<u>The Origins of Life</u>

Before the Scientific Revolution, people believed that much new life could be explained by *spontaneous generation.* Many also believed that a "vital force" was carried in the air that could spark life from nonlife. During the Scientific Revolution, several scientists offered up new hypotheses regarding the creation of new life. Based on 200 years of evidence, a consensus was finally reached: spontaneous generation was refuted, and a new concept called *biogenesis* was supported. Ongoing research and the discovery of fossils helped scientists to better understand the origins of the Earth and the life it has supported and will continue to sustain over time.

SECTION 1 - Early Experiments in the Origins of Life

While most people at the time believed in spontaneous generation and/or creationism, a few early scientists were hard at work trying to uncover the mechanisms responsible for the origins of life.

Francisco Redi

In the mid-1600s, the Italian scientist Francisco Redi observed fly development and began to question the commonly held assumption that maggots generated spontaneously from dead meat. He conducted an experiment to test his hypothesis that flies laid eggs on the meat and the eggs developed into maggots, a form of fly larva. While the experimental group, one that contained meat in a jar covered with netting, did not produce any maggots, the uncovered meat in the control group did. Redi's work definitively disproved the previously held belief in the spontaneous generation of maggots, but it did not disprove the general notion entirely. That would take 200 yrs!

Lazzaro Spallanzani

Nearly a century later, another I talian scientist, Lazzaro Spallanzani, attempted another experiment to disprove spontaneous generation, this time involving microbes. He knew that microorganisms could easily contaminate food, so he chose to experiment on an organic broth. Spallanzani first boiled the broth in two glass flasks to kill off any existing microbes and then sealed one to make the experimental group. The other flask was left open and exposed to microbes in the air; this was the control group. Not surprisingly, no growth was observed in the broth in the sealed experimental group, but the broth in the control group teemed with microbial life. While Spallanzani and many others in the scientific community were satisfied that the results further disproved spontaneous generation, critics said the sealed flask kept out the vital force in the air that was required to spontaneously generate life from non-life. Another century would pass until the concept was tested one final time.

Louis Pasteur

Well-known French scientist Louis Pasteur attempted to disprove spontaneous generation once and for all in the mid-1800s. He devised an ingenious flask that had a long, thin, curved neck. This neck would allow the air (and Broth without contamination Organisms) to mix with the contents of the flask but would not allow any microorganisms from the air to enter, due to its long, convoluted pathway. Pasteur boiled organic broth in the flask to decontaminate it and then let it sit for one year. No growth occurred in the broth during that entire time. Pasteur then broke the curved part of the neck off the flask to create a standard straight neck through which microorganisms could fall from the air into the broth. The broth became cloudy with microbial life within a day. Finally, the concept of spontaneous generation was disproved and a new principle, biogenesis, was embraced. *Biogenesis* simply states that only life can generate life. But that raises the question: how did the first life on Earth begin?

SECTION 2 - From **an Inorganic World to Cellular Life**

Early Earth was tumultuous and inhospitable to life, characterized by high temperatures, ongoing volcanic activity, and bombardment by meteorites and other space debris. Eventual and significant cooling over time made the Earth habitable with the condensation of bodies of liquid water from the atmosphere.

Primordial Soup

After cooling, Earth consisted of large bodies of liquid water covering much of the terrestrial (rock) formations. The water would have acted as a solvent for many of the simple, inorganic molecules present at the time. Others would have been found in the mixture of gases that remained in the atmosphere.

Organic Molecules

If conditions are optimal, organic molecules can form from inorganic ones such as hydrogen gas (H2), methane (CH4), ammonia (NH4), and water (H2O) — without the coordinated metabolic activity of organisms. The synthesis of these more complex molecules required a large input of energy, as in lightning or ultraviolet bombardment. In 1924, biochemist Alexander Oparin proposed this idea but never determined how to test it scientifically.

Finally, in 1953, graduate student Stanley Miller, working under the supervision of chemistry professor Harold Urey, devised the Miller-Urey apparatus and experiment. The two demonstrated that simple organic molecules like amino acids, ATP, and nucleotides can be produced from a gaseous mixture of inorganic molecules that are heated, sparked with energy via electrodes, and then condensed.

Protocells

When a variety of simple organic molecules interact in a solution, certain assemblages commonly form (much like soap bubbles). Small, spherical structures with a protein membrane that spontaneously form under certain conditions are called *microspheres.* Additional spherical structures, called *coaceruates,* are composed of other substances, including lipids and sugars. When some of these spontaneous structures actually formed early in the Earth's history, they trapped **RNA** molecules, **ATP,** and other helpful substances. These likely gave rise to *protocells,* the multiple attempts at early cellular life that were largely unsuccessful.

First True Cells

Around 3.8 billion years ago (bya), true cells formed from protocells. These cells were likely *heterotrophic,* relying on a solution of organic molecules for energy. Due to the lack of oxygen gas at the time, these cells are also presumed to have been *anaerobic.* Organisms living today that most closely resemble these first life-forms belong to the Archaebacteria kingdom. Don't worry if remembering the sequence of events in the origin of the first true cells seems overwhelming. It is important to remember that one level easily influences the next as the structure becomes closer and closer to one that can actually be classified as living. That is, inorganic molecules were needed to build organic ones, then larger, cell-like spontaneous assemblages formed due to the interactions of the organic molecules in a particular environment. Only protocell assemblages that contained some form of nucleic acid, ATP for energy, and so on were likely fit and potentially able to account for some of the first true cells.

SECTION 3 - Early Events in Evolutionary History

The period of time between the creation of the Earth more than 4.5 bya and the origin of the first prokaryotic cells more than 3.8 bya allowed for many spontaneous "attempts" at life before producing some that actually worked in a particular environment. Prokaryotes flourished on the Earth as the lone inhabitants for at least 2 billion years, along the way diversifying in structure and function as evolution occurred.

Anaerobic Prokaryotes

Anaerobic prokaryotes dominated the Earth and eventually would have consumed all of the organic molecules present if left to their own devices. Levels of carbon dioxide (CO>) began to increase significantly as a by-product of anaerobic metabolism, and conditions became suitable for a new type of life to evolve.

Autotrophic Prokaryotes

Chemoautotrophic prokaryotes likely evolved first. These were able not only to tolerate but also to thrive in the conditions present on early Earth. Using CO2 and producing simple organic molecules, these prokaryotes relied on energy from inorganic molecules in their surroundings. Only after a significant period, approximately 3 bya, did *photoautotrophic prokaryotes* evolve that were capable of producing glucose by means of photosynthesis. These autotrophic prokaryotes, however, changed the fate of the world forever, because the by-product of their metabolic pathway was oxygen gas (02).

Aerobic Prokaryotes

Significant levels of O2 began to accumulate over time. It was still toxic to many anaerobic organisms at the time, but some prokaryotes developed a way to use the molecule as energy. Aerobic respiration and the first aerobic prokaryotes then evolved some 2.5 bya.

Eukaryotic Cells

Many prokaryotes became more effective and efficient metabolically. This, in turn, supported the growth of more complex structures. First, eukaryotic cells evolved approximately 1.5 – 2bya through a process called *endosymbiosis.* Imagine that a large, heterotrophic bacterium engulfs a smaller prokaryote but cannot break it down. By chance, the ingested prokaryote is a specialist at cellular respiration and continues to function while inside the other cell. If, over time, the two cells become completely interdependent on each other, the eukaryotic cell evolves. The internal prokaryote would then become reclassified as a mitochondrion. This same process occurred to create the chloroplast, but the ingested prokaryote was a specialist at photosynthesis.

Multicellular Life

Eukaryotes were quite successful in their new, more complex form, but even more complex structures evolved over time. First, eukaryotic cells began living together in groups called *colonies.* In a colony, each individual organism contributes something to the whole but gains more in return. Some colonies became completely interdependent over time, and true multicellular life was formed for the first time approximately 1 mya (million years ago).

Chemoautotrophs and photoautotrophs are easily mixed up. It is important to remember that the prefix in each word describes the energy source on which the autotroph relies to build its own food. Both autotrophs use CO2 as the inorganic building block for their organic products, but the specific product generated depends on the type of metabolism employed.

ASSESSMENT QUESTIONS

1. Which of the following is true regarding spontaneous generation?
   a. It is responsible for the origin of some simple life.
   b. It works only when a vital force is present.
   c. It was finally disproved by Spailanzani.
   d. It was eventually replaced by the concept of biogenesis.
2. Which of the following best describes Pasteur's experimental group?
   a. He didn't have one.
   b. It was the flask with the original curved neck.
   c. It was the flask with the broken straight neck.
   d. It was not adequately described.
3. Use the theme of continuity and variation to describe the concept of biogenesis.
4. Which of the following statements is *not* true of the Miller-Urey experiment?
   a. Some of the products were amino acids and nucleotides.
   b. Some of the reactants were water and oxygen.
   c. Electrodes were used to simulate a major energy event.
   d. The reactants simulated a primordial soup.
5. Which of the following structures are *not* spontaneously generating or significant in understanding the origins of the first life on Earth?
   a. Protocells
   b. Coacervates
   c. Microspheres
   d. Archaebacteria
6. Use the theme of continuity and variation to describe the concept of the origin of the first true cells.
7. Which of the following characteristics would *not* accurately describe the first cells?
   a. Prokaryotic
   b. Colonial
   c. Anaerobic
   d. Heterotrophic
8. Which of the following significant evolutionary events occurred after all the others?
   a. Endosymbiosis
   b. Aerobic prokaryotes
   c. Photosynthetic prokaryotes
   d. Multicellularity
9. Use the theme of interdependence in nature to describe the concept of endosymbiosis.