CHAPTER 19 ORIGIN AND HISTORY OF LIFE

Chapter Outline

19.1 Origin of Life

A. **Chemical evolution** is the increase in complexity of chemicals that led to the first cells.
   1. Today, life only comes from life.
   2. However, the first cells had to arise from an increased complexity of chemicals.

B. The Primitive Earth
   1. The earth came into being about 4.6 billion years ago.
   2. Heat from gravitation and radioactivity formed the earth in several layers with iron and nickel in a liquid core, silicate minerals in a semi-liquid mantle, and upwellings of volcanic lava forming the first crust.
   3. The earth's size provides a gravitational field strong enough to hold an atmosphere.
   4. Earth's *primitive atmosphere* differed from current atmosphere, consisting of:
      a. water vapor (H_2O),
      b. nitrogen (N_2),
      c. carbon dioxide (CO_2),
      d. small amounts of hydrogen (H_2), and
      e. carbon monoxide (CO).
   5. Primitive atmosphere was formed by volcanic out-gassing characteristic of the young earth.
   6. The primitive atmosphere contained little free oxygen (O_2) and was probably a *reducing atmosphere* as opposed to the *oxidizing atmosphere* of today.
      a. A **reducing atmosphere** lacks free O_2 and allows formation of complex organic molecules.
      b. An **oxidizing atmosphere** contains free O_2 and inhibits formation of complex organic molecules.
   7. The earth was so hot that H_2O only existed as a vapor in dense, thick clouds.
   8. As the earth cooled, H_2O vapor condensed to form liquid H_2O, and rain collected in oceans.
   9. The earth's distance from the sun allows H_2O to exist in all phases: solid, liquid, and gas.
   10. NASA photos seem to confirm that earth is bombarded by comets adding substantial water vapor.

C. Monomers Evolve
   1. Larger comets and meteorites have pelted the earth perhaps carrying organic chemicals.
   2. A meteorite from Mars (ALH84001) landed on earth 13,000 years ago; may have fossilized bacteria.
   3. Aleksandr Oparin's 1938 Hypothesis
      a. Oparin suggested organic molecules could be formed in the presence of outside energy sources using:
         1) methane (CH_4)
         2) ammonia (NH_3)
         3) hydrogen (H_2)
         4) water (H_2O)
      b. Experiments performed by Stanley Miller and others show these gases in the primitive atmosphere reacted with one another to produce small organic molecules.
   4. Lack of oxidation and decay allowed organic molecules to form a thick, warm organic soup.
   5. Ammonia may have been scarce; undersea thermal vents however produce much ammonia and additional natural reactions form peptides.

D. Polymers Evolve
   1. Newly formed organic molecules polymerized to produce larger molecules and *macromolecules*.
      a. Gunter Wachtershauser and Claudia Huber have secured peptides using iron-nickel sulfides under ventlike conditions.

b. Such minerals have a charged surface that attracts amino acids and provides electrons so they bond together.
2. Protein-first Hypothesis
   a. Sidney Fox demonstrated amino acids polymerize abiotically if exposed to dry heat.
   b. Amino acids collected in shallow puddles along the rocky shore; heat of the sun caused them to form **proteinoids** (i.e., small polypeptides that have some catalytic properties).
   c. When proteinoids are returned to water, they form cell-like **microspheres** composed of protein.
   d. This assumes DNA genes came after protein enzymes; DNA replication needs protein enzymes.
3. The Clay Hypothesis
   a. Graham Cairns-Smith suggests that amino acids polymerize in clay, with radioactivity providing energy.
   b. Clay attracts small organic molecules and contains iron and zinc atoms serving as inorganic catalysts for polypeptide formation.
   c. Clay collects energy from radioactive decay and discharges it if temperature or humidity changes.
   d. If RNA nucleotides and amino acids became associated so polypeptides were ordered by and helped synthesize RNA, then polypeptides and RNA arose at the same time.
4. RNA-first Hypothesis
   a. Only the macromolecule RNA was needed at the beginning to lead to the first cell.
   b. Thomas Cech and Sidney Altman discovered that RNA can be both a substrate and an enzyme.
   c. RNA would carry out processes of life associated with DNA (in genes) and protein enzymes.
   d. Supporters of this hypothesis label this an "RNA world" four billion years ago.

E. A Protocell Evolves
1. Before the first true cell arose, there would have been a protocell.
2. A **protocell** would have a lipid-protein membrane and carry on energy metabolism.
3. Fox showed that if lipids are made available to microspheres, lipids become associated with microspheres producing a lipid-protein membrane.
4. Oparin demonstrated a protocell could have developed from *coacervate droplets.*
   a. **Coacervate droplets** are complex spherical units that spontaneously form when concentrated mixtures of macromolecules are held in the right temperature, ionic composition, and pH.
   b. Coacervate droplets absorb and incorporate various substances from the surrounding solution.
   c. In a liquid environment, phospholipid molecules spontaneously form **liposomes,** spheres surrounded by a layer of phospholipids; this supports a semipermeable-type membrane.
   d. A protocell could have contained only RNA to function as both genetic material and enzymes.
5. If a protocell was a heterotrophic fermenter living on the organic molecules in the organic soup that was its environment, this would indicate *heterotrophs* preceded *autotrophs*.
   a. A **heterotroph** is an organism that cannot synthesize organic compounds from inorganic substances and therefore must take in preformed organic compounds.
   b. An **autotroph** is an organism that makes organic molecules from inorganic nutrients.
6. If the protocell evolved at hydrothermal vents, it would be chemosynthetic and autotrophs would have preceded heterotrophs.
7. The first protocells may have used preformed ATP, but as supplies dwindled, natural selection would favor cells that could extract energy from carbohydrates to transform ADP to ATP.
8. Since glycolysis is a common metabolic pathway in living things, it evolved early in the history of life.
9. As there was no free O_2, it is assumed that protocells carried on a form of fermentation.
10. The first protocells had a limited ability to break down organic molecules; it took millions of years for glycolysis to evolve completely.
11. Fox has shown that a microsphere has some catalytic ability; Oparin found that coacervates incorporate enzymes if they are available in the medium.

F. A Self-Replication System Evolves
1. In living systems, information flows from DNA → RNA → protein; it is possible that this sequence developed in stages.
2. The RNA-first hypothesis suggests that the first genes and enzymes were RNA molecules.
   a. These genes would have directed and carried out protein synthesis.
   b. Ribozymes are RNA that acts as enzymes.
   c. Some viruses contain RNA genes with a protein enzyme called reverse transcriptase that uses RNA as a template to form DNA; this could have given rise to the first DNA.

3. The protein-first hypothesis contends that proteins or at least polypeptides were the first to arise.
    a. Only after the protocell develops complex enzymes could it form nucleic acids from small molecules.
    b. Because a nucleic acid is complicated, the chance that it arose on its own is minimal.
    c. Therefore, enzymes are needed to guide the synthesis of nucleotides and then nucleic acids.
4. Cairns-Smith suggests that polypeptides and RNA evolved simultaneously.
    a. The first true cell would contain RNA genes that replicated because of the presence of proteins; they become associated in clay in such a way that the polypeptides catalyzed RNA formation.
    b. This eliminates the chicken-and-egg paradox; both events happen at the same time.
5. Once the protocell was capable of reproduction, it became a true cell and biological evolution began.
    a. After DNA formed, the genetic code still had to evolve to store information.
    b. Because the current code is subject to less errors than other possible codes, and because it minimizes mutations, it likely underwent a natural selection process.
6. Most biologists suspect life evolved in basic steps.
    a. Abiotic synthesis of organic molecules such as amino acids occurred in the atmosphere or at hydrothermal vents.
    b. Monomers joined together to form polymers at seaside rocks or clay, or at vents; the first polymers could have been proteins or RNA or both.
    c. Polymers aggregated inside a plasma membrane to make a protocell that had limited ability to grow; if it developed in the ocean it was a heterotroph, if at a hydrothermal vent, a chemoautotroph.
    d. Once the protocell contained DNA genes or RNA molecules, it was a true cell.

19.2 History of Life

A. **Macroevolution** is the large scale pattern of change taking place over very long time spans.

B. Fossils Tell a Story
1. A **fossil** is the remains or traces of an organism usually preserved in sedimentary rock.
2. Most dead organisms are consumed by scavengers or decompose.
3. The great majority of fossils are found embedded in or recently eroded from sedimentary rock.
4. **Sedimentation** has been going on since the earth was formed; it is an accumulation of particles forming a stratum, a recognizable layer in a stratigraphic sequence laid down on land or in water.
5. The sequence indicates the age of fossils; a stratum is older than the one above it and younger than the one below it.
6. **Paleontology** is the study of fossils and the history of life.

C. **Relative Dating of Fossils**
1. Strata of the same age in England and Russia may have different sediments.
2. However, geologists discovered that strata of the same age contain the same fossils.
3. Therefore, fossils cab be used for the **relative dating** of strata.
4. A particular species of fossil ammonite is found over a wide range and for a limited time period; therefore, all strata in the world that contain this ammonite are of the same age.
5. However, relative dating does not establish the absolute age of fossils in years.

D. **Absolute Dating of Fossils**
1. Radioactive dating determines the absolute age of fossils in years.
2. Radioactive isotopes have a *halflife*, the time it takes for half of a radioactive isotope to change into a stable element.
3. Carbon 14 (^{14}C) is a radioactive isotope contained within organic matter.
    a. Half of the carbon 14 (^{14}C) will change to nitrogen 14 (^{14}N) every 5,730 years.
    b. Comparing ^{14}C radioactivity of a fossil to modern organic matter calculates the age of the fossil.
    c. After 50,000 years, the ^{14}C radioactivity is so low it cannot be used to measure age accurately.
4. It is possible to use potassium 40 (^{40}K) and uranium 238 to date rocks and infer the age of a fossil.
    a. Half of the potassium 40 (^{40}K) will change to argon 40 every 1.3 billion years.
    b. If the ratio is 1:1, then half the ^{40}K has decayed and researchers know the rock is 1.3 billion years old.

E. **The Precambrian**
1. Life arose in the **Precambrian** from 570 million years ago to 4,600 million years ago.
    a. The Precambrian encompasses 87% of the geologic time scale.
    b. Early bacteria probably resembled Archaea that live in hot springs today.

c. 3.8 billion years ago (BYA) the first chemical fingerprints of complex cells occur; at 3.46 BYA, photosynthetic prokaryotic cells appear.
d. Stromatolites from this early time resemble living stromatolites with cyanobacteria in the outer surface.
e. Oxygen-releasing photosynthesis by cyanobacteria in stromatolites caused the atmosphere to become oxidizing rather than reducing.
f. By 2 billion years ago, oxygen levels were high enough that anaerobic prokaryotes were declining.
g. Accumulation of O_2 caused extinction of anaerobic organisms and rise of aerobic organisms.
h. O_2 forms ozone or O_3 in the upper atmosphere, contributing to the **ozone shield** and blocking ultraviolet radiation from reaching the earth's surface; this allowed organisms to live on land.

2. Eukaryotic Cells Arise
   a. The eukaryotic cell of 1.5 billion years ago is always aerobic and contains a nucleus and organelles.
   b. The Endosymbiotic Hypothesis
      1) Mitochondria were probably once free-living aerobic prokaryotes.
      2) Chloroplasts were probably once free-living photosynthetic prokaryotes.
      3) A nucleated cell probably engulfed these prokaryotes that became various organelles.
      4) Cilia and flagella may have originated from slender undulating prokaryotes that attached to the host cell.
3. Multicellularity Arises
   a. It is not known exactly when multicellular organisms appeared; they would have been microscopic.
   b. Separating germ cells from somatic cells may have contributed to the diversity of organisms.
   c. Fossils of the Ediacara Hills of South Australia from about 600 MYA were soft-bodied primitive invertebrates.
      1) These bizarre animals lived on mudflats in shallow marine waters.
      2) They lacked internal organs and could have absorbed nutrients from the sea.

F. **The Paleozoic Era**

1. The **Paleozoic era** lasted over 300 million years and was a very active period with three major *mass extinctions*.
   a. An extinction is the total disappearance of a species or higher taxonomic group.
   b. Mass extinction is the disappearance of a large numbers of species or higher groups in a short geological time, just a few million years.
2. Cambrian Fossils
   a. The **Cambrian period** saw invertebrates flourish; invertebrates lack a vertebral column.
   b. Today's invertebrates all trace their ancestry to the Cambrian period, and possibly earlier.
   c. A **molecular clock**, based on a fixed rate of changes in base pair sequences, allows us to trace backward how long current species have evolved separately.
   d. Why fossils are easy to find in the Cambrian but not before is a complex question; most likely the animals evolved earlier but without outer skeletons.
   e. Cambrian seafloors were dominated by trilobites, now extinct, that had armored exoskeletons.
   f. Perhaps the evolution of exoskeletons was due to the presence of plentiful O_2 in the atmosphere.
   g. Exoskeletons may have been due to the increased pressures of predation.
3. Invasion of Land
   a. Early in the **Paleozoic era**, marine algae expanded to freshwater.
   b. Fungi associated with plant roots to form mycorrhizae, allowing plants to live on bare rocks.
   c. In the **Silurian period**, vascular plants invaded land and later flourished in warm swamps in the Carboniferous period.
   d. Spiders, centipedes, mites and millipedes all preceded the appearance of insects on land.
   e. The evolution of wings on insects in the Carboniferous allowed insects to radiate into a diverse group.
   f. The vertebrate line of descent began in the early Ordovician period.
   g. The **Devonian period** is called the Age of Fishes and saw jawless and then jawed fishes, including both cartilaginous and ray-finned fishes.

h. The **Carboniferous period** was an age of coal-forming forests with an abundance of club mosses, horsetails, and ferns.
   1) It is called the "Age of the Amphibians" because amphibians diversified at this time.
   2) Primitive vascular plants and amphibians were larger and more abundant during the Carboniferous period; a climate change to colder and drier began the process that produced coal.

G. **The Mesozoic Era**
1. Although there was a mass extinction at the end of the Paleozoic, evolution of some plants and animals continued into the Triassic, the first period of the **Mesozoic era**.
2. The **Triassic period** (208–245 million years ago)
   a. Gymnosperms flourished, especially cycads; the Triassic and Jurassic are called the "Age of Cycads."
   b. One group of reptiles, the therapsids, had the first mammal features.
   c. Reptiles, originating in the Permian, underwent adaptive radiation.
3. The **Jurassic period** (144–208 million years ago)
   a. Many dinosaurs flourished in the sea, on land and in air.
   b. Recent finds of *Caudipteryx* suggests that birds descended from dinosaurs, *Archeopteryx* remains an excellent intermediate.
4. The **Cretaceous period** (66.4–144 million years ago)
   a. Another new Chinese fossil, *Jeholodens*, reveals early mammal with a long snout but sprawling reptile-like hind limbs.
   b. Controversy surrounds dinosaurs being ectothermic or endothermic.
   c. The era of dinosaurs ended in a mass extinction in which dinosaurs, most reptiles, and many marine organisms perished.

H. **The Cenozoic Era**
1. The Cenozoic (66.4 MYA to present) is divided into the Paleogene and Neogene periods.
2. During the **Cenozoic era**, mammals with hair and mammary glands diversified and human evolution began.
3. Mammalian Diversification
   a. During the **Paleocene epoch** (58–66 MYA), mammals were small and resembled a rat.
   b. In the **Eocene epoch** (37–58 MYA), all of the modern orders of mammals had developed.
   c. Many of the types of herbivores and carnivores of the late Paleogene period are extinct today.
4. Evolution of Primates
   a. Flowering plants were diverse and plentiful by the Cenozoic era; primates were adapted to living in flowering trees.
   b. The first primates were small squirrel-like animals; from them evolved the first monkeys and apes.
   c. Apes diversified during the **Miocene epoch**; this includes the first hominids, the group that includes humans.
   d. During the Neogene period, the world's climate cooled with the last two epochs known as the Ice Age.
   e. The Pleistocene saw many large sloths, beavers, wolves, bison, woolly rhinoceroses, mastodons, and mammoths; modern humans arise and may have contributed to extinction.

19.3 Factors That Influence Evolution

A. **Continental Drift**
1. Earth's crust is dynamic, not immobile as was once thought.
2. In 1920, German meteorologist Alfred Wegener presented data from across disciplines supporting continental drift.
3. Continental drift was confirmed in the 1960s; the continents move with respect to one another.
4. At 225 MYA, continents were joined to form one supercontinent called Pangaea which later divided into Gondwanaland and Laurasia and then split to form today's configuration.
5. Continental drift explains why the coastlines of several continents (e.g., the outline of the west coast of Africa and that of the east coast of South America) are mirror images of each other.
6. The same geological structures (e.g., mountain ranges) are found in many areas where continents once touched.
7. Continental drift explains unique distribution patterns of several fossils (e.g., species of the seed fern *Glossopteris*).

8. Continental drift explains why some fossils (e.g., reptiles *Cynognathus* and *Lystrosaurus*) are found on different continents.
9. Continental drift explains why Australia, South America, and Africa have distinctive mammals; current mammalian biological diversity is the result of isolated evolution on separate continents.
10. **Plate tectonics** is the study of the behavior of the earth's crust in terms of moving plates that are formed at ocean ridges and destroyed at subduction zones.
11. **Ocean ridges** are ridges on ocean floors where oceanic crust forms; regions in oceanic crust where molten rock rises and material is added to the ocean floor results in seafloor spreading.
12. **Seafloor spreading** is lateral movement of oceanic crust away from ocean ridges due to material added to ocean floor.
13. **Subduction zones** are regions where oceanic crust collides with continental crust, causing the oceanic crust to descend into the mantle where it is melted.
14. Where the ocean floor is at leading edge of a plate, a deep trench forms bordered by volcanoes or volcanic island chains.
15. Two continents colliding form a mountain range (e.g., the Himalayas are the result of the collision of India and Eurasia).
16. **Transform boundaries** are regions where two crustal plates meet and scrape past one another resulting in relatively frequent earthquakes.

B. **Mass Extinctions**

1. Five mass extinctions occurred at ends of Ordovician, Devonian, Permian, Triassic, and Cretaceous periods.
2. Mass extinctions have been attributed to tectonic, oceanic, and climatic changes.
3. Walter and Louis Alvarez, in 1977, proposed that the Cretaceous extinction was due to the aftereffects of a bolide (an asteroid that explodes producing meteorites) striking the earth.
    a. A layer of iridium soot has been identified in the Cretaceous clay, the correct strata.
    b. A huge crater near the Yucatan is the impact site.
    c. The effect would have resembled a worldwide atomic explosion.
4. David Raup and John Sepkoski proposed, in 1984, that marine fossils show mass extinctions every 26 million years, in periodicity with astronomical movement through the galaxy.
5. Continental drift contributed to Ordovician extinction; Gondwanaland arrived at the south pole and glaciers chilled oceans and land until Gondwanaland drifted away from pole.
6. The Devonian extinction may have been bolide event; this saw an end to 70% of the marine invertebrates; other possibilities include drifting back toward the south pole.
7. The Permian extinction was very severe; 90% of ocean species and 70% of land species disappeared perhaps due to an excess of carbon dioxide due to a change in ocean circulation due to a lack of polar ice caps.
8. The Triassic extinction has been attributed to meteorite collision with earth; a crater in Central Quebec may have been the impact site.