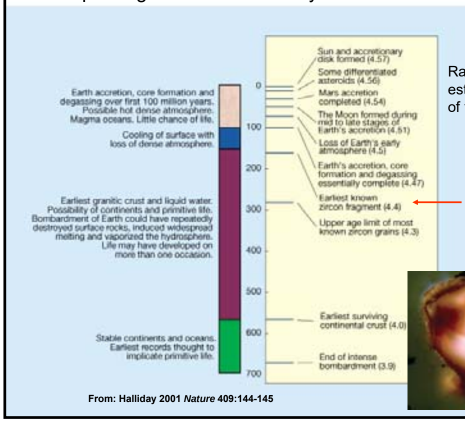
AND NOW FOR A BRIEF INTRODUCTION TO:

THE HISTORY OF LIFE…

FUNDAMENTAL CHARACTERISTICS OF LIFE

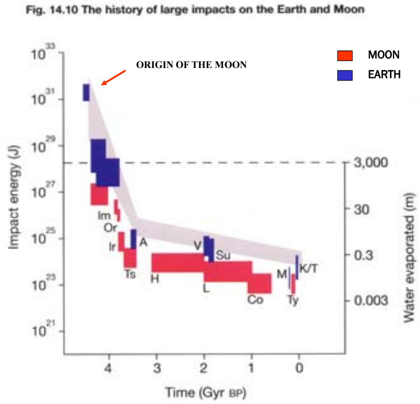
- **Energy acquisition and utilization** --- metabolism, growth, behavior.
- **Information storage** --- presence of a genome that specifies a phenotype.
- **Reproduction** --- ability to produce progeny of the same type.
- **EVOLUTION BY NATURAL SELECTION** – ability to change in ways that improve capabilities of energy acquisition, survivorship, and reproduction.

Deciphering the Earliest History of the Earth: Zircon Grains



Radiometric dating estimates the age of the earth at **4.56 BY**

Fig. 14.10 The history of large impacts on the Earth and Moon

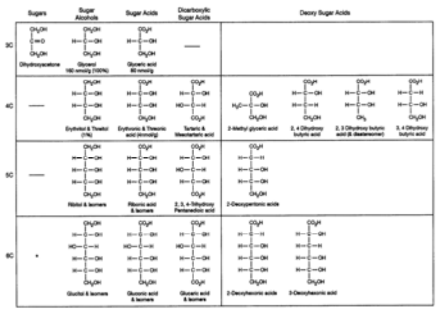


EXTRATERRESTRIAL ORIGIN OF LIFE???

PANSPERMIA

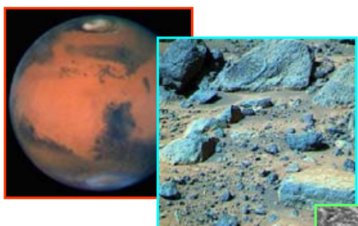
- **Murchison Meteorite**

SUGARS FOUND IN THE MURCHISON METEORITE

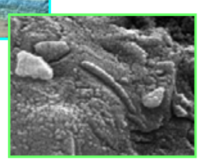


From: Cooper et al. 2001 Nature 414:897-883

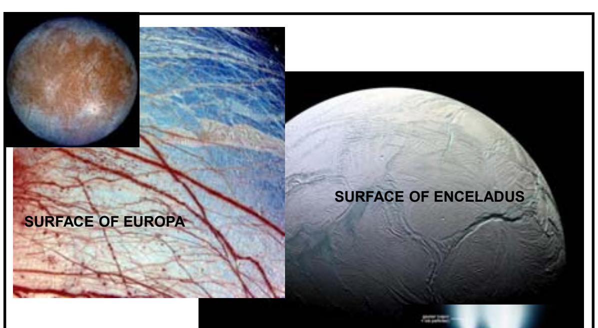
▪ EVIDENCE OF LIFE ON MARS?



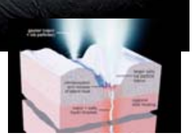
Are these biological microfossils?

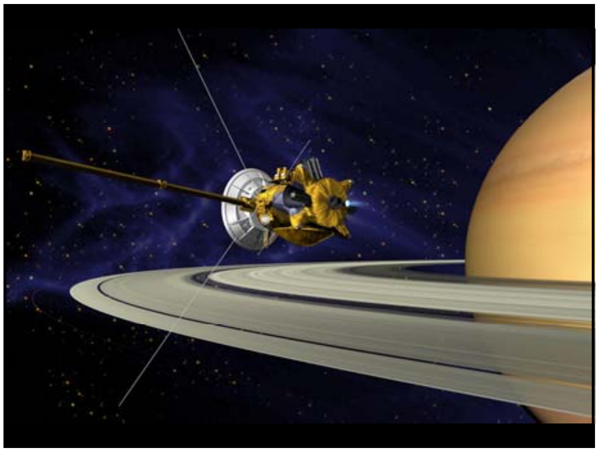


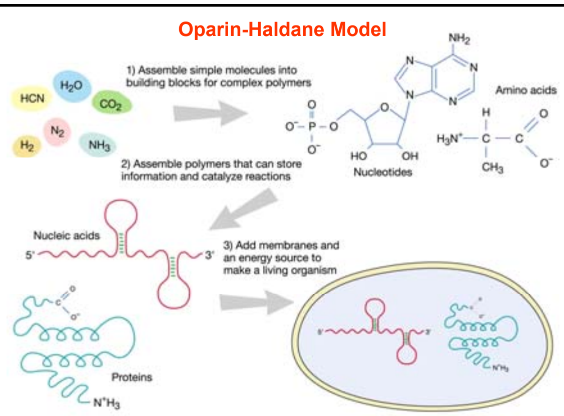
From: MacKay et al. 1996 *Science*



Life on the moons of Jupiter or Saturn?



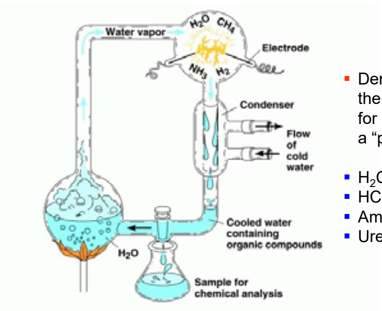




BIG UNANSWERED QUESTIONS IN ORIGIN-OF-LIFE RESEARCH

- How did the "primordial soup" acquire the simple **monomeric building blocks** essential for the production of information bearing polymers?
- What conditions are necessary for the initial(pre-biotic) **assembly** of such polymers?
- Can a polymer be produced that is capable of **self-replication** as well as information storage?
- How did **compartmentalization**, necessary for self-recognition during replication and for the diffusion of gene products, evolve?
- **Which came first**---DNA, RNA, protein, or something else, or did complex systems involving all of these emerge simultaneously?

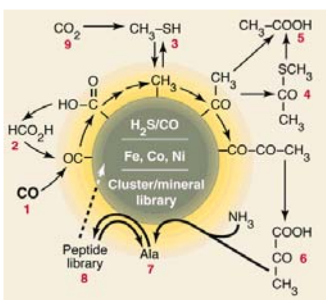
Urey – Miller Experiment 1952:

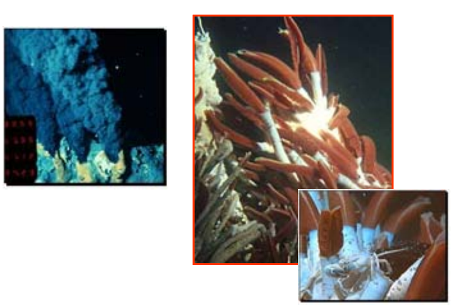


- Demonstrated that many of the compounds necessary for life could be produced in a "pre-biotic" atmosphere.

- H_2CO - Formaldehyde
- HCN – Hydrogen Cyanide
- Amino Acids
- Urea

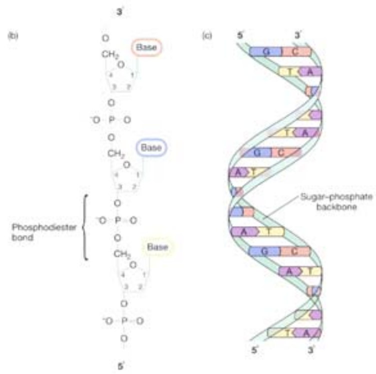
REACTIONS IN THE IRON-SULFER WORLD:





DEEP-SEA THERMAL VENTS:

- Support a diverse fauna completely dependent on hydrogen sulfides.



ASSEMBLY OF AN INFORMATION BEARING POLYMER:

PROTEINS FIRST?

Strong points:

- Easy to synthesize amino acids under a variety of conditions ***and*** polymers can also be formed.
- Even small peptides can exhibit catalytic activity.
- 20 amino acids provides for high information content.

Weak points:

- Globular structure and lack of complementarity preclude self-replication.
- Modern proteins can not function without DNA.

ASSEMBLY OF AN INFORMATION BEARING POLYMER:

AN RNA WORLD?

Strong points:

- RNA has some catalytic properties (self-splicing introns).
- RNA is capable of making proteins (Noller 1992).

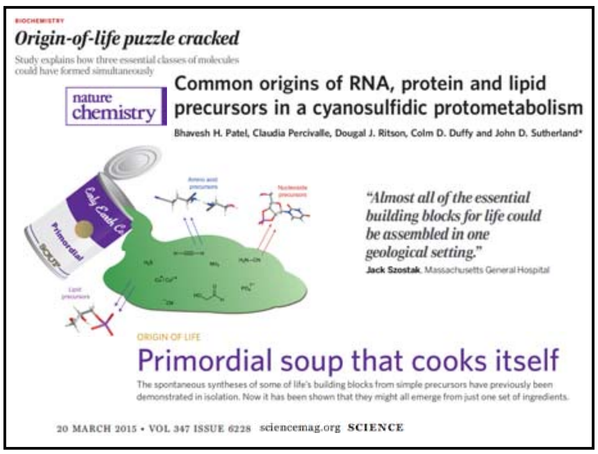
Weak points:

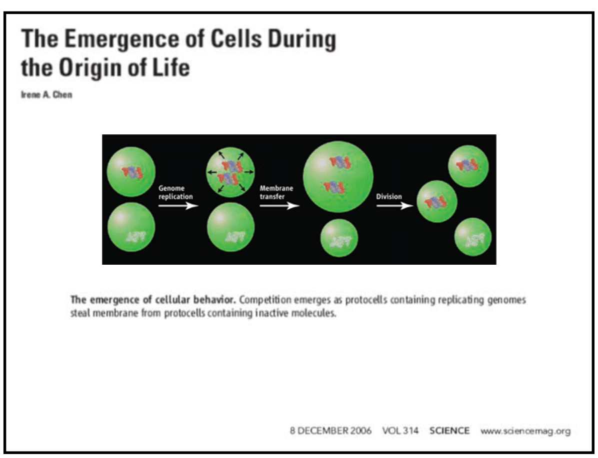
- RNA lacks the ability to self-replicate.

A DNA WORLD?

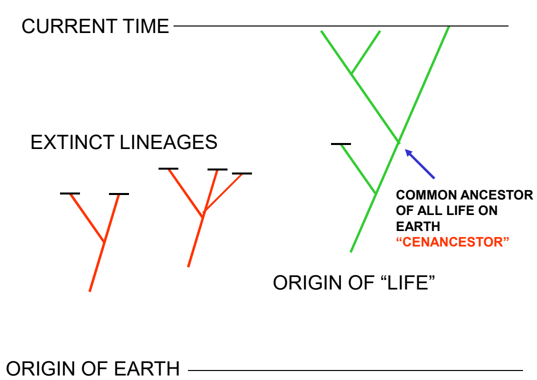
- DNA is almost completely lacking in catalytic ability

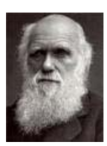

NEWS FEATURE
BASE
INVADERS
Could viruses have invented DNA as a way to sneak into cells? John Whitfield investigates.


BIOCHEMISTRY
Origin-of-life puzzle cracked
Study explains how three essential classes of molecules could have formed simultaneously
nature chemistry
Common origins of RNA, protein and lipid precursors in a cyanosulfidic protometabolism
Bhavesh H. Patel, Claudia Percivalle, Dougal J. Ritson, Colm D. Duffy and John D. Sutherland*
"Almost all of the essential building blocks for life could be assembled in one geological setting."
Jack Szostak, Massachusetts General Hospital
ORIGIN OF LIFE
Primordial soup that cooks itself
The spontaneous syntheses of some of life's building blocks from simple precursors have previously been demonstrated in isolation. Now it has been shown that they might all emerge from just one set of ingredients.
20 MARCH 2015 • VOL 347 ISSUE 6228 sciencemag.org SCIENCE


The Emergence of Cells During the Origin of Life
Irene A. Chen
Genome replication
Membrane transfer
Division
The emergence of cellular behavior. Competition emerges as protocells containing replicating genomes steal membrane from protocells containing inactive molecules.
8 DECEMBER 2006 VOL 314 SCIENCE www.sciencemag.org

EVOLUTION OF EARLY LIFE FORMS





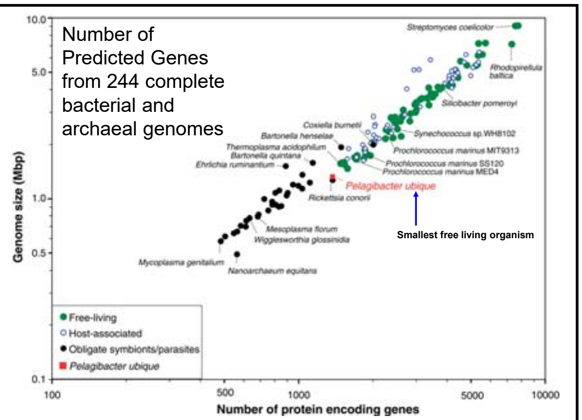
If the theory (of evolution) be true it is indisputable that before the Cambrian stratum was deposited long periods elapsed…and that during these vast periods the world swarmed with living creatures… (However), to the question why we do not find rich fossiliferous deposits belonging to these earliest periods…I can give no satisfactory answer. The case at present must remain inexplicable….

Charles Darwin 1859

RECONSTRUCTING “LUCA”
Last Universal Common Ancestor

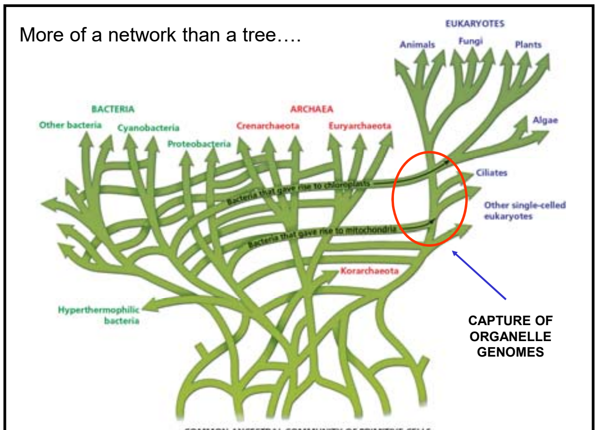
- The properties of LUCA have been difficult to reconstruct given the extremely long time periods involved.
- Whole genome sequences of diverse prokaryotic lineages reveal ~60 “universal genes”. Far short of the ~600 genes it is estimated are required for a minimal set in a functioning organism.
- Extensive gene shuffling through horizontal transfer may make it impossible to deduce the properties of “LUCA”.
- Hyperthermophiles seem to at the base of the phylogenetic tree.

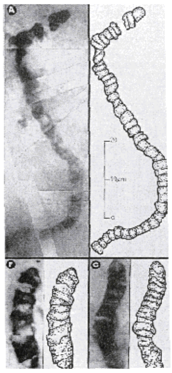
Number of Predicted Genes from 244 complete bacterial and archaeal genomes



Giovannoni et al. 2005 Science 309:1242-1245

More of a network than a tree….



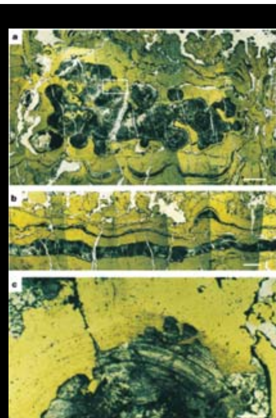


Ancient prokaryotes from Western Australia.

Filamentous “Cyanobacteria”

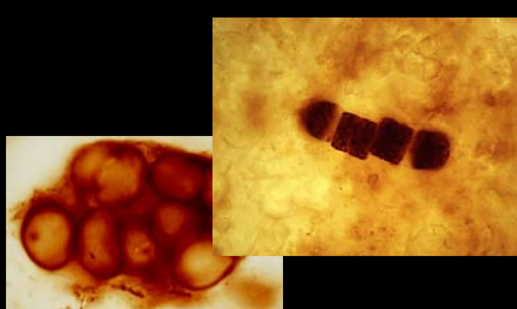
3.5 BYA

Earliest filamentous microfossils 3.23 BYA



FROM: Rasmussen 2000 *NATURE*

Microfossil Cyanobacteria

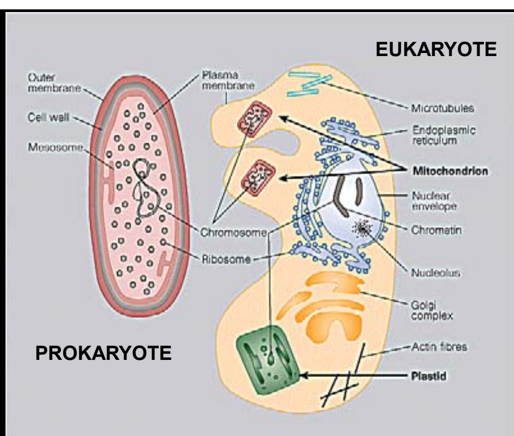


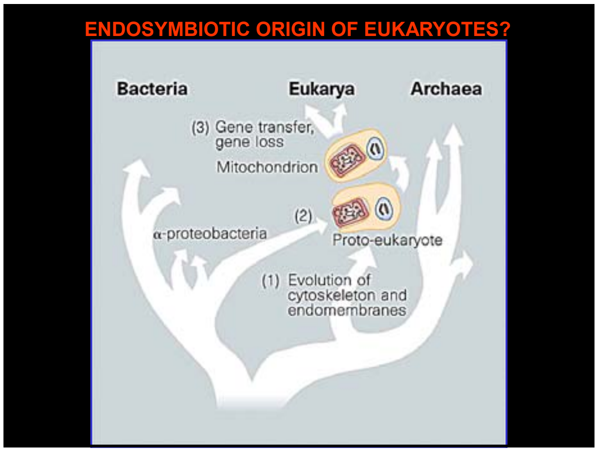
Stromatolites from Western Australia:

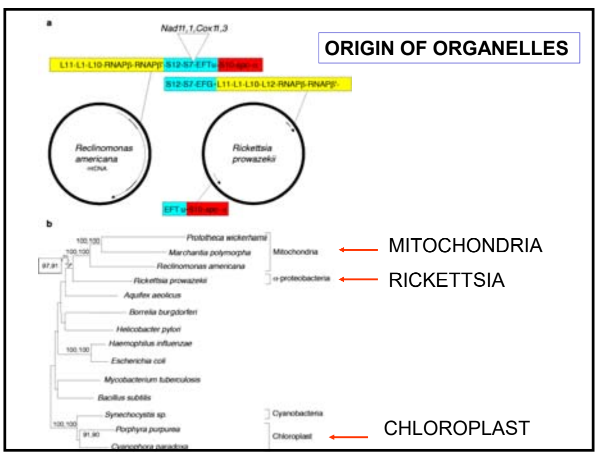
THE ORIGIN OF EUKARYOTES

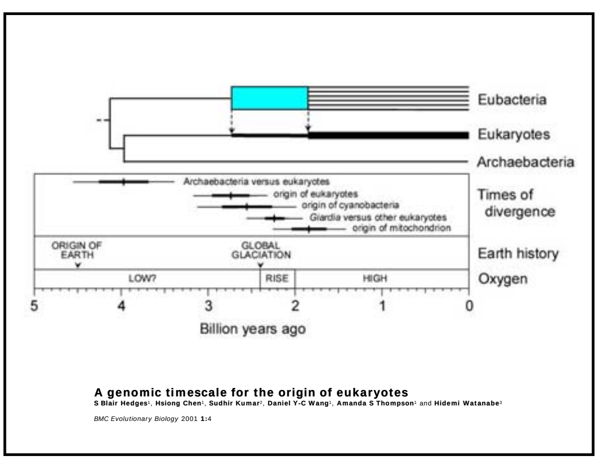
- **EARLIEST PROBABLE EUKARYOTES ARE SINGLE-CELLED ALGAE FROM 1.6 BYA.** (Although some researchers suggest there is evidence as old as 2 BYA)
- **Definitive evidence for eukaryotes exists from about 1.2 BYA in the form of fossils of multi-cellular algae.**

Red algae fossil; 1.2 bya



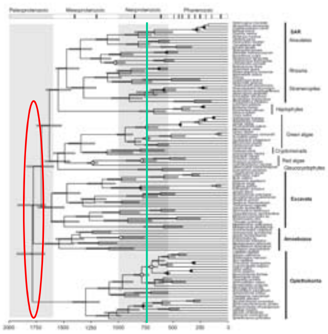

ENDOSYMBIOTIC ORIGIN OF EUKARYOTES?
Bacteria
Eukarya
Archaea
(3) Gene transfer, gene loss
Mitochondrion
(2)
α-proteobacteria
Proto-eukaryote
(1) Evolution of cytoskeleton and endomembranes


ORIGIN OF ORGANELLES
a
b
Reclinomonas americana
Rickettsia prowazekii
Mitochondria
α-proteobacteria
Cyanobacteria
Chloroplast
MITOCHONDRIA
RICKETTSIA
CHLOROPLAST


Eubacteria
Eukaryotes
Archaebacteria
Archaebacteria versus eukaryotes
origin of eukaryotes
origin of cyanobacteria
Giardia versus other eukaryotes
origin of mitochondrion
Times of divergence
ORIGIN OF EARTH
GLOBAL GLACIATION
Earth history
LOW?
RISE
HIGH
Oxygen
5
4
3
2
1
0
Billion years ago
A genomic timescale for the origin of eukaryotes
S Blair Hedges, Hsiong Chen, Sudhir Kumar, Daniel Y-C Wang, Amanda S Thompson and Hidemi Watanabe
BMC Evolutionary Biology 2001 1:4

Estimating the timing of early eukaryotic diversification with multigene molecular clocks

Laura Wegener Parfrey[a,b,2], Daniel J. G. Lahr[a,b], Andrew H. Knoll[c,1], and Laura A. Katz[a,b,1]



- The beginning of eukaryotic diversification dates as far back as 1.75 BYA.
- Most of the diversification of the major lineages occurred prior to 750 MYA

13624–13629 | PNAS | August 16, 2011 | vol. 108 | no. 33

EVOLUTION OF SEXUAL REPRODUCTION

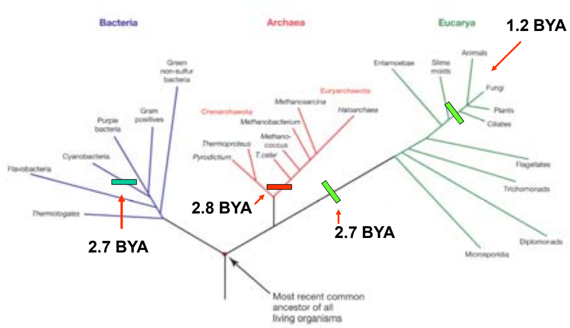
Primitive Eukaryote:
Giardia lamblia

- *Giardia* has two haploid nuclei
- No mitochondria (???)

EVOLUTION AND DIVERSIFICATION OF THE EUKARYOTES

- **What factors contributed to the rapid diversification of eukaryotic lineages?**
  - Increased atmospheric O_2 concentration – switch to aerobic respiration?
  - Global climate change – Major ice age around 2.7 BYA?
  - Evolution of sexual reproduction?

Divergence dates based on ribosomal RNA genes

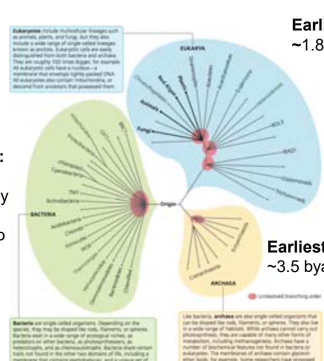


FROM: Knoll 1999 *Science*

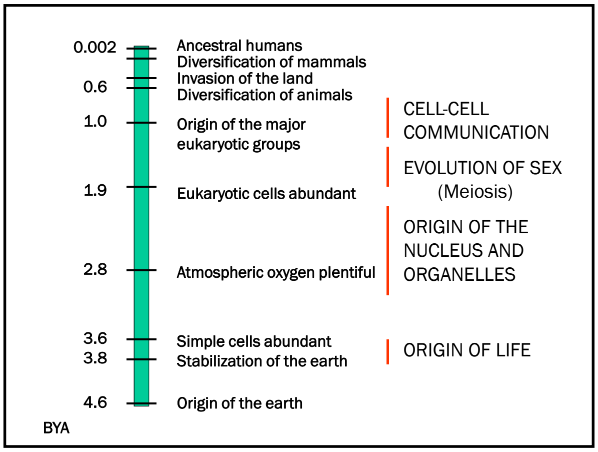
How do early organisms fit in the tree of life?

Earliest fossils: ~1.8 bya

Earliest fossils: potentially 3.45 bya; abundant by ~2.6 bya, corresponding to rise in oxygen



Earliest fossils: ~3.5 bya


0.002
0.6
1.0
1.9
2.8
3.6
3.8
4.6
BYA
Ancestral humans
Diversification of mammals
Invasion of the land
Diversification of animals
Origin of the major eukaryotic groups
Eukaryotic cells abundant
Atmospheric oxygen plentiful
Simple cells abundant
Stabilization of the earth
Origin of the earth
CELL-CELL COMMUNICATION
EVOLUTION OF SEX (Meiosis)
ORIGIN OF THE NUCLEUS AND ORGANELLES
ORIGIN OF LIFE