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Why Earth’s water could be older than Earth itself

How did water survive Earth's searingly hot birth? A radical new answer turns planetary history on its head – and could revolutionise the search for alien life

Vince Cavataio/plainpicture

By Natalie Starkey

MILTON KEYNES has the dubious distinction of being the town that supposedly has the most roundabouts in the UK. It is not the sort of place you might expect to be at the centre of a profound debate about Earth’s deep history.

And yet, on its outskirts there is a lab housing a seemingly haphazard set of metal tubes, canisters, wires, cables and control boards, assembled into a piece of apparatus the size of a small car. My colleagues and I have used it to make the most precise measurements ever of rocks bearing traces of Earth’s earliest atmosphere.

We believe that those measurements may put to bed a perplexing scientific mystery.

This planet is a lush world of rivers, lakes and streams. But it shouldn't be, according to our traditional interpretation of Earth's past. Our measurements at the Open University in Milton Keynes provide a strong indication that this explanation is past its sell-by date. The true story of how Earth got its water looks to be far stranger. If we are right, it means water, and potentially life that thrives in it, is probably far more widespread in the universe than we dared dream.

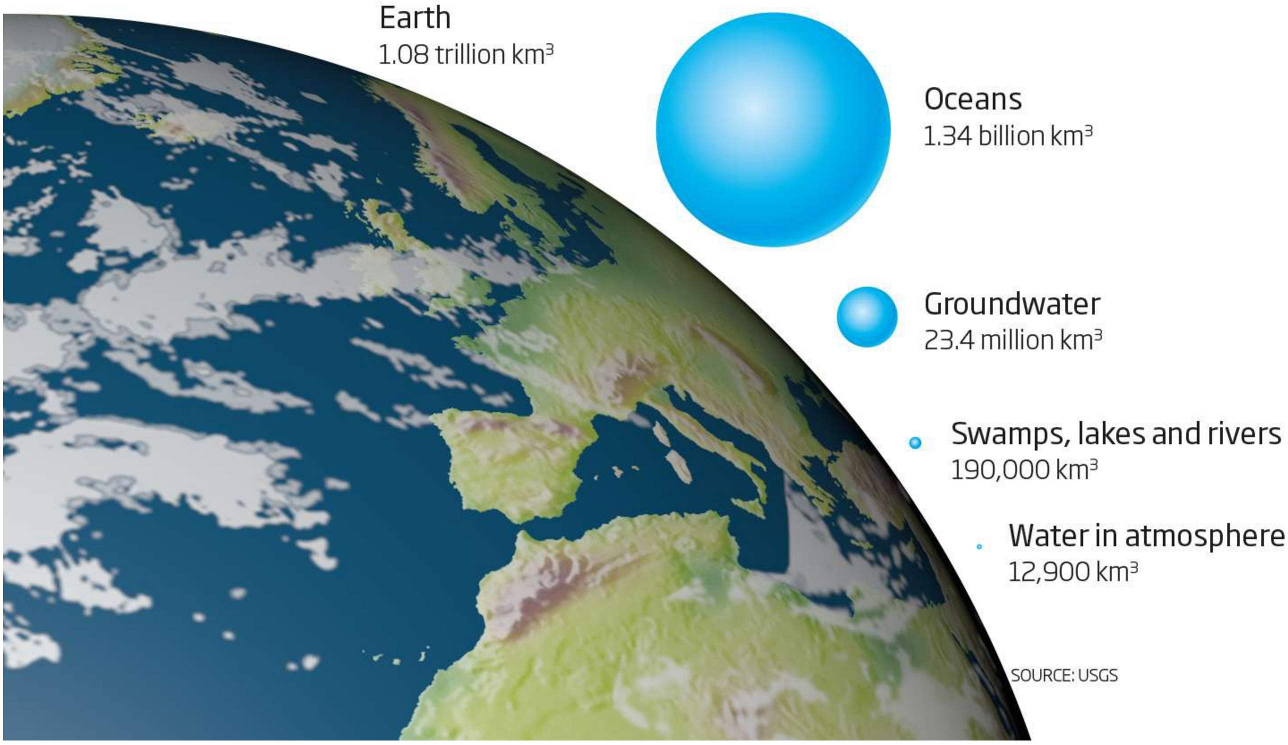
To understand why the presence of so much water on Earth is so unlikely, we need to go back more than 4.6 billion years. The young sun is shining, and encircling it is a maelstrom of gas and dust that will clump into the planets. Any water exists as ice in interstellar space. If any of that ice found itself in the inner part of the solar system, where the rocky planets like Earth will form, the heat and radiation split it into its constituent atoms of hydrogen and oxygen. This means the material that formed Earth shouldn't have contained a speck of moisture.

Let's imagine that, somehow, interstellar water did survive the tumultuous star-forming process to condense into oceans on Earth's surface. It would then have the small matter of the impact that formed the moon to contend with. There are many details about how the moon formed that are contested. But our best understanding is that a Mars-sized object called Theia smashed into Earth about 4.5 billion years ago. The scientific consensus is that the impact was so epic that it vaporised our planet. Some of that cloud of gas coalesced into the moon and some of it collapsed under its own gravity to remake Earth. The conventional view was that water couldn't have survived this.

Yet here we are all the same. Free water may make up only a tiny proportion of the total stuff on Earth, but there's more than enough to go around: some 1.3 billion cubic kilometres in the oceans alone (see "Diagram"). How can this be so?

Skin deep

Crucial to Earth's life though water is, its total volume is tiny compared with that of the planet



Many planetary scientists used to think that Earth must have received its water after the moon formed, by special delivery from space. The couriers could have been comets and asteroids, many of which formed far enough from the sun for water to survive. These space rocks rained down on us in abundance during a period known as the late veneer, shortly after the moon's formation. They brought with them an inventory of precious metals, organic matter and volatile compounds, including water. We can see evidence of this frenzied pelting if we look upwards: the surface of the moon is still pockmarked with the impact craters.

There is no denying that Earth was bombarded in this way. But a strong blow to the idea that cosmic missiles delivered our water came from the Rosetta probe, which visited comet 67P/Churyumov-Gerasimenko in 2014 and found it had the "wrong type of water".

All chemical elements, including those in water molecules, come in varieties called isotopes that have different masses. The proportions of the different isotopes of hydrogen in Earth's water didn't match those in the comet's water. And this was one in a series of failed matches. For decades, astronomers have been hunting for a comet or asteroid that contains the right type of water together with the right mix of other elements we know were delivered in the late veneer. So far, nothing fits.

"We've sought the comets that delivered Earth's water for years – but nothing fits"

That brings us to an impasse. Our story so far says that water shouldn't have been present when Earth formed. It shouldn't have survived the moon-forming impact. And it seems our water can't have been delivered by any comet or asteroid we know of.

I never intended to get mixed up in this intractable mystery. The reason I did dates back to my PhD in the mid-2000s, when I was looking at rocks that originated from the boundary between Earth's core and mantle. These samples were brought to the surface millions of years ago by upwellings of hot rock called mantle plumes. They only occur in rare places, like Baffin Island, Canada, and western Greenland in the case of my samples. I looked at tiny pockets of gas trapped in these rocks. Each pocket is a time capsule, allowing you to study an untouched sample of the young Earth's atmosphere.

A few years ago, I began working with Richard Greenwood at the Open University, who helped build that seemingly haphazard contraption. It is actually a precision mass spectrometer, which can separate and measure the isotopes in rock samples. Greenwood and his colleagues had been tinkering with it for years and had finally reached the point where they could make incredibly accurate measurements of oxygen isotopes in tiny samples of rock.

We decided to compare the rock samples I studied during my PhD with moon rocks collected by the Apollo astronauts. We thought we could put to bed a long-running fracas over whether there is any isotopic difference between the moon and Earth. If the story we tell ourselves about our satellite's formation is true, the isotopes from the two bodies should match. When Earth was vaporised during the giant impact, the isotopes of all elements should have been mixed up and then distributed evenly between the two. A long series of measurements of their isotopes had gone back and forth, first showing there was a difference, then there wasn't, then there was again. It was a mess.

Just like the moon

Our more-precise analyses showed that there was a tiny yet clear difference between the isotopic composition of Earth and the moon – but that this could be accounted for by the shower of space rocks that bombarded our planet during the late veneer, so the two really could have started out the same.

In trying to close the esoteric debate about Earth and the moon, we ended up shedding light on the mystery of our planet's water. Based on our conclusions, we could tell that at least 70 per cent of the water on Earth today was here before the moon formed. Any less would have required there to have been more impacts from space to deliver the rest of the water. Yet if this were so, we would have expected to see a larger difference between the isotopic compositions than we did.

But hang on: haven't we already said it is impossible for Earth's water to have been here before the moon formed?

Unlikely as it seems, some recent studies find that it might have been possible to hang on to our life-giving liquid through such a catastrophe. For example, a computer simulation of the vapour cloud, developed in 2015 by Robin Canup at the Southwest Research Institute in Texas, shows that it could have had enough gravity to cling on to the vaporised water.

However, water first had to clear another hurdle: surviving the high temperatures of Earth before the moon-forming impact. This was the Hadean, a geological aeon named after hell because it was so hot. It sounds like a tough environment for water to endure. But some now think that any water our planet contained could have been locked inside minerals deep in the mantle. Others say that Earth had cooled enough that a crust of rock could have formed over the molten surface, sealing in water.

Funny seeing you here: it is a puzzle why Earth has any water
Michael Christopher Brown / Magnum Photos

There is an even weirder twist. Not only did some of our water at least apparently survive the infernal conditions of Earth's early years and the moon-forming impact, it might be even older than our planet itself. This conclusion comes from observations of hydrogen and its sister isotope deuterium in the water inside comets, asteroids, planets and the space between stars. Interstellar space has traces of water with a high ratio of deuterium to hydrogen. This is reflective of the environment. Interstellar space is cold and continuously bombarded by high-energy cosmic rays, producing conditions that favour the inclusion of deuterium in water ice.

We have also discovered that all the objects – comets, asteroids, planets – in the solar system also have large amounts of deuterium in their water. That is odd. If this water were originally interstellar, it must have somehow made its way into the inner solar system during its early years. As the water arrived, the young sun's extreme radiation should have broken it into its constituent atoms. When they recombined to form water that eventually ended up on the planets, more of the regular hydrogen should have been picked up than we actually see. It was another mystery.

A few years ago, a team led by Ilse Cleeves, now at the Harvard-Smithsonian Center for Astrophysics, set up a simulation of the early solar system to investigate whether there were any parts of the disc of gas and dust that formed around the young sun that might have been able to manufacture water with excess deuterium – perhaps places where there was lots of radiation. They couldn't find any.

“In this radical story, our rivers are filled with water that is older than the sun”

That brings us to the surprising conclusion that our planet's water isn't just older than the moon. It must have come from interstellar space, which means it is older than the sun itself. It is hard to fathom how it survived entry into the solar system. But once you have eliminated the impossible, it forces you to this conclusion. Cleeves suggests, drawing on other simulations, that there was probably a short window of opportunity – after the sun had cooled enough, but before the planets formed – for interstellar water ice to sneak into the solar system, raining down as the planets were beginning to form.

All this adds up to a radically new story for how Earth got its water, one in which our planet's rivers and oceans are filled with liquid that came from the void between the stars. Strange as it seems, I am confident this is the best explanation of the evidence we have.

This has wide-ranging implications, including for the search for life beyond our solar system. If interstellar water is preserved on Earth, despite what we thought were incredible odds, it could be common in star systems across the universe. We believe all planets ultimately form from the same range of materials that collect around young stars. So if interstellar water survived here, then there is every chance that this life-fostering ingredient is widely available.

Astronomers using NASA's Spitzer space telescope have detected water in the discs around the young stars DR Tau and AS 205A, more than 350 light years from Earth. Water exists in their inner disc regions, the hottest zones close to the stars. These discs are yet to have formed planets, but this is evidence that water is available to newly forming planets from the early stages of a star's history.

True, it is not enough for water to have survived the first few million years of a star system's life. It also has to cling to a planet during its chaotic early years. In the search for potentially life-sustaining exoplanets, those that were bombarded throughout their early years by comets and asteroids are usually discounted, the thinking being that large impacts would drive off any water. But as we showed, that too needs a rethink. Right now, the evidence suggests watery planets are common throughout the universe.

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Article amended on 1 November 2018

We have corrected Natalie Starkey's byline