

ABIOTENESIS: The Origins of Life***By the end of this lecture, you should:***

- Understand when life must have originated on Earth, and the fossil evidence that we see for it.
- Understand the significance of the pre-biotic chemistry experiments performed by Miller, Fox, Oro, and others.
- Understand the limitations of our knowledge of the transition from lifeless chemicals to the simplest living cells.

Chicken or egg? It's irrelevant! Before chickens or eggs could exist, there had to be **CELLS!**

Cell theory:

1. All living things are composed of one or more cells.
2. All cells arise from pre-existing cells.

SO... WHERE DID THE FIRST CELLS COME FROM?

Questions to ponder... What were the earliest life forms? When did life originate on Earth? How did life originate? Where did life originate? Is life unique to Earth?

When did life begin?

- When is the earliest life could have begun?
 - Constrained by the age of the Earth's crust
- When is the latest life could have begun?
 - Constrained by the age of the oldest fossil evidence

The age of the crust:

- Earth formed **4.53 Ga**
- Moon formed **4.48 Ga**
- Oldest known terrestrial rocks are *ca.* **3.9 Ga, BUT**
 - they are *meta-sedimentary*
 - contain *zircon*s that are **4.4 Ga!**
 - Zircon is a mineral formed in igneous rocks
 - Resists physical & chemical breakdown
 - Melts only at very high temperatures
 - Contains uranium -- can use for U-Pb method dating

When did life begin?

- SO, within ~100 Ma after formation,
 - Earth was largely differentiated
 - Earth had a primitive crust
- ***Potentially, life could have begun as early as 4.4 Ga!***

What were the earliest life forms?

- Primitive, single-celled organisms = prokaryotic bacteria

The oldest fossils

- Prior to mid-1950's, no fossils older than *ca.* 600 Ma (Cambrian period) were known
 - These fossils were *complex, multicellular animals*
 - And therefore could not represent the origins of life
- The oldest fossils must be older than 600 Ma
- Must be extremely simple: *prokaryotic bacteria*

Where do you look for fossilized single-celled organisms?!

- ***Stromatolites***
 - Currently form in tidal waters in the tropics
 - Thin mats of blue-green algae (*cyanobacteria*)
 - *Prokaryotic cells!*
 - Recognized in Precambrian rocks!
- ***Black chert***
 - Microcrystalline form of quartz
 - Black color comes from *organic compounds*
 - Precipitates from seawater as a sticky gel - traps bacteria
 - Bacteria are preserved when material hardens

Gunflint Chert

- Thunder Bay, Lake Superior, Ontario, Canada
- **1.9 Ga**
- *Prokaryotic cells!*

Fig Tree Formation

- Black chert
- Southern Africa
- **3.1 Ga**
- Prokaryotic cells
- *Stromatolites also present!*

Apex Chert

- Northwest Australia
- **3.465 Ga**
- Colonial prokaryotic cells

Swaziland microfossils

- Swaziland, southern Africa
- similar age to Apex Chert
- cellular mitosis (*asexual reproduction*)

Chemical fossils

- Chemical analysis reveals presence of organic compounds in Precambrian black cherts
 - *Pristane* and *phytane* -- organic compounds created by degradation of chlorophyll
- Carbon isotopes: biological materials have higher $^{12}\text{C}/^{13}\text{C}$ ratios than non-biological materials
 - high $^{12}\text{C}/^{13}\text{C}$ ratios are found in 3.8 Ga banded iron formations (BIFs) in Greenland

When did life on Earth begin?

- No earlier than **4.4 Ga**, no later than **3.5 Ga**
 - *maybe no later than 3.8 Ga?*

What happened during that billion-year interval? How did life originate? How did lifeless chemical compounds become the first living cells? What thresholds had to be crossed?

Spontaneous generation?

- Accepted from the Roman era through the mid-19th century
- Life forms could arise spontaneously from non-living matter
 - ex. maggots from rotting meat
- Disproved by **Louis Pasteur** in 1859
 - **showed that microorganisms are everywhere - even in air**

The Miller/Urey experiment

- Performed by Stanley Miller in 1953 at Univ. of Chicago (*suggested by Harold Urey*)
- Attempt to recreate Earth's earliest atmosphere & oceans
- Methane (CH₄), ammonia (NH₃), hydrogen (H₂), water vapor (H₂O)
- After 8 days, brown "gunk" had formed in the apparatus:
 - ~15% of the carbon present had formed organic compounds
 - **2% of the carbon had formed amino acids!**

Amino acids

- Building blocks of **proteins**
- Proteins act as building materials for cells, and as **catalysts** for chemical reactions within organisms

Criticism of the Miller/Urey experiment

- It is now believed that the Earth's early atmosphere **did not contain** large amounts of methane, ammonia, and hydrogen; and, the energy input in the experiment was too great
- *In other words, the experiment did not realistically portray the young Earth*
 - **Regardless of whether or not the Miller experiment realistically recreated conditions on the young Earth, it demonstrated that amino acids can be easily be created without divine intervention.**

The Murchison Meteorite

- Fell on Murchison, Australia on Sept. 28, 1969
- 100 kg of material was recovered
- contained **more than 90 different amino acids**
 - **19 of which are known to exist on Earth!**

Proteinoids

- To form protein-like molecules ("**proteinoids**"), amino acids must be "de-watered"
- Can be accomplished by heating concentrations of amino acids to at least 140°C
- But biochemist S.W. Fox discovered that proteinoids could be formed at temperatures *as low as 70°C*, in the presence of phosphoric acid
- Reasoned that heat and acidic discharges from volcanoes on the young Earth could have created proteinoids
- Found proteinoids adjacent to vents of Hawaiian volcanoes!

Proteinoids

- When cooled, proteinoids form tiny spheres called **microspheres**, which share some characteristics with living cells
- **BUT** they are still not living cells

Other biomolecules?

- In 1961 Juan Oro produced amino acids from an aqueous solution containing hydrogen cyanide (HCN) and ammonia (NH₃)
- AND the experiment also produced a large amount of the nucleotide base adenine
- Adenine is one of the four nucleotide bases in both RNA and DNA
- It is also a component of adenosine triphosphate (ATP), a major energy-releasing molecule in living cells
- ***Later experiments showed that the other nucleotide bases could also be created through simulated pre-biotic chemistry***

So you made biomolecules... how do they turn into cells?

A probable scenario:

- Constant mixing of the ocean waters favored frequent collisions of vital molecules
- Gradually increased the probability of combination into larger, more complex bodies
- Thousands and thousands of infinitesimally small steps needed to create something transitional between lifeless chemicals and the simplest possible *living cells*

What are the odds?

Can it happen today?

- **NO**...now that we have life:
 - Too much free oxygen in the atmosphere
 - Too many microbial predators
 - Would destroy these delicate prebiotic structures

Questions to keep you awake at night:

- How did simple cells develop into more complex cells, containing organelles with specialized functions?
- How did individual cells become organized into complex, multicellular organisms?
- How did the earliest multicellular organism develop into the great diversity of organisms that exist today (and have existed in the past)?
- How do humans fit into the picture? Are we really that different from these "lower" life forms???