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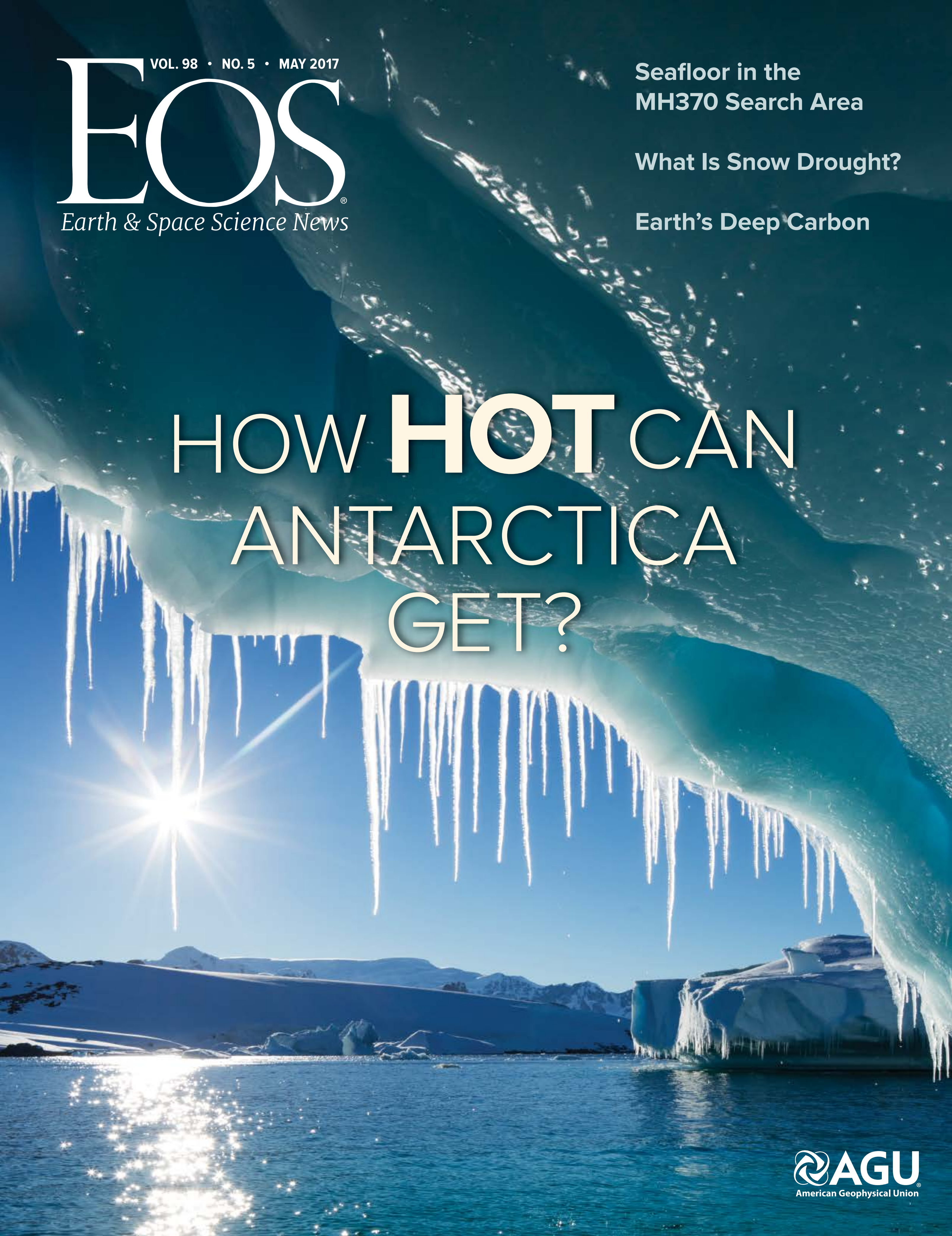


AGU
American Geophysical Union

Lunar Lava Tubes Could Offer Future Moon Explorers a Safe Haven

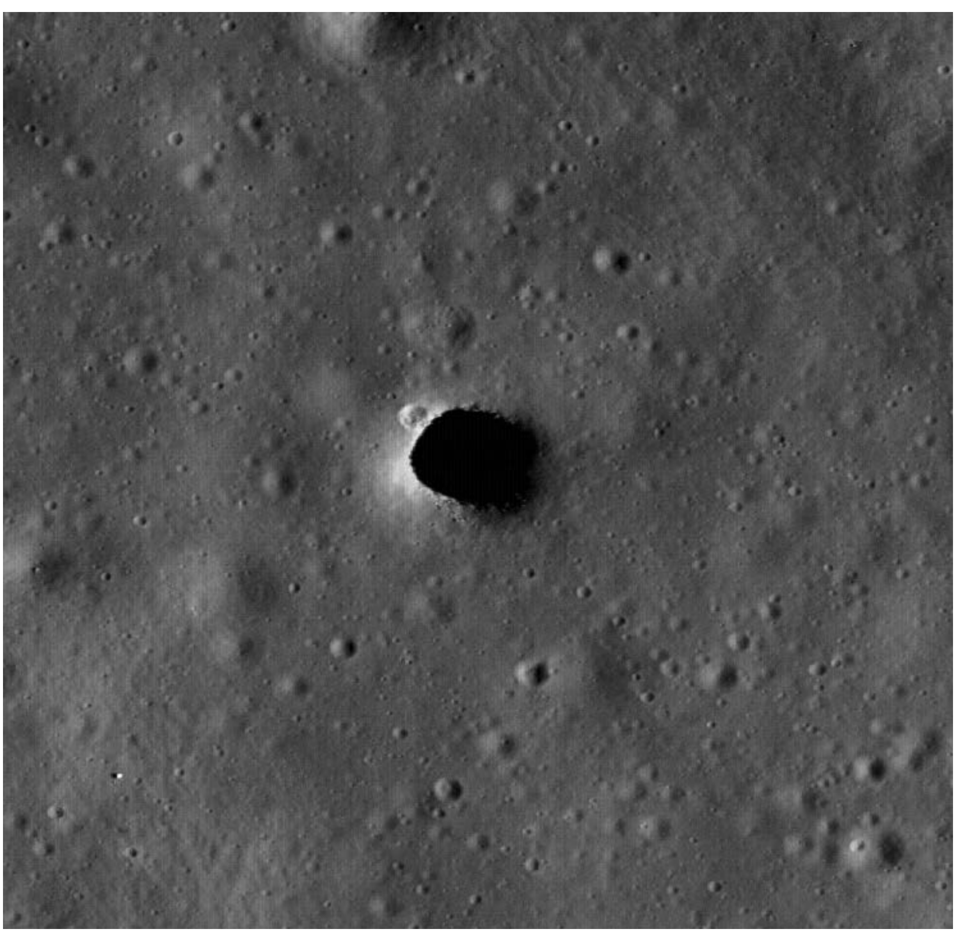
Lunar colonization isn't mere science fiction anymore. Billionaires plan to send tourists on once-in-a-lifetime trips, and politicians say that they hope to colonize the Moon in the next few decades. There may even be ways for human colonists to harvest water from ice that may be permanently shadowed in certain caves.

But where could a human colony actually live? The Moon has no atmosphere or magnetic field to shield it from solar radiation, and micrometeorites constantly rain onto its surface. That's no environment for our squishy, earthling bodies.

Scientists studying the Moon's surface may have found the answer: Humans could shelter in lunar lava tubes. The Moon is covered in huge swaths of ancient basaltic lava flows. Earth's volcanoes can also erupt in similar flows, with basalt sometimes running as molten rivers. In these rivers, the outside cools faster than the inside, creating a hard shell. The remaining lava pours out, leaving a hollow space behind.

Do similar lava tubes exist on the Moon?

In a presentation on 22 March at the 48th Lunar and Planetary Science Conference (LPSC) in The Woodlands, Texas, Junichi Haruyama, a senior researcher at the Japan Aerospace Exploration Agency (JAXA), discussed one such lava tube that he suspects may be snaking underneath the Moon's surface.



NASA/GSFC/Arizona State University

The Marius Hills pit on the Moon, spotted in 2009 by scientists at the Japan Aerospace Exploration Agency. The pit stretches 65 meters across and could be a skylight leading down to a lava tube, the scientists say.

Searching for Lava Tubes

In 2009, Haruyama and his team spotted evidence of a dark hole in the Moon's Marius Hills region in data from the Japanese lunar orbiter SELENE (Selenological and Engineering Explorer), also known as Kaguya. What the researchers didn't know was whether the pit led to something larger below. Two narrow surface depressions called sinuous rilles, which scientists think represent collapsed portions of lava tubes, stretch away from the pit. Could the pit be a skylight opening to an intact lava tube's long, narrow passage?

Ancient basaltic lava flows called maria cover much of the Moon, similar to the much younger Columbia River basalts in the western United States. Because the Moon's gravity is one sixth that of Earth's, gravity doesn't impede lava flow as much, allowing lava to spread widely across the surface. Nonetheless, lunar lava tubes may have formed in an Earth-like way, Haruyama said.

If humans ever got access to the tubes, "the science would be amazing."

Last year, another team spotted gravity anomalies that suggested hollow, narrow spaces around the Marius Hills pit. These data came from NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission, which consists of two spacecraft orbiting the Moon. The orbiters can detect these anomalies by measuring how much the Moon's gravity tugs on them. Areas of more mass tug on the spacecraft more, whereas hollow areas have less mass and so tug on GRAIL less.

To confirm GRAIL's findings, Haruyama and his colleagues turned again to SELENE's data, looking closer at the sinuous rilles. They specifically looked at data from SELENE's Lunar Radar Sounder (LRS), which imaged the subsurface using low-frequency radio waves.

The LRS data revealed hollow space more than 100 meters deep in some places and tens of kilometers long underneath one of the rilles near the pit. The pit itself looked to be 50 meters deep. These data led researchers to believe that the pit could, indeed, be a collapsed portion of a lava tube roof. These data also match the gravity readings from GRAIL, Haruyama said.

Exploring the Tubes

If humans, via rover or their own two feet, ever got access to the tubes, "the science would be amazing," said Brent Garry, a geophysicist at NASA Goddard Space Flight Center. The tube's interior tempts with pristine surfaces, absent of lunar soil or bombardment by micrometeorites, he said. These surfaces could offer answers to questions about the Moon's origin and formation.

In another LPSC presentation on 22 March, Garry described a way to closely explore these tubes, using lidar. On Earth, scientists use lidar scanners to map both land and the ocean floor. More recently, they have started using lidar to map Earth's many cave systems.

Over the past 2 years, Garry and his team used a lidar scanner to map the inside of a lava tube at Craters of the Moon National Monument and Preserve in Idaho. The park is named for the otherworldly feel of its basaltic lava flows. Apollo astronauts even studied the geology of the park before ever stepping on its namesake.

Lidar scanners work by pinging their surroundings with beams of laser light and measuring the time it takes for the light to bounce back. The scanners can take millions of data points every second, allowing for the creation of highly detailed 3-D maps. They also don't depend on sunlight, which could make them useful in a shadowy lunar pit. Garry suggests that lidar would be extremely useful in mapping centimeter- to millimeter-scale features, helping future explorers determine the structure of a lava tube.

How to get the scanner into a tube is another story, one that would involve transportation using a rover, Garry said.

Future of Lunar Exploration

Haruyama and Garry agree that lava tubes could, in theory, shield humans from the Sun's unfiltered radiation and the wide surface temperature fluctuations experienced on the Moon: Temperatures over 1 Moon day (27 Earth days) can range between 123°C and −153°C. In contrast, Earth's average temperature is only about 16°C.

What's more, lunar lava tubes likely have flat floors like those on Earth, easing the way for vehicles or instruments, Haruyama said.

However, long-term human colonies on the Moon likely won't happen in the near—or even far—future. Ben Bussey, chief exploration scientist for the Human Exploration and Operations Mission Directorate at NASA, explained during a NASA town hall meeting at LPSC that NASA's deep-space habitability plans are currently focused on reaching Mars and that "plans don't call for going onto the lunar surface before going to Mars."

But if those plans ever change, at least we know we might have a place to crash—figuratively, at least.

By **JoAnna Wendel** (@JoAnnaScience), Staff Writer

Study Finds That Coastal Wetlands Excel at Storing Carbon

Bethany Augliere

Mangroves currently cover 14–15 million hectares around the world but are steadily disappearing. These coastal forests trap an estimated 31–34 billion kilograms of carbon every year, making them carbon storage powerhouses.

As humans continually add carbon dioxide to the atmosphere, getting rid of the excess greenhouse gas has become a priority. Scientists are searching for new ways to remove carbon from the atmosphere and put it into long-term lockdown.

The ocean's ability to soak up carbon like a sponge is well known, but researchers are now taking a fresh look at ocean shores. Our planet has about 620,000 kilometers of coastline, long enough to wrap around Earth about 15 times.

In a recent paper in *Frontiers in Ecology and the Environment* (http://bit.ly/Environ2017), researchers analyzed multiple ways in which nature captures carbon in marine ecosystems, a reservoir known as blue carbon. They found that coastal mangroves, seagrasses, and tidal marshes, or coastal blue carbon, provided particularly effective and long-lasting carbon storage.

The 2015 Paris Agreement has intensified pressure on nations that signed the pact to meet carbon goals and find better ways to sequester carbon. There are many solutions, but deciding which is most effective—oceans, forests, mangroves, or kelp farming, for example—can be daunting. In addition, many studies use different timescales or measurements, further muddying carbon storage comparisons.

"The goal of the paper was to try and compare apples to apples," said Jennifer Howard, lead author of the paper and marine climate change director at Conservation International in Arlington, Va. On 1 February, she and her colleagues published their detailed report online, which compares carbon storage by coastal blue carbon ecosystems with storage by algae and marine animals.

Carbon Storage Powerhouses

Plants take carbon out of the atmosphere, storing it in leaves, roots, and branches. On land, when vegetation falls to the ground, the bits break down quickly, releasing carbon back into the atmosphere. Not so in coastal wetlands. There, Howard explained, tidally driven