When did life begin on Earth?

• Have to study fossils
• Geological record is incomplete and we may not even have discovered oldest fossils
• Three lines of fossil evidence point to very early life
  – Stromatolites – preserved remains of microbial activities
  – Microfossils - preserved remains of microbial bodies
  – Isotopic evidence – preserved remains of microbial metabolism
Stromatolites

- Virtually identical to mats formed today by microbe colonies
- Evidence of microbial colonies as far back as 3.5 bya
- If used photosynthesis --> more primitive life must have existed prior to them!
Microfossils

- Hard to be sure...have to use careful chemical analysis [3.5 bya rock in NW Australia]
- 3.2-3.5 bya rock in Africa – appear to be fossilized cells
- 2.7-3.0 bya – biologically-originating molecules
Isotopic Evidence

• Living organisms change the ratios of isotopes from their initial, non-living values
  – Living organisms/rocks with living organisms show lower fraction of C\textsuperscript{13}

• Akilia Island (off Greenland) found lower C13 ratio in rocks that are > 3.85 byo, also see isotopic ratios of other elements (F, N, S) altered by life

• Would expect to find life in these rocks only if life was already widespread on Earth
Oldest Evidence of Life?

Akilia & Isua: oldest evidence of life?
~3.85-3.7 billion years (carbon isotopes)

Coonterunah: oldest signs of life
~3.52 billion years (carbon isotopes)

- Early Archean rocks (>3.0 Ga)
- Late Archean rocks (2.5-3.0 Ga)
Oldest VISIBLE evidence of life

North Pole:
3.47 billion years
(stromatolites)

- **Early Archean rocks (>3.0 Ga)**
- **Late Archean rocks (2.5-3.0 Ga)**
Molecular evidence of life

- Early Archean rocks (>3.0 Ga)
- Late Archean rocks (2.5-3.0 Ga)

Jeerinah: 2.69 Ga (hydrocarbon biomarkers)
DNA is the Key!

• Base sequence of DNA in currently living organisms = map of genetic changes through time --> follow backwards!

• Biologists compare small pieces of DNA of many species to map evolutionary history of genes
**FACT** - We have characterized less than 1% of our planet's microbial diversity. No natural microbial community has ever been fully characterized. Millions of unknown or poorly defined species inhabit engineered reactor systems and our local and immediate surroundings (including our mouth, skin, and gastro-intestinal tract)

**Point of reference:** The human genome is ~3.5 billion base pairs. This is exceeded by the microbial DNA in a tablespoon of seawater.

**FACT** - The greatest repository of genetic and evolutionary information is in the microbes. Profound significance to biotechnology, environmental engineering, environmental studies, and evolutionary and astrobiological science.
Where did life begin?

• On land? Unlikely
  – Early atmosphere contained almost no O2 --> no ozone (O3) layer to protect

• Shallow ponds? Maybe
  – Cycles of wetting/evaporation could have increased concentration of organic compounds on edges
  – Not much protection from UV

• Deep sea or underground? Most likely
  – Lots of chemical energy to fuel reactions
  – No UV radiation to worry about
Astrobiological Implications

• Earth had life soon after its origin, and maybe within 100 million years, under extreme conditions.
• Soon after the heavy meteorite bombardment ended, microbes as metabolically complex as now were widespread and abundant.
• So...life arose and diversified rapidly, and occupied an amazing array of evolutionary niches.
• Planets with early but short-lived habitable windows (e.g. Mars, Venus) could have been lively!
• Intelligence does not rapidly follow evolution of complex cells (eukaryotes), so microbial life may be abundant while intelligence is rare.
LIFE ON EARTH: HOW?
Life in a “bottle” : Miller & Urey

- Tested idea that sunlight-fueled chemical reactions could lead to spontaneous creation of organic molecules
- 1953; Stanley Miller & Harold Urey
- Since debated...do not really know early Earth conditions
- Other sources of organic molecules?
This Research Showed That:

Building blocks of life form readily (22 amino acids, sugars, lipids)

Results depend sensitively on the atmospheric composition (needing H)

No replicating molecule or anything remotely as complex as a cell resulted
How was life made/assembled?

• Intermediate steps between chemistry and biology --> work backward from organisms living today
• DNA is too complex, but RNA is much simpler
• 1980s – RNA can catalyze biochemical reactions like enzymes can = ribozymes!
• DNA-based life may have come from RNA-based world, with RNA serving as both genes and catalysts
DNA

RNA

proteins

Structure and function of organism
How was life made/assembled?

• But then how did RNA form?
  – Experiments show that inorganic minerals can facilitate – CLAY
  – Short chains of a few dozen bases first...
  – We know simple ribozymes can be just 5 strands long...
  – Short RNA strands peel away from clay, attach together via catalysis by ribozymes to make RNA strand longer and more complex
1. Clay minerals catalyze the formation of RNA strands up to a few dozen bases long.

2. RNA strands peel away from clay and fold; some are capable of catalyzing chemical reactions.

3. Aided by catalysis, folded RNA molecules attach to make longer RNA strands.

4. Longer strands can perform more catalysis, eventually leading to self-replication.
Clay stimulates vesicle formation and becomes trapped inside.
Pre-cells

- RNA and other organic molecules confined inside
- Can selectively allow in/out some types of molecules
- Can store energy in form of electric voltage
- Can split into daughter spheres
- Can form on surface of same minerals that help assemble RNA
- Increased likelihood of RNA self-replication
- Facilitated natural selection on molecular level
DNA
↓
RNA
↓↓↓↓
proteins
↓
Structure and function of organism

natural selection
This Research Shows That:

Complex molecules (RNA fragments) form naturally or on clay substrates

Vesicles (simple cell containers) form readily and concentrate bio-polymers

Chemical natural selection will act to increase biochemical complexity
Big Picture

1. Naturally forming organic molecules are the building blocks of life.

2. Clay minerals catalyze production of RNA and membranes that form pre-cells.


4. True living cells with RNA genome give rise to "RNA world."

5. DNA evolves from RNA and biological evolution.