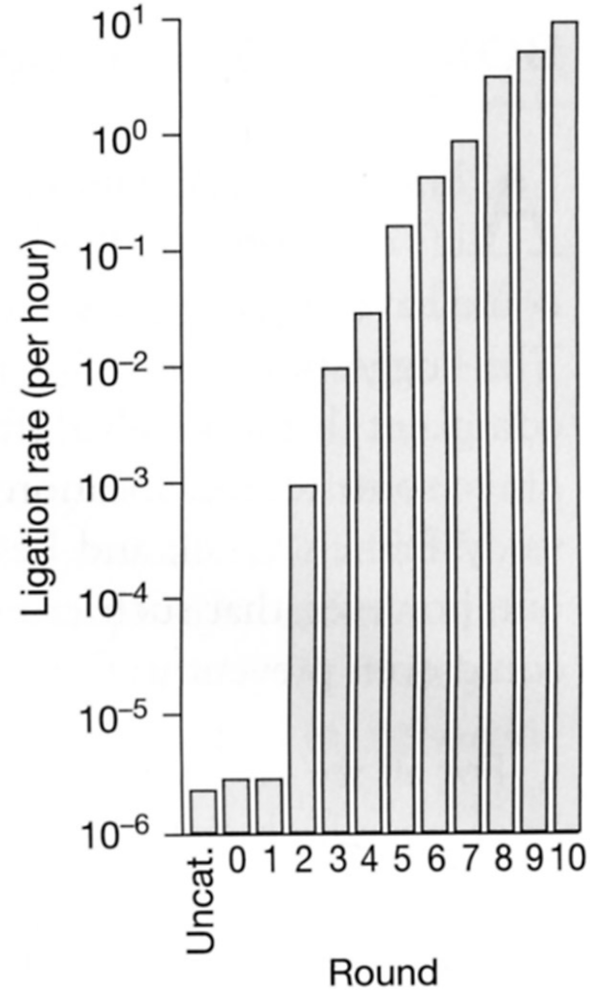
- Q-beta replicase taken from bacteriophage
- Q-beta + Q-beta replicase -> RNA copies
  - Copies may be made with error (mutation)
- After four serial transfers Q-beta RNA had reduced ability to infect bacteria
- RNA had shortened by 83%



Short RNA out-reproduced long RNA because it has faster generation time

Ekland & Bartel catalytic RNA

- Catalytic RNA that self replicates
  - works on RNA substrate
- Adds up to 6 nucleotides to growing RNA chain



Oparin-Haldane model

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  - Add membranes and energy source -> life

Going cellular

- Adding membrane
  - Allows compartmentalization
  - Allows concentration of chemicals
- How did cell membranes evolve?
  - Perhaps self-organization of hydrophilic and hydrophobic molecules into sphere
  - Fox and colleagues mixed polyamino acids in water and salt solutions
    - Spontaneously self-organize into microspheres

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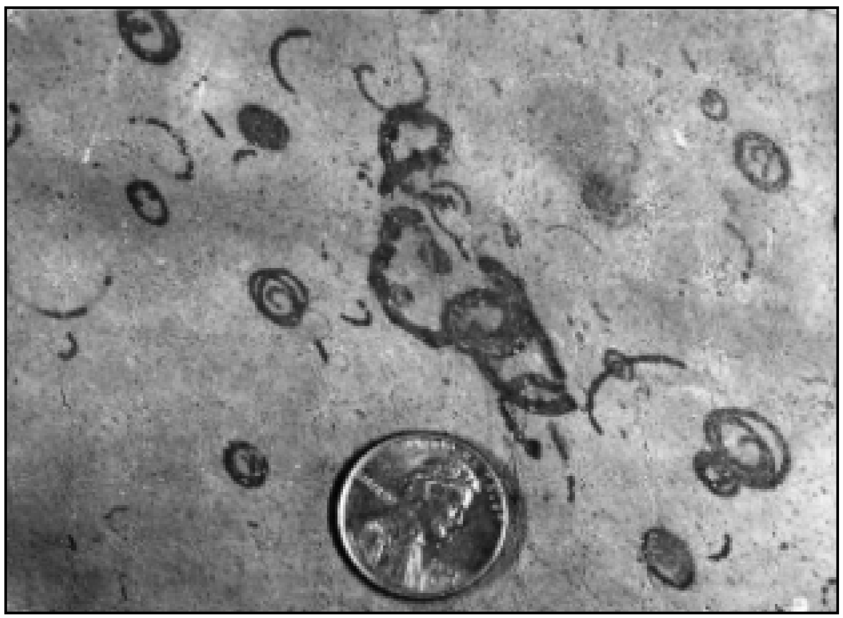
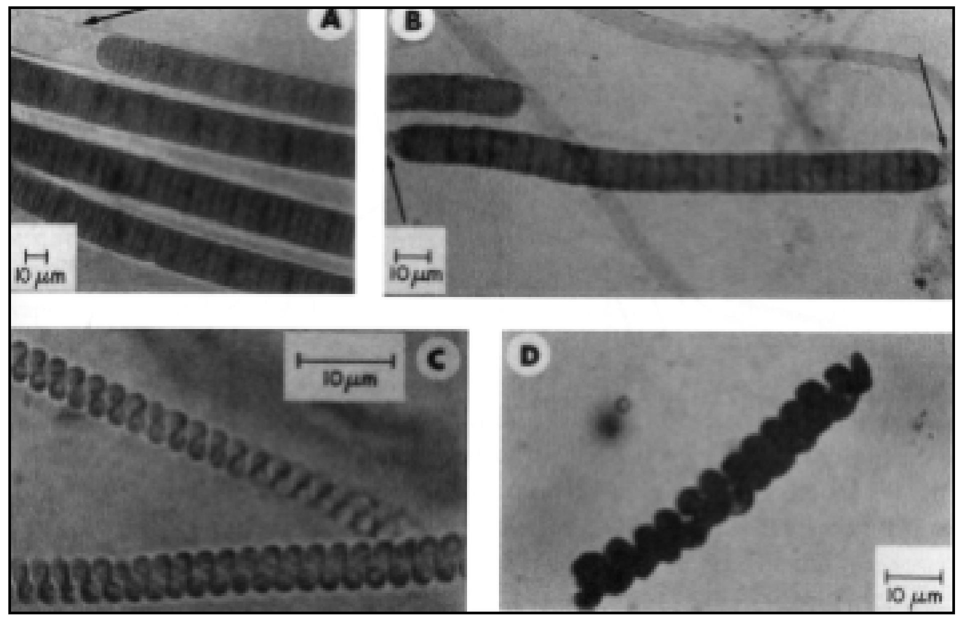
  - Add membranes and energy source -> life perhaps self organized

Cells existed minimum 3.465 bya

- Fossil cells similar to cyanobacteria found in Apex chert in Western Australia

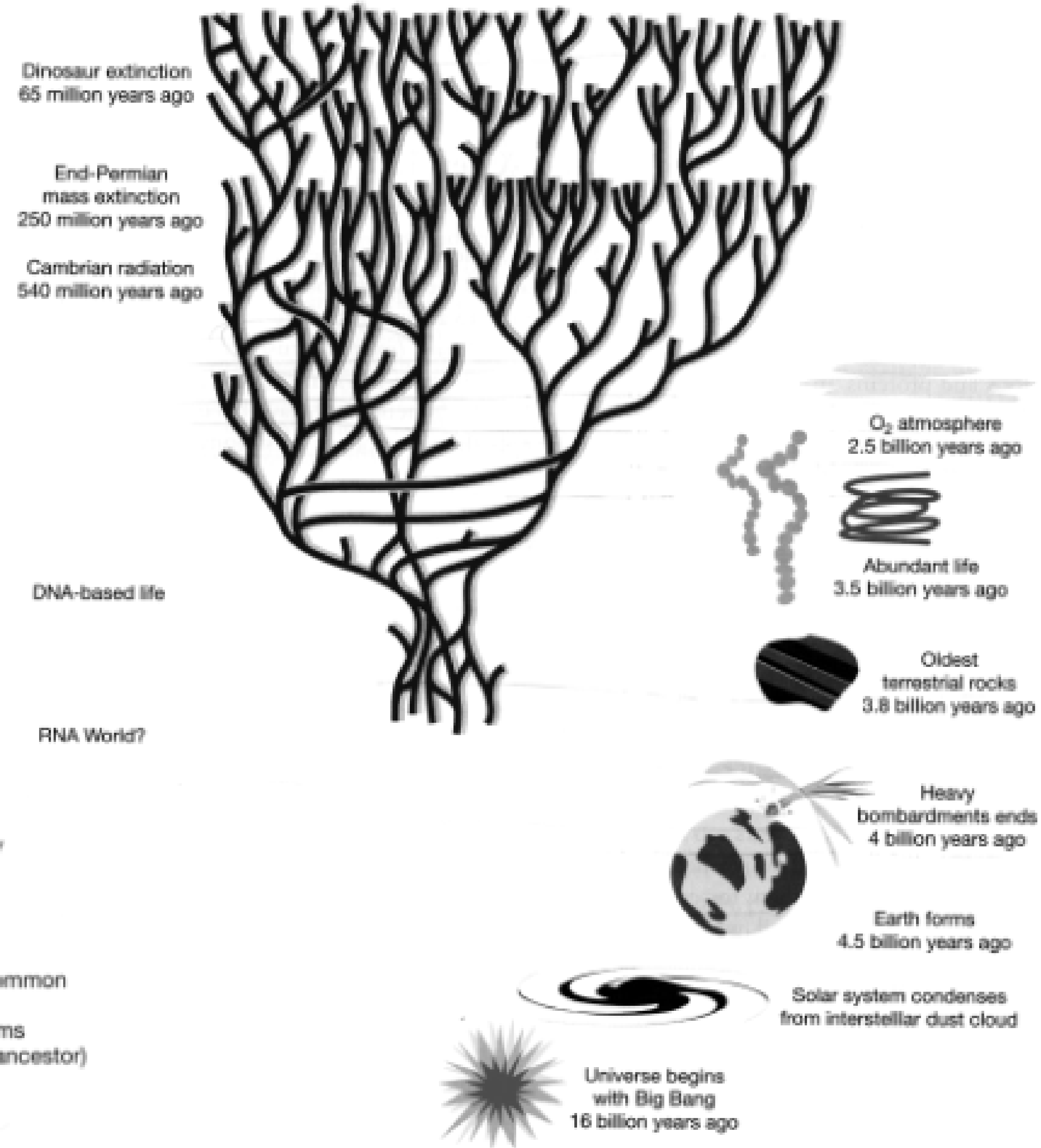




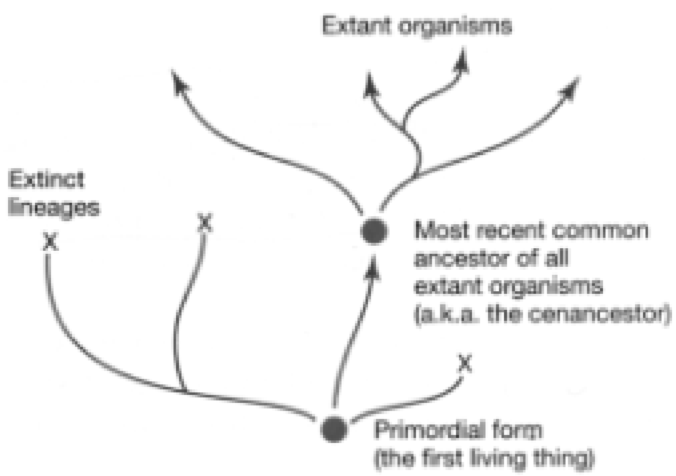
Precambrian evolution and the phylogeny of all living things

- Life arose and was cellular by 3.465 bya
  - Resembled cyanobacteria
- What was most recent common ancestor like?

History



Dinosaur extinction
65 million years ago
End-Permian
mass extinction
250 million years ago
Cambrian radiation
540 million years ago
DNA-based life
RNA World?
O2 atmosphere
2.5 billion years ago
Abundant life
3.5 billion years ago
Oldest
terrestrial rocks
3.8 billion years ago
Heavy
bombardments ends
4 billion years ago
Earth forms
4.5 billion years ago
Solar system condenses
from interstellar dust cloud
Universe begins
with Big Bang
16 billion years ago



Extant organisms
Extinct
lineages
Most recent common
ancestor of all
extant organisms
(a.k.a. the cenancestor)
Primordial form
(the first living thing)

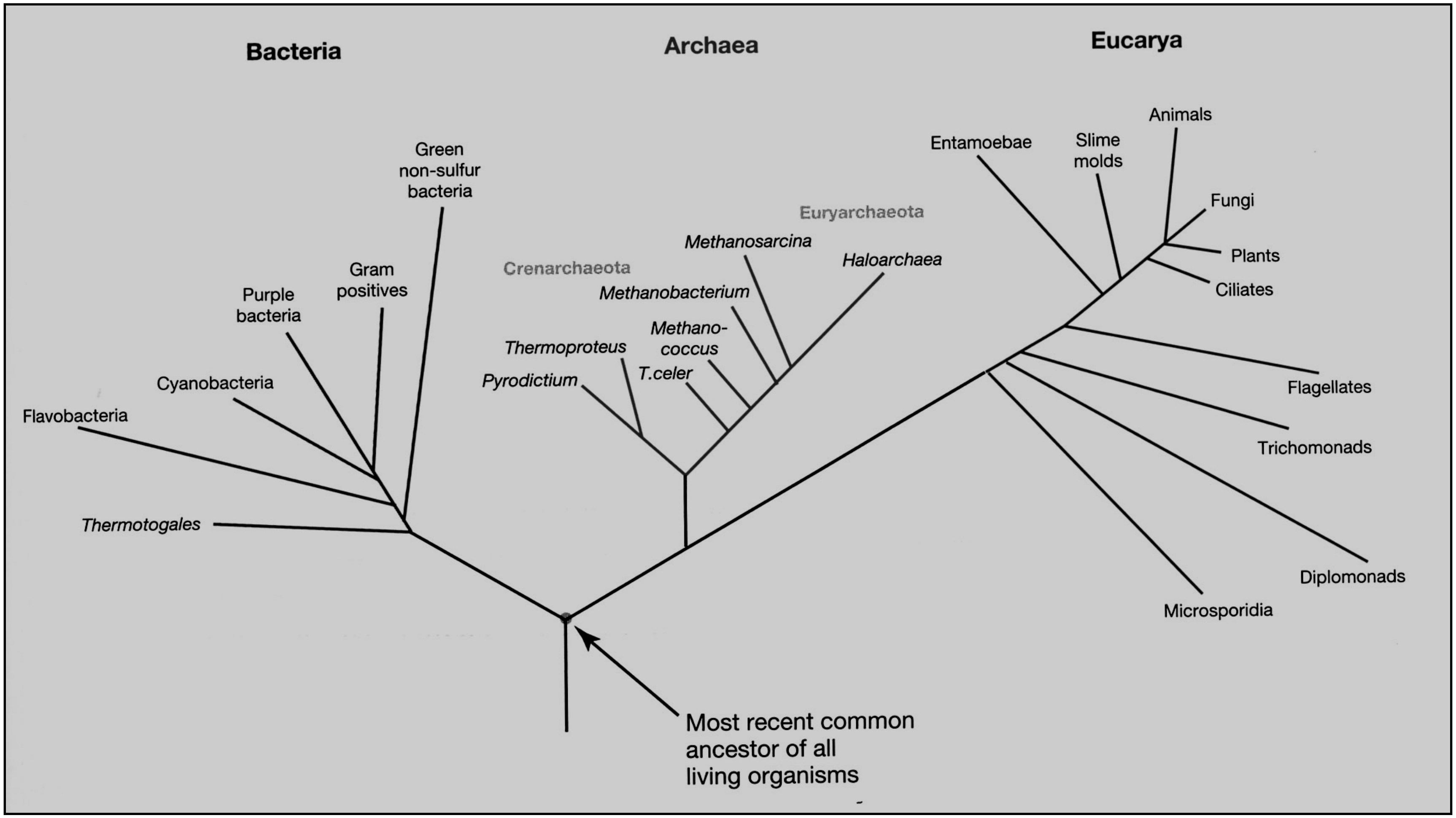
Making an all life phylogeny

- DNA sequencing revolutionized our view of early life evolution
  - What properties of genes would be suitable to examine very early life?
  - Genes that evolve fast? Slow?
  - Coding or non-coding?
  - Do you need a gene that is homologous in all living things?

Small-subunit ribosomal RNA

- All organisms have ribosomes
  - Consistent with RNA world hypothesis
- Ribosomes in all organisms have large and small subunits
- Functional in translation
  - Strong stabilizing selection -> slow rate of change

Ribosomal RNA phylogeny of life



Conclusions

- Five kingdom scheme does not represent true divisions of life
  - Used to be:
    - Bacteria (Monera); Protists (single cell eukaryotes); Plants; Fungi; Animals
- Now three “domains”
  - Bacteria, Archaea, Eucarya
- Note that plants, fungi, and animals are closely related newcomers
  - Together possess less than 10% of small subunit ribosomal RNA nucleotide diversity

Timing of divergence

- Most recent common ancestor had to live before recognizable eucaryotes lived
  - And after life started
- Oldest probable fossil eucaryotes 1.85-2.1 bya
- Cyanobacterial fossils to at least 2 bya
- If Apex chert fossils are cyanobacteria then 3.465 bya

What was that common ancestor like

- Probably DNA based not RNA
  - Because all three domains currently use DNA
  - Because all three domains have DNA dependent RNA polymerases

  - Parsimony suggests that the ancestor of extant organisms did as well
    - Probably basically similar to some modern bacteria

Recent advances

- Information about Archaea growing rapidly
  - Extreme environments (heat, methane, salt, sea vents)
  - Do not grow well in laboratory
    - Many found just by sequencing DNA from mud
- Whole genome sequencing

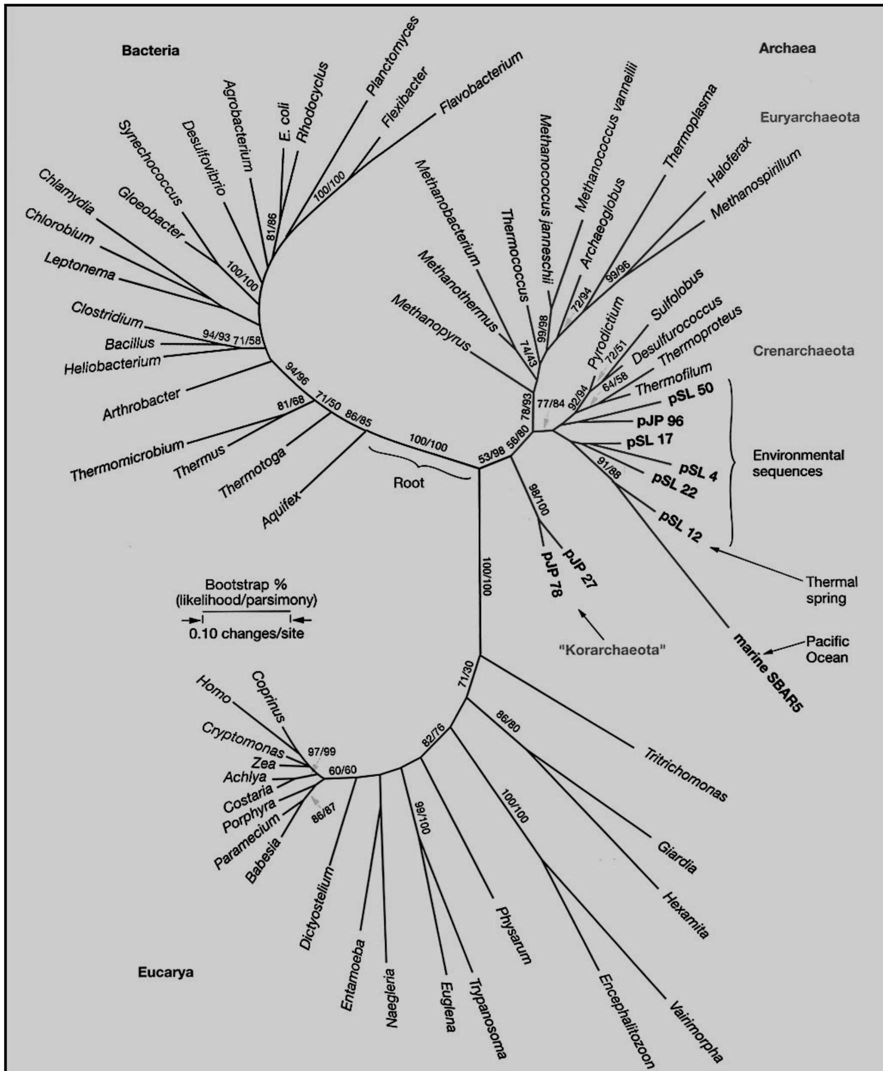


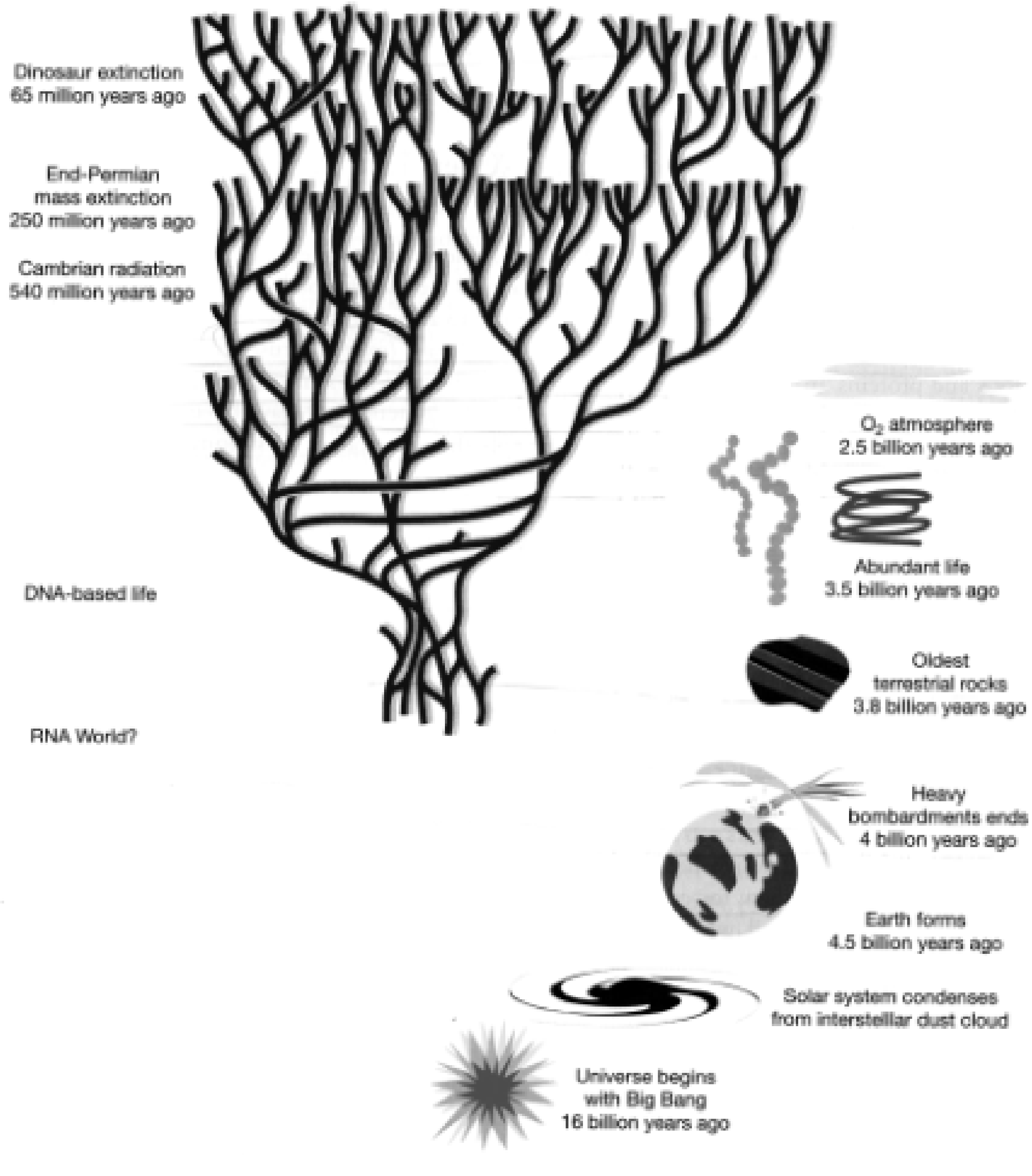
Figure 14.19 An estimate of the phylogeny of all extant organisms based on rRNA sequences Codes such as "pSL 22" designate organisms known only from their ribosomal RNA genes. From Barns et al. 1996.

Whole genome sequencing

- Allows comparison of phylogenies based on different genes
- If genes reflect organismal history, then all gene trees should agree
- If genes can be passed among taxa then different genes might produce different phylogenies

Lateral gene transfer

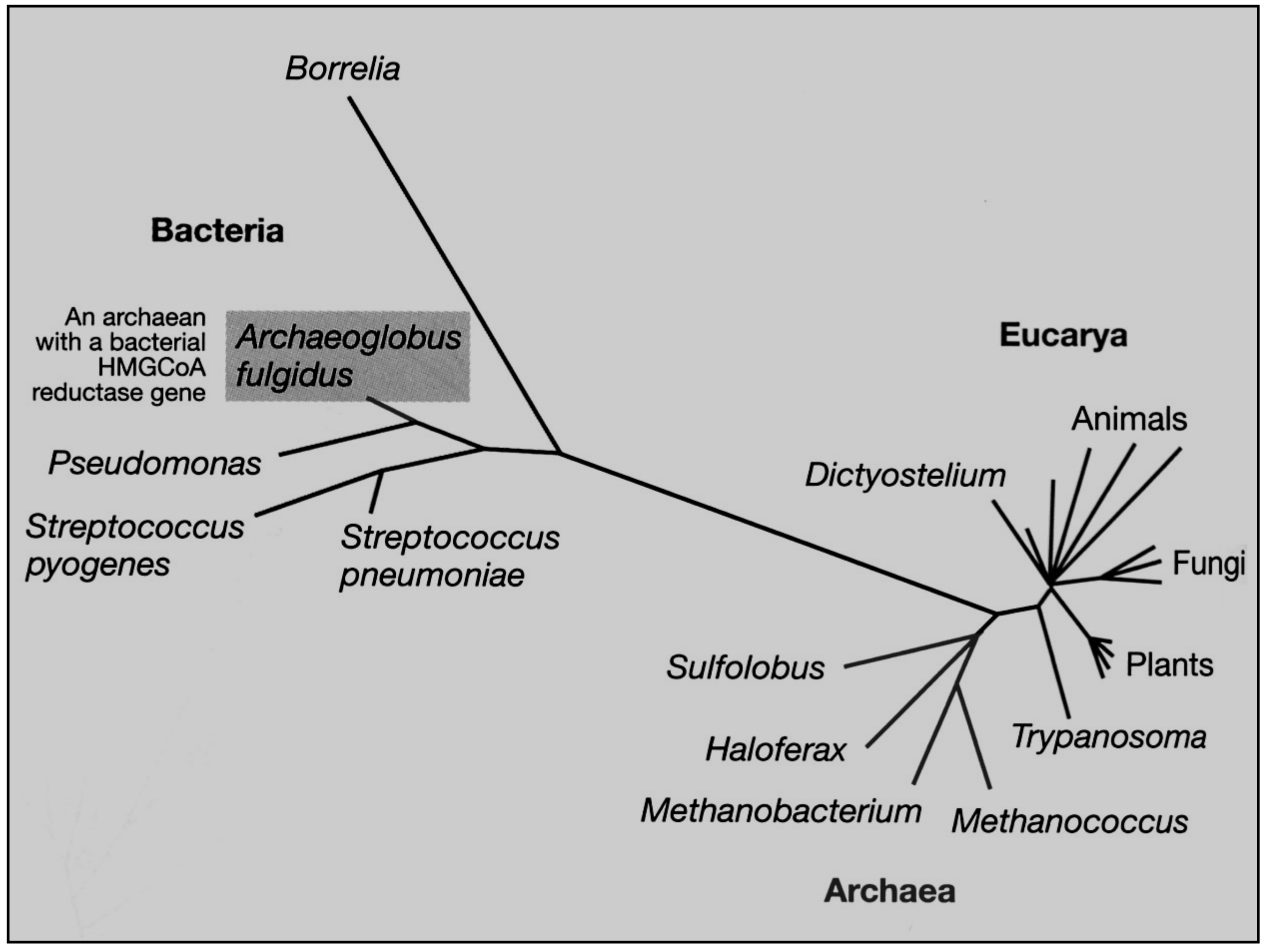
- Bacterial conjugation
- Viruses as vectors for DNA exchange



Evidence of lateral gene transfer

- Phylogeny based on HMGCoA reductase gene

3-hydroxy-3-methylglutaryl coenzyme A



Lateral organism transfer

- genes can hop from organism to organism
- were whole sets of genes transferred by entire organisms?

- How did cellular organelles arise?

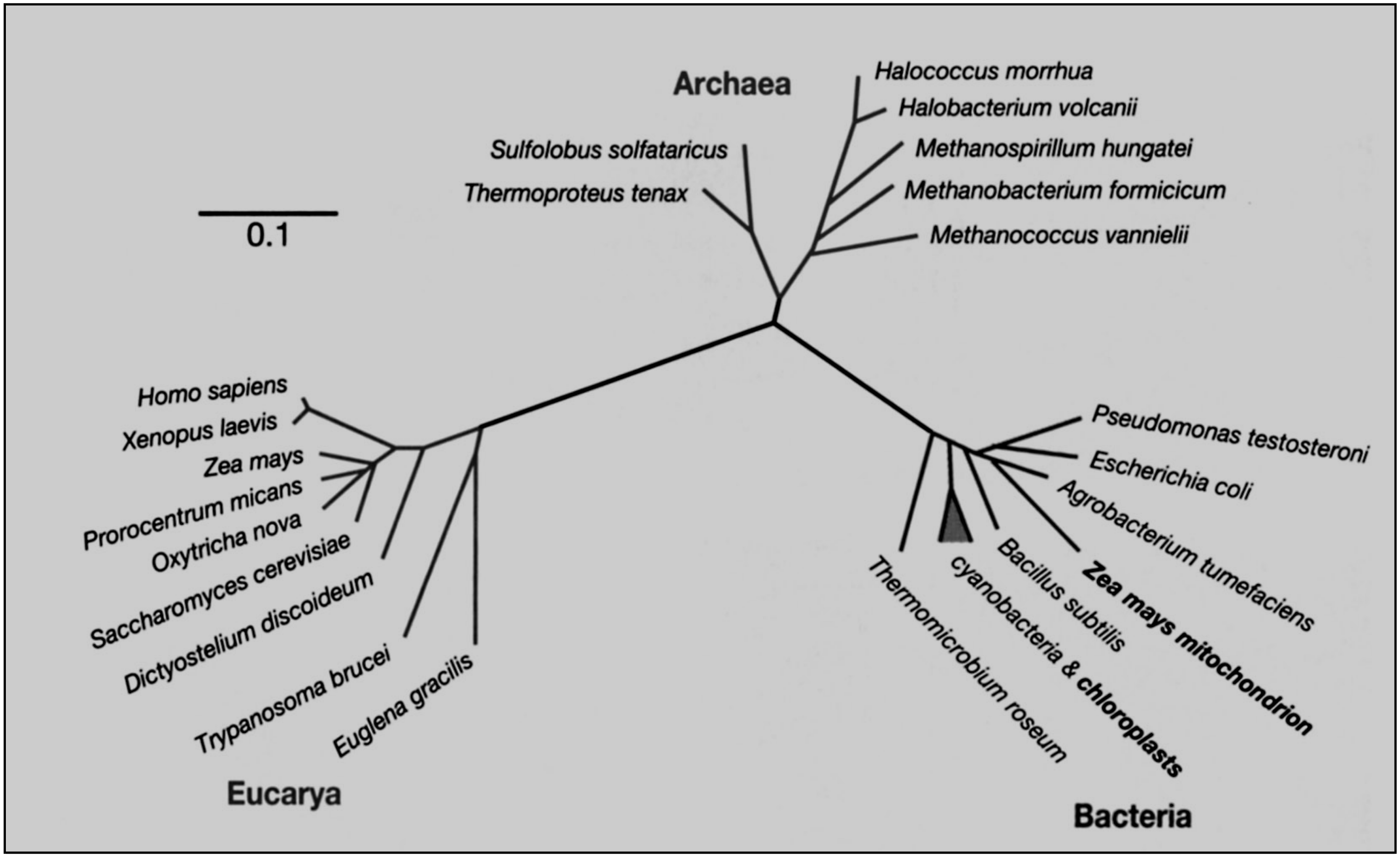
Organelles

- Energy makers, Mitochondria and Chloroplasts
- Superficially resemble bacteria
- Have their own chromosomes
  - Simple loop of circular DNA
- Did these organelles arise as internal bacterial symbionts of other cells?

Endosymbiont hypothesis

- Lynn Margulis proposed this idea in 1970
  - Based mostly on morphology and membrane structure
- If true, then organelle DNA sequence should be similar to bacterial DNA sequence
- And the results are…..

Endosymbiont organelles



You are a chimera

- Mitochondria are proteobacteria
- Chloroplasts are cyanobacteria