**When did land appear over water (and why does it matter)?**

Ilya Bindeman, University of Oregon and University of Geneva

When Yuri Gagarin first saw the earth from the space in 1961 in looked as blue-yellow planet with white clouds, this fragile view was reinforced by the American astronauts who saw the earth from the moon. The blue aquaplanet, completely covered with water and tiny continents, with white clouds would have a very different feel to it. Even more dramatic difference is a bright white cloudless planet completely covered with ice. During such “snowball earth” episodes which happened at 5-6 times in the past oceans froze around the world. The color of planet from space affects its albedo – how much of the solar radiation is getting reflected by the planet, and how much is retained by the greenhouse gases. Archean atmosphere in the first half of its history in the (4.55-2.5 billion years ago) was free of oxygen and rich in CO2 to keep the planet warm. Our sun was also 30% less luminous in the Archean – hydrogen in its interior was not fusing as effectively to form helium as it does today. So this delicate balance of the incoming solar energy, planet reflectivity, and chemistry of the atmosphere are all important to understand the temperature on the surface, panglobal perturbations such as snowball earth glaciations, and the appearance of oxygen 2.4 billion years ago, and the origin and evolution of life.

Geologists commonly use the term “uniformitarianism” that implies that physical and chemical processes occurring today, such as volcanic eruptions, riverine flow and erosion, sand dune formation were likely the same in the Archean as they are today. However, many things in Earth’s Archean are still not known very well because rocks of that old age are poorly preserved well or are metamorphosed. So we have to rely on sophisticated chemical and isotopic proxies in sedimentary rocks to gain insights into ancient paleoenvironments.

In our work we looked into the rare isotopic signatures of oxygen in shale, the Earth's most common sedimentary rock. It forms when the rocks in the exposed crust weathers subairially under rain and sun thus recording isotopic signatures of ancient rainwater. A typical granite will become river mud and secondary minerals in this mud record both the chemical composition of the average exposed and eroding crust, and signatures of the eroding waters. When areas of the exposed and eroding crust are small (think of small islands such as Madagascar) isotopic composition of rain water is not very variable and is closed to coastal rain. When continents are large and extensive (think of N America), they span vast latitudes, altitudes of mountain ranges and areas at high altitude and near polar areas all have snowcaps. These combined effects that we call “continentality” can be understood to the first order, using a meteoric water cycle. In hydrologic cycle, when a cloud travels inland, its rain becomes progressively more depleted in heavy isotopes of oxygen (17O, 18O) relative to 16O. Recent advances in analytical methods involving small variations in triple oxygen analysis has allowed to distinguish signatures of the meteoric water in shales acquired during weathering reactions. Having two isotopes of the same element – oxygen – the main element in rocks and waters, has allowed for the first time to resolve isotopic values of the meteoric waters that participate in weathering reactions, and the temperature of alteration. It appears that waters in the Archean were less diverse than today and the temperatures were in general higher.

Additionally, we observe a step-wise change in the triple oxygen signature of oxygen at the Archean/Proterozoic boundary 2.5 Ga: reconstructed rain became suddenly more isotopically diverse. We interpret this change, through the hydrologic water cycle, to indicate that much more land suddenly appeared from the oceans at this time. Documentation of this rather rapid vs gradual increase in land surface at 2.4 Ga, is the main result of our study. Reasons for it can vary and are currently being discussed. The simplest is the formation of the formation of the first supercontinent Kenorland. As earth’s crust grew steadily over time most remained under water, but when enough smaller and flooded land masses crumbled together by plate tectonic forces, they emerged over oceans with mountains and vast erosional plains, exposed to the powers of weathering and erosion. Regardless of exact reasons, the temporal coincidences, and implications of this sudden appearance of land 2.5-2.4Ga are rather sweeping: dry land free of vegetation (no plant life until 300 million years ago!) will look bright yellow to an extraterrestrial ship.

Suddenly appearing land would have disturbed the energy balance between solar radiation from the dim, early sun and warming greenhouse gases, such as CO2. The CO2 is a major agent in carbonic acid weathering of rocks, would have also been drawn down by extra exposed land, as mudrocks provide fertile ground to sequester CO2 from the air. As a consequence, the earth would then freeze into its first “snowball” state and the planet would look white. Why the free oxygen appeared after the first continent-wide glaciers have melted, remains a mystery. There must be a connection between land emergence and the series of events that followed.

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, rivers) point to a rapid rise of land above the ocean 2.4 billion years ago that possibly triggered dramatic changes in climate and life.

In a study published in the May 24 issue of the journal *Nature*, researchers report that shale sampled from around the world contains archival quality evidence of almost imperceptible traces of rainwater that caused weathering of land from as old as 3.5 billion years ago.

Notable changes in the ratios of oxygen 17 and 18 with more common oxygen 16, said lead author Ilya Bindeman, a geologist at the University of Oregon, allowed researchers to read the chemical history in the rocks.

In doing so, they established when newly surfaced crust was exposed to weathering by chemical and physical processes, and, more broadly, when the modern hydrologic process of moisture distillation during transport over large continents started.

The evidence is from analyses of three oxygen isotopes, particularly the rare but stable oxygen 17, in 278 shale samples drawn from outcrops and drill holes from every continent and spanning 3.7 billion years of Earth's history. The analyses were done in Bindeman's Stable Isotope Laboratory.

Based on his own previous modeling and other studies, Bindeman said, total landmass on the planet 2.4 billion years ago may have reached about two-thirds of what is observed today. However, the emergence of the new land happened abruptly, in parallel with large-scale changes in mantle dynamics.

Isotopic changes recorded in the shale samples at that time also coincides with the hypothesized timing of land collisions that formed Earth's first supercontinent, Kenorland, and high-mountain ranges and plateaus.

"Crust needs to be thick to stick out of water," Bindeman said. "The thickness depends on its amount and also on thermal regulation and the viscosity of the mantle. When the Earth was hot and the mantle was soft, large, tall mountains could not be supported. Our data indicate that this changed exponentially 2.4 billion years ago. The cooler mantle was able to support large swaths of land above sea level."

Temperatures on the surface when the new land emerged from the sea would have likely been hotter than today by several tens of degrees, he said.

The study found a stepwise change in triple-isotopes of oxygen around that time frame. That, the scientists said, resolves previous arguments for a gradual or stepwise emergence of land between 1.1 and 3.5 billion years ago. At 2.4 billion years ago, Bindeman said, the newly emerged land began to consume carbon dioxide from the atmosphere amid chemical weathering.

The timing also coincides with the transition from the Archean Eon, when simple prokaryotic life forms, archaea and bacteria, thrived in water, to the Proterozoic Eon, when eukaryotes, such as algae, plants and fungi, emerged.

"In this study, we looked at how weathering proceeded over 3.5 billion years," Bindeman said. "Land rising from water changes the albedo of the planet. Initially, Earth would have been dark blue with some white clouds when viewed from space. Early continents added to reflection. Today we have dark continents because of lots of vegetation."

Exposure of the new land to weathering, he said, may have set off a sink of greenhouse gases such carbon dioxide, disrupting the radiative balance of the Earth that generated a series of glacial episodes between 2.4 billion and 2.2 billion years ago. That, he said, may have spawned the Great Oxygenation Event in which atmospheric changes brought significant amounts of free oxygen into the air. Rocks were oxidized and became red. Archean rocks are gray.

In the absence of much land, he said, photons from the sun interacted with water and heated it. A bright surface, provided by emerging land, would reflect sunlight back into space, creating additional torque on radiative-greenhouse balance and a change in climate.

"What we speculate is that once large continents emerged, light would be reflected back into space and initiate runaway glaciation," Bindeman said. "Earth would have seen its first snowfall."

Shales are formed by the weathering of crust.

"They tell you a lot about the exposure to air and light and precipitation," Bindeman said. "The process of forming shale captures organic products and eventually helps to generate oil. Shales provide us with a continuous record of weathering."