Life on Earth. II
The Archean Era

4Gya - 2.5 Gya

Bombardment over:
• Oceans had formed and stabilized
• Atmosphere had stabilized
First Life

What was the first life on Earth?

- The first living things must have been simple
- All existing life is advanced.
- The fossil record is incomplete.

Where do we look?
Rocks

The fossil evidence is preserved in rocks.

• **Igneous** rock: solidified lava
• **Sedimentary** rock: sediment laid down and compressed into rock.
• **Metamorphic** rock: sedimentary rock that has been modified by heat and/or pressure (but not melted).

Fossils are not found in igneous rock.
The Oldest Rocks (<2.5Gya)
The Oldest Fossil Evidence

• >3.85 Gya: isotopic evidence. $C^{12}/C^{13} > 89$ suggests biochemical processes. Other isotopic evidence agrees.
• 3.5 Gya: fossil stromatolites
• 3.5 Gya: possible fossil micro-organisms
• 3.2-3.5 Gya: fossil cells

Fossil Cyanobacteria
~1 Gyr
Bitter Springs Chert, Australia
http://www.ucmp.berkeley.edu/precambrian/bittersprings.html
Stromatolites

Layered mats of bacteria and other micro-organisms

Now ➔
Shark’s Bay,
Australia

← Then
Implications

Life formed very early on - probably within 100 million years of the Earth’s surface becoming inhabitable.
The Last Common Ancestor

• Used DNA with 4 bases to encode information
• Had a cell wall
• Metabolized something, perhaps $\text{H}_2\text{S}$
• Used 19 left-handed amino acids

• Nature inferred from evolutionary relationships
• Results in the Tree of Life
• The LCA may be a *Thermophile*
The Tree of Life
The Archaea

Archaea often inhabit extreme environments
Archaea superficially resemble bacteria, but are genetically distinct
Archaea are anaerobic (don't use oxygen)
   • Acidophiles - acidic environs (pH~0)
   • Alkalophiles - inhabit alkaline lakes (pH~10)
   • Barophiles - high pressure
   • Thermophiles - hot environments (>45°C)
   • Lithophiles - live in/metabolize igneous rock
   • Methanogens - metabolize hydrogen
   • Halophiles - live in salty environs
   • Psychrophiles - adapted to cold (<0°C)
Extremophiles all!
Life on the Fringe

Life on Earth
- Does not need Oxygen or CO$_2$
- Does not need to metabolize Carbon
- Does not need Sunlight
- Can thrive at 110C
- Can survive in ice
- Can lie dormant for millions of years
- Needs H$_2$O
Origin of Life

Raw ingredients are available in space

Complex organic molecules can be produced in a reducing atmosphere, given energy (UV photons or lightning)

Life probably began in water, not on land
Black Smokers

Mid-ocean hydrothermal vents (geysers)

• Temperature >100°C (to 400°C)
• Spew iron and sulfides (metabolized by *thermophiles*)
Origin in the Ocean

• Water protects against UV radiation
• Water is needed for biochemistry
• Hydrothermal vents provide nutrients
• Protected from surface impacts
Earliest Life

• May have used RNA (a self-catalyzing molecule)

• First cell wall may have been a coacervate
  • lipids have hydrophobic and hydrophilic ends.
  • surface tension will draw it into a sphere.
  • coacervates exhibit osmotic pressure

• DNA replaces RNA.
  • DNA is more robust, but requires ribozymes (enzyme catalysts) to function
Metabolism

Anaerobic photosynthesis:
\[ 12\text{H}_2\text{S} + 6\text{CO}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{H}_2\text{O} + 12\text{S} \]
(what some anaerobes and archaea (chemoautrophs/photoheterotrophs) do)

Aerobic photosynthesis:
\[ 6\text{H}_2\text{O} + 6\text{CO}_2 \rightarrow \text{C}_6\text{H}_{12}\text{O}_6 + 6\text{O}_2 \]
(what plants (photoautotrophs) do)

Respiration:
\[ \text{C} + \text{O}_2 \rightarrow \text{CO}_2 \]
(what animals (chemoheterotrophs) do)

(C\textsubscript{6}H\textsubscript{12}O\textsubscript{6} is glucose, a common sugar)
Prokaryotes

Archaea and Bacteria

• no cell nucleus
• single strand of DNA
• no cell structure
• asexual/sexual reproduction
  (gene swapping by transduction)
• earliest record:
  stromatolites and fossil cells at 3.5 Gya
Eukaryotes

- DNA segregated in a cell nucleus
- double strands of DNA
- organelles - symbiotes of bacteria
- sexual reproduction
- earliest record: fossil protists at 2.4 Gya


Eukaryotes likely evolved when a large prokaryote with a cytoskeleton, perhaps similar to *Magnetobacter*, engulfed but failed to digest, a smaller prokaryote.
Oxygen

Highly reactive
Deleterious to organic molecules

Oxidation offers very efficient metabolism
$3\text{O}_2 \rightarrow 2\text{O}_3$ (ozone) in presence of UV

First indications of $\text{O}_2$ in atmosphere: 2.35 Gya

Enough $\text{O}_2$ (10%) to support fire: 200 Mya
It’s a Long Way from Amphioxus
The Molecular Basis of Evolution

DNA Base pairs encode amino acids (e.g., TAC encodes Tyrosine). Genes encode proteins (strings of amino acids).

- Some proteins are structural - they make parts of things
- Some proteins are controls - they control gene expression

Mutations result from:
- incorporation of new genes (viruses and bacteria readily share genetic material)
- substitutions of bases (TAC → TTC replaces tyr with phe)
- breaks in genes (TAC → TAA replaces tyrosine with stop)
The Molecular Basis of Evolution. II

- Most mutations are deleterious.
- Some mutations are neutral.
- A few mutations are beneficial.
- Mutations in structural genes have small effects.
- Mutations in control genes have major effects.
- Mutations are random, but
  - since deleterious changes kill,
  - advantageous and neutral mutations accumulate.

That which does not kill me makes me stronger
Natural Selection

Black dots represent deleterious mutations

Evolution results from the accumulation of advantageous mutations
How Evolution Really Works

Mutations accumulate at a more-or-less constant rate. **Darwinian** evolution is **Uniformitarian**: changes are slow and almost imperceptible. The Darwinian model is refuted by the data. **Most evolutionary change seems to be rapid.**

**Catastrophism** or **Punctuated equilibrium**:
- Pool of variants (or mutants) exist in populations
- Variants may be advantageous when conditions change, as they may be better adapted to the new conditions
- Monocultures can be ill-adapted to change
- Evolutionary change occurs in short bursts when environments change
How Evolution Really Works

New phyla do not appear gradually throughout the fossil record: they appear almost all at once in the Cambrian Explosion, 530 Mya.

• Well-adapted species need not change (e.g., cyanobacteria, thermophilic bacteria)
• Eukaryotes evolved in response to the first major global environmental disasters: Oxygen and the first ``snowball Earth”
• Animal life appeared in the Cambrian Explosion, perhaps in response to the second “snowball Earth"
• New species appear, and new classes arise to dominance, following global disasters (catastrophism).
Proof of Evolution

• Genetic control sequences (*homeobox genes*) are common in all terrestrial life.

• Humans and bacteria have genes and proteins in common.

• The TATA gene, which encodes the protein that activates genes, is **40% identical** between humans and bacteria.

• The human and chimpanzee genomes are about **98% identical**.
Is Evolution only a Theory?

Yes. But so is gravity.

It is a fact that evolution happens.

There is also a theory of evolution which explains the facts. Some details of the theory are incompletely understood. Darwinian evolution may be an incorrect theory; the Punctuated Equilibrium theory may be better.

- Microevolution is observed - e.g., drug resistance in bacteria.
- Macroevolution is observed in the fossil record.
- Evolutionary theory makes clear predictions, many of which have been borne out.
- Many criticisms of evolution reflect a misunderstanding of science and how it operates.
- The strength of science is that theories change in response to better knowledge.
- Most criticisms of evolution are philosophical, not scientific.
What About Intelligent Design?

*Well-adapted* is not synonymous with *well-designed*.

- The eye has evolved >65 times, with 10 different designs.
  - The mammalian eye evolved from brain tissue.
  - The molluscan eye evolved from skin tissue.
  - The molluscan eye has a superior optical design. In mammalian eyes the light must pass through the nerves and blood vessels before reaching the retina. We have a large blind spot where the optic nerve is located. It takes a large brain, and lots of processing, to make the undistorted images we perceive.

- The genome is redundant (inefficient design)
  - $\beta$ globin, a protein used in hemoglobin, is encoded 6 times in humans. Adults use two versions of the protein; children use 3
  - one version contains 6 known errors, and is non-functional.
What About Intelligent Design?

~97% of our DNA is not expressed (inefficient design).
   It is gene fragments, pseudogenes, or repeated nonsense segments.

Upon close examination, our DNA is a hodgepodge of "borrowed, copied, mutated, and discarded sequences, cobbled together by millions of years of trial and error."
(S.J. Gould)

Further Reading:
A well-written essay on the topic can be found at http://www.talkorigins.org/faqs/cosmo.html
Another good essay, with lots of references, is at http://skepdic.com/intelligentdesign.html (from the Skeptic's Dictionary)
A recent article discussing the inroads intelligent design is making in academia is located at http://chronicle.com/free/v48/i17/17a00801.htm (from the Chronicle of Higher Education)