19.3 Earth's Early History

THINK ABOUT IT How did life on Earth begin? What were the earliest forms of life? How did life and the biosphere interact? Origin-of-life research is a dynamic field. But even though some current hypotheses likely will change, our understanding of other aspects of the story is growing.

The Mysteries of Life's Origins

What do scientists hypothesize about early Earth and the origin of life?

Geological and astronomical evidence suggests that Earth formed as pieces of cosmic debris collided with one another. While the planet was young, it was struck by one or more huge objects, and the entire globe melted. For millions of years, violent volcanic activity shook Earth's crust. Comets and asteroids bombarded its surface. About 4.2 billion years ago, Earth cooled enough to allow solid rocks to form and water to condense and fall as rain. Earth's surface became stable enough for permanent oceans to form.

This infant planet was very different from Earth today. **Earth's early atmosphere contained little or no oxygen. It was principally composed of carbon dioxide, water vapor, and nitrogen, with lesser amounts of carbon monoxide, hydrogen sulfide, and hydrogen cyanide.** If you had been there, a few deep breaths would have killed you! Because of the gases in the atmosphere, the sky was probably pinkish-orange. And because the oceans contained lots of dissolved iron, they were probably brown. This was the Earth on which life began.

Key Questions

What do scientists hypothesize about early Earth and the origin of life?

What theory explains the origin of eukaryotic cells?

What is the evolutionary significance of sexual reproduction?

Vocabulary

endosymbiotic theory

Taking Notes

Flowchart Construct a flowchart that shows what scientists hypothesize are the major steps from the origin of Earth to the appearance of eukaryotic cells.

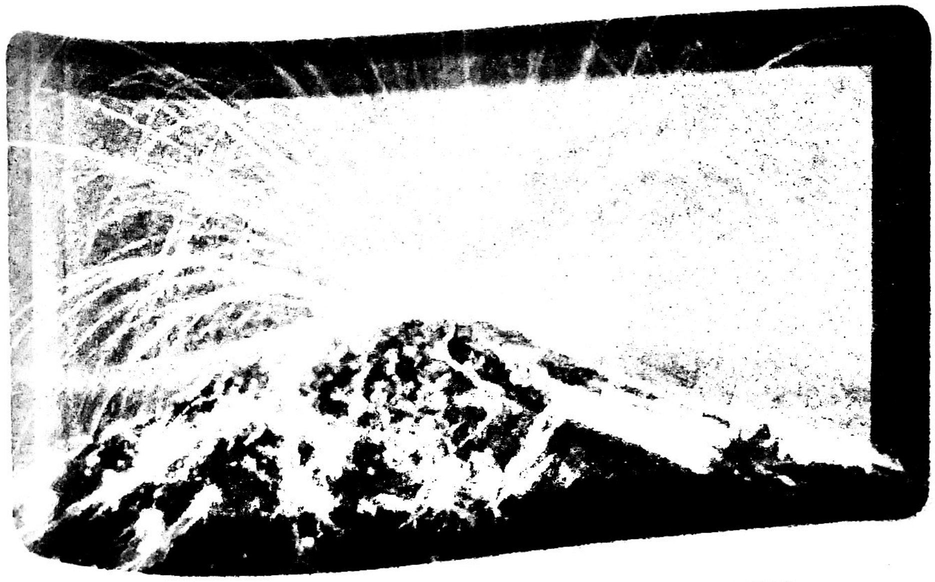


FIGURE 19–14 Early Earth Violent volcanic eruptions helped shape Earth's early history.

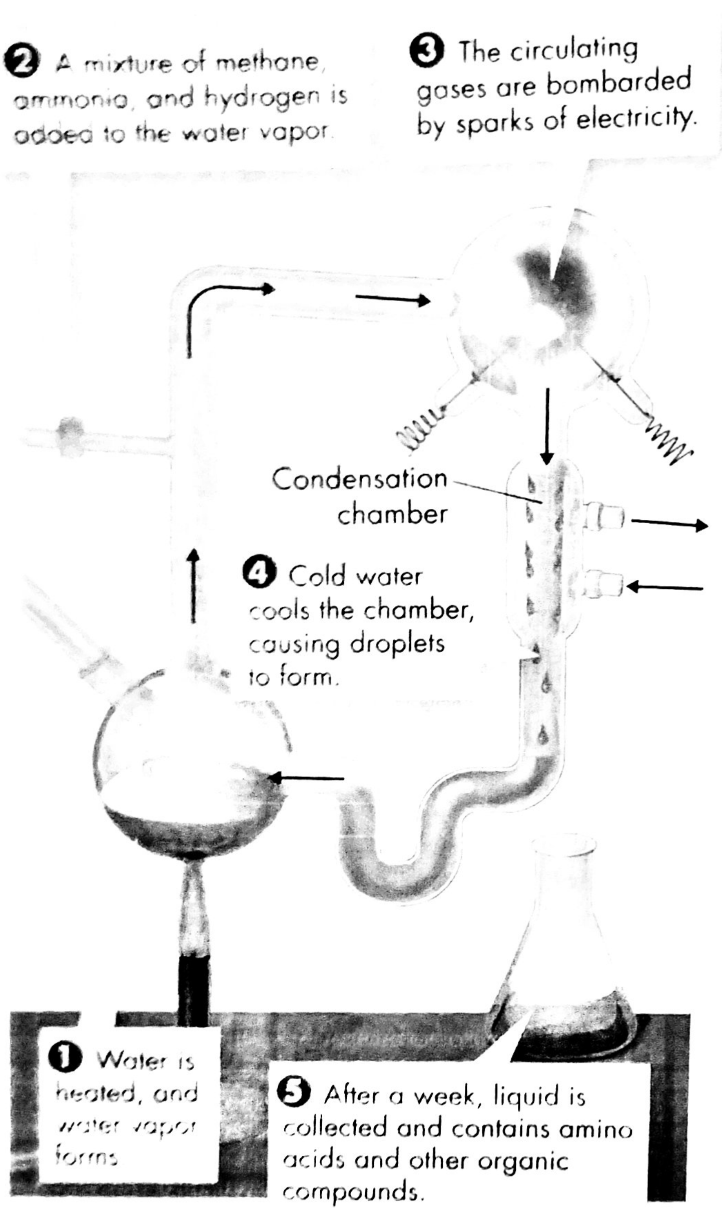


FIGURE 19–15 Miller-Urey Experiment Miller and Urey produced amino acids, which are needed to make proteins, by passing sparks through a mixture of hydrogen, methane, ammonia, and water vapor. Evidence now suggests that the composition of Earth's early atmosphere was different from their 1953 experiment. However, more recent experiments with different mixtures of gases have produced similar results.

The First Organic Molecules Could organic molecules assemble under conditions on early Earth? In 1953, chemists Stanley Miller and Harold Urey tried to answer that question. They filled a sterile flask with water, to simulate the oceans, and boiled it. To the water vapor, they added methane, ammonia, and hydrogen, to simulate what they thought had been the composition of Earth's early atmosphere. Then, as shown in **Figure 19–15**, they passed the gases through electrodes, to simulate lightning. Next, they passed the gases through a condensation chamber, where cold water cooled them, causing drops to form. The liquid circulated through the experimental apparatus for a week. The results were spectacular: They produced 21 amino acids—building blocks of proteins. **Miller and Urey's experiment suggested how mixtures of the organic compounds necessary for life could have arisen from simpler compounds on a primitive Earth.**

We now know that Miller and Urey's ideas on the composition of the early atmosphere were incorrect. But new experiments based on current ideas of the early atmosphere have also produced organic compounds. In fact, in 1995, one of Miller's more accurate mixtures produced cytosine and uracil, two bases found in RNA.

Formation of Microspheres A stew of organic molecules is a long way from a living cell, and the leap from nonlife to life is the greatest gap in scientific hypotheses of life's early history. Geological evidence suggests that during the Archean Eon, 200 to 300 million years after Earth cooled enough to carry liquid water, cells similar to bacteria were common. How might these cells have originated?

Large organic molecules form tiny bubbles called proteinoid microspheres under certain conditions. Microspheres are not cells, but they have some characteristics of living systems. Like cells, they have selectively permeable membranes through which water molecules can pass. Microspheres also have a simple means of storing and releasing energy. Several hypotheses suggest that structures similar to proteinoid microspheres acquired the characteristics of living cells as early as 3.8 billion years ago.

Evolution of RNA and DNA Another unanswered question is the origin of RNA and DNA. Remember that cells are controlled by information stored in DNA, which is transcribed into RNA and then translated into proteins. How could this complex biochemical machinery have evolved?

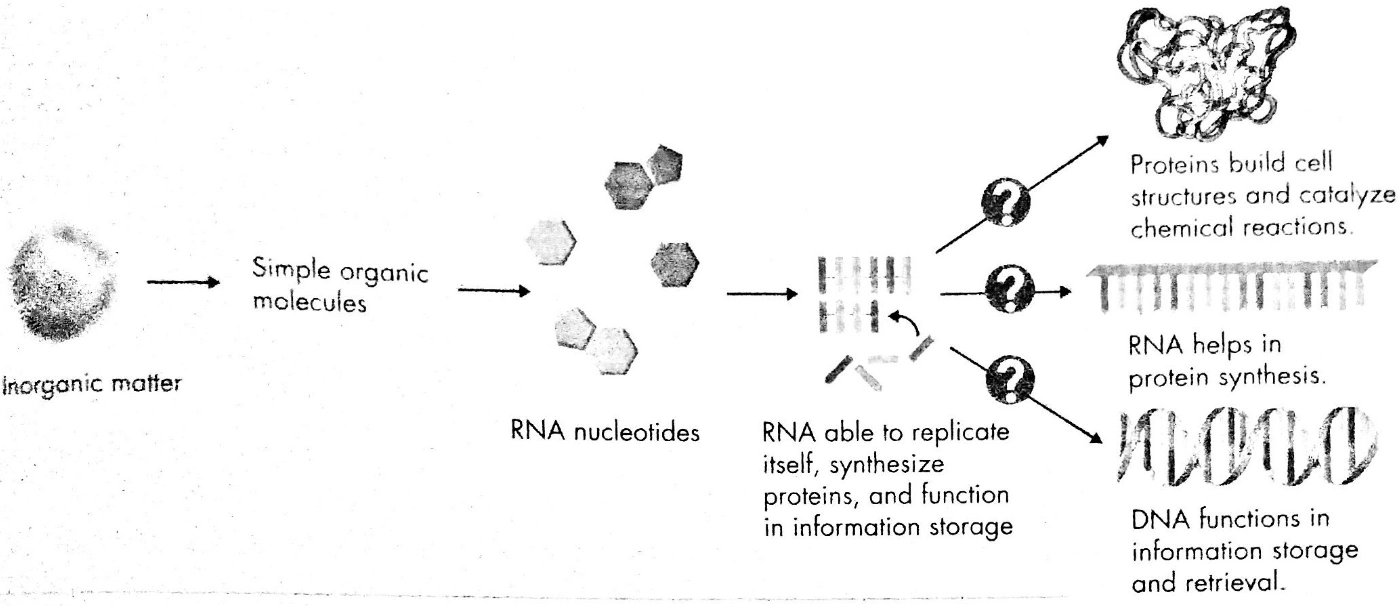


FIGURE 19–16 Origin of RNA and DNA The "RNA world" hypothesis about the origin of life suggests that RNA evolved before DNA. Scientists have not yet demonstrated the later stages of this process in a laboratory setting. **Interpret Visuals** ***How would RNA have stored genetic information?***

Scientists haven't solved this puzzle, but molecular biologists have generated intriguing hypotheses. A number of experiments that simulated conditions on early Earth suggest that small sequences of RNA could have formed from simpler molecules. Why is that interesting? It is interesting because we now know that, under the right conditions, some RNA sequences help DNA replicate. Other RNA sequences process messenger RNA after transcription. Still other RNA sequences catalyze chemical reactions, and some RNA molecules even grow and replicate on their own. **The "RNA world" hypothesis proposes that RNA existed by itself before DNA. From this simple RNA-based system, several steps could have led to DNA-directed protein synthesis.** This hypothesis, shown in **Figure 19–16,** is still being tested.

Production of Free Oxygen Microscopic fossils, or microfossils, of prokaryotes that resemble bacteria have been found in Archean rocks more than 3.5 billion years old. Those first life forms evolved in the absence of oxygen because at that time Earth's atmosphere contained very little of that highly reactive gas.

During the early Proterozoic Eon, photosynthetic bacteria became common. By 2.2 billion years ago, these organisms were churning out oxygen. At first, the oxygen combined with iron in the oceans, producing iron oxide, or rust. Iron oxide, which is not soluble in water, sank to the ocean floor, forming great bands of iron that are the source of most iron ore mined today. Without iron, the oceans changed color from brown to blue-green.

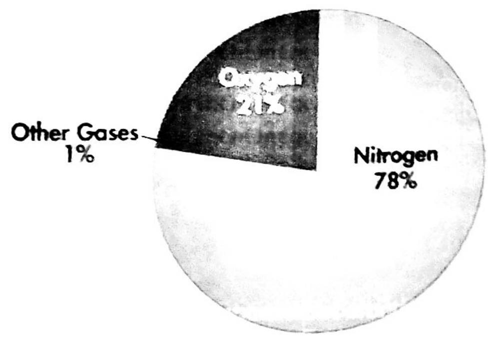
Next, oxygen gas began to accumulate in the atmosphere. The ozone layer began to form, and the skies turned their present shade of blue. Over several hundred million years, oxygen concentrations rose until they reached today's levels. In a sense, this increase in oxygen created the first global "pollution" crisis. To the first cells, which evolved in the absence of oxygen, this reactive gas was a deadly poison! The rise of oxygen in the atmosphere drove some early life forms to extinction. Some organisms, however, evolved new metabolic pathways that used oxygen for respiration. These organisms also evolved ways to protect themselves from oxygen's powerful reactive abilities.

FIGURE 19–17 Fossilized Bacteria Fossilized bacteria are the earliest evidence of life on Earth. These rod-shaped bacterial cells (red) are seen calcified on the shell of a single-celled protozoan.

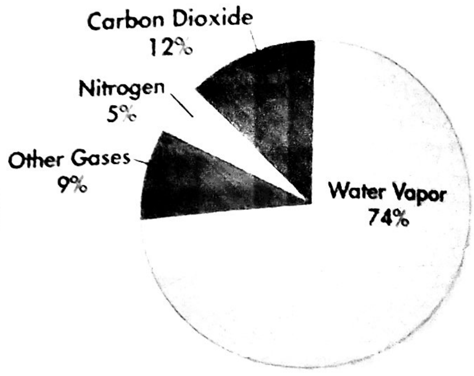
Analyzing Data

Comparing Atmospheres

Many scientists think that Earth's early atmosphere may have been similar to the gases released by a volcano today. The graphs show the composition of the atmosphere today and the composition of gases released by a volcano.



Composition of Earth's Atmosphere Today



Composition of Gases From Volcanoes

1. Interpret Graphs Which gas is most abundant in Earth's atmosphere today? What percentage of that gas may have been present in the early atmosphere?

2. Interpret Graphs Which gas was probably most abundant in the early atmosphere?

3. Infer Where did the water in today's oceans probably come from?

Origin of Eukaryotic Cells

What theory explains the origin of eukaryotic cells?

One of the most important events in the history of life was the evolution of eukaryotic cells from prokaryotic cells. Remember that eukaryotic cells have nuclei, but prokaryotic cells do not. Eukaryotic cells also have complex organelles. Virtually all eukaryotes have mitochondria, and both plants and algae also have chloroplasts. How did these complex cells evolve?

Endosymbiotic Theory Researchers hypothesize that about 2 billion years ago, some ancient prokaryotes began evolving internal cell membranes. These prokaryotes were the ancestors of eukaryotic organisms. Then, according to **endosymbiotic** (en doh sim by AHT ik) **theory,** prokaryotic cells entered those ancestral eukaryotes. These intruders didn't infect their hosts, as parasites would have done, and the host cells didn't digest them, as they would have digested prey. Instead, the small prokaryotes began living inside the larger cells, as shown in **Figure 19–18.**

The endosymbiotic theory proposes that a symbiotic relationship evolved over time, between primitive eukaryotic cells and the prokaryotic cells within them. This idea was proposed more than a century ago. At that time, microscopists saw that the membranes of mitochondria and chloroplasts resembled the cell membranes of free-living prokaryotes. This observation led to two related hypotheses.

BUILD Vocabulary

PREFIXES The prefix *endo-* in **endosymbiotic theory** means "within" or "inner." The endosymbiotic theory involves a symbiotic relationship between eukaryotic cells and the prokaryotes within them.

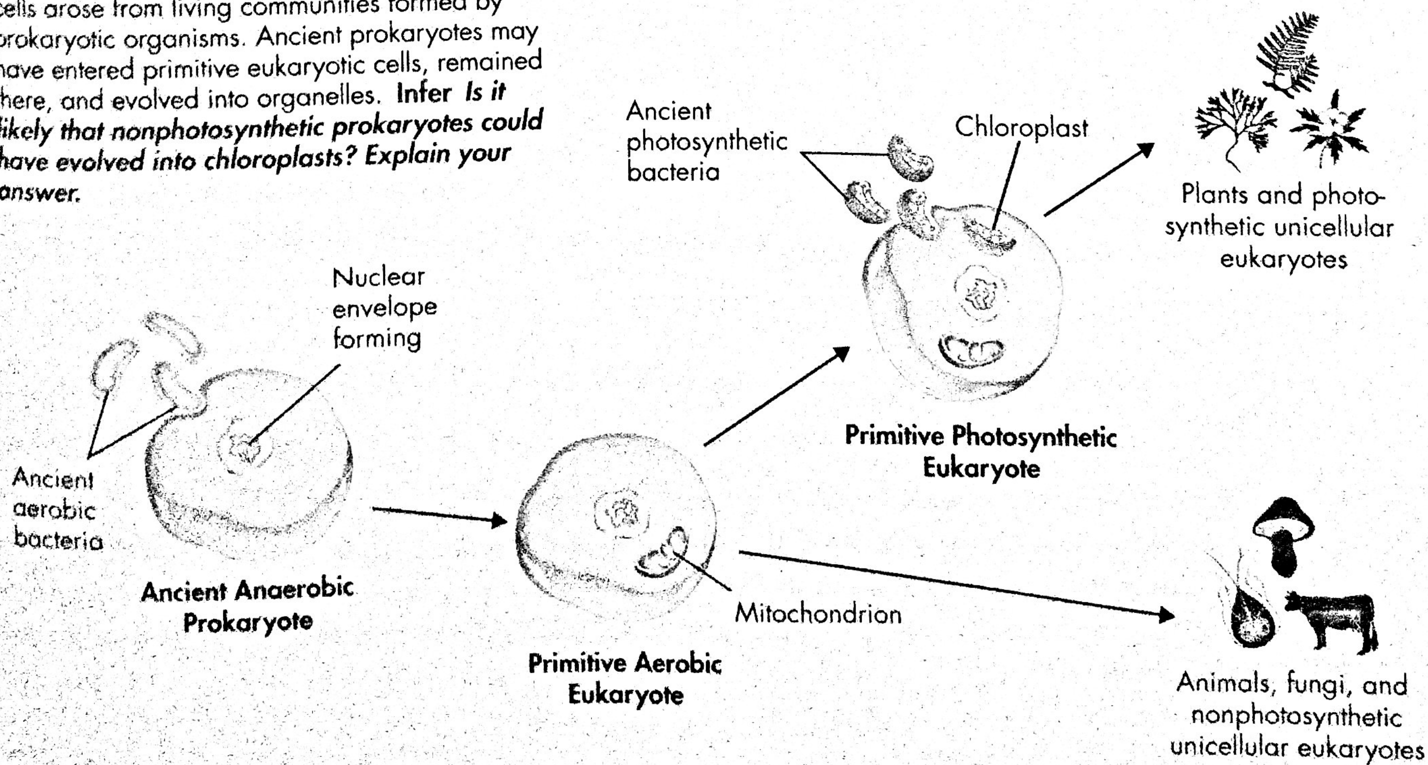
One hypothesis proposes that mitochondria evolved from endosymbiotic prokaryotes that were able to use oxygen to generate energy-rich ATP. Inside primitive eukaryotic cells, these energy-generating prokaryotes evolved into mitochondria that now power the cells of all multicellular organisms. Mitochondria enabled cells to metabolize oxygen. Without this ability, cells would have been killed by the free oxygen in the atmosphere.

Another hypothesis proposes that chloroplasts evolved from endosymbiotic prokaryotes that had the ability to photosynthesize. Over time, these photosynthetic prokaryotes evolved within eukaryotic cells into the chloroplasts of plants and algae.

Modern Evidence During the 1960s, Lynn Margulis of Boston University gathered evidence that supported the endosymbiotic theory. Margulis noted first that mitochondria and chloroplasts contain DNA similar to bacterial DNA. Second, she noted that mitochondria and chloroplasts have ribosomes whose size and structure closely resemble those of bacteria. Third, she found that mitochondria and chloroplasts, like bacteria, reproduce by binary fission when cells containing them divide by mitosis. Mitochondria and chloroplasts, then, share many features of free-living bacteria. These similarities provide strong evidence of a common ancestry between free-living bacteria and the organelles of living eukaryotic cells.

In Your Notebook *Describe two hypotheses relating to the endosymbiotic theory.*

FIGURE 19–18 The Endosymbiotic Theory
The endosymbiotic theory proposes that eukaryotic cells arose from living communities formed by prokaryotic organisms. Ancient prokaryotes may have entered primitive eukaryotic cells, remained there, and evolved into organelles. **Infer** ***Is it likely that nonphotosynthetic prokaryotes could have evolved into chloroplasts? Explain your answer.***



Sexual Reproduction and Multicellularity

What is the evolutionary significance of sexual reproduction?

Sometime after eukaryotic cells arose, they began to reproduce sexually. **The development of sexual reproduction sped up evolutionary change because sexual reproduction increases genetic variation.**

Significance of Sexual Reproduction When prokaryotes reproduce asexually, they duplicate their genetic material and pass it on to daughter cells. This process is efficient, but it yields daughter cells whose genomes duplicate their parent's genome. Genetic variation is basically restricted to mutations in DNA.

In contrast, when eukaryotes reproduce sexually, offspring receive genetic material from two parents. Meiosis and fertilization shuffle and reshuffle genes, generating lots of genetic diversity. That's why the offspring of sexually reproducing organisms are never identical to either their parents or their siblings (except for identical twins). The more heritable variation, the more "raw material" natural selection has to work on. Genetic variation increases the likelihood of a population's adapting to new or changing environmental conditions.

Multicellularity Multicellular organisms evolved a few hundred million years after the evolution of sexual reproduction. Early multicellular organisms underwent a series of adaptive radiations, resulting in great diversity.

19.3 Assessment

Review Key Concepts

1. **a. Review** What was Earth's early atmosphere like?
   b. Explain What does Miller and Urey's experiment tell us about the organic compounds needed for life?
   c. Predict You just read that life arose from nonlife billions of years ago. Could life arise from nonlife today? Why or why not?
2. **a. Review** What does the endosymbiotic theory propose?
   b. Explain According to this theory, how did mitochondria evolve?
   c. Apply Concepts What evidence supports the theory?
3. **a. Review** Why is the development of sexual reproduction so important in the history of life?
   b. Sequence Put the following events in the order in which they occurred: *sexual reproduction, development of eukaryotic cells, free oxygen in the atmosphere,* and *development of photosynthesis.*

WRITE ABOUT SCIENCE

Explanation

4. Write a paragraph explaining the "RNA world" hypothesis. What parts of the hypothesis have yet to be proved? Is it possible that we will never know the origins of RNA and DNA? Explain your answer.