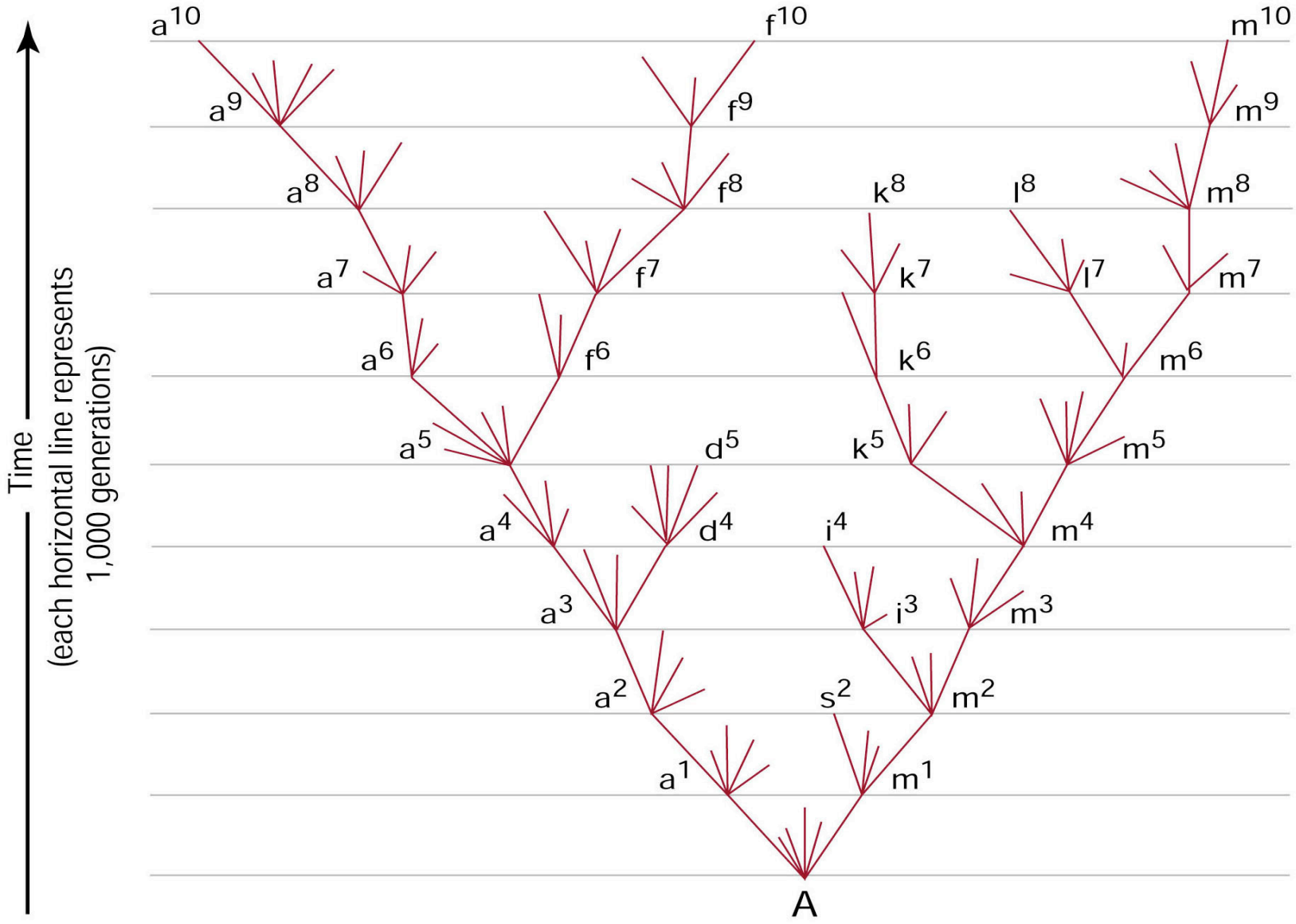
The Evolution of the first Earth Life

A subject of an evolution course: one of Darwin's tenets was that all life came from a single source - there was some first living cell.

Outline of lecture 2

- What is life? Definitions
- What is Earth life - life as we know it?
- Could there be alternatives to Earth life - “Life as we do not know it”?
- When, where, and how did Earth life form?
- Could we be Martians (or from some other planet?
- What were the pathways that led to the three Dominions of life?



What is life?

- Metabolism
- Reproduction
- Evolution
- *Life is a chemical system capable of Darwinian Evolution.*
- "The arrangement of the atoms in the most vital parts of an organism and the interplay of these arrangements differ in a fundamental way from all those arrangements of atoms which physicist and chemists have hitherto made the object of their experimental and theoretical research."
- --Edwin Schrodinger

From Schrodinger:

- “Living matter evades the decay to equilibrium”, and life “feeds on negative entropy”. Life does this through metabolism, overtly by eating, drinking, breathing, or the exchange of material, which forms the root of the word from its original Greek definition.

Paul Davies:

- *Life metabolizes*. All organisms process chemicals, and in so doing bring energy into their bodies. Life requires an environment *not* at what chemists would call "thermodynamic equilibrium".
- *Life has complexity and organization*.
- *Life reproduces*.
- *Life develops*. Once a copy is made, life continues to change; this can be called development.
- *Life evolves*. This is one of the most fundamental properties of life, and one that is integral to its existence.
- *Life is autonomous*. This one might be the toughest to define, yet is central to being alive. An organism is autonomous, or has self-determination.

What do you need for life?

- A membrane
- Metabolic machinery
- A chemistry set
- An information system
- A method of reproduction

- **Living *Earth-life* cells: biochemical factories surrounded by porous membranes and including genetic material (DNA) and ability to translate DNA into protein (RNA, ribosomes).**

- **Parts of a living cell:**
  - **A. Cell wall – lipid – has polar structure – attracts water on one side, repels on other**
  - **B. Genetic material – DNA**
  - **C. Protein construction equipment RNA**

Steps toward life

A. Synthesizing basic components: organic molecules necessary to make cell walls and cell contents

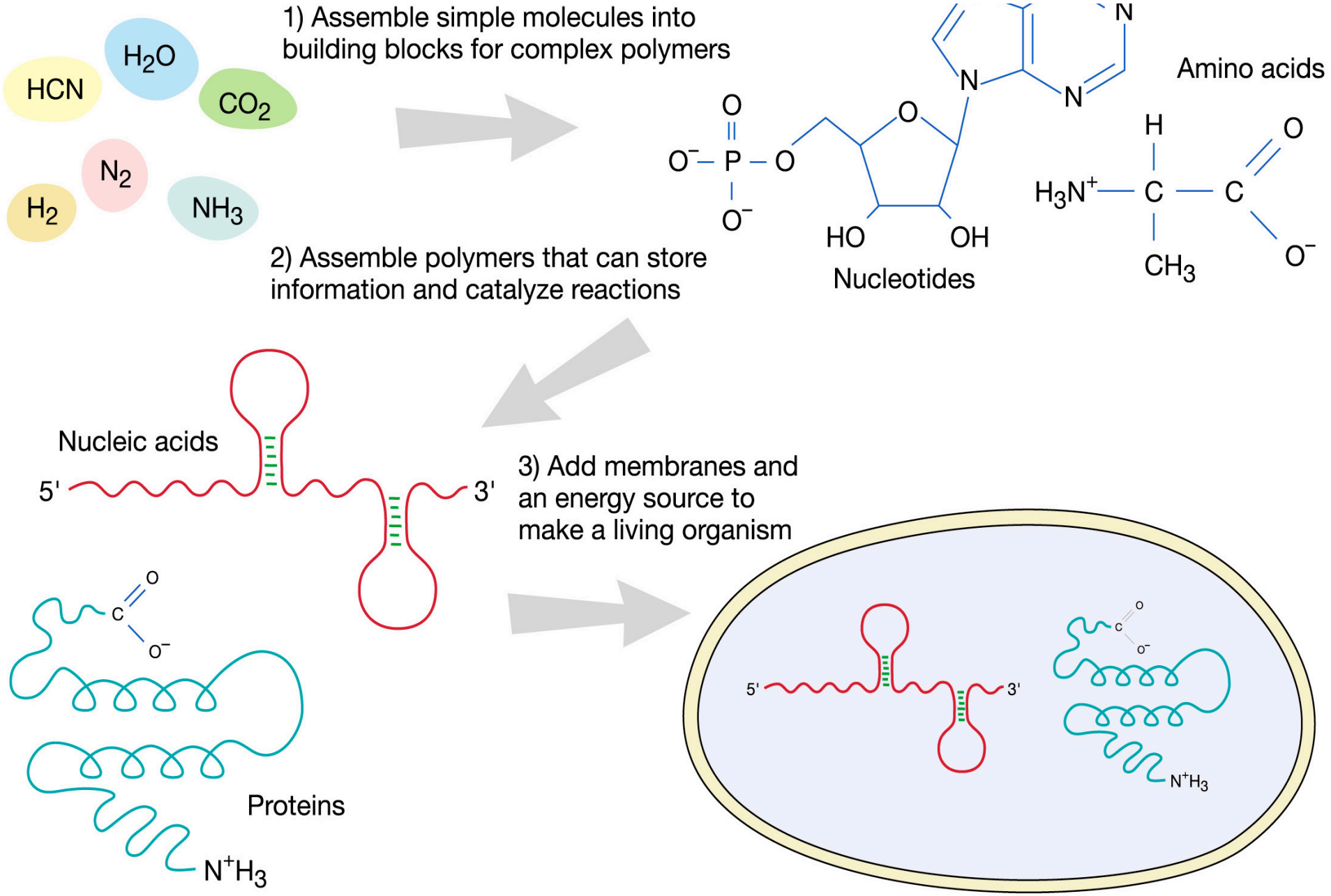
B. Concentrating building material

1. Evaporation

2. Concentration by freezing

3. Concentration on mineral scum, droplets, bubbles

4. On mineral grains –clays, pyrites

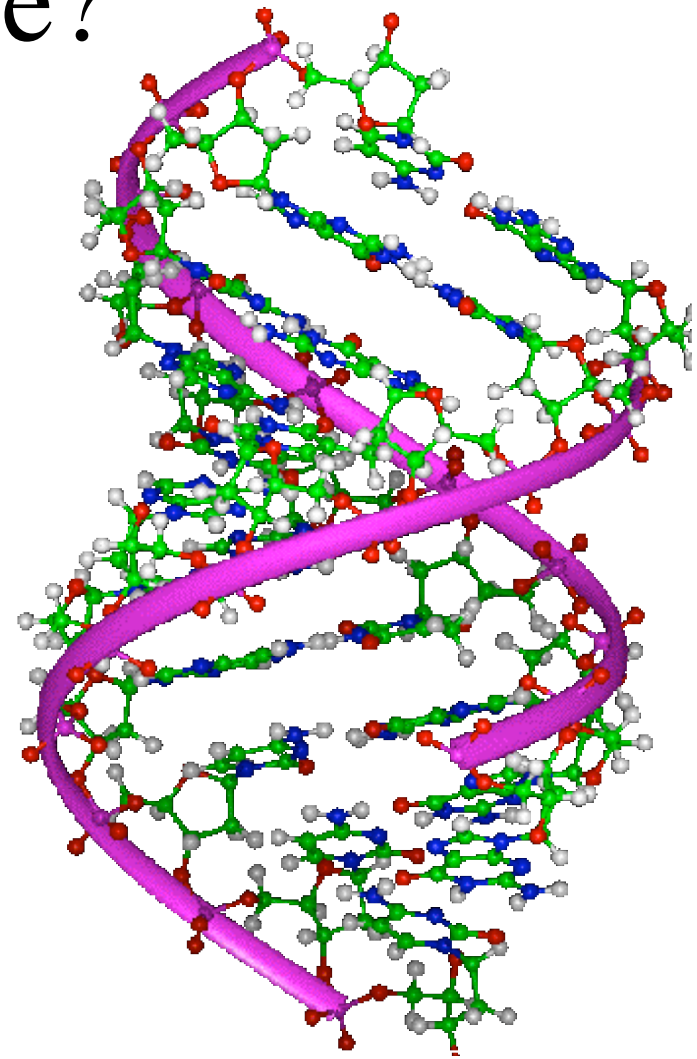


How can our kind of life be defined?

- Uses DNA
- A specific genetic code
- Only twenty (and the same twenty) amino acids
- Always cellular
- Is a virus “alive”, or is it even “Life as we know it?” - not cellular, some without DNA

DNA- one way, or the only way to store information necessary for life?

- DNA is hugely complex
- How was it first synthesized?



DNA

- Is our form of DNA the first out of the gate, or the best out of the gate - was there "survival of the fittest" among early DNA molecules?
- How did we arrive at a unified genetic code on Earth? - John Baross, UW, suspects that viruses were the agent that unified a diverse zoo

Energy sources

A. Heterotrophy

1. primitive – adsorb environmental ATP

2. Fermentation break down sugar, anaerobic

3. Methanogenic reactions

$4H^2 + CO^2 \rightarrow CH^4$ (methane) = $2H^2$ + energy

Methanogen bacteria – Archaeans.

4. Predation – ingest other cells

B. Autotrophy; Energy comes from inorganic sources: light

Porphyrins: complex ring shaped molecules that capture light energy and store it by raising the energy of electrons within the molecule. Hemoglobin, cytochrome – chlorophyll

$H_2O = CO^2 + \text{light} \rightarrow (CH_20) + 2O$

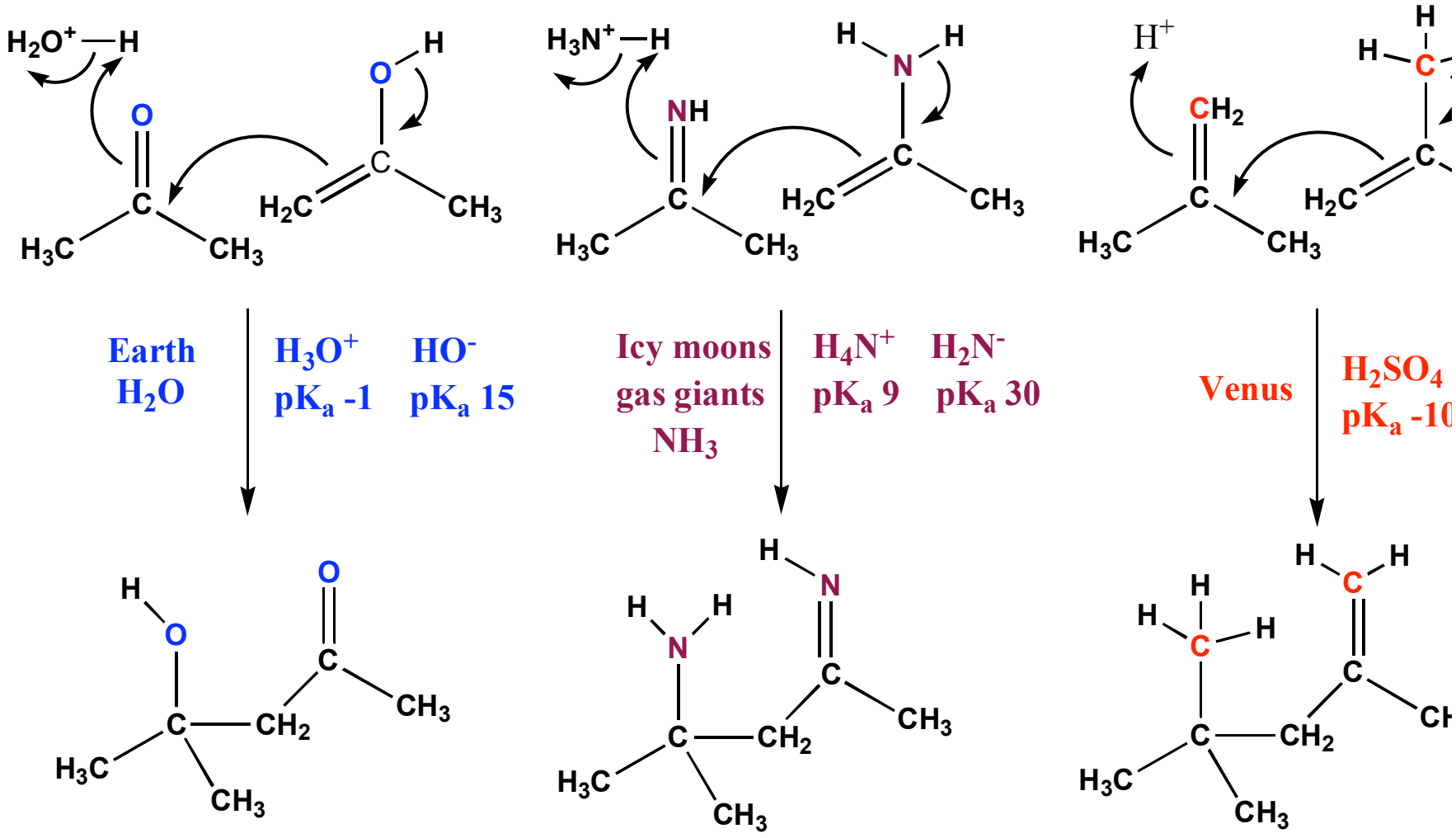
Variable kinds of life

1. DNA life -Earth life
2. Non-DNA life
   A. Does it exist?
   B. What does chemistry permit?
      Different information system
      Different solvent
      Different membrane

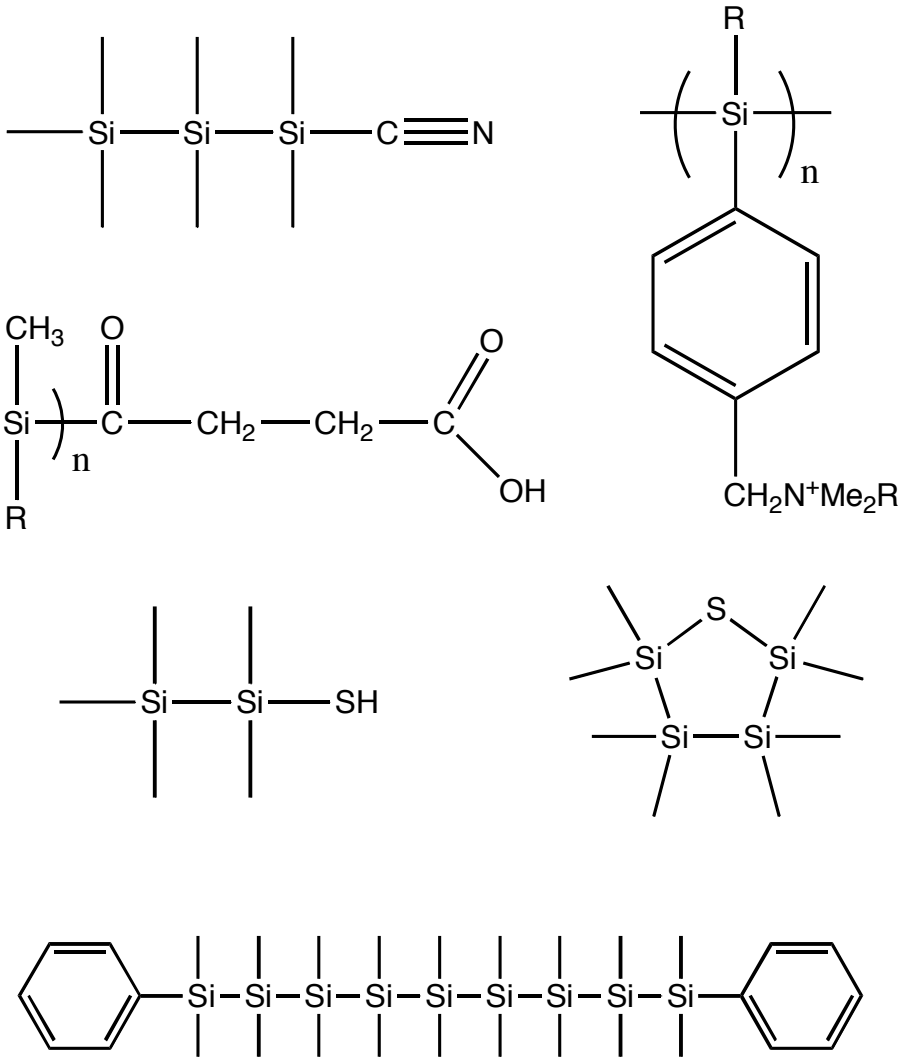
Varieties of “alien” life

- Change nature of information storage molecule
- Change solvent within cell- ammonia instead of water
- Is there “Life as we do not know it” presently on Earth - and how would we know?

How different solvents could produce new chemistry of life



Silanes: Silicon life structure. From Benner, 2005



Origin of Life on Earth

- When?
- Where?
- How?
- *How else* could this process have occurred on Earth and *what else* might have resulted?

Early Earth conditions Archean 3.8-2.5GA

Lithosphere:

Oceanic lithosphere. Virtually no land – 5% globe

50-60% Precambrian crust formed in Late Archean – from 2.7-2.5 GA

Continents thus late development

Atmosphere – CO_2, H_20, N_2 – 100 to 1000 times CO_2 levels –Greenhouse effect

No glacial deposits till 2.4-2.2 GA

Very low level of free O_2 in Archean: However, some availability of O_2 in surface waters – suggested by abundance of sulfate minerals

Oceans – strongly and permanently stratified – deep anoxic bottom and thin, wind mixed upper layer

Biosphere: 3.5-3.3GA Barberton Greenstone, South Africa, and Warrawoona Group – Pilbara Greenstone- microfossils and stromatolites

Earth's History

- Origin of planet: 4.6 Ga
- Origin of life: 3.5(?) Ga

- Evidence that life is "easy" to form on an Earth-like planet?

So where did life begin on Earth (if it began on Earth)

"Some warm little pond"- Darwin

Hydrothermal vents

Bubbles in tide pools/intertidal

In clouds

Brine ponds

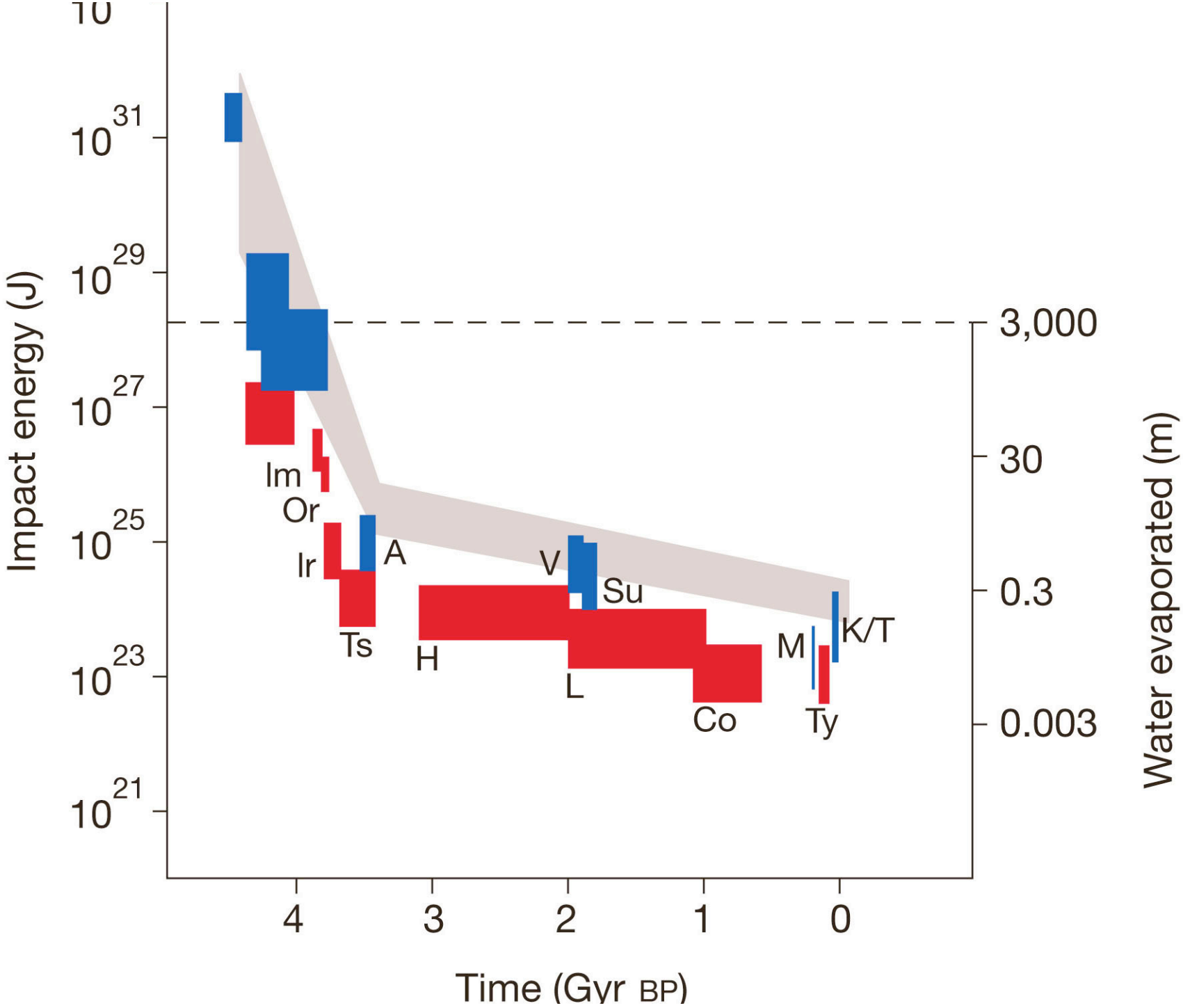
Coupled impact craters! (?)

Why impact craters?

- Making RNA the hardest step. Ribose sugars unstable at high temperatures.
- Ribose can be made by serial evaporations and decanting of borate mineral reactions with water
- Need a desert to do this - and much chemical glassware - or impact craters in a desert

Intense and large meteoritic bombardment.

- Kinetic energy of impact vaporizes meteorite and ejects excess heat into atmosphere. Object > 440 km diameter would heat atmosphere to 1500^0C for 1000 years. Significant evaporation of oceans.
- These impacts would cauterize the Earth's surface - impact frustration of life.
- Deep ocean vents may have been refugium.


Impact energy (J)
10
10^31
10^29
10^27
10^25
10^23
10^21
3,000
30
0.3
0.003
Water evaporated (m)
Im
Or
Ir
A
Ts
H
V
Su
L
Co
M
K/T
Ty
4
3
2
1
0
Time (Gyr BP)

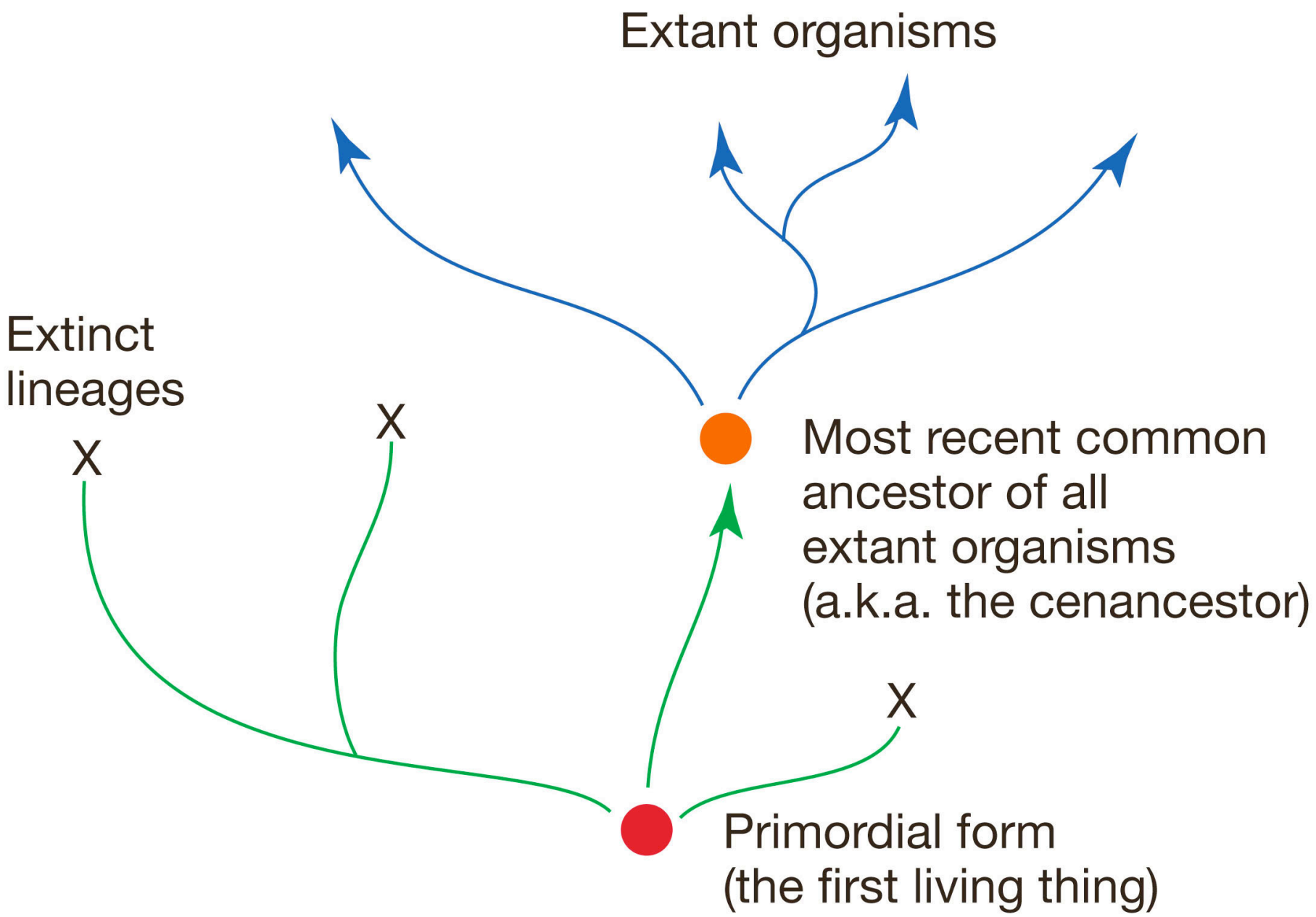
Primordial soup or primordial zoo?

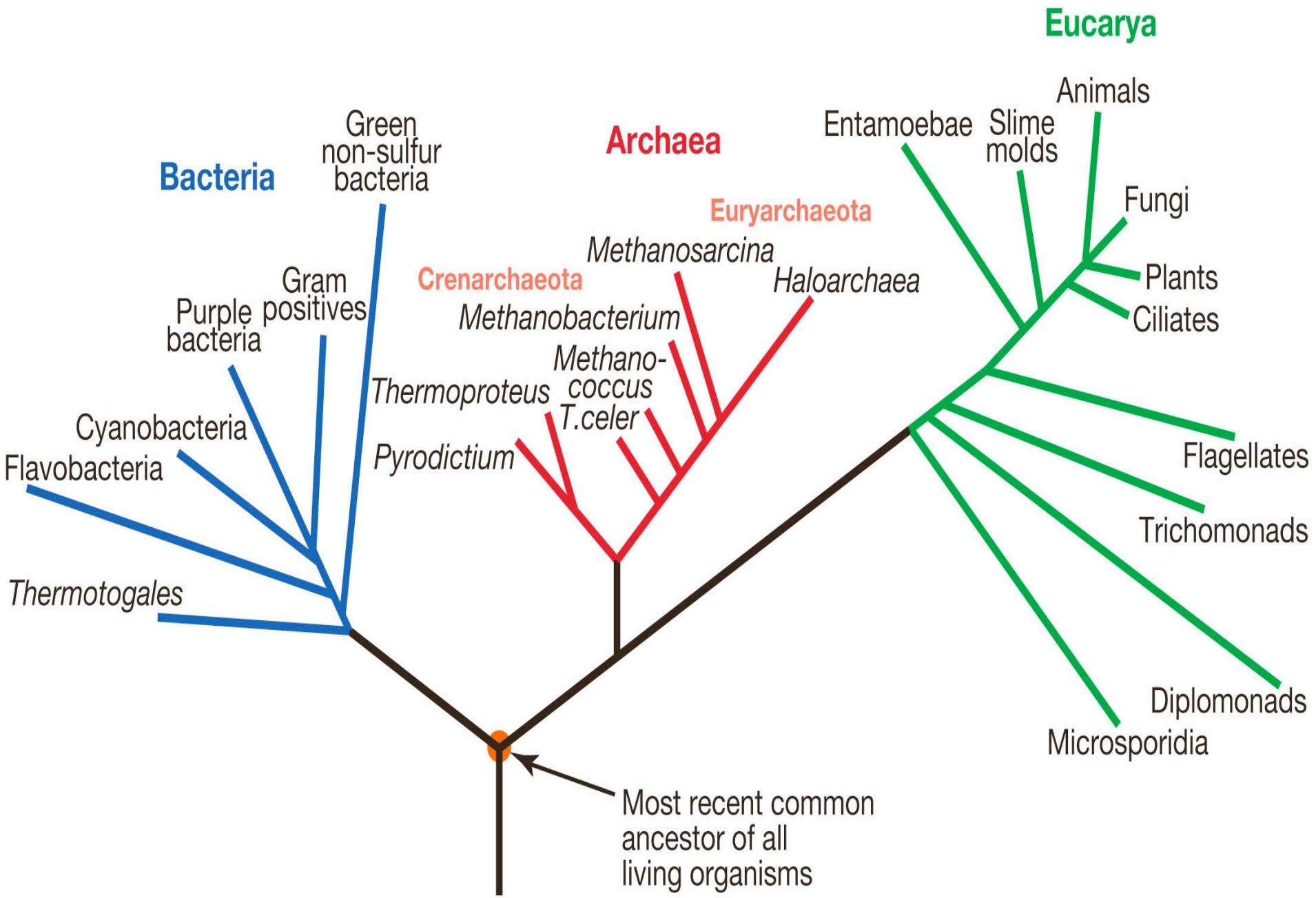
- Much nonsense about low diversity of early life.

- Probably there was a zoo of different membrane types, and different genetic systems within them

RNA life

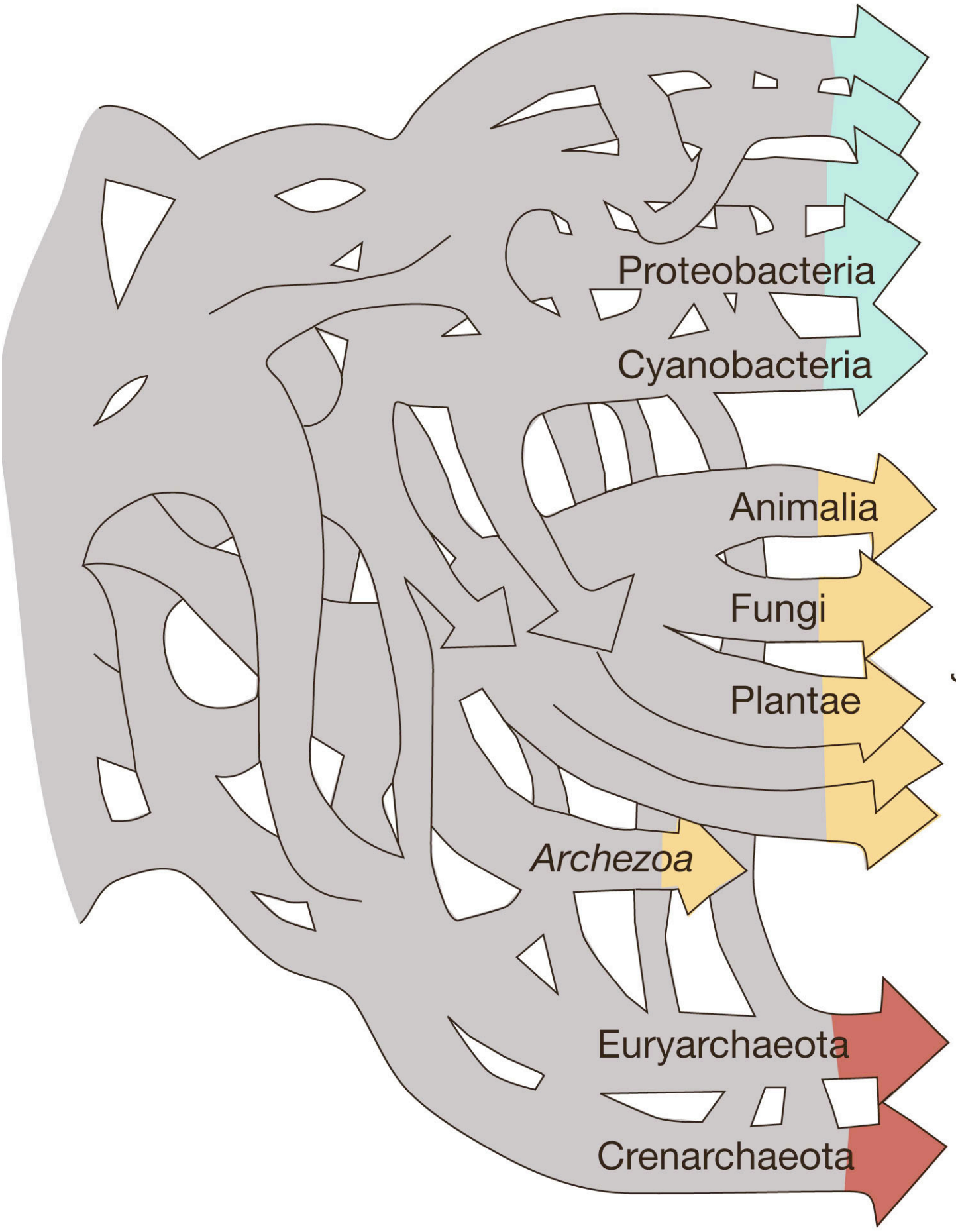
- Self catalyzing. RNA serves as information system, and enzyme to catalyze self reproduction.
- Does it also need a membrane, or could there have been “naked” RNA?
- How did DNA take over?

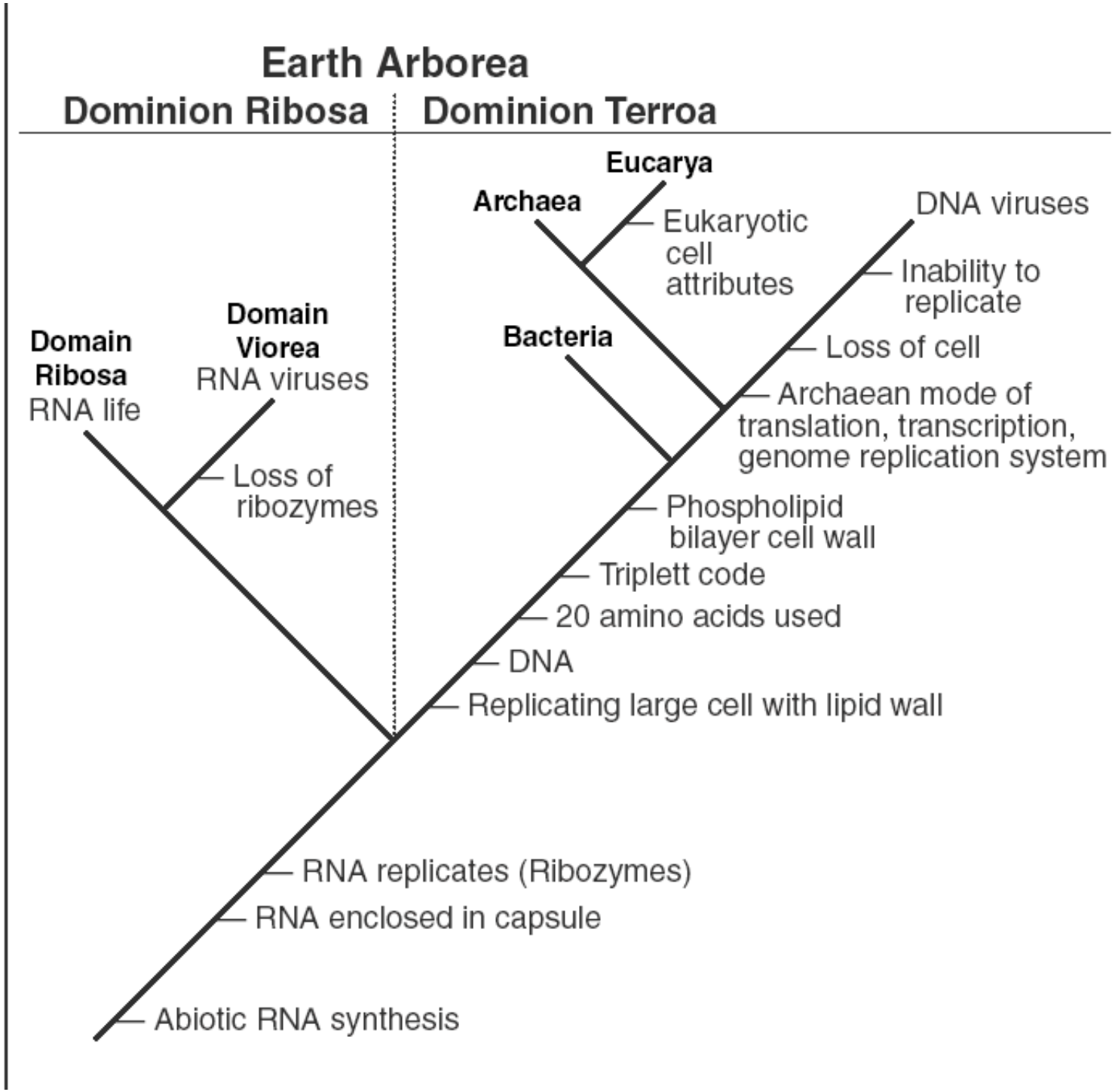




The Last Universal Common Ancestor

- Today scientists believe all current life forms could have evolved from a single, simple progenitor –an organism now referred to as life's Last Universal Common Ancestor (**LUCA**).
- Facts that support this view:
  - All living things consist of **similar organic** (carbon-rich) compounds.
  - Proteins found in all present-day organisms are fashioned from one set of **20 standard amino acids**.
  - The proteins include **enzymes** (biological catalysts) that are essential to development, survival and reproduction.
  - All contemporary organisms carry their genetic information in nucleic acids (**RNA and DNA**) and use the same genetic code.
  - The genetic code specifies the **amino acid sequences** of all the proteins each organism needs


Proteobacteria
Cyanobacteria
Animalia
Fungi
Plantae
Archezoa
Euryarchaeota
Crenarchaeota


Earth Arborea
Dominion Ribosa
Dominion Terroa
Eucarya
Archaea
Eukaryotic cell attributes
DNA viruses
Inability to replicate
Loss of cell
Bacteria
Domain Viorea
RNA viruses
Domain Ribosa
RNA life
Loss of ribozymes
Archaean mode of translation, transcription, genome replication system
Phospholipid bilayer cell wall
Triplett code
20 amino acids used
DNA
Replicating large cell with lipid wall
RNA replicates (Ribozymes)
RNA enclosed in capsule
Abiotic RNA synthesis

Earth's earliest life

Rocks older than 3.5 billion years very rare

Oldest known rock formations; Isua in Greenland: 3800 million years old

Isua lithologies: volcanic and sedimentary rocks – shallow marine.

Isua carbon – graphite.

Carbon isotope analyses – C^{12} preferentially uptaken in presence of photosynthesis – carbon from Isua enriched in C^{12}/C^{13}

Warrawoona, Australia – 3550 ma – contain stromatolites – layered bacterial mats- formed today by blue green algae – cyanobacteria

Fig Tree, South Africa – 3400 ma - more complex and varied than at Warrawoona

Variable Histories of Life

- 1. Life does not evolve
- 2. Life evolves, has a history, dies out as life systems age
- Life evolves, is exterminated by intrinsic or extrinsic mass extinction, never re-evolves
- 3. Life evolves, is exterminated, independently re-evolves
- 4. Life evolves, is exterminated, and is later re-seeded from a planetary companion

Variable Histories of Life (2)

- One type of life evolves, has a history
- Multiple lines of life evolve, one out-competes others and is unique line on planet
- Multiple lines of life evolve, and more than one line co-exists