Early Earth – Tutorial Script

After having watched the **Earth Formation** video tutorial, we now have an understanding of how our universe, solar system, and planet formed. But what was early Earth like? How did the rocks we see on the surface form? The atmosphere? The oceans?

Since the Earth formed through the collision and accretion of meteorites, studying what meteorites are made of helps us learn what our planet is made of. About ½ of the meteorites in our solar system are dense stony-iron and nickel; the other ½ are made of less dense carbonaceous materials. Combined together, they represent the total composition of Earth's rocks: estimated at mass percentages of 31.9% Iron, 29.7% Oxygen, 16.1% Silicon, 15.4% Magnesium. But that composition is very different from what we see on Earth's surface, which is 47% oxygen, 28% silicon, 8% aluminum, and only 5% iron. Why? Early Earth formed through meteorite accretion would have been homogenous. Present Earth has layers. Where did these layers come from?

To understand the characteristics of early Earth, we need to demonstrate the process of **accretion**. Take your hands – hold them as far away from each other as possible. Then bring them together quickly in a loud clap. What do you notice? Are your hands warm? The collision of your hands should have produced a large amount of heat, which causes your hands to sting and be warmer than they were before. Now imagine an early Earth formed by billions of these collisions. The continual bombardment of small asteroids combined with all the previous collisions would have produced so much heat that early Earth would have been almost entirely molten. In such a state, the material would have separated by **density**.

The denser materials (most of the iron) would have sunk to the center to form Earth's innermost layer known as the **core**. The less dense material would have risen to the top to form the outer surface layer known as the **crust** (mostly aluminum silicates). The remainder sits between and is known as the **mantle**. A similar process happens when we put chocolate and marshmallows in water – the marshmallows are less dense and float on top. The chocolate is more dense and sinks to the bottom. The water sits in the middle. Through density separation we form Earth's three compositional layers – the crust, the mantle, and the core. When did that happen? With early Earth mostly molten, it would have all happened within in a few million years at most – so basically concurrent with Earth's formation – 4.6 billion years ago.

So what? Why is it important that Earth has layers? How does that affect us? First, let's look closer at the core, which is composed of two parts – the liquid iron **outer core**, and the solid iron **inner core**. Both of them are under high pressure and are very hot. As you know from heating water in a pot on a stove, hot fluids will **convect** – the hotter bits at the bottom expand and become less dense, rising above the cooler denser material around them. This constant overturning or cycling is an excellent method for transferring heat. However, if the convecting material is a hot, liquid metal, the convection will also produce a **magnetic field**. So forming layers on the earth also led to the formation of a magnetic field. This magnetic field successfully deflected the early Sun's fierce, hot winds, allowing gases that were bubbling up out of the molten earth to begin accumulating on Earth's surface. Prior to the magnetic field formation, any gases would have been stripped away and blown to the outer solar system. 4.6-billion-year-old Earth had no atmosphere. However, once its layers formed, it did. Another important layer that formed was a plastic portion of the mantle, called the **asthenosphere**, that starts about 100 km below the surface and that, like the outer core, also convects. Plastic means that while the asthenosphere is, technically, considered solid, it behaves like silly putty and is capable of flow over long periods of time. Thus it can convect, and convection of this slow-flowing plastic asthenosphere causes the more rigid section of Earth that sits above it, called the **lithosphere**, to break into pieces, which we call plates. These plates are pushed around by the convection currents underneath them and produce a surface-altering process known as **Plate Tectonics**. We'll address both these processes –- the magnetic field and Plate Tectonics – in future video tutorials.

Pause now.

With a magnetic field now deflecting solar winds, Earth's atmosphere started to collect. What was the source of the gases that collected? The molten Earth – with gases bubbling up from the molten rock. Once the earth's surface cooled enough to create a solid surface. these gases continued to erupt from volcanoes. Volcanoes are a major source of gases like water, carbon dioxide, and sulfur dioxide. Gases also entered the newly growing atmosphere from comets colliding with Earth. As we reviewed in the Earth Formation video tutorial, comets contain water, ammonia, and carbon dioxide.

Here is an artist's rendition of what early Earth would have looked like with cometary and asteroid collisions and erupting volcanoes on a mostly molten surface.

Let's look closer at early earth's atmosphere, which was hot and toxic. Its primary ingredient was carbon dioxide, but it also contained small amounts of sulfurous compounds, carbon monoxide, methane, and cyanide. Let's compare early earth's atmosphere with the atmospheres of other rocky planets in our solar system today. The three rocky planets with atmospheres (Mercury has no atmosphere) show two very similar atmosphere and one very different one – Earth's. Venus and Mars both have carbon dioxide as the major atmospheric gas, much like Earth's early atmosphere, followed by nitrogen and argon. Notice the lack of any oxygen. Why is Earth's atmosphere today so different than it was originally and so different than the other two rocky planets that are its neighbors??

First, as the early Earth lost some of its initial heat of formation and cooled, not only did the surface crust harden, but it also allowed the water present in the early atmosphere to cool enough for it to rain down and cover the hard crust with oceans. These early rains would have removed most of the water from the atmosphere, leaving it, like today, as only 1-4% by mass, depending on the climate. What happens next? Water is a giant absorber for carbon dioxide (we say that carbon dioxide is highly soluble in water), so once the oceans formed, much of the carbon dioxide in the atmosphere would have dissolved into it. We take advantage of the high solubility of carbon dioxide today when we use it to carbonate beverages.

The oldest evidence we have of liquid oceans on the surface of the Earth is from 4.4 billion years ago. What is that evidence? Scientists found and dated 4.4-billion-year-old crystals in rocks in Australia – these crystals, called **zircons**, are grains that collected on a beach long ago. The original rock that contained these zircons and then weathered leaving them behind is itself long gone. But the rock that formed from cementing the old beach grains, a beach sandstone, is still on Earth's surface. Not only do these ancient zircon grains indicate the presence of solid rock on Earth's surface 4.4 billion years ago, but they also retain isotopic evidence of liquid water. The ratio of isotopes we see in the Uranium atoms in the crystal are ratios known only to occur in the presence of liquid water.

The formation of oceans explains where the water and most of the carbon dioxide went in Earth's early atmosphere, but where did the rest of the carbon dioxide go and what formed the oxygen? The rest of this mystery is resolved when we review the impact of life on our planet. To learn more, continue to the video tutorial, **Life on Earth**.

Pause now.

For more information and more detail, continue on to the next video in this series.

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<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

Early Earth
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