Ch. 1: What we’ll cover

- Know the brief history of life as discussed in class.
- Know what the spontaneous generation is.
- What’s biogenesis?
- Know the 4 hypothesized stages for the origins of life.
- Know the generalized makeup of the early atmosphere – was it a reducing or oxidizing atmosphere & why?
- What was the first genetic material and why?
- What are ribozymes and how they work?
- What’s the RNA hypothesis? What are protobionts?
- Early metabolic pathway?
- How has the fossil record illustrated intermediate steps between present day mammals and our early synapsid ancestors?
- What’s the “oxygen revolution” and what did that cause?
- Understand the origins of mitochondria and plastids (autogenous vs endosymbiotic).
- What’s the evidence for the endosymbiotic origins?
- Cause for major changes in body form: rate, timing & spatial pattern (homeotic genes). Heterochrony and paedomorphosis? How did changes in gene regulation affect changes in body form? What are HOX genes?
- Understand plate tecnoics and continental drift (Pangea, Laurasia & Gondwana). How did this affect living organisms? Contribution to mass extinctions? Is evolution goal oriented?
- Scientists: Francesco Redi, Lazzaro Spallanzani, Pasteur, Oparin and Haldane, Miller & Urey, Cech & Altman, Gould & Eldridge (any other discussed but not listed here)

See the study guide for the possible short answer questions – type them out thoroughly as there will be some on your exam.
Early Earth Conditions

• First atmosphere:
  • Water vapor
  • CH
  • NH₃
  • H₂
  • H₂S
  • CO₂
  • N₂

• Possible for:
  ➢ Pre-biotic or Abiotic organic molecule synthesis
    ➢ Nucleotides & amino acids
    ➢ Macromolecule formation
    ➢ Protobionts formation
    ➢ Membrane enclosed polymers
    ➢ Origins of self-replication
Oparin & Haldane

- 1920’s
- Reducing atmosphere hypothesis
- Energy from:
  - Lighting
  - Sunlight
  - UV radiation
  - Volcanoes
- “Primitive soup”
Reducing Atmosphere Hypothesis
Miller & Urey (1958)

Not Reducing Atmosphere Idea
- CO, CO₂, N₂ and H₂O (neutral)
- Volcanic

Jeffery Bada, Scripps (2011)
23 AA, 10 more 4 amines
H₂S

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Deep-sea vent vs. Extraterrestrial Hypothesis

Water temperature (50°C cooler ~ 100 °C)

N₂ → NH₃ → amino acids & nucleic acids

Meteorites, asteroids, comets
Organic C
J. Bada compared H₂S with meteorites
Organic Polymer, Clay Surfaces and Protobionts

Clays, muds & inorganic crystals
- RNA & polypeptides

Protobionts
- Membrane boundary
- Internal polymers
- Catalytic activity
- Self-reproduction

(a) Self-assembly
- Relative turbidity, an index of vesicle number
- Precursor molecules plus montmorillonite clay
- Precursor molecules only

(b) Reproduction
- Vesicle boundary

(c) Absorption of RNA
Protobionts - Coacervates & liposomes → metabolic pathways

Coacervate droplets formed by interaction of gelatin (a protein) & gum arabic
A.I. Oparin.

Figure 3. Structure of conventional liposome encapsulating hydrophilic and hydrophobic drugs.

(a) Simple reproduction by liposomes

(b) Simple metabolism

What metabolic pathway does not require oxygen?
Cech & Altman (1980’s)

- RNA world hypothesis
  - RNA in vesicles → protocells
  - Information storage
  - Base pairing → self-replication
  - Various catalytic functions
  - Template for DNA

Ribozymes
- genetic info & catalyzes different reactions
- Ribozymes complementary RNA copies (short)
  - How stable?
  - How quickly replicated?

Protobionts → Self-Replication → RNA World Hypothesis

Step 1: synthesis of random RNA fragments
Step 2: conforming with structural motif
Step 3: forming self-assembling replication system
Step 4: increasing variation of RNAs
Step 5: sophistication of RNA systems (general RNA polymerase etc...)
Step 6: present life system (ribosome, tRNA, group I intron, etc...)
RNA World Hypothesis → Why do all organisms use DNA?

Genotype → Phenotypes

DNA → RNA → Protein

• Information Storage
  - DNA more stable
  - RNA catalytic
  - RNA → DNA

• Metabolic Functions
  - Catalytic processes (proteins)
Spontaneous Generation

- Prevailing theory before Pasteur
- Life arises spontaneously from nonlife
- Abiogenesis
Redi disproves Spontaneous Generation

- Conclusion: flies from eggs from other flies

Francesco Redi (1626-1697)
Lazzaro Spallanzani’s 1729 Experiment

Why not widely supported?

- Others got bad results (contamination)
1860’s Pasteur Experiment

Nonsterile liquid poured into flask
Neck of flask drawn out in flame
Liquid sterilized by heating
Air forced out open end

Dust and microorganisms trapped in bend
Open end

Liquid cooled slowly
Long time
Liquid remains sterile indefinitely

Flask tipped so microorganism-laden dust contacts sterile liquid
Short time
Microorganisms grow in liquid
Spallanzani and Pasteur Experiments:

**Spallanzani's Experiment**
- Gravy is boiled
- Flask is open
- Gravy is teeming with microorganisms

**Pasteur's Experiment**
- Nutrient broth is heated
- Nutrient broth is free of microorganisms
- Curved neck is removed
- Nutrient broth is teeming with microorganisms
<table>
<thead>
<tr>
<th>Relative Duration of Eons</th>
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<td>Angiosperm dominance increases; continued radiation of most present-day mammalian orders</td>
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<td>Cretaceous</td>
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<td>Major radiation of mammals, birds, and pollinating insects</td>
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<td>Sudden increase in diversity of many animal phyla (Cambrian explosion)</td>
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<td>2,500</td>
<td>Oldest fossils of cells (prokaryotes) appear</td>
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<td>Concentration of atmospheric oxygen begins to increase</td>
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<td>Approx. 4,600</td>
<td>Origin of Earth</td>
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</table>
Fossil Record (sedimentary layers)

- Limitations
- Dating & origins of new groups

Radioactive Dating

Dimetrodon

Coccosteus cuspidatus

Stromatolites

Hallucigenia

Dickinsonia costata

Tappania

Rhomaleosaurus victor

Tiktaalik

Present

100 mya

175

200

270

300

375

400

500

510

560

600

1,500

3,500

1 m

2.5 cm

1 cm

4.5 cm

0.5 m

518
Accumulating "daughter" isotope

Remaining "parent" isotope

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Half-life of parent (years)</th>
<th>Useful range (years)</th>
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<td>Carbon 14</td>
<td>5,730</td>
<td>100 - 30,000</td>
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<td>Potassium 40</td>
<td>1.3 billion</td>
<td>100,000 - 4.5 billion</td>
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<td>Rubidium 87</td>
<td>47 billion</td>
<td>10 million - 4.5 billion</td>
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<td>Uranium 238</td>
<td>4.5 billion</td>
<td>10 million - 4.6 billion</td>
</tr>
<tr>
<td>Uranium 235</td>
<td>710 million</td>
<td>10 million - 4.6 billion</td>
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</table>
Fossil Record – gradual changes
Fossil Record – Transitional Forms

Modern whales trace their ancestry to land mammals that evolved into species progressively more adapted to the water.
Most mammals

(a) *Canis* (dog)

Cetaceans and even-toed ungulates

(b) *Pakicetus*

(c) *Sus* (pig)

(d) *Odocoileus* (deer)
Stromatolites – 3.5 BYA, earliest prokaryotes

Origin of solar system and Earth

Hadean

Archaean

4

3

Billions of years ago

Prokaryotes

Atmospheric oxygen
Photosynthesis and the Oxygen Revolution

Source of O₂? Cyanobacteria like bacteria
Photosynthesis and the Oxygen Revolution

- Most atmospheric oxygen ($O_2$) is of biological origin
- Reacted with Fe oxides
  - Posed a challenge for life
  - Provided opportunity to gain energy from light
  - Allowed organisms to exploit new ecosystems
Geologic Time

Single-celled eukaryotes

Multicellular eukaryotes
Endosymbiosis & Eukaryotic Origins
Serial endosymbiosis

5 Evidence?
• Inner membrane similar cell membrane
• DNA structure
• Cell division
• Protein synthesis
• Ribosomes
Geologic Time

1. Origin of solar system and Earth
2. Proterozoic
   - Billions of years ago
   - Hadean
3. Archaean
4. Prokaryotes
5. Atmospheric oxygen
6. Multicellular eukaryotes
7. Single-celled eukaryotes
8. Colonization of land
9. Animals
10. Paleozoic
11. Mesozoic
12. Cenozoic
13. Humans
14. Origin of solar system and Earth

Multicellular eukaryotes
Single-celled eukaryotes
Atmospheric oxygen
Prokaryotes
Cambrian Explosion

Gould & Eldridge
Punctuated Equilibrium

PROTEROZOIC

PALEOZOIC

Ediacaran

Cambrian

Time (millions of years ago)

635 605 575 545 515 485 0

Stasis  Speciation  Stasis

Stasis  Speciation  Stasis

Stasis  Subspeciation

Cladogenesis  Stasis

Cladogenesis  Stasis

Cladogenesis  Mean thorax width of Trilobite species

Core depth [cm]

Genetic distance

Time

Sponges

Cnidarians

Echinoderms

Chordates

Brachiopods

Annelids

Molluscs

Arthropods

Stephen Jay Gould, 1941-2002

Niles Eldredge, 1943-

Gould & Eldridge
Punctuated Equilibrium

Cambrian Explosion
Rise & Fall of Organisms

1) Continental drift
2) Mass extinctions
3) Adaptive radiation (speciation)

• Environmental changes
  ➢ Temperature
  ➢ Atmospheric O₂
  ➢ Landmasses
  ➢ Floods & glaciations
  ➢ Volcanic eruptions
  ➢ Meteorite impacts
Colonization of land

Billions of years ago

Fungi
- Mutualists of photosynthetic bacteria
- Commensalists
- Pathogens

Cambrian green algae → First land plants → Devonian land plants → Living land plants
1) Continental drift

(a) Cutaway view of Earth

(b) Major continental plates
1) Continental drift

- Changes habitat
- Reduction in shallow water habitat
- Climatic changes on land
- Oceanic circulation
- Allopatric speciation

Collision of India with Eurasia
Present-day continents
Laurasia and Gondwana landmasses
The supercontinent Pangaea
1) Continental drift

- Allopatric speciation
- Geographic barrier

Mantellinae (Madagascar only): 100 species
Rhacophorinae (India/Southeast Asia): 310 species
Other Indian/Southeast Asian frogs

- Allopatric
- Sympatric

Timeline:
- 88 mya
- 65 mya
- 56 mya

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1) Continental drift

- Allopatric speciation
- Geographic barrier
2) Mass Extinctions

- Climate change $\rightarrow$ temperature, precipitation, atmospheric composition, changes in sea levels
- Geologic events $\rightarrow$ (continental drift, earthquakes, mountain formations)
- Asteroid impact

![Graph showing relative extinction rate of marine animal genera versus relative temperature. The x-axis represents relative temperature, ranging from -3 to 4, with labels for Cooler and Warmer. The y-axis represents relative extinction rate of marine animal genera, ranging from -2 to 3. The graph includes a trend line labeled Mass extinctions, indicating a decrease in extinction rate with increasing temperature.]
5 Major Mass Extinctions

- Volcanoes eruptions
- Global warming
- Ocean acidification
- Decrease O2 in oceans

Meteors? Iridium

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Rise & Fall of Organisms

2) Mass Extinctions

Cretaceous mass extinction
Rise & Fall of Organisms

Mass Extinctions (alters ecological niches available) → Adaptive radiation

(especially predators) → competition & selection
Dinosaurs gone → **adaptive radiation** of mammals

- Following mass extinctions
- Novel characteristics
- Colonization of new regions
Adaptive Radiation

- Colonization (environmental conditions change)
- Adaptations
- Reproductive isolation
- Mass Extinctions (new niches)
Adaptive Radiation - colonization

Close North American relative, the tarweed *Carlquistia muirii*

Dubautia laxa

Dubautia waialealae

Dubautia scabra

Dubautia linearis

OAHU 3.7 million years

MAUI 1.3 million years

MOLOKAI

KAUAI 5.1 million years

LANAI

HAWAII 0.4 million years

1.3 million years

HAWAII

MOLOKAI

OAHU

KAUAI

Adaptive Radiation - colonization

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Major changes in body form

1) Heterochrony $\rightarrow$ developmental rate or timing
   - More stages, longer time
   - More stages, same time
   - Start earlier

(a) Differential growth rates in a human

(b) Comparison of chimpanzee and human skull growth

Burchell’s  Grevy’s  Mountain
Major changes in body form

2) Paedomorphosis → Timing (repro rate faster than body development)
Neotony – retention of juvenile features as adults
Major changes in body form

3) Spatial Pattern

- Homeotic genes (placement & organization of body parts)
- HOX genes (positional information)

Hypothetical vertebrate ancestor (invertebrate) with a single Hox cluster

Hypothetical early vertebrates (jawless) with two Hox clusters

Vertebrates (with jaws) with four Hox clusters
Changes in Spatial Pattern → limb bud

- Homeotic genes → HOX

Snake

Chicken
Changes in genes and gene regulation (timing & location)

Hox gene 6  Hox gene 7  Hox gene 8

About 400 mya

Drosophila  Artemia

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Evolutionary Novelties

(a) Patch of pigmented cells
Pigmented cells (photoreceptors)
- Epithelium
- Nerve fibers

(b) Eyecup
Pigmented cells
- Nerve fibers

(c) Pinhole camera-type eye
- Epithelium
- Fluid-filled cavity
- Optic nerve
- Pigmented layer (retina)

(d) Eye with primitive lens
- Cornea
- Cellular mass (lens)
- Optic nerve

(e) Complex camera lens-type eye
- Cornea
- Lens
- Retina
- Optic nerve

Example: Nautilus
Example: Murex, a marine snail
Example: Loligo, a squid
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<td>0.01 Historical time</td>
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<td>1.8 Ice ages; humans appear</td>
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<td>Pliocene</td>
<td>5.3 Origin of genus Homo</td>
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<td>23 Continued radiation of mammals and angiosperms; apelike ancestors of humans appear</td>
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<td>Oligocene</td>
<td>33.9 Origins of many primate groups, including apes</td>
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<td>199.6 Gymnosperms continue as dominant plants; dinosaurs abundant and diverse</td>
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