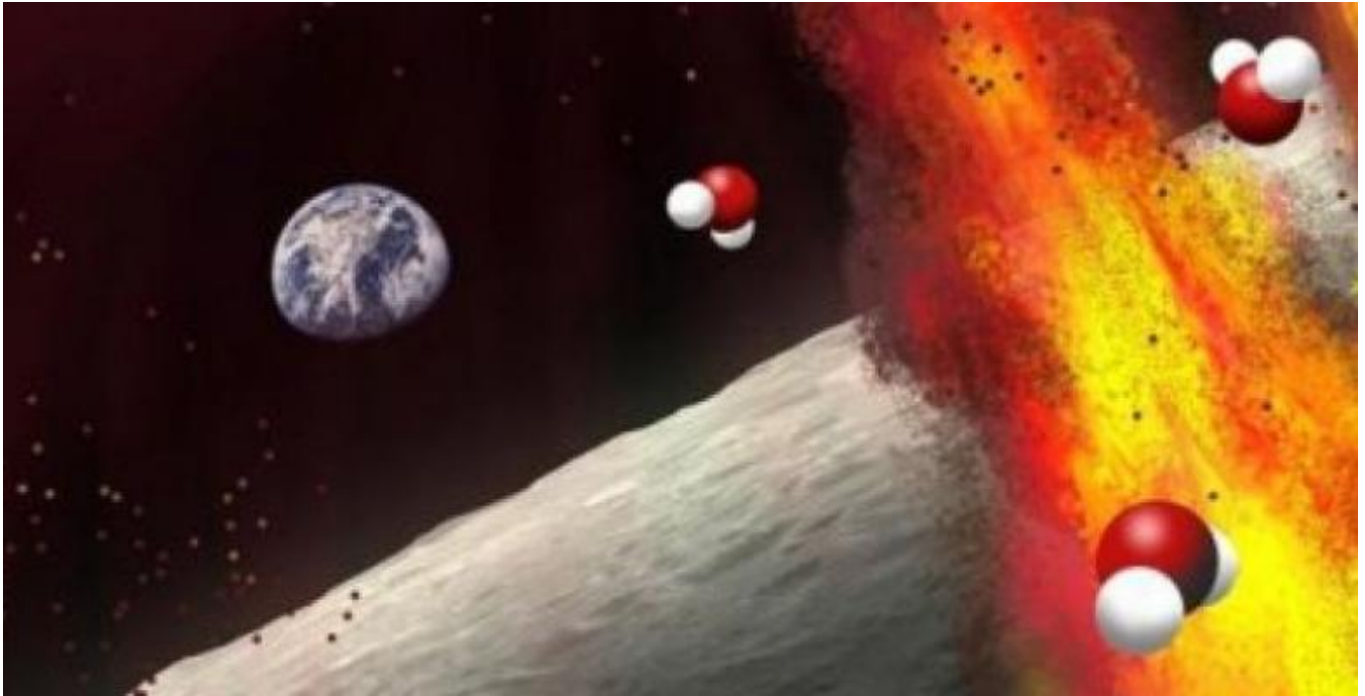

Moon has a water-rich interior

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A new study of satellite data finds that numerous volcanic deposits distributed across the surface of the Moon contain unusually high amounts of trapped water compared with surrounding terrains. The finding of water in these ancient deposits, which are believed to consist of glass beads formed by the explosive eruption of magma coming from the deep lunar interior, bolsters the idea that the lunar mantle is surprisingly water-rich.

Scientists had assumed for years that the interior of the Moon had been largely depleted of water and other volatile compounds. That began to change in 2008, when a research team including Brown University geologist Alberto Saal detected trace amounts of water in some of the volcanic glass beads brought back to Earth from the Apollo 15 and 17 missions to the Moon. In 2011, further study of tiny crystalline formations within those beads revealed that they actually contain similar amounts of water as some basalts on Earth. That suggests that the Moon's mantle -- parts of it, at least -- contain as much water as Earth's.

"The key question is whether those Apollo samples represent the bulk conditions of the lunar interior or instead represent unusual or perhaps anomalous water-rich regions within an otherwise 'dry' mantle," said Ralph Milliken, lead author of the new research and an associate professor in Brown's Department of Earth, Environmental and Planetary Sciences. "By looking at the orbital data, we can examine the large pyroclastic deposits on the Moon that were never sampled by the Apollo or Luna missions. The fact that nearly all of them exhibit signatures of water suggests that the Apollo samples are not anomalous, so it may be that the bulk interior of the Moon is wet."

The research, which Milliken co-authored with Shuai Li, a postdoctoral researcher at the University of Hawaii and a recent Brown Ph.D. graduate, is published in *Nature Geoscience*.

Detecting the water content of lunar volcanic deposits using orbital instruments is no easy task. Scientists use orbital spectrometers to measure the light that bounces off a planetary surface. By looking at which wavelengths of light are absorbed or reflected by the surface, scientists can get an idea of which minerals and other compounds are present.

The problem is that the lunar surface heats up over the course of a day, especially at the latitudes where these pyroclastic deposits are located. That means that in addition to the light reflected from the surface, the spectrometer also ends up measuring heat.

"That thermally emitted radiation happens at the same wavelengths that we need to use to look for water," Milliken said. "So in order to say with any confidence that water is present, we first need to account for and remove the thermally emitted component."

To do that, Li and Milliken used laboratory-based measurements of samples returned from the Apollo missions, combined with a detailed temperature profile of the areas of interest on the Moon's surface. Using the new thermal correction, the researchers looked at data from the Moon Mineralogy Mapper, an imaging spectrometer that flew aboard India's Chandrayaan-1 lunar orbiter.

The researchers found evidence of water in nearly all of the large pyroclastic deposits that had been previously mapped across the Moon's surface, including deposits near the Apollo 15 and 17 landing sites where the water-bearing glass bead samples were collected.

"The distribution of these water-rich deposits is the key thing," Milliken said. "They're spread across the surface, which tells us that the water found in the Apollo samples isn't a one-off. Lunar pyroclastics seem to be universally water-rich, which suggests the same may be true of the mantle."

The idea that the interior of the Moon is water-rich raises interesting questions about the Moon's formation. Scientists think the Moon formed from debris left behind after an object about the size of Mars slammed into the Earth very early in solar system history. One of the reasons scientists had assumed the Moon's interior should be dry is that it seems unlikely that any of the hydrogen needed to form water could have survived the heat of that impact.

"The growing evidence for water inside the Moon suggest that water did somehow survive, or that it was brought in shortly after the impact by asteroids or comets before the Moon had completely solidified," Li said. "The exact origin of water in the lunar interior is still a big question."

In addition to shedding light on the water story in the early solar system, the research could also have implications for future lunar exploration. The volcanic beads don't contain a lot of water -- about .05 percent by weight, the researchers say -- but the deposits are large, and the water could potentially be extracted.

"Other studies have suggested the presence of water ice in shadowed regions at the lunar poles, but the pyroclastic deposits are at locations that may be easier to access," Li said. "Anything that helps save future lunar explorers from having to bring lots of water from home is

a big step forward, and our results suggest a new alternative."

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