Origin of Life on Earth: The Precambrian Fossil Record

Geology 230
Fossils and Evolution
Time Line

- 0.55 BY – animals with hard parts, start of the Phanerozoic Era
- 2.0 BY – first definite eukaryotes
- 2.0-3.5 BY – formation of BIF’s, stromatolites common
- 3.5 BY – oldest probable fossils: stromatolites
- 3.8 BY – C\(^{12}\) enrichment in sedimentary rocks, chemical evidence for life; not definitive of life
- 4.0 BY – oldest rocks of sedimentary origin
Fossil Evidence

• 3.8 BY ago: small carbon compound spheres - early cells?
• 3.5 BY ago: probable fossils consisting of stromatolites and the microbes that formed them.
• 3.2 BY ago: rod-shaped bacteria
Fossil Cell?
3.8 BY old
from
Greenland
Modern stromatolites, Bahamas
Modern stromatolites produced by cyanobacteria, Sharks Bay, Australia
Modern stromatolites produced by cyanobacteria, Sharks Bay, Australia
2 B.Y. old stromatolites from Canada
Stromatolites, 2 BY old, Minnesota
Mat of cyanobacteria traps fine-grained carbonate sediment

Threadlike cyanobacteria grow upward through the trapped sediment

Many layers accumulate to form a stromatolite
Cyanobacteria, makers of stromatolites since 2.6 Ga

Microscopic views

© Dennis Lukas
Cyanobacteria, makers of stromatolites

1.0 Ga
Cyanobacteria fossils, 1 BY old
3.5 BY old Australia, cyanobacteria or not?

Microscopic views
Stromatolite, 3.5 BY old, Australia
Closeup of stromatolite layers in last slide
Modern archaea

Fossil archaea or bacteria, 3.2 BY old from Africa
Modern bacteria

Fossil bacteria 2BY old from Minnesota
The Banded Iron Formations

• Billions of tons of iron ore, the world’s chief reserves.
• Formed between 3.5 and 2.0 BY ago.
• They record the gradual oxidation of the oceans by photosynthetic cyanobacteria.
• When the oceans finished rusting, oxygen accumulated in the atmosphere.
Banded Iron Formations are the World’s primary source of iron ore.
A piece of Banded Iron Formation, 2 BY old
BIF: Banded Iron Formations

- $\text{Fe}^{+2}$ reduced iron
- $\text{Fe}^{+3}$ oxidized iron
- $\text{O}^{-2}$ oxygen
- $2\text{Fe} + \text{O}_2 \rightarrow 2 \text{FeO}$ ferrous oxide (soluble)
- $2\text{FeO} + \frac{1}{2}\text{O}_2 \rightarrow \text{Fe}_2\text{O}_3$ ferric oxide (rust)
- Between 3.5-2.0 BY ago, the ocean slowly rusted as dissolved iron was removed.
- The bands are alternating layers of rust and silica ($\text{SiO}_2\cdot\text{H}_2\text{O}$), formed during summer and winter, respectively.
Evolution of Eukaryotes

• Strict requirement for oxygen.
• Oldest eukaryote about 2.1 BY old, a multicellular algae.
• Evolved by symbiosis:
  – first protist evolved chromosomes
  – absorbed aerobic bacteria became mitochondria
  – absorbed cyanobacteria became chloroplasts
The oldest-known macrofossil, *Grypania spiralis*, a eukaryotic algae from 2.1 billion years ago.
Endosymbiosis
Plant-Animal Dichotomy

- All protists have mitochondria, but only some have chloroplasts.
- Those with chloroplasts gave rise to algae and eventually plants.
- Those without chloroplasts gave rise to heterotrophs, including animals.
- Split happened before 2.1 BY ago.
Endosymbiosis, showing the heterotroph and autotroph split

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<th>Heterotrophs</th>
<th>Photosynthetic autotrophs</th>
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<td><strong>Single-celled eukaryotes</strong></td>
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Eukaryotic heterotroph fossils: Amoebozoa, 1 BY old

Figure 12-7
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Plant-Animal or Heterotroph-Autotroph Dichotomy shows the Origin of Eukaryotes >2.1 BY ago

Protozoans and Animals (0.6 BY)

True Algae and Plants

Grypania, 2.1 BY

Chloroplasts from cyanobacteria

Mitochondria from purple bacteria

Was the 1.5 BY delay in the evolution of animals required to evolve the nerve cell?
Delayed Rise of Animals

• Multicellular algae arose 2.1 BY ago.
• Animals can be thought of as multicellular heterotrophic protists. They first appear 0.6 BY ago.
• Why the delay of over 1.5 BY? That’s a long time for heterotrophs to remain single-celled.
Cause of the Delay?

- The time required for the complex **nerve cell** to evolve. It coordinates muscular movement.
- All animals more complex than sponges have nerve cells. Sponges don’t move, nor do plants or fungi.
The First Animals

- The first animal fossils appear around 600 MY ago. They consist of trace fossils and impressions of soft bodied animals.
- The impressions are called the Ediacaran fossils.
Ediacaran Fossils

- Jellyfish
- Sea Pens
- Segmented worms
- A variety of “quilted” animals of unknown biological affinities.
Ediacaran Fossils

- Very thin for direct absorption of oxygen. No evidence of gills.
- No hard parts because there were no predators. These animals ate algae.
- Predators appeared by the end of the Proterozoic as shown by hard part fossils at the base of the Cambrian.
Cambrian

Age (million years)

542
550
560
570
580
590
600

Very small animals and animal embryos

Mobile Ediacaran forms

Frond-like Ediacaran forms

Simple horizontal burrows

Small skeletonized animals

Figure 12-14
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Animal embryos, about 600 MY old, preserved in phosphate
Latest Proterozoic Life: The Ediacaran Fossils

Figure 12-9
Latest Proterozoic Life: The Ediacaran Fossils
Latest Proterozoic Life: The Ediacaran Fossils
Ediacaran fossils exposed in sandstone
A modern sea pen, a relative of corals
A fossil sea pen from the Ediacaran of Australia
Mawsonites, a fossil jellyfish?
A variety of Ediacaran fossils
Dickinsonia – a segmented worm or placozoan?
Dickinsonia – a segmented worm or placozoan?
Kimberella – a probable mollusc
Spriggina – an arthropod? Proto-trilobite?
Spriggina – an arthropod? Proto-trilobite?
Tribrachidium – what is it?

Arkarua – oldest echinoderm?
Tribrachidium – what is it?
Evidence of bacterial mats on the sea floor
Late Proterozoic trace fossils made by animals digging in the seafloor.