Milestones in the first 3 billion years of life

- Origin of life - before 3.8 Ga
- Origin of eukaryotes - before 1.4 Ga; before 2.7 Ga?
- Origin of animals ( multicellularity) - 600-800 Ma?
- Origin of skeletons - 550 Ma?
- The Cambrian Explosion - 550-544 Ma?
Types of Fossils

- Body fossils
- Trace Fossils
- Chemical fossils
Isua, Greenland
Ca. 3.8 Ga

Figure 8. Summary of isotopic compositions of organic and inorganic carbon. A: Swaziland and Pilbara Supergroup strata. Dots (circles and squares) = average values of samples; numbers above dots = number of samples; horizontal bars = ranges of values. B: Extant microbial photosynthesists and inorganic-carbon reservoirs.
Archaean stromatolite from the Warrawoona Group, Western Australia
Cyanobacteria
(aka “blue-green algae”)

*Spirulina*, a modern cyanobacterium

St. Petersburg Beach, FL
Archean stromatolites, South Africa
Figure 6. A: The relative diversity through time of the Coniophyllum and its octomeres. B: The diversity through time of all stromatolites. See Walker & Heys (1995) for data and details of the statistical treatment. The original data have been recalculated to allow for the recent understanding of the ages of the base of the Cambrian (540 Ma) and the base of the Vendian (680 Ma).

AwraniK (1971) Total number of columnar stromatolite forms

Fig. 1. Diversity curve for Precambrian columnar stromatolites.
Apex Chert microfossils (3.465 Ga) J. William Schopf; 1993
http://www.uni-muenster.de/GeoPalaeontologie/Palaeo/Palbot/seite1.html

Swaziland microfossils, S-Africa (3.5 Ga)
Knoll & Barghoorn http://www.uni-muenster.de/GeoPalaeontologie/Palaeo/Palbot/seite1.html
Gunflint microfossils (2 Ga)

http://www.uni-muenster.de/GeoPalaeontologie/Palaeo/Palbot/seite1.html

How were these bacteria making a living?

• Photoautotrophy (photosynthesis)

  \[ 6 \text{CO}_2 + 6 \text{H}_2\text{O} \Rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6 \text{O}_2 \]

• Chemoautotrophy (e.g. methanogenesis)

  \[ \text{CO}_2 + 4 \text{H}_2 \Rightarrow \text{CH}_4 + 2 \text{H}_2\text{O} \]
Sedimentological indicators of Precambrian atmospheric composition (i.e., oxygen content, which is a ± proxy pH)

Banded iron formation (BIF)
Formation of Banded Iron Formation

After combining the Fe and O₂ ions into Magnetcite (Fe₃O₄), the mineral grains sink to the sea floor, where they accumulate into iron-rich and iron-poor layers.
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2 Kingdoms $\Rightarrow$ 5 Kingdoms $\Rightarrow$ 3 Domains

If it’s green: Kingdom Plantae

If it moves: Kingdom Animalia

- Monera - prokaryotes
- Protista - single-celled eukaryotes
- Fungi - Heterotrophic (decomposer)
- Plantae
- Animalia - multicelled eukaryotes
- Heterotrophic (consumer)
2 Kingdoms $\Rightarrow$ 5 Kingdoms $\Rightarrow$ 3 Domains

- Bacteria (aka “Eubacteria”)
- Archaea
- Eukarya
  - Protista
  - Fungi
  - Plantae
  - Animalia

The “Universal Tree of Life” based on 18sRNA
The origin of eukaryotes

• How?
  – not a paleontological question
  – The Endosymbiotic Theory
The Endosymbiotic Theory
of the Origin of the Eukaryotic Cell

The Endosymbiotic Theory
(a fuller version)
The “Universal Tree of Life” based on 18sRNA

The origin of eukaryotes

• How?
  – not a paleontological question
  – The Endosymbiotic Theory

• When?
  – Body fossils: > 1.4 Ga
  – Chemical fossils: > 2.7 Ga
  – Molecular clocks: > 2.7 Ga
Chemical Fossils of Eukaryotes Ca. 2.7 Ga

A time-calibrated phylogeny of life

(from Porter, 2004, Paleontological Society Papers vol 10)
Proterozoic Eukaryotes

(from Porter, 2004)

More Proterozoic Eukaryotes

Acritarchs ↑  Vase-shaped microfossils ↓
Proterozoic Acritarchs

http://faculty.uca.edu/~benw/biol4415/lecture10a/sld031.htm

Milestones in the first 3 billion years of life

- Origin of life - before 3.8 Ga
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When did the first multicellular eukaryotes arise?

- **Body fossils**
  - “good” fossil evidence at 600-800 Ma
  - Questionable fossil evidence earlier (but stay tuned)

- **Molecular clocks**
  - Wide variety of dates (600-1500 Ma)
  - Most dates focus on 800-1000 Ma

*Grypania*, ca. 2.1 Ga from Michigan
Eukaryotic (triploblastic) Traces, India

1.0 or 0.6 Ga

From Seilacher et al. 1998, Science 282: 80-83

Multicellular algae (?), Proterozoic (ca. 800 Ga), Montana and NW Canada
Table 1. Recent molecular date estimates of the protostome-deuterostome split

<table>
<thead>
<tr>
<th>Date Estimate</th>
<th>Sequence Data</th>
<th>Calibration Date [Myr ago]</th>
<th>Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1200</td>
<td>seven protein coding (mitochondrial and nuclear), 18S-rRNA</td>
<td>&gt; 15 dates (mostly vertebrate)</td>
<td>Wray et al. (1996)</td>
</tr>
<tr>
<td>730, 850</td>
<td>21 protein coding (mitochondrial and nuclear)</td>
<td>six dates (vertebrate: 100-450)</td>
<td>Feng et al. (1997)</td>
</tr>
<tr>
<td>670, 736</td>
<td>18 protein coding (mitochondrial and nuclear)</td>
<td>more than eight dates</td>
<td>Ayala et al. (1998)</td>
</tr>
<tr>
<td>&gt; 680</td>
<td>11 protein coding (mitochondrial), 18S-rRNA</td>
<td>12 dates (protostome and deuterostome: 280-530)</td>
<td>Bromham et al. (1998)</td>
</tr>
<tr>
<td>650</td>
<td>ten protein coding (mitochondrial), 50 genes</td>
<td>one date (fish-terrapod: 430)</td>
<td>Lynch (1999)</td>
</tr>
<tr>
<td>993</td>
<td></td>
<td>three dates (primate-rodent: 100; mammal-bird: 310; animal-fungus: 1100)</td>
<td>Wang et al. (1999)</td>
</tr>
</tbody>
</table>

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The oldest known skeletonized organism

*Cloudina – ca 550 Ma*
*Namacalathus*, a calcified metazoan
550-543 Ma
Namibia

From Grotzinger et al., 2000
*Paleobiology* 26(3)