Minerals in ancient meteorites offer insights into the origin of most of the Earth's surface

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Dr. Alice Stephant, an astrophysicist, is helping to solve a longstanding mystery about water on Earth: where it came from.

Scientists long thought that water, which covers 70% of the Earth, is probably rare or non-existent on other planets. The assumption was that water on Earth resulted from a unique series of galactic events billions of years ago.

Stephant, who works at the National Institute of Astrophysics in Italy's capital Rome, is challenging these longstanding assumptions.

She has produced research that suggests the chemical components of water—hydrogen and oxygen—could have come from the giant cloud of dust and gas that gave rise to Earth's solar system.

If water from that cloud could go directly into forming planets, it could exist all over the universe. "Maybe this way of bringing water to a planetary body can occur in any other solar system," said Stephant, a French native who has also worked in the U.K. and U.S.

She led a research project called POSEIDON that received EU funding to try to determine the origins of water on Earth. The team looked at the chemical components of hydrogen and oxygen in a particular type of meteorite: primitive achondrites.

The project wrapped up in January 2023 after 29 months.

Solar births

Earth's solar system was born around 4.5 billion years ago out of a swirling cloud of dust and gas known as the solar nebula. Over time, gravity pulled this material together and towards the middle of the nebula.

Once almost all of it—more than 99%—had gathered in the center, the pressure and heat created by the compression triggered nuclear fusion and the sun was born.

The remaining material orbited the sun and eventually started to combine to form larger objects. Some grew into the planets and moons seen today. Others didn't and instead became meteoroids, comets and asteroids.

These pieces of rocky debris are important to scientists because they are relics from the early history of the solar system. Primitive achondrites are of particular interest because they come from asteroids that were among the very first planetary building blocks in the solar system.

New meteorite group

Stephant identified a new group of primitive achondrites that provide important clues to the source of water on Earth—and on other planets in the solar system.

Previously, there were only two known groups of primitive achondrites. Stephant has identified a third, which is distinguished by what's called an isotypic composition of oxygen. This means these meteorites come from different material in the early solar system.

They also contain a different hydrogen isotope. That means the hydrogen has a different number of neurons in its nucleus. "There were probably several sources of water, not just one," said Stephant.

One of the possible sources is primordial hydrogen, which likely came from nebular gases in the early formation of the solar system.

The components of water might have been present in the earliest building blocks of planets. If so, it's more likely that the components of water were incorporated into the chemical makeup of many planets. And that significantly increases the likelihood of water existing on the surfaces of other planets in the universe.

"People used to say that the water on Earth is from a combination of many events that make it unique," said Stephant. "But maybe in fact it is not."

Time test

As Stephant seeks further evidence of the origin of water, Dr. Sandrine Péron is exploring elements that came with it to Earth to learn more about the early solar system. Péron is a geochemist at ETH Zürich, a university in Switzerland, and a native of France.

Péron leads an EU-funded research project called VolatileOrigin, which runs for 29 months through April 2024. It focuses on two noble gases in the Earth's crust: krypton and xenon.

Krypton and xenon isotopes help scientists understand the origins of Earth's volatile elements like carbon, nitrogen and water. That's because these isotopes were brought to Earth along with volatile elements including water. Because the isotopes are much less reactive, they retain the ancient chemical fingerprints that point to their origins in the early solar system.

The chemical signatures of krypton and xenon in a class of primitive meteorites known as carbonaceous chondrites match those in the Earth's mantle. That shows that these meteorites were incorporated into the mantle.

Krypton anomaly

Several years ago, Péron and her colleagues sampled krypton in the Earth's mantle from geological hot spots in Iceland and the Galapagos Islands that throw up magma from deep in the Earth.

The researchers discovered a relative scarcity of krypton with the isotope number 86. "We found that, in the Earth's deep mantle, we have a deficit of krypton 86 compared to the average composition of carbonaceous chondrites," Péron said.

If the krypton 86 deficit is the result of an anomaly in the creation of atomic nuclei in the primitive solar system, it would indicate that water—and other volatile elements—were brought to Earth before nebula material was well mixed.

Museum pieces

The krypton anomaly indicates that, as well as carbonaceous chondrites, other meteorites contributed to the Earth's mantle.

In VolatileOrigin, Péron is examining meteorites that have landed on Earth and now sit in museums to determine whether any have the same krypton anomaly as the Earth's deep mantle.

The project is also looking for krypton deficits in the Earth's upper mantle. Such anomalies were created before the solar system was formed and show that various isotopes weren't well mixed, according to Péron.

"These different isotopes are produced by different types of stars or supernovas," she said. "When this material is incorporated in the solar system, we could have some parts that are getting more of one particular isotope or another."

The chemical signatures left over from these ancient cosmic events provide clues to the journey that materials took between different parts of the solar system during its early development.

"When we see these anomalies, either in meteorites or in the Earth, it gives us information about the processes occurring during the early phases of the formation of the solar system," said Péron.

More information:

- POSEIDON
- VolatileOrigin

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