Chapter 25
The History of Life on Earth
Question

• How have events in the Earth’s history contributed to life as we know it?
How did Life get started?

• One Idea - Chemical Evolution: the evolution of life by abiogenesis.
Steps

1. Monomer Formation
2. Polymer Formation (macromolecules)
3. Protobiont Formation
4. Origin of self-replicating molecules (heredity)
Primitive Earth Conditions

- Reducing atmosphere present.
- Simple molecules
  - Ex: $\text{H}_2\text{O}$, $\text{CH}_4$, $\text{H}_2$, $\text{NH}_3$
Complex Molecule Formation

• Requires energy sources:
  – UV radiation
  – Radioactivity
  – Heat
  – Lightning
Oparin and Haldane 1920s

• Hypothesized steps of chemical evolution from primitive earth conditions.
Miller and Urey, 1953

• Tested Oparin and Haldane’s hypothesis.
• Experiment - to duplicate primitive earth conditions in the lab.
Results

• Found organic monomers including Amino Acids.
• Suggested that under the primitive Earth’s conditions, monomers could form.
Other Investigator's Results

- All 20 Amino Acids
- Glucose, Ribose, Deoxyribose etc.
- Glycerol and fatty acids
- Nucleotides
- ATP
- Monomers for all macromolecules have been found.
Polymer Synthesis

• Problem:
  – Monomers dilute in concentration.
  – No enzymes for bond formation.
Possible Answer

1. Clay
2. Iron Pyrite
   • Both could have served as a substrate to position monomers close together.
   • Have metals that can act as catalysts.
Another possibility

• Waves could have placed monomers on beaches.
• Sun could have concentrated the solutions.
Protobionts

• Aggregates of abiotically produced molecules.
• Exhibit some properties of life.
  – Ex: Osmosis, Electrical Charge, Fission
Protobionts

(a) Simple reproduction

(b) Simple metabolism

Glucose-phosphate

Phosphate

Starch

Amylase

Maltose

Maltose

Phosphorylase
Results

• Protobionts have membrane-like properties and are very similar to primitive cells.

• Start for natural selection that may have led to cells?
Question?

- Where did the energy come from to run these early cells?
Answers

• ATP
• Reduction of sulfur compounds
• Fermentation
• H+ gradients
• Rs and Ps developed much later.
Self-replicating molecules (Heredity)

• DNA → RNA → Protein
• Too complex for early life.
• Other forms of genetic information?
RNA Hypothesis

• RNA as early genetic information:
  – RNA polymerizes easily.
  – RNA can replicate itself.
  – RNA can catalyze reactions including protein synthesis.
RNA monomers  

Formation of short RNA polymers  

Assembly of a complementary RNA chain (pairing rules are G with C and A with U)  

Complementary chain serves as template for making copy of original "gene"
Ribozymes

• RNA catalysts found in modern cells.
  – e.g. ribosomes

• Possible relic from early evolution?
Molecular Cooperation

• Interaction between RNA and the proteins it made.
• Proteins formed may serve as RNA replication enzymes.
Molecular Cooperation

- Works best inside a membrane.
- RNA benefits from the proteins it made.
(a) A molecular “free-for-all” in the prebiotic soup of organic molecules.

(b) Exclusive cooperation among membrane-enclosed molecules.
Selection favored:

• RNA/protein complexes inside membranes as they were the most likely to survive and reproduce.
DNA

- Developed later as the genetic information.
- Why? More stable than RNA
Alternate View

Life developed in Volcanic Vents.
Volcanic Vents

• Could easily supply the energy and chemical precursors for chemical evolution.
• Most primitive life forms today are the prokaryotes found in or near these vents.
New Idea

• Life started in cold environments.
• Interface between liquid and solid allows concentration of materials and formation of polymeres.
• Molecules last longer too.
Modern Earth

- Oxidizing atmosphere.
- Life present.
- Prevents new abiotic formation of life.
- However – some suggest that “alien” life is still present.
Hypothesis

• Life as a natural outcome of chemical evolution.
• Life possible on many planets in the universe (?).
Fossils

- Any preserved remnant or impression of a past organism.
Types of Fossils

1. Mineralized
2. Organic Matter
3. Trace
4. Amber
Mineralized Fossils

- Found in sedimentary rock.
- Minerals replace cell contents.
- Ex: bone, teeth, shells
Organic Matter Fossils

- Retain the original organic matter.
- Ex: plant leaves trapped in shale.
- Comment – can sometimes extract DNA from these fossils.
Trace Fossils

• Footprints and other impressions. No organic matter present.
Amber

- Fossil tree resin.
- Preserve whole specimen.
- Usually small insects etc.
Fossils - Limitations

- Rare event.
- Hard to find.
- Fragmentary.
- Dating.
Fossil Dating Methods

1. **Relative** - by a fossil's position in the strata relative to index fossils.

2. **Absolute** - approximate age on a scale of absolute time.
Absolute - Methods

1. Radioactive
2. Isomer Ratios
Radioactive

• Estimated from half-life products in the fossil.
• Ex: Carbon - 14
  Potassium – 40
• Different isotopes have different half-lives.
The diagram illustrates the concept of radioactive decay, specifically the relationship between time and the remaining concentration of parent isotopes and the accumulation of daughter isotopes.

- The top row shows clocks, each representing a different time interval, increasing by half-lives: 1, 2, 3, and 4 half-lives.
- The bottom section of the diagram displays a graph with time (in half-lives) on the x-axis and the concentration of isotopes on the y-axis.
- The graph shows the exponential decay of parent isotopes, indicated by the red line, and the accumulation of daughter isotopes, indicated by the blue arrows.
- At each half-life, the concentration of parent isotopes decreases to half its previous value, and the concentration of daughter isotopes increases by half the amount of the parent isotopes.

The diagram visually represents the principle of constant decay, indicating that with each half-life, the amount of parent isotopes decreases, while the amount of daughter isotopes increases proportionally.
What do fossils tell us?

• That the geographical distribution of organisms has changed over time.
• Reason? – The Earth has changed over its history.
Key Events

- Origin of Life and single-celled organisms
- Ps and Oxygen revolution
- First Eukaryotes
- Origin of Multicellularity
- The Cambrian Explosion
- Colonization of Land
- Mass extinctions and radiations
Origin of Life

• Dates to about 3.5 billion years ago.
• Stomatalolites are a fossil evidence.
• Prokaryotic cells – asexual reproduction only.
Fossilized stromatolite

Stromatolites
Ps and Oxygen Revolution

- Early atmosphere was a reducing atmosphere.
- Oxygen produced by Ps.
- Oxygen caused Fe precipitation (rusting).
- Oxygen levels up to 30+%. 
Result

- Favored aerobic Rs.
- Loss of many anaerobic life forms.
First Eukaryotes

• Appeared about 2.1 billion years ago.
• Serial endosymbiosis model suggests how.
Serial Endosymbiosis

- Folding of cell membrane to create nuclear and endomembrane system.
- Engulfing of aerobic heterotrophic prokaryote.
- Engulfing of photosynthetic prokaryote.
Evidences

• Circular DNA without nucleosomes in mitochondria and chloroplast.
• Small ribosomes in mitochondria & chloroplasts.
Origin of Multicellularity

- Started about 1.2 billion years ago.
- Time of “snowball” Earth.
- Diversification started about 565 million years ago when Earth thawed.
Cambrian Explosion

• 535-525 million years ago.
• Explosion of life forms especially large predators.
• Many prey capturing adaptations and defense mechanisms seen in fossils.
Hallucigenia
Colonization of Land

• Plants – 420 million years ago.
• Animals – 365 million years ago.
• Problems – desiccation, gravity, light, temperature
Mass Extinctions & Adaptive Radiations

• Fossils indicate that life on earth has shifted regularly.
• Most life has gone extinct.
• Severe climate changes have happened.
• Why?
Continental Drift

- The movement of the earth's crustal plates over time.
- Drift is correlated with events of mass extinctions and adaptive radiations of life.
Result of plate movement

- Geographical Isolation.
- New environments formed.
- Old environments lost.
- As the environments changed, so did Life.
Example

- Australian fauna and flora are unique.
- Separated early and remained isolated for 50 million years.
Mass Extinctions

• The sudden loss of many species in geologic time.
• May be caused by asteroid hits or other disasters.
Examples

• 5 major extinction events
  – Permian Extinction
  – Cretaceous Extinction
Permian Extinction

- 250 million years ago.
- 90% of species lost.
Cretaceous Extinction

• 65 million years ago.
• Loss of the dinosaurs.
• Good evidence that this event was caused by an asteroid that hit in the Yucatan, causing a “nuclear winter”.
Result of Mass Extinctions

• Climate changes.
• Areas are open for the surviving species to exploit.
• Rapid period of speciation (adaptive radiation).
• Many new species are formed in a very short period of time.
Evolution Novelty

• Where can new body forms come from?
• Evo-Devo – slight genetic divergences can produce major body form changes.
Examples

• Heterochrony – change in the timing of developmental events or growth rates.
• Homeotic genes – changes in spatial patterns.
(a) Differential growth rates in a human

(b) Comparison of chimpanzee and human skull growth
Hypothetical vertebrate ancestor (invertebrate) with a single *Hox* cluster

First *Hox* duplication

Hypothetical early vertebrates (jawless) with two *Hox* clusters

Second *Hox* duplication

Vertebrates (with jaws) with four *Hox* clusters
Specific examples

- Expression of Hox Gene 7 and Ubx for the insect body plan.
- Pitx1 in stickleback fish
RESULTS

Test of Hypothesis A:
Differences in the coding sequence of the *Pitx1* gene?

Result: No

The 283 amino acids of the *Pitx1* protein are identical.

Test of Hypothesis B:
Differences in the regulation of expression of *Pitx1*?

Result: Yes

*Pitx1* is expressed in the ventral spine and mouth regions of developing marine sticklebacks but only in the mouth region of developing lake sticklebacks.

Marine stickleback embryo

Lake stickleback embryo

Close-up of mouth

Close-up of ventral surface
Species Selection

• Speciation = birth
• Extinction = death
• Species that leave the most new species are the most successful.
• Encourages “branches” in the Tree of Life.
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<td>Hippidion and other genera</td>
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Key:
- Green: Grazers
- Brown: Browsers
Summary

• Chemical Evolution steps.
• Recognize the use and limits of fossils.
• Key Events in Earth’s History.
• What happens to evolution after mass extinctions.
• Examples of Evo-Devo.