Life on Earth – Tutorial Script

After having watched the **Early Earth** video tutorial, we now have an understanding of how Earth's early atmosphere, crust, and oceans formed. But how about life? When did that evolve and what was early Earth's life like?

With a liquid ocean layer present on Earth's surface, 4.4 billion years ago, the stage was set for the earliest life to form. Why were oceans necessary for life? Early Earth had no oxygen in its atmosphere. That means it also had no ozone layer. Ultraviolet radiation from the Sun readily reached the surface and would have irreparably damaged any biological material. Surface waters in the ocean block ultraviolet radiation, and thus oceans are the perfect place for life to first form. What were these first organisms like? The very simplest single-celled bacteria – likely ones that could handle extreme conditions, such as high heat and no light – also known as **extremophiles**.

All living organisms can be classified as autotrophs or heterotrophs. **Heterotrophs** acquire their food by eating other organisms. **Autotrophs** make their own food, usually through a process called **photosynthesis**. Photosynthesis uses the pigment known as **chlorophyll** to capture light energy from the Sun, which it then uses to combine abundant surrounding molecules like carbon dioxide and water to synthesize sugar molecules. **Respiration** is the opposite process and happens when organisms later break down sugar to release its stored energy and use it for growth, reproduction, and energy-intensive metabolic processes. Whether an organism makes its own sugar or gets its sugar by ingesting other organisms, it still must perform respiration to access the stored energy.

Although photosynthesis is by far the most common form of sugar synthesis at work on Earth today, another process at work where light is absent is called **chemosynthesis**. Instead of harnessing energy from the sun, chemosynthesis harnesses energy held within chemical bonds of gases and minerals. We see chemosynthesis happening today in a number of dark locations, including deep in underground mines, at the bottom of the seafloor where gases seep out of cracks and sediments, and in caves near sulfur-rich mineral deposits. In all these locations, autotrophs use energy to combine surrounding ingredients and form sugars. Any of these locations could have been the cradles in which early life formed on Earth.

In South African gold mines, in shafts nearly 3 km underground, at temperatures as hot as 120°F or 49°C, there are colonies of bacteria surviving without sunlight or oxygen, making their own food from energy stored in chemicals in the rocks, like iron. Other species of bacteria have been found deep in mine shafts and in *1,000-m-deep volcanic rocks along the Columbia River.* In limestone caves, near volcanic sulfur-rich hot springs, bacteria capture energy from hydrogen sulfide gas and use that energy to synthesize sugar. Sulfuric acid is one of the toxic byproducts, and these bacteria live in highly acidic mucous-rich mats attached to the cave walls. The mats are called **snottites**. This example is from *Cueva de Villa Luz in Tabasco, Mexico. These snottites have acid drops at their tips, with a pH of 0.*

In hydrothermal vents and hydrocarbon seeps on the bottom of the seafloor, bacteria capture energy from hydrogen sulfide or methane gases and use that energy to synthesize sugar. These bacteria provide the base of an exotic and diverse food web.

Pause now.

One of the first experiments to simulate the formation of the basic molecules of life was done by Stanley Miller as a graduate student at the University of Chicago in the early 1950s. Into a closed system of flasks, Miller put methane, ammonia, hydrogen gas, and water vapor—all materials that would have been major components of the early Earth's atmosphere. He warmed a soup of these chemicals, circulated them through a region where they were subjected to electric sparks (simulating lightning), and cooled them and returned the products to the soup. Within a few days, the soup was a brown slime that contained amino acids, the building blocks of proteins. Although scientists no longer think the components of his experiment were an exact match to early Earth's environment, Miller's experiment showed scientists that it was possible to create, through natural processes, the building blocks needed for life. Many scientists around the world are currently studying the synthesis of living cells and creating life in its simplest forms from building blocks that would have been available in early Earth.

When did life first evolve on planet Earth? Oxygen isotope ratios in 4.4-billion-year-old zircon minerals indicate temperatures on the surface would have been cool enough for liquid water to be stable. Since life requires water, 4.4 billion years represents a possible oldest date for life on Earth. A 3.85-billion-year-old rock from Greenland was found to have carbon isotope ratios suggestive of microbial activity. However, the first fossil evidence we have are stromatolite mounds found in 3.7-billion-year-old rocks from Greenland. Stromatolite mounds form by successive layers of photosynthesizing cyanobacterial mats growing in a coastal environment and doming upwards toward the light. Each layer traps sand within it, ultimately blocking the light, requiring new layers to form atop the old ones. The cyanobacteria are protected from the ultraviolet rays of the sun by the thick mucus coating in which they live. This image shows what fossilized stromatolite mounds look like. Today, photosynthesis is primarily oxygenic: producing oxygen as a waste product. However, the earliest form of photosynthesis was not an oxygen-producing one.

Why does the evolution of oxygenic photosynthesis matter? Advanced life can evolve only in the presence of large amounts of atmospheric oxygen, and oxygenic photosynthesis is the dominant natural process at work on Earth that produces that oxygen. What evidence would we look for to tell us oxygenic photosynthesis had evolved? Minerals such as manganese or iron oxides that form through chemical reactions between oxygen gas and either dissolved metals in the oceans or metals in weathering surface rocks on land. While as far back as 3.23 billion years ago there appear to be small localized precipitations of iron oxide minerals on the seafloor, now visible in layered rocks known as Banded Iron Formations, additional evidence suggests those were formed as a byproduct of anoxygenic photosynthesis by bacteria that used iron as an electron donor.

However, the largest known deposit of banded iron formations have been determined to be due to a large scale release of oxygen by photosynthetic stromatolite colonies. These deposits are about 2.5 billion years old and can be found today in the Pilbara region of Western Australia. These rock layers are now the source of the world's largest iron ore mines. Here are two samples from the Pilbara Desert, Australia. On the left you see small fossilized stromatolites (the oxygen producers) and next to it the banded iron.

Once the majority of the dissolved iron in the oceans was removed through iron oxide precipitation, or "rusting", oxygen was free to mix through the oceans and bubble up and enter the atmosphere, where it became available for the oxidation of amospheric gases and dissolved metals in weathering surface rocks and rivers and lakes. The oldest evidence we find of this activity and thus oxygen gas accumulating in our atmosphere are from the north shore of Lake Huron, Ontario, Canada: Red Beds (iron-oxide-rich rocks formed on Earth's surface) dated between 2.2 and 2.4 billion years old.

We call this period of time, about 2.3 billion years ago, when oxygen gas began to accumulate in the atmosphere for the first time in amounts as large as 1% of current values, the Great Oxygenation Event. It was over 1 billion years later before another large oxygen-increase event brought oxygen levels up to today's levels. It took that long for the oxygen to complete its chemical reactions with other atmospheric gases and dissolved metals on Earth's surface. After that work was done, oxygen gas could begin to accumulate in amounts necessary to support more advanced life.

Pause now.

The first step towards that advanced life was developing a nucleus and sexual reproduction. The oldest evidence we have of this evolution are fossils of *Grypania spiralis* – found in 2.1-billion-year-old banded-iron formations in Michigan. However, it was quite a long time before organisms like these really proliferated and cooperated to create multicelled life, because it had to wait until the oxygen levels in the atmosphere built up enough to support the increased metabolism that goes along with multicelled life. The stromatolites and other photosynthesizing bacteria still had a lot of work to do. How much work? The oldest evidence of multicelled life was discovered in fossils of soft-bodied marine organisms in 600-million-year old rocks in the Ediacaran Hills of Australia. That's 4 billion years after Earth formed, and in the last 1/9 of Earth's history.

After oxygen levels rose to current levels and multicelled life evolved, evolution really took off. 544 million years ago, we see the first evidence of hard parts, thus contributing to many orders of magnitude more fossils forming as hard parts make fossilization much easier. It was also the beginning the Age of the Trilobites – crab-like animals with exoskeletons that scuttled across the seafloor. Ammonites came next, a nautilus-like cephalopod -- imagine a giant octopus-like organism living in an ornate hard shell and floating at various depths within the water column. The first vertebrates – jawless fish with cartilaginous skeletons – evolved about 520 million years ago. Again, the evidence for this timeline comes from fossils we find in rocks that we date through radiometric dating. Watch the video tutorial on radiometric dating for more information on that process.

438 million years ago is our first evidence we have of organisms moving onto land – including the first plants and insects.

245 million years ago was the largest mass extinction on the planet, during which the trilobites and many other early forms of life went extinct. Dinosaurs evolved soon after and dominated the planet during the Age of the Dinosaurs, which lasted from 230 to 65 million years ago.

Early mammals co-existed with the dinosaurs, but after the dinosaurs went extinct, 65 million years ago, mammals continued to evolve to fill the now-empty niches left behind by the dinosaurs.

50 million years ago, some land mammals returned to the ocean, evolving into whales, sea lions, seals, and other marine mammals.

The earliest monkeys and apes evolved 40 million years ago.

And the oldest evidence we have of early bipedal hominids is 4 million years ago.

2 million years ago we began the period of cyclical ice ages that we are coming out of today. The last ice age ended only 20,000 years ago.

Pause now.

Understanding the magnitude and scale of Earth's history is a challenging task for organisms that live only on average 75 years and that are primarily focused on events that happened in the last week or month. But it's a challenge that must be tackled if we want to understand the important processes that created the world around us and continue to shape it today.

[end credits]

<u>Earth Formation Series:</u>
Part I: Earth Formation
Part II: Radiometric Dating
Part III: Density
Part IV: Early Earth
Part V: Life on Earth

Life on Earth
Produced by Katryn Wiese
City College of San Francisco

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