Earth & Space

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

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ABSTRACT

Our Earth did not always look like the yellow-blue planet surrounded by clouds that we know to-day. Changes in the relative abundance of markers present in ancient waters and trapped in old rocks, indicate a sudden emergence of land from the oceans 2.4 billion years ago. This is likely to have perturbed the energy balance of the planet at the time, and could be linked to the appearance of free oxygen in the atmosphere.

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When Yuri Gagarin first saw the earth from the space in 1961 it looked as a blue-yellow planet with white clouds, a fragile view that was reinforced by the American astronauts who saw the Earth from the moon. The blue aquaplanet, completely covered with water and tiny continents, would have a very different feel to it, and so would a bright white cloudless planet completely covered with ice. During such "snowball earth" episodes which happened 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. The atmosphere of the Archean (4.55-2.5 billion years ago) was free of oxygen and rich in CO2, keeping the planet warm. Our sun was also 30% less luminous – hydrogen in its interior was not fusing as effectively as it does today.

This delicate balance of the incoming solar energy, planet reflectivity, and chemistry of the at-mosphere are all important to understand the temperature on the surface, global perturbations such as snowball earth glaciations, 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 or riverine flow and erosion, were likely the same in the Archean as they are today. However, rocks of that old age are poorly preserved, so we have to rely on sophisticated markers in sedimentary rocks to gain insights into ancient paleoenvironments.

Isotopes are variants of the same chemical element. Oxygen, the most common element on earth, contains 3 isotopes, the most abundant 16O, and heavier and rare 18O, and even more ra-re 17O that was not studied in detail before. In our work, we looked into the relative abundances, or signatures, of these 3 isotopes of oxygen in shale, the Earth's most common sedimentary rock. Shale forms when rocks such as granite are exposed to weathering, a process that changes a typical granite into clay and mud. No ancient rain or snow-water can survive billions of years (obviously); however, recent advances in analytical methods involving measurements of small variations of oxygen isotopic abundances in ancient clays has allowed us to distinguish the signatures of ancient rains and snow waters.

The hydrologic cycle describes the continuous movements of water on, above and below the surface of the Earth, a flow that modifies the isotopic signature of the water: for example, when a cloud travels inland, its rain becomes progressively poorer in heavy isotopes of oxygen relative to 16O. This water cycle, and the consequent variations in water isotopic signatures, are affected by the size of the continents. When the area of exposed land is small (think of small islands such as Madagascar) the hydrologic cycle is limited and the isotopic composition of the rain is close to that of the ocean. However, when continents are large and extensive (think of Eurasia), they span vast latitudes and contains mountain ranges and areas with snowcaps, which dilute these isotopic abundances during the water cycle.

It appears that waters in the Archean were less diverse than today and the temperatures on the surface were in general higher. We also observed a step-wise change in the 17O oxygen signa-ture 2.4 billion years ago: reconstructed rain became suddenly more isotopically diverse, and, more speculatively, Earth’s first ever snow fell. We interpret this change to indicate a rather rapid emergence of land surface from the oceans at 2.4 Ga. We are currently trying to explain this key result. One simple hypothesis is the formation of the first supercontinent Kenorland from the col-lision of small pieces of land, which would become suddenly exposed to weathering and erosion. Regardless of the exact reasons, the temporal coincidences and implications of this sudden ap-pearance of land 2.5-2.4Ga ago are rather sweeping: a dry land free of vegetation (no trees on land until 380 million years ago!) would look bright yellow to an extraterrestrial ship.

The 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 would also have been drawn down by extra exposed land and sequestered by mudrocks. As a conse-quence, 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, but must be connected with land emergence.