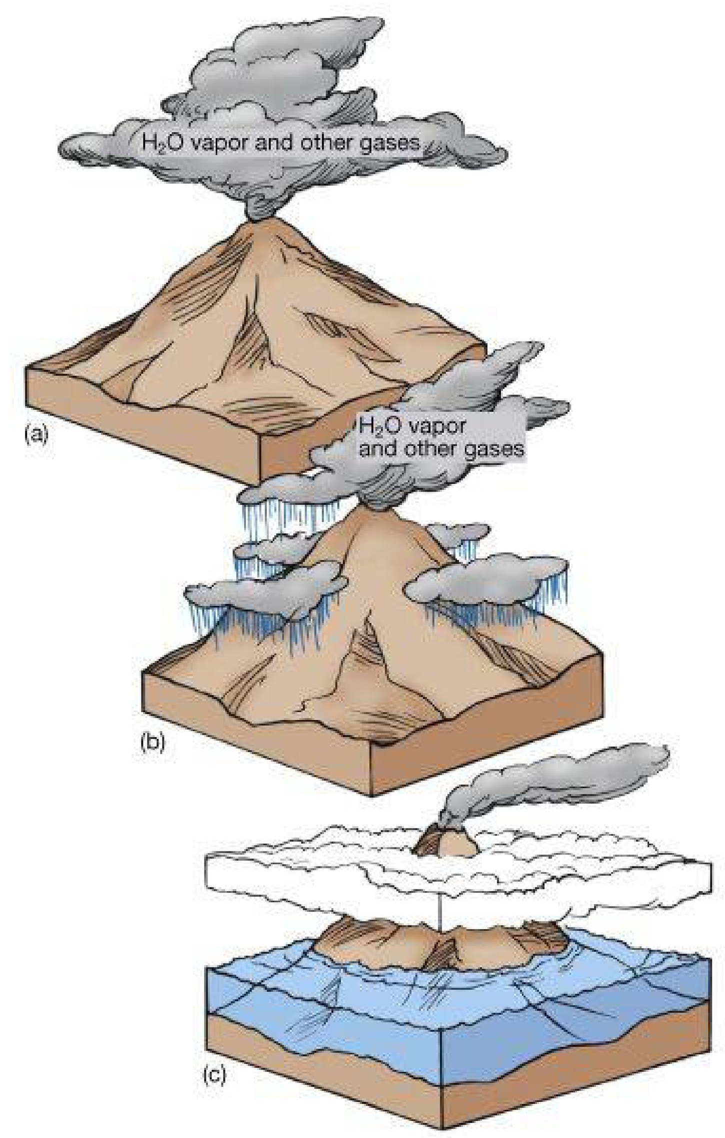
THE GREAT FLOOD — OCEANS — 4.4 BILLION YEARS AGO

Where land goes, ocean follows

The most important thing necessary for the oceans to form on this planet was time—time for water to collect in the atmosphere from volcanic eruptions and incoming comets and time for the surface to cool enough for this water to rain down and cover low-lying areas on the planet. The oldest evidence for oceans comes from the same rocks and minerals that represent the oldest evidence for a hard crust. Scientists believe that Earth's crust and oceans formed at the same time because the isotope ratios of oxygen in the oldest zircons indicate that 4.4 billion years ago temperatures were cool enough for liquid water to exist at Earth's surface and that the magmas that produced these zircons interacted with water from the surface at some point during their formation.



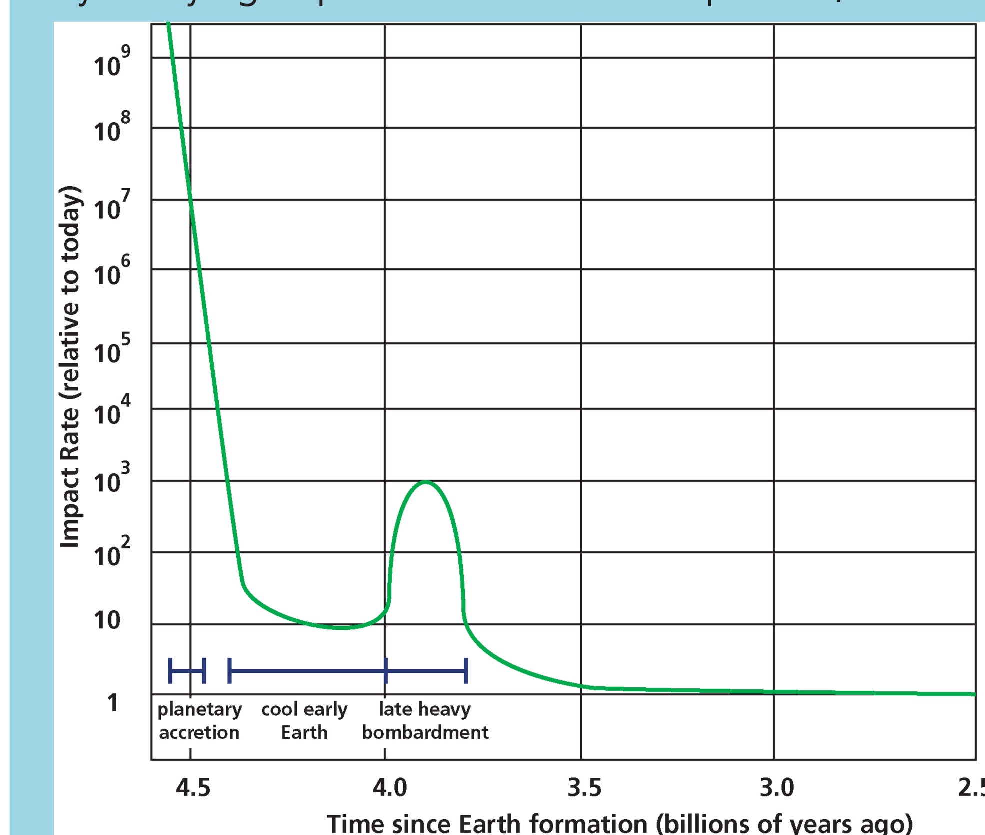
What Earth might have looked like during the days that oceans were forming. Notice the gases accumulating in the atmosphere from volcanoes. Eventually once enough water has collected, and the surface is cool enough that water can exist as a liquid on the surface, rains begin to fill low-lying areas to form the first oceans. Prentice Hall Publishing ©

Other evidence of an ocean exists in the form of evaporite minerals, like halite (salt) and gypsum, found in rocks as old as 3.85 billion years. These minerals form when salty water present on Earth's surface evaporates.

A rainstorm over San Francisco Bay. Photo by Francis Parchaso ©
Header image: Hawaii. Photo by Francis Parchaso ©

The meteorite problem

Early Earth was heavily bombarded by meteorites until about 3.8 billion years ago. This bombardment would have made it difficult to keep water in the early oceans, as it would have vaporized from the heat produced during large impacts. Scientists now believe that Earth's oceans likely were vaporized and reformed several times during early Earth history. Scientists have modeled this early heavy bombardment by studying impact craters on other planets, including the Moon.



Estimate of meteorite impact rate for the first two billion years of Earth history. Model based on a cool early Earth with late heavy bombardment, confirmed by the study of lunar craters and dating of lunar rocks. Impact rates dropped precipitously by 4.4 Ga, consistent with relatively cool conditions and liquid water on the surface of the Earth.

Stable isotope ratios and what they tell us about early Earth

Oxygen is found naturally in three different forms, called **isotopes**. All atoms of oxygen have 8 protons in their nucleus—the signature of oxygen—but each isotope has a different number of neutrons. The **mass number** of an atom is the combined number of protons and neutrons, so *heavy* oxygen (^{18}O) has 8 protons and 10 neutrons, while *light* oxygen (^{16}O) has 8 protons and 8 neutrons.

All isotopes of oxygen are stable, which means they don't decay over time like radioactive isotopes do. Thus we can't use stable isotopes for dating, but we can use their ratios—like heavy to light oxygen (^{18}O:^{16}O)— to tell us about past environmental conditions. For example, lighter water molecules evaporate more easily than heavier ones. So as temperatures warm and global evaporation increases, the more enriched atmospheric oxygen will be in ^{16}O and the more enriched ocean water will be in ^{18}O. Because of the ease of separation of heavy and light isotopes of the same element, each reservoir on Earth—atmosphere, oceans, biological organisms, crust, mantle, core, etc.—has its own unique isotopic ratio signature. We use these to tell when different reservoirs interact.

The 4.4-billion-year-old Jack Hills zircons are relatively higher in ^{18}O than the mantle. Since the magmas that produced the zircons came directly from the mantle, something must have happened during transit to the surface or at the surface to modify the oxygen ratios. Liquid waters at Earth's surface have an isotopic signature closer matched to the zircons. The most likely explanation, then, is that the magmas that produced the zircons interacted with liquid water in a near surface environment during eruption. We see the same thing happening today when eruptions occur near or with water, and their resulting isotopic ratios match what we see in the old zircons.

Where does ocean salt come from?

Weathering of rocks on land brings dissolved ions into the ocean via rivers. Although rivers carry what we think of and taste as fresh water, they actually contain some dissolved material. Much less than 1% of a unit of fresh water consists of dissolved ions. But if water of only 0.0001% dissolved ions (which we can safely drink) daily arrives at the ocean, drops off its barely detectable ions and then evaporates to return back to the land (water cycle), what happens to the ions left behind? They do not evaporate with the water. They stay behind and increase in concentration day after day, year after year, century after century, millennium after millennium. The oceans have been getting saltier over time. Today they have a salinity of, on average, 3.5% dissolved ions (which we know makes ocean water undrinkable).

Ocean acidity

When the oceans first formed, they were much more acidic than today's pH of 8.1. Why? Carbon dioxide gas (CO_2) was the main gas in the atmosphere and it is highly soluble in water. (CO_2 is much more soluble in water than oxygen or nitrogen, which is why we use it to make carbonated sodas.) As soon as a liquid ocean formed on Earth, it absorbed large amounts of CO_2 gas. CO_2 dissolved in water produces carbonic acid, which increases ocean acidity. The more CO_2, the more acidic.

With the onset of photosynthesis, CO_2 values began decreasing, eventually reaching the values we have today. However, as CO_2 increases in the atmosphere today, it reflects an even greater rise of CO_2 in the oceans. That means that we are once again increasing ocean acidity. The more acidic, the more likely $CaCO_3$ (calcium carbonate) shells will dissolve. As a result of increased CO_2 in the oceans, we have already noticed the destruction of carbonate shells on the backs of living organisms in certain areas of the oceans and reduced populations as a whole.