Eos
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CREVASSES IN GREENLAND

AN OCEAN ON CALLISTO

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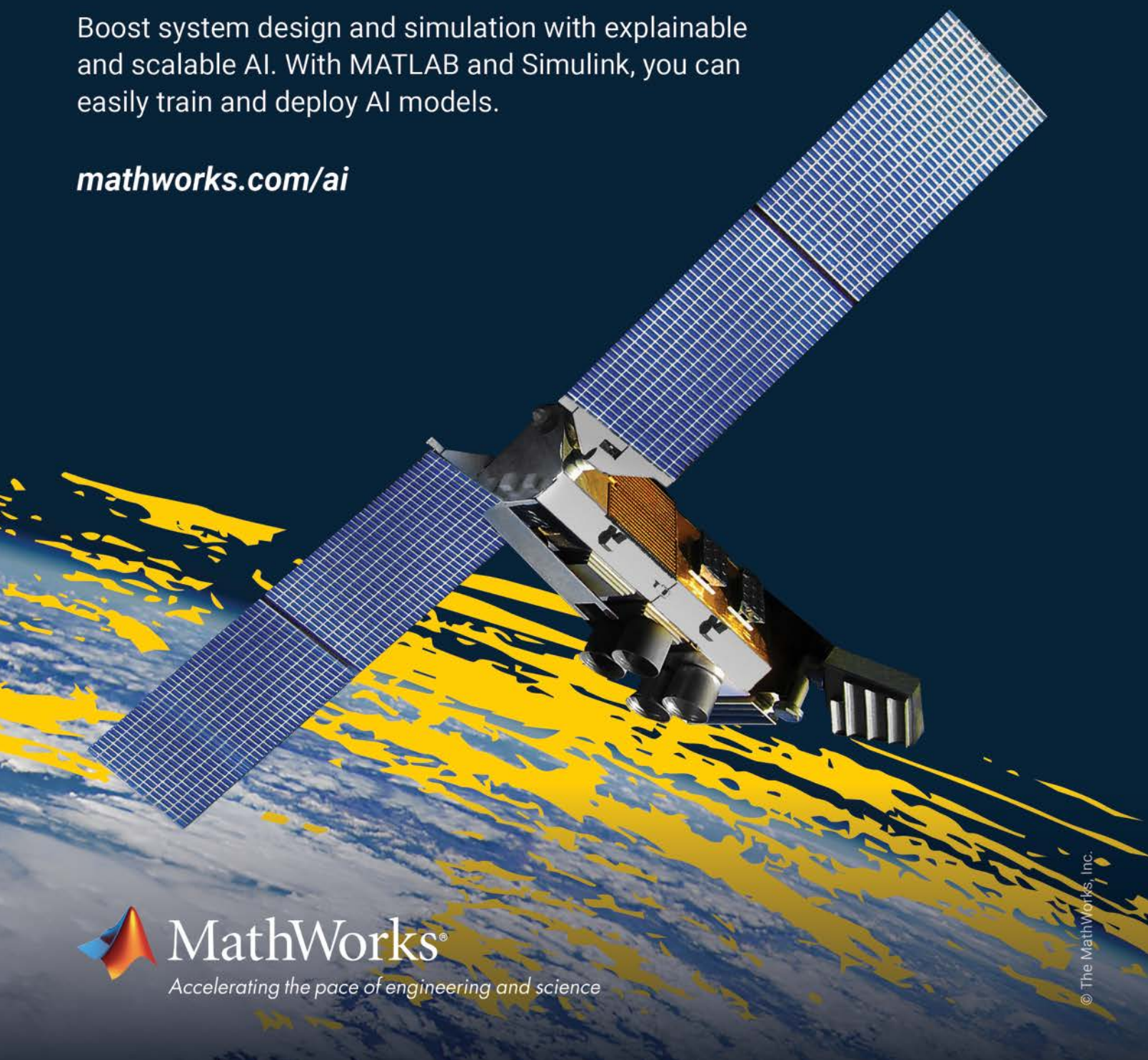

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From the Editor

New generations of submersibles and retired stalwarts of the seas are helping scientists put the depths of the ocean at the tips of their fingers. *Alvin*, probably the world's most famous human-occupied deep-sea submersible, has been flexing its newfound capabilities after receiving a major upgrade that allows it to dive to 6,500 meters—a full 2,000 meters more than its previous limit—and explore 99% of the seafloor. Read all about it in "An Upgraded *Alvin* Puts New Ocean Depths Within Reach," on page 18.

Alvin isn't alone out there. As reported on page 4, two midsize remotely operated vehicles will join the U.S. Academic Research Fleet to help scientists study coastal and nearshore environments.

Although the research fleet is exploring new depths, the legendary research vessel *JOIDES Resolution* has retired. See what three early-career geoscientists learned on "Expedition 403: Sailing the Last Expedition of the *JOIDES Resolution*," on page 13.

We hope this issue of *Eos* brings you closer to the scientists, tools, and technologies exploring the deep blue sea.

On the Cover

ROV *Deep Discoverer* images an outcrop during the second of three expeditions to the mid-Atlantic Ridge that comprised Voyage to the Ridge 2022. Credit: NOAA Ocean Exploration, Voyage to the Ridge 2022.

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Crevasses in the Greenland Ice Sheet Are Growing

Crevasses in the Greenland Ice Sheet are expanding faster than previously thought.

Between 2016 and 2021, cracks at the edge of the ice sheet grew much larger and deeper in response to the ice's rapid movement from the sheet's domed center toward the ocean, researchers reported in *Nature Geoscience* (bit.ly/growing-crevasses). This growth could drive feedbacks that accelerate ice loss on relatively short timescales.

Covering the majority of Greenland, the ice sheet contains nearly 3 million cubic kilometers of ice, which could raise sea levels by more than 7 meters if it were to melt completely. Ice sheets spread out under their own weight continuously, but they maintain their mass as long as the loss of ice is balanced out by winter snowfall. Rising temperatures, however, can cause the ice to flow faster. This acceleration has contributed to a growth in the number and volume of crevasses, which form where stress is great enough to fracture the ice sheet's surface.

"Crevasses are essentially the pathway by which water could make its way into the belly of the ice sheet," said study coauthor Thomas Chudley, a glaciologist at Durham University. Of the hundreds of gigatons of meltwater that the Greenland Ice Sheet generates every year, the vast majority flows through crevasses to the bed of the ice sheet, where it can buoy the ice on its path to the ocean.

Because crevasses affect how quickly meltwater and ice enter the sea, they play an important role in predictions of future mass loss from the ice sheet. But crevasses are difficult to observe with satellites: Crevasse surface widths range from less than a meter to a few tens of meters, whereas the resolution of satellites used to study them is a few tens of meters to hundreds of meters.

"We have been observing the Greenland Ice Sheet with satellites for decades, but crevasses have always been overlooked—literally—because they were smaller than satellite pixels," William Colgan, a glaciologist at the Geological Survey of Denmark and Greenland, wrote in an email to *Eos*. Colgan was not involved in the new study. "Actually being able to inventory individual crevasses with this new analysis brings our observation to a completely different level of detail."

To capture how crevasse volume changed over the study period, the team used digital elevation models of the Arctic surface. These 3D maps, created from overlapping high-resolution satellite images, capture elevation data at 2-meter resolution across the entire Arctic. From the maps, the researchers calculated crevasse volumes over the full Greenland Ice Sheet in 2016 and 2021.

Crevasses line the surface of Store Glacier in the western Greenland Ice Sheet. Credit: Tom Chudley, Durham University

"This is leading edge computer science applied to the ice sheet, stuff that would not have been possible ten years ago," Colgan wrote.

Near-Ubiquitous Expansion

Crevasse volume increased in regions where ice flow into the ocean was also increasing, the team found. Volume changes varied by region but were particularly pronounced in eastern Greenland and at low elevations where ice meets sea. Central northern Greenland saw the largest relative increase in crevasse volume, at 25%.

Averaged across the whole of the ice sheet, the increase wasn't significant. But that's mainly because of a temporary decrease in crevassing in just one glacier, Chudley said. A brief influx of cold ocean water from the North Atlantic caused Sermeq Kujalleq, a fast-moving glacier in western Greenland, to slow down between 2016 and 2019.

"What our study captured was almost like squeezing an accordion," Chudley said. "All the crevasses kind of closed up."

That slowdown has since ended, and Sermeq Kujalleq is accelerating once again, which means it likely won't offset increased crevassing and acceleration in the rest of Greenland going forward, Chudley said.

The team's findings support anecdotal reports from field researchers. "Those of us working in the field sense that we are seeing more crevasses out there, and indeed we have started assessing crevasse risk at ice-sheet sites where it was traditionally not an issue," Colgan wrote. "But this is the first study to unequivocally say that the expansion of crevasse zones is ubiquitous across Greenland's outlet glaciers, which have accelerated in recent years."

The results also highlight how crevasses affect other processes on the ice sheet. When meltwater flows through crevasses to the bed of the ice sheet, it lubricates the ice, speeds its progress into the ocean, and helps melt the ice that enters the sea. Faster ice flow could open more crevasses in a feedback that could further increase ice loss from Greenland and raise sea levels.

Chudley's team plans to use the findings to better predict future ice sheet behavior and sea level rise, he said. And because digital elevation models of the Arctic will continue to be released each year, the team will be able to add new crevasse data to refine their predictions.

"Hopefully, it's something we can do again in 5 years," Chudley said. "We can watch some time pass and see how things have changed."

By **Skyler Ware** (@skylerdware), Science Writer

Asteroid Samples Suggest a Solar System of Ancient, Salty Incubators

Researchers have found salts in samples from asteroid Ryugu. Combined with similar salty discoveries from asteroid Bennu, the finding suggests that aqueous incubators of life's first ingredients may have been relatively common in the early solar system.

Astrochemists have found sugars and nucleotide bases outside of Earth before, but an extraterrestrial environment in which these ingredients could combine—and possibly create life—remained elusive. The salts lifted from the two asteroids are evidence that just such an incubator (salty liquid water) existed in the early solar system.

The results from Ryugu were reported in *Nature Astronomy* in November 2024 (bit.ly/Ryugu-salts), and those from Bennu were reported in January 2025 (bit.ly/Bennu-organics). The parallel discoveries paint a compelling picture of the early solar system.

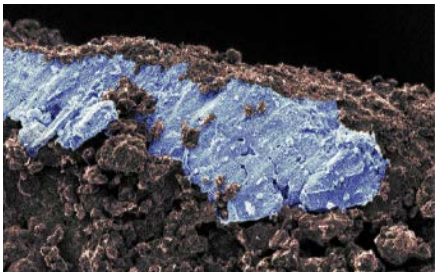
"We can now say, for the first time, that 4.5 billion years ago—long before most of us thought it could happen—we had both the ingredients and the environment in which the early stages of organic evolution towards life could begin," said Tim McCoy, a curator of meteorites at the Smithsonian's National Museum of Natural History who studied the Bennu samples.

Such evolution "didn't happen on a large, icy moon or a large, warm planet like Earth," McCoy said. "It was actually happening in asteroids at the birth of the solar system. From day one of the solar system, we were seeing this organic evolution."

Avoiding the Elements

Meteorites, typically fragments of larger space rocks, are exposed to moisture as they fall to Earth. When this happens, any water-soluble materials they may have had react and disappear. The atmosphere, McCoy said, is "actually removing some of what was there to start with." That means meteorites themselves are not always reliable for studying whether their parent bodies contained water.

"Meteorites have been studied for about 150 years. But nobody had found such kind of salts, so we are surprised."



A colorized electron microscope image shows a sodium carbonate vein in a Ryugu grain. Credit: Toru Matsumoto

Two recent space missions sought to bring back regolith directly from asteroids. JAXA's (Japan Aerospace Exploration Agency) Hayabusa2 visited Ryugu in 2019, returning samples in 2020. NASA's Origins, Spectral Interpretation, Resource Identification, and Security–Regolith Explorer (OSIRIS-REx) collected samples of Bennu in 2020 and returned them to Earth in 2023.

Most researchers think common, carbon-rich asteroids like Ryugu and Bennu, known as C-type asteroids, contain water and organic material left over from the formation of the solar system.

Toru Matsumoto, an astromaterials scientist from Kyoto University, and his colleagues found thin white veins in tiny samples from Ryugu. Using electron microscopy and radiation X-ray analysis, they identified the minerals and their chemical compositions.

The Ryugu samples showed a composition remarkably similar to that of samples from Bennu. Both asteroids contain clays, iron oxides, iron sulfides, and carbonates, suggesting they were altered by water.

The Ryugu samples also contained sodium carbonate salts. "Meteorites have been studied for about 150 years," Matsumoto said. "But nobody had found such kind of salts, so we are surprised."

Aqueous Evidence

Salty water provides a unique environment for the development of life. A sodium-rich solution with minimal calcium allows phosphate to remain in the solution, which is important because phosphate combined with sugar forms the backbone of RNA and DNA. Sodium-rich solutions can also catalyze chemical reactions between organics and precipitate minerals that act as templates for those reactions.

Evaporite salts such as sodium carbonate are the last minerals to precipitate out of salty water. Their presence on Ryugu suggests that "there were really large volumes of water on this asteroid, which is kind of weird, because it's a small rock floating in space, so it's not going to have [an] actual ocean on it," said Prajkta Mane, a planetary scientist at the Lunar and Planetary Institute in Texas who was not involved with the research.

"In order to get something like these evaporites, you have to have a pocket of water that's evaporating," McCoy said. "I don't think we had any proof of that before, and now we do."

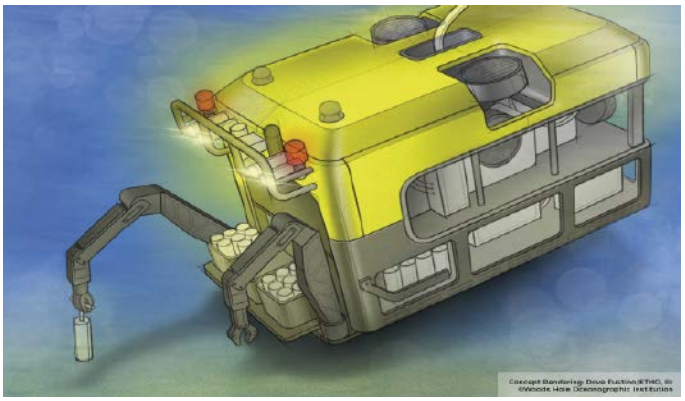
"These two sample sets really provide our first glimpse of a portion of the solar system that was previously poorly sampled."

That samples from both Bennu and Ryugu contain salts suggests that watery environments were common in the outer solar system, where the asteroids' parent bodies likely formed. "Processes that occurred on one likely occurred on many or most similar asteroids, and likely [on] icy moons," McCoy said. The salts resemble those recently discovered on the dwarf planet Ceres and on icy moons orbiting Jupiter and Saturn, which likely host subsurface oceans.

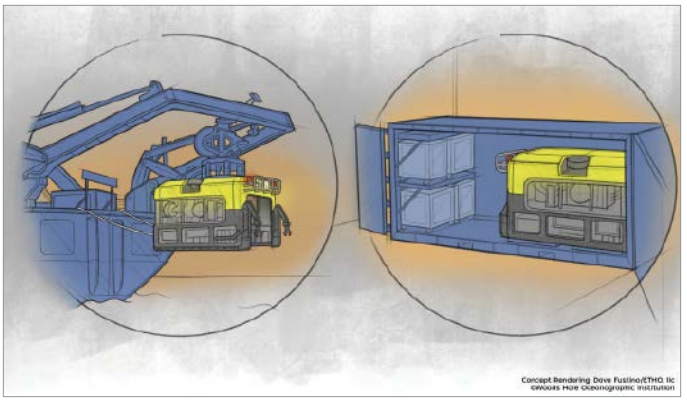
"These two sample sets really provide our first glimpse of a portion of the solar system that was previously poorly sampled," McCoy said.

By **Molly Herring** (@mollyherring.bsky.social), Science Writer

Two ROVs to Join the U.S. Academic Research Fleet



The Woods Hole Oceanographic Institution plans to produce two midsize remotely operated vehicles for use by scientists. Credit: Dave Fustino/ETHO, LLC/©Woods Hole Oceanographic Institution



The mROVs are designed to be used with three Regional Class Research Vessels that will operate in coastal and nearshore waters. Credit: Dave Fustino/ETHO, LLC/©Woods Hole Oceanographic Institution

In a review of the status of U.S. ocean sciences, published in February, members of the National Academies of Sciences, Engineering, and Medicine emphasized the need to invest in ocean research equipment. In doing so, they echoed calls from the ocean sciences community for more funding and support to maintain the United States' position as a leader in the field (bit.ly/forecasting-the-ocean).

"We have much work to do," the authors wrote. "We need all hands on deck."

Two new midsize remotely operated vehicles (mROVs), supported by awards from the U.S. National Science Foundation (NSF) and NOAA, will be part of that effort. The new submersibles will be used by scientists for undersea research in coastal and nearshore waters.

Design of the mROVs, led by the Woods Hole Oceanographic Institution (WHOI) and Greensea IQ, an ocean robotics company, has begun.

"We are eagerly anticipating the ability to support even more exciting science in some of the most challenging-to-access regions of the planet," said Brian Midson, program director for Ship and Submersible Support at the National Science Foundation, in a statement.

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Submersible Science

The current deep-submergence vehicles available to the U.S. scientific community as part of the Academic Research Fleet are operated by the National Deep Submergence Facility, a WHOI group funded by NSF, the Office of Naval Research, and NOAA. These vehicles include *Jason*, an ROV equipped with video and sampling equipment that is capable of submerging to 6,500 meters (4 miles); *Alvin*, which can carry three people and also submerge to 6,500 meters (4 miles); and *Sentry*, which is used for autonomous mapping and imaging and can submerge to 6,000 meters (3.7 miles).

"We are eagerly anticipating the ability to support even more exciting science in some of the most challenging to access regions of the planet."

The existing vehicles have played a "key role in advancing ocean science in the last decade," according to the National Academies report. However, they are designed to operate on existing ships within the Academic Research Fleet, which can limit their research scope. And growing interest from researchers in using ROVs in coastal and nearshore waters revealed a need for additional, smaller ROVs, according to the report.

In 2022, a committee at the University-National Oceanographic Laboratory System, which oversees the operation of the Academic Research Fleet, also recommended funding a new midsize ROV. "An NDSF [National Deep Submergence Facility] mROV would bring increased capability and accessibility to American deep-submergence scientists," the committee wrote.

"What is needed now are platforms that fill the niche between large, work-class vehicles such as *Jason* and small vehicles used primarily for observation," said Andy Bowen, director of the National Deep Submergence Facility, in a statement.

The two new mROVs are meant to operate with smaller crews and with a smaller footprint than the existing deep-submergence vehicles. They'll be able to reach depths of 4,000 meters (2.5 miles). Equipment such as cameras, lights, manipulator arms, sensors, and samplers will be added as needed, depending on mission requirements. The new mROVs will free up the ROV *Jason*, in particular, to prioritize science that requires the larger ROV, Midson said in the statement.

The two mROVs are designed to be used with three under-construction Regional Class Research Vessels intended for scientific missions in the coastal and nearshore waters of the Atlantic, Pacific, and Gulf of Mexico.

Sea trials for the mROVs are expected to start in 2026, according to an NSF spokesperson. They are planned to be available for use by the scientific community in 2027. One mROV will be operated by WHOI's National Deep Submergence Facility, and the other will be operated by the University of Southern Mississippi as part of the NOAA Ocean Exploration Cooperative Institute.

Deep-Sea Investigations

The mROV that the University of Southern Mississippi will operate is planned to support a project that aims to restore seafloor habitats damaged by the Deepwater Horizon oil spill in 2010.

Growing interest from researchers in using ROVs in coastal and nearshore waters revealed a need for additional, smaller ROVs.

"This ROV is going to be instrumental to the restoration effort," said Leila Hamdan, a marine microbial biologist and associate vice president for research for coastal operations at the University of Southern Mississippi, in a statement.

The new mROVs will also help scientists better understand the "vastly unexplored" deep ocean, which contains mineral resources such as polymetallic nodules and supports important fisheries, an NSF spokesperson said in an email.

"The mROVs themselves are only the tip of the iceberg," Bowen said in the WHOI statement. "The mROV concept advances exploration and understanding and we're excited to be expanding our impact through this unique new program."

Despite funding uncertainties, both projects are expected to move forward as planned, according to NSF and NOAA. However, NOAA public affairs officer Theo Stein wrote in an email that the agency "can't speculate on the effects of the recent terminations or how that may or may not affect certain programs."

By **Grace van Deelen** (@gvd.bsky.social), Staff Writer

The Deleterious Dust of the Salton Sea

Southern California's Salton Sea is evaporating. Credit: Dicklyon/Wikimedia, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

California's Salton Sea is impressive—it's the largest lake by surface area in the Golden State and a haven for migratory birds. But its waters also contain high levels of agricultural runoff. As the lake water evaporates, those pollutants are becoming increasingly concentrated, and the Salton Sea's shrinking shorelines are leaving behind a perimeter of dry, toxic dust.

Researchers recently mined hospitalization records and showed that people are more likely to experience respiratory distress when particulate matter blows from the Salton Sea. These findings could inform efforts to limit the health impacts of Salton Sea–derived particulates, according to the team.

Located roughly 260 kilometers (160 miles) southeast of Los Angeles, the Salton Sea is a vast inland lake. But it's shrinking: Water levels have fallen by more than 3 meters (9 feet) over the past 25 years. That's because the rate of water flowing into the lake—mainly due to agricultural runoff from farms in the surrounding Coachella and Imperial Valleys—is far lower than the rate of evaporation.

As the Salton Sea shrinks, wide swaths of dusty, dry lake bed known as playa are continuously being exposed. At the same time, the lake's waters are becoming more saline and rich in agriculturally important compounds such as nitrogen and phosphorus, conditions that can promote algal blooms.

William Porter, an atmospheric physicist at the University of California, Riverside, and his colleagues wanted to understand the implications of the lake's geochemical shifts. "For decades, there have been concerns about what that means for the ecology, what that means for animals in the environment, and what that means for people," Porter said.

Dust levels in the Coachella Valley routinely exceed national standards set by the U.S. EPA, and previous work showed that children living near the Salton Sea suffer from asthma at nearly twice the national rate.

"The air quality in the area is pretty darn suspect."

"The air quality in the area is pretty darn suspect," said Amato Evan, an atmospheric scientist at the Scripps Institution of Oceanography in La Jolla, Calif., who was not involved in the research.

Both the shoreline and the surface of the Salton Sea produce particulate matter that can become airborne. Credit: Marc Cooper/Flickr, CC0 1.0 (bit.ly/cc01-0)

Yaning Miao, previously a graduate student in Porter's research group, led the new work. Miao and her colleagues collected records of airborne particulate matter from six ground stations—three to the north of the Salton Sea and three to the south.

These tiny airborne particles can be readily inhaled and become lodged in the lungs, where they can have deleterious health effects.

The researchers focused on coarse particulate matter, which ranges in diameter from 2.5 to 10.0 micrometers. They gathered 12 years' worth of hourly data from 2008 to 2019, amounting to more than 630,000 individual measurements.

From Whence It Came

The team then used simulations of atmospheric transport to investigate what types of surfaces the dusty air had passed over before being measured. That step allowed the researchers to estimate how much dust had originated from various sources, including the Salton Sea. "For all the observations of particulate matter that are taken up and down the valley, we ran thousands and thousands of back trajectories to see where it was arriving from," Porter said.

Most of the dust the team analyzed came from landscapes dominated by shrubs or crops; less than 3% of the total dust mass likely came from the Salton Sea, the researchers estimated. But the big question was whether that Salton Sea–derived dust was more harmful than dust from other types of landscapes.

Miao and her collaborators also analyzed public hospitalization records for individuals living in zip codes within 5 kilometers (3 miles) of each of the ground stations. But working with health data is challenging, Porter said, because there are so many different factors that affect how many people are hospitalized on a given day. Day-of-week, seasonal, and annual trends can all have a significant impact on hospitalization numbers, he said.

"For all the observations of particulate matter that are taken up and down the valley, we ran thousands and thousands of back trajectories to see where it was arriving from."

The team tried to control for as many confounding variables as possible by comparing records from a particular day with the same day of the week in the same month of the same year. "We're only comparing apples to apples," Porter said.

The researchers found that the risk of respiratory-related hospitalizations increased by about 9% for each 10-microgram-per-cubic-meter increase in coarse particulate matter coming from the Salton Sea. A similar uptick in dust from the other nine landscape types was not statistically correlated with an increase in respiratory-related hospitalizations.

"This is a problem for many, many other communities."

Furthermore, the same increase in coarse particulate matter from the Salton Sea was associated with a nearly 25% increase in the risk of respiratory-related hospitalizations during times of algal blooms. Those numbers suggest that particulate matter coming from the water itself is particularly harmful to human health, Porter said. That finding can inform mitigation strategies.

Current efforts to address the poor air quality in the Salton Sea region have been largely focused on the playa surfaces. "We're talking about millions of dollars' worth of infrastructure work," Evan said. But such efforts may not be getting at the root of the problem, which appears to be particulate matter deriving from the water surface itself, he said. "This is a new finding."

These results were published in *Environmental Research: Health* (bit.ly/Salton-Sea-dust).

Unfortunately, the situation at the Salton Sea isn't unique—similar situations are playing out at other lakes worldwide, Porter said. Utah's Great Salt Lake is a prime example, he said. "This is a problem for many, many other communities."

By **Katherine Kornei** (@KatherineKornei), Science Writer

Buried Sediments Point to an Ancient Ocean on Mars

From alluvial fans to lake beds, Mars has no shortage of surface features that were clearly sculpted by flowing water. But evidence of a planetary-scale body of water on the Red Planet—that is, an ocean—has been comparatively lacking.

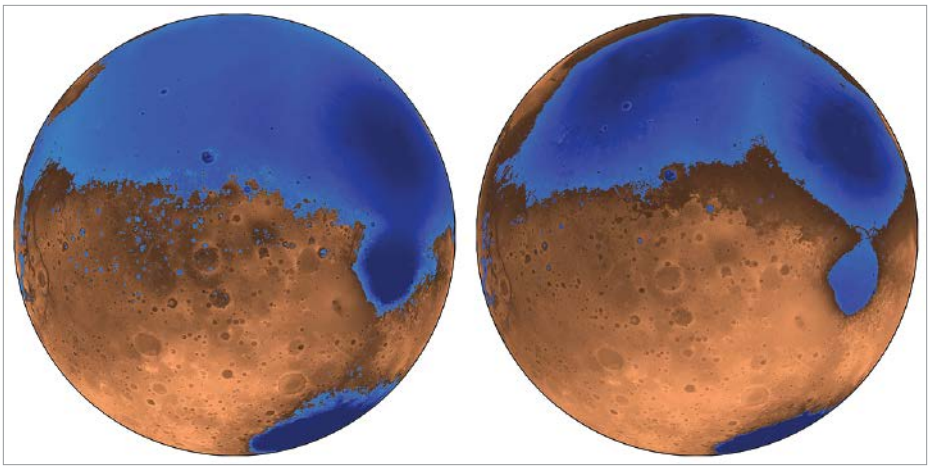
Now, researchers have analyzed radar data collected by a Mars rover and found buried sediments arranged much in the same way as terrestrial coastal deposits. The discovery is evidence that an ancient ocean once persisted over much of the Red Planet's northern hemisphere, according to the team.

In 2021, China's Tianwen-1 spacecraft touched down on Mars's northern hemisphere in the Utopia Planitia region. Its payload, the 250-kilogram Zhurong rover, spent the next 12 months making a 1,921-meter traverse of Mars's northern lowlands.

Some of the data the rover collected included ground-penetrating radar measurements. Ground-penetrating radar works by directing electromagnetic waves into the ground and measuring at what depths they're reflected by boundaries between different materials.

It's commonly used by geoscientists on Earth to map buried layers of sediment and is also used by archaeologists to find buried artifacts.

"It allows us to see beneath the Martian surface," said Hai Liu, a geophysicist at Guangzhou University in China. "We can generate a profile of the subsurface structure." Liu and his graduate student Jianhui Li, also a geophysicist at Guangzhou University, coled the new research.



Mars may once have hosted a large ocean covering much of its northern hemisphere. Credit: Robert Citron

A Layer Cake, but Tilted

The team used the radar method to probe tens of meters below the Martian surface.

The data revealed layers of sedimentary deposits that were tilted, like a partially collapsed layer cake. The tilt ranged from about 6° to 20°, sloping down to the north.

The level of tilting and its consistent orientation, similar to coastal sedimentary deposits on Earth, suggests that the region was once home to a coastline, the researchers concluded.

Shorelines Here and There

The idea that Mars once hosted an ocean isn't new—data from spacecraft orbiting the planet have revealed surface features consistent with shorelines roughly 300 kilometers south of Zhurong's location. (Some research has called those findings into question, however.) And one way of explaining the so-called Martian dichotomy—the stark difference in elevation, cratering, and crustal thickness between the planet's northern lowlands and southern highlands—is that much of the northern hemisphere was once under water.

If an ocean did once cover Mars's north, it must have retreated over time given that the Red Planet is a dry and dusty world today. That shrinking ocean would have left imprints of successive generations of coastlines north of its southernmost reach, said Abdallah Zaki, a geomorphologist at the Jackson School of Geosciences at the University of Texas at Austin who was not involved in the research.

Because Zhurong explored an area that might have once been a shoreline, it's logical for the rover to have spotted coastal deposits, said Zaki, who studies landscapes shaped by water on both Earth and Mars. "It makes sense."

It's unlikely that a smaller body of water such as a lake could have produced these deposits, Li, Liu, and their colleagues concluded. Lakes experience only limited tides, and their waves tend to be much smaller than those in oceans. The tilted sediments around lakes therefore tend to be significantly shallower than what the team measured.

These results were published in the *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/Mars-shoreline).

Going Underground

If there was once an ocean on Mars, future datasets could answer an important question: Where did all the water go? It's likely that some evaporated and was lost to space, but some of it could still be lurking under the Martian surface.

"A lot of it could have moved underground," said Michael Manga, a planetary scientist at the University of California, Berkeley and a member of the research team.

Last year, Manga and his colleagues published a study in which they used seismic data from the InSight lander on Mars to constrain the amount of water potentially permeating subsurface rocks. The team concluded that it was a lot, enough to cover the entirety of Mars to a depth of 1–2 kilometers.

Continuing to explore what lies beneath Mars's surface is critical to understanding how the Red Planet was influenced by water, Zaki said. "We need to get more subsurface data."

Zaki and other researchers are looking forward to the European Space Agency's upcoming launch of the ExoMars mission, which will include a rover known as Rosalind Franklin. The roughly 300-kilogram rover will be equipped with ground-penetrating radar and a 2-meter drill.

By **Katherine Kornei** (@KatherineKornei), Science Writer

First 3D Map of Exoplanet Weather Reveals Superfast Jet

An extreme exoplanet has gotten even more extreme in the eyes of astronomers. In mapping the 3D structure of its atmosphere for the first time, scientists have discovered that a high-speed atmospheric jet whips around WASP-121b, an ultrahot gas giant. They have also confirmed the presence of titanium in the planet's atmosphere, solving a mystery about the planet's atmospheric chemistry.

"This planet's atmosphere behaves in ways that challenge our understanding of how weather works—not just on Earth but on all planets."

"This planet's atmosphere behaves in ways that challenge our understanding of how weather works—not just on Earth but on all planets," said Julia Seidel, an astrophysicist at the European Southern Observatory (ESO) in Santiago de Chile and colead researcher on the discoveries. "It feels like something out of science fiction."

An ESPRESSO Boost

WASP-121b closely orbits a star bigger and hotter than the Sun in just 1.27 days, making its atmosphere a blistering 2,085°C (3,785°F). The so-called marshmallow planet is about 75% bigger but just 16% heavier than Jupiter. As WASP-121b zooms around its star, its low-density atmosphere distorts into the shape of an American or Australian football.

Astronomers have studied this planet extensively with ground- and space-based telescopes since it was discovered in 2016.

The planet is big and bright and easy to see against its similarly big and bright star. That made it an easy pick when astronomers needed to test a new observing mode of ESO's Very Large Telescope (VLT), a set of four 8-meter telescopes in Chile's Atacama Desert.

"They wanted to go for a safe choice when trying out the mode. WASP-121b fell into their lap," said Bibiana Prinoth, an astrophysicist at Lund University in Sweden and colead researcher on the discoveries.

In its new capacity, VLT's four telescopes combine their observing power and achieve the resolution of a telescope twice their size. That light can then be fed into the Echelle Spectrograph for Rocky Exoplanets and Stable Spectroscopic Observations (ESPRESSO) instrument, which produces a high-resolution visible-light spectrum.

Testing that mode during the instrument's commissioning phase in 2018, astronomers observed WASP-121b cross in front of its star and imprint its atmospheric spectrum on the star's light.

When researchers looked at the ESPRESSO spectrum, they noticed something weird about the spectral lines from sodium. Seidel proposed a second set of VLT observations, which took place in 2023.

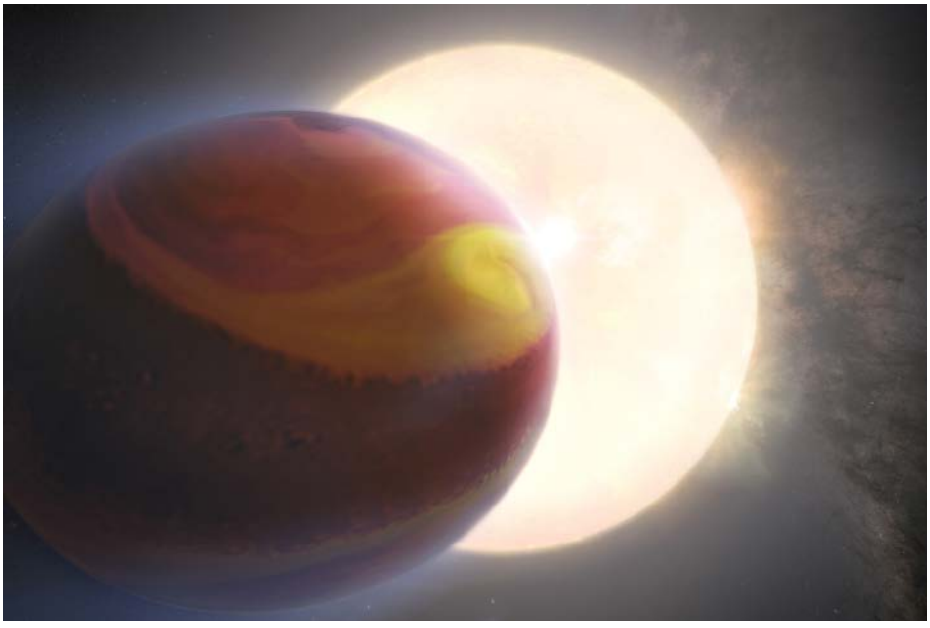
"I got my data as a follow-up to the strange thing that they saw completely by accident," Seidel said.

She and her colleagues homed in on the spectral signatures of iron, sodium, and hydrogen, which were emitted from different depths within WASP-121b's atmosphere. The planet's puffiness helped turn its transmission spectrum into a 3D map of its atmosphere.

"I got my data as a follow-up to the strange thing that they saw completely by accident."

As a star's light passes through a planet's atmosphere, each wavelength of that light penetrates down to a different atmospheric depth, called the optical depth. An element's strongest emission lines come from the physical depth that matches its optical depth. For planets of average density, those optical depths correspond to roughly the same physical depths, so transmission spectra map an atmosphere in one or two dimensions.

But for marshmallows like WASP-121b, those optical depths are more physically spread out, allowing astronomers to use the transmission spectrum to create a 3D map. Using atmospheric circulation models, the researchers traced the movement of material in three layers in the planet's upper atmosphere—its "outer whimsical shell," Seidel called it.



WASP-121b, illustrated here, orbits so close to its star that it has deformed into an oblong football shape. Credit: NASA, ESA, Quentin Changeat (ESA/STScI), Mahdi Zamani (ESA/Hubble), Public Domain

Superspeed Jet and Hidden Titanium

In the deepest observed layer, traced with iron's spectral signature, the team found that heat flows from the planet's permanent dayside to its permanent nightside both clockwise and counterclockwise. This behavior is typical for hot gas giant planets that, like WASP-121b, are tidally locked to their star, Seidel explained. In the shallowest observed layer, traced with hydrogen's spectral lines, the team confirmed the puffy planet's football shape, which is most pronounced in the outermost layer.

"We have given it to the theorists, and they have to fix it now."

In the middle layer, traced with sodium, an atmospheric jet zips around the planet's equator faster than the planet's rotation. The oddity that first caught Seidel's attention was the atmospheric jet distorting sodium's well-known spectral lines.

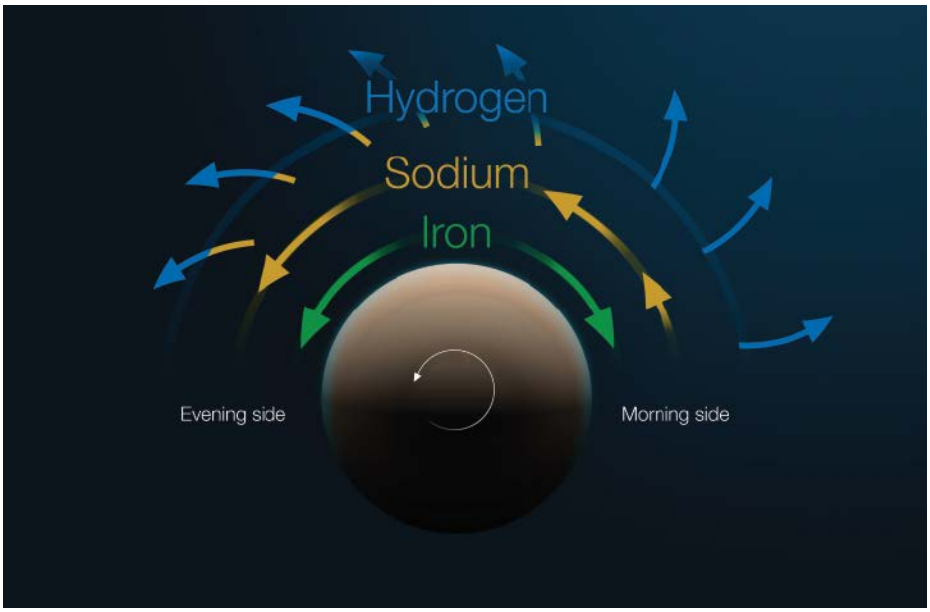
The observation is a first, Seidel said. In solar system planets, atmospheric jets flow through deeper layers, and shallow layers dominate heat transport. For WASP-121b, "it's flipped, and that's weird, and we don't know why."

What's more, the jet accelerates as it travels across the planet's dayside, speeding up from 14 kilometers per second in the morning to about 27 kilometers per second in the evening.

"We have given it to the theorists, and they have to fix it now," Prinoth joked.

That the upper and lower atmospheres flow so distinctly suggests different mechanisms drive wind in each layer, said Elspeth Lee, an exoplanet climate modeler at the University of Bern in Switzerland who was not involved with this research. "This has been suggested in previous 3D atmospheric modeling efforts…but these observations provide much needed observational evidence of this phenomenon and provide guidance as to where 3D models require future improvement."

The observations also revealed that WASP-121b's atmosphere contains titanium, which is known to shape the temperature and pressure structures of hot Jupiter atmospheres. Astronomers have debated for years whether WASP-121b has titanium—some telescopes could see it, whereas others could not. Prinoth explained that the signal from titanium was weaker than they expected it to be, which might explain conflicting past reports.



The upper atmosphere of WASP-121b contains three distinct layers, diagrammed here in a top-down view from one of the planet's poles. In the deepest layer, traced with spectral features from iron, winds carry heat in both directions from the dayside to the nightside. In the middle layer, traced with sodium, an atmospheric jet speeds around the planet's equatorial region faster than the planet's rotation. In the upper layer, traced with hydrogen, the star's intense radiation puffs up the atmosphere to a low density, distorts the planet's shape, and causes some of the atmosphere to be lost to space. Credit: ESO/M. Kornmesser, CC BY 4.0 (bit.ly/ccby4-0)

"There must be some mechanism that depletes it from the atmosphere or from the gas phase," Prinoth said.

"These two studies pave the way for a super promising ELT era of exoplanet atmosphere characterization."

"This new [VLT] capability allowed a much deeper dive into the atmospheric composition and dynamical structure of WASP-121b, a canonical and well-studied ultrahot Jupiter, than ever before," Lee said. This is also the strongest evidence yet that WASP-121b's titanium exists and is just trapped deep within the atmosphere, "hiding it from being detected at expected levels," she added.

The results were published in *Nature* and *Astronomy and Astrophysics* (bit.ly/exoplanet-jets, bit.ly/WASP-121b-titanium).

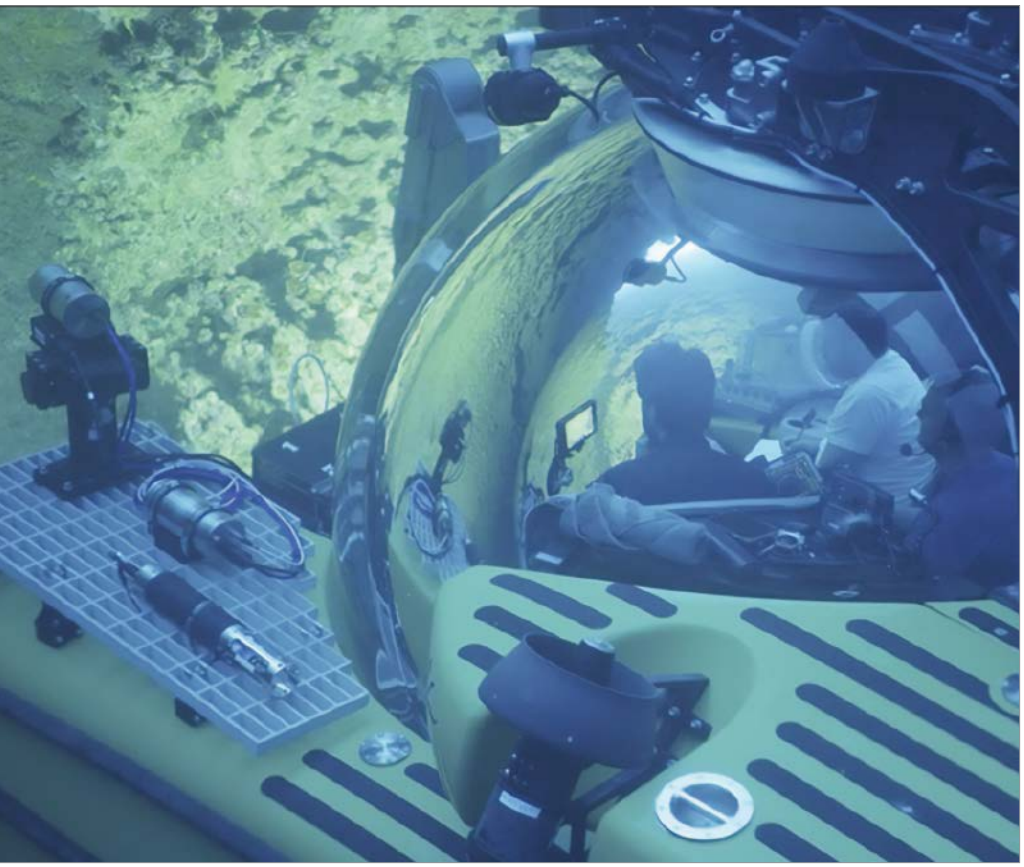
These observations of WASP-121b push the boundaries of what current telescopes and atmospheric models can map within exoplanetary atmospheres, Prinoth said. Prinoth, Seidel, and their colleagues plan to use the new VLT observing mode to study planets a bit smaller than WASP-121b and those on peculiar orbits.

Observations will help astronomers prepare for the next generation of giant ground-based telescopes, like the Giant Magellan Telescope or ESO's upcoming Extremely Large Telescope (ELT), which will provide even higher resolution spectra and enable this kind of 3D atmospheric study of planets that more closely resemble Earth.

"These two studies pave the way for a super promising ELT era of exoplanet atmosphere characterization," Lee said.

By **Kimberly M. S. Cartier** (@astrokimcartier.bsky.social), Staff Writer

Red Sea Corals Survived the Late Glacial Crisis



Sam Purkis and other crew members aboard the OceanX Triton submersible approach a deepwater coral mound in the Red Sea. Credit: OceanX

Slowly descending hundreds of meters into the Red Sea, Sam Purkis looked out the bubble-like window of a Triton submersible into the darkness. He was hunting for long-dead corals scattered on sea mounds.

"It's like being on a spacecraft."

"It's like being on a spacecraft," said Purkis, a marine geoscientist at the University of Miami. He and Ph.D. student Morgan Chakraborty have been collaborating with OceanX to collect fossil deep-sea corals throughout the northern Red Sea since 2020.

Some of these fossils revealed that corals had grown during a catastrophic drop in sea level during the Last Glacial Maximum, a time when scientists thought life couldn't survive there. That's according to a new study published in the *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/Red-Sea-corals).

During the Last Glacial Maximum (around 19,000–26,500 years ago) the water level of the Red Sea dropped to almost 120 meters below what it is today. The event isolated the gulf from the Indian Ocean and contributed to a salinity crisis—water evaporated and, without inflow from the ocean, salt concentrated in the Red Sea basin.

Because single-celled organisms known as planktonic foraminifera (forams) were absent from seafloor sediments deposited during this period, scientists thought that high salinity must have completely extinguished life in the Red Sea.

But forams tend to live in shallower water and move around, so they offer only a limited picture of the ocean ecosystem, said Beverly Goodman, a marine geoarchaeologist at the University of Haifa in Israel who has done research in the Red Sea but was not involved in the new study.

"It's incredible to find these corals growing when conditions were so much different than they are now."

To find out whether other organisms survived the salinity crisis, Purkis, Chakraborty, and their colleagues turned to fossil corals. Unlike motile forams, "corals are sessile. So they were definitely alive in the particular position we were sampling," Purkis said.

A Coral Time Machine

During three expeditions in the submersible, the researchers collected 27 fossil coral samples belonging to two species, *Rhizosmilia valida* and *Leptoseris striatus*, which still exist today, Chakraborty said.

The corals started life in deep-sea mounds before they died and slowly cemented into rock. The now-fossilized corals sit within beds that are exposed in mounds on the seafloor. The submersible pilots tried to use a mechanical arm to sample fossils directly from the beds, but the corals were attached so strongly that "even the hammer of Thor wasn't going to get [them] out of it," Purkis said. Instead, the team gathered fossilized coral that fell onto the seafloor below.

In the laboratory, the researchers compared uranium-thorium ages from the corals, which reveal when they were living, with data from radiogenic strontium isotopes, which document sea level fluctuations, and oxygen isotopes, which indicate water salinity.

Leptoseris corals were 900–7,800 years old, younger than the salinity crisis. But to the researchers' surprise, the *Rhizosmilia* corals were 800–17,800 years old. The older

corals were alive during the Last Glacial Period. "That was the eureka moment of the study," Purkis said.

Consistent with previous research, the strontium isotope ratio of the oldest coral indicated that when the corals were alive, the water level was more than 110 meters below current levels. Salinity was about 10% higher than it is today.

"It's incredible to find these corals growing when conditions were so much different than they are now," Chakraborty said.

The results could mean that Red Sea corals evolved to be a little more tolerant than other corals, Goodman explained. She cited recent studies demonstrating the resilience of Red Sea corals (bit.ly/resilient-coral-1, bit.ly/resilient-coral-2).

But Purkis was hesitant to endorse this conclusion. "Typically, an organism as it exists today holds up to how it existed in the past," he said. Such a pronounced change in biological traits would require rapid evolution, which he argued is unlikely within the relatively short time frame.

Their analyses could, instead, suggest that even when the sea level was at its lowest, changes in water temperature and salinity weren't as drastic as previously reported and may well have been within a range that the deepwater coral could tolerate, Purkis said.

"I think it really shows how dramatic the human impact on present-day climate is."

The findings put the current climate reality in context, Purkis said. The fossils show that these delicate corals were able to survive major changes on the planet, he said. "Yet today, it's a complete massacre. I think it really shows how dramatic the human impact on present-day climate is."

Both Purkis and Goodman agreed that more studies are needed to understand the ebbs and flows of the species that survived various conditions in the Red Sea. "The Red Sea is unique in just so many ways but so poorly understood," Purkis said.

By **Kristel Tjandra** (@ktjandra.bsky.social), Science Writer

Brazil's Rivers Are Leaking

The São Francisco River in northeastern Brazil may be shrinking because of wells pumping groundwater. Credit: Fronteira/Wikimedia Commons, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

In 2017, Paulo Tarso Oliveira, a professor of hydrology at the Universidade de São Paulo, came across a news report about a small village along the banks of the São Francisco River, one of the main rivers in northeastern Brazil.

The article said villagers were experiencing unusually high rates of high blood pressure, and linked the anomaly with the region's dry climate and low river flow. As the water table dropped, ocean water began infiltrating the region's groundwater, raising salt levels in the water supply and making people sick.

Intrigued, Oliveira investigated further. Streamflow was slowing, he later found, because wells were pumping water from the aquifer below. "Oftentimes, people don't realize, but surface and groundwater are connected and must be seen as an entirety," Oliveira said.

In places where a water table lies beneath a riverbed, the river can leak water down into the aquifer. This process, known as streamflow leakage, occurs naturally depending on underlying rock formations and groundwater levels, but the construction of wells that overpump water from aquifers may intensify the issue.

The situation in the São Francisco basin is not unique, Oliveira and his colleagues found. In evaluating wells across Brazil, the researchers discovered that water levels in more than half the wells were below the level of nearby streams.

Mapping Wells

In 2023, Oliveira and master's student José Gescilam Uchôa began mapping Brazilian rivers to identify areas at risk of water loss. They relied on public data on river levels and the locations of wells from the Geological Survey of Brazil. The data, however, were insufficient for most of the registered wells. As a result, they focused on 18,000 wells with comprehensive data spread across thousands of rivers in Brazil.

The researchers compared the water level in each well with the elevation of the nearest stream. In 55% of the wells, water topped out below the elevation of neighboring streams.

"Our data suggest that the groundwater use is significantly impacting the rivers'

José Gescilam Uchôa takes measurements in a river in São Paulo. Credit: Laboratório de Hidráulica Computacional da Universidade de São Paulo

streamflow," Uchôa said. "This is and will continue to be a growing worry for water management in the country."

The study, published in *Nature Communications*, also identified critical regions, including the São Francisco basin, where more than 60% of rivers may be losing water because of extensive groundwater pumping (bit.ly/BR-river-leaks). Pumping is mainly associated with irrigation activities.

In the Verde Grande basin in eastern Brazil, where irrigation is responsible for 90% of water consumption, 74% of rivers may be losing water to aquifers.

Oliveira thinks the results are conservative and that the situation could actually be worse because the researchers did not account for illegal wells. A 2021 study by geologist Ricardo Hirata, also at the Universidade de São Paulo, estimated that around 88% of Brazil's 2.5 million wells are illegal, lacking a license or registration for pumping (bit.ly/BR-illegal-wells).

Hirata, who was not involved with the new work, warned that the new study was limited to only 5% of existing wells, primarily located in regions where groundwater is more intensely exploited.

He also stressed that though the researchers identified rivers that are potentially losing water to aquifers, these data alone are insufficient to determine whether the rivers are drying up. To assess that, other factors would need to be considered, such as the amount of water extracted from an aquifer compared to the river's streamflow, how connected the aquifer is to the river, and how much water is drawn from the aquifer in relation to seasonal variations in streamflow.

"The fact that the water level of a well is lower than that of a nearby river doesn't necessarily affect the river or the aquifer," Hirata said.

The areas identified as critical by the study are mostly arid regions where stream leakage was expected to occur naturally, pointed out hydrologist André F. Rodrigues at the Universidade Federal de Minas Gerais in Brazil. Rodrigues was not involved with the research.

The study is important because it highlights a growing issue, he said, but more local analyses are necessary to get a more detailed picture of the problem and consider, for example, the effects of climate and seasonal changes. "Perhaps this is also happening in other parts of the country with high irrigation demands, and we just don't know it because we lack data," Rodrigues said.

Overexploitation of groundwater is a global concern.

A Growing Issue

Uncontrolled expansion of wells and excessive pumping not only affect people's health, water supplies, and agriculture but also can make soil unstable, leading to ground sinking (subsidence). Similar phenomena have been observed in regions of China, the United States, and Iran.

The outlook is not good for Brazil. Wells will likely multiply because irrigated land areas are expected to increase by more than 50% in the coming 20 years, according to the Brazilian water agency.

"We will likely see a vicious cycle of degradation, where a decrease in surface water quality and quantity, coupled with an increase in drought periods, will force farmers to drill more wells for food production, further intensifying groundwater extraction and exacerbating the problem," Oliveira said.

Overexploitation of groundwater is a global concern. Most aquifers have declined in the 21st century, and modeling studies suggest that stream leakage will become more common in the coming decades. Still, the issue is largely overlooked in tropical places such as Brazil, which holds 12% of the world's renewable water resources.

This oversight is partly due to a lack of funding and surveillance and partly due to a long-standing belief that rivers in tropical and humid countries mostly gain water from aquifers rather than losing it, Oliveira said. "We must act to avoid having entire regions devastated in the future."

Researchers are calling for more studies and systematic monitoring of wells to identify critically dry areas and assess the impact on rivers of drilling new wells. Brazil has only 500 observational wells that are constantly monitored by the government, compared with 18,000 in the United States, despite the countries having similar land area.

"Surveillance is extremely important and highly undervalued," Uchôa emphasized.

By **Sofia Moutinho** (@sofiamoutinho.bsky.social), Science Writer

Expedition 403: Sailing the Last Expedition of the *JOIDES Resolution*

Scientific ocean drilling (SciOD) aboard the riserless drill ship *JOIDES Resolution* (JR) provided unique opportunities and laid career foundations for thousands of scientists who participated as early-career researchers (ECRs). Hundreds of JR alumni have continued sailing throughout their careers, thriving in the fast-paced environment, conducting science at sea, and working with collaborators from all over the world.

On 30 September 2024, the contract between the National Science Foundation (NSF) and SEA1 Offshore (the private company that owns the JR) came to an end, with no plan in place for a replacement vessel.

Expedition 403 concluded the scientific work of the JR and was the second-to-last expedition of the International Ocean Discovery Program (IODP), "an international marine research collaboration that explores Earth's history and dynamics using ocean-going research platforms to recover data recorded in seafloor sediments and rocks and to monitor subseafloor environments."

The JR drilled its last cores along the western margin of the Svalbard archipelago. The selected sites sit along a major ocean gateway modulating the flow of currents between the North Atlantic and Arctic oceans. Questions regarding changes in meridional overturning circulation, the climatic evolution of Northern Hemisphere ice sheets, and so much more can now be more fully addressed with 5.5 kilometers of newly acquired marine sediment cores.

"After analyzing a few thousand meters of sediment, one earns the badge 'Professional."

Sailing as an ECR on the last expedition of the JR came with heartbreak and longing alongside the excitement. Aside from the cutting-edge science that can be conducted with the newly cored sediments, Expedition 403 was incredibly special to the three scientist-authors on board, as it was led by two women, it involved a very diverse and international group of scientists, and the majority of the U.S.-based science party were ECRs and women.

From left, Adriane Lam, Aruggoda K. Isuri U. Kapuge, Yi Zhong, and Nicole Greco sing karaoke on the helipad deck of the JOIDES Resolution, *celebrating the return of night after sailing out of the Arctic Circle. Credit: Khyber Jones/IODP*

Here three ECR share their personal accounts of sailing on the last voyage of the JR. These accounts have been edited for length and clarity.

Who We Are and Who We Were on Board the JR

Adriane Lam: My research lies in three main arenas: paleontology, paleoceanography, and science communication (SciComm). I use fossil marine plankton to investigate evolutionary processes through geologic time, and the chemical signatures of those same fossils help me reconstruct the behavior of surface currents across analogue warm periods. Within SciComm, my colleagues and I study how best to conduct outreach on social media platforms.

However, on Expedition 403, the three of us sailed as sedimentologists.

Gryphen Goss: I am not a sedimentologist—I'm more of an isotope geochemist—but as Adriane said, on Expedition 403 I sailed as a sedimentologist. This role provided me with a whole new skill set (characterizing sediment deposited over millions of years) and a new perspective on marine glacial environments.

For 2 months, each day on the JR involved 12 hours of sediment analysis, one 10-meter section at a time. Analysis included precise identification of lithology (clay, silt, silty clay, sandy mud), color (10R 4/1—know your Munsell color chart), boundary contacts (curved), clasts (how many and what size), and much more. After analyzing a few thousand meters of sediment, one earns the badge "Professional."

Thankfully, after the day shift and midnight dinner, I could sip tea on the bow or escape to the gym to hangboard.

Gryphen Goss (left), Alba Gonzalez-Lanchas, and Sijin K. A. Veedu are appropriately garbed in the sedimentology lab aboard the JOIDES Resolution. *Credit: Sijin K. A. Veedu*

Nicole Greco: Although I have since transitioned my work more toward science outreach and communication, my background is in glacial sedimentology, where I used particle size as a proxy for meltwater events and bottom current speeds. Although I joined the expedition with experience describing and sampling sediment cores, the pace and number of cores far surpassed anything I had previously done.

Sailing as ECRs

Adriane: Expedition 403 was my third on the JR. I first sailed on Expedition 371 to the Tasman Sea when I was a second-year Ph.D. student in 2017 and participated as a shore-based scientist on Expedition 393 in the southwestern Atlantic when I was a postdoc in 2022. Sailing during three phases of my career was amazing, as I became more and more independent and confident during each expedition.

Read the article at Eos.org

Sailing with IODP literally launched my career, as I was able to grow an international team of colleagues quickly and branched out into other research avenues. Today I get to train my undergraduate and graduate students to conduct research on SciOD data and samples, and some have even participated on seagoing expeditions and opportunities!

> **"If you ever wanted to conduct a social experiment to see 25 scientists slowly revert to childlike behavior over a 2-month period, the JR would be a great laboratory."**

Gryphen: My involvement with the IODP began in August 2021, when I started my Ph.D. My supervisor, Dr. Alan Rooney, handed me more than a hundred sediment samples collected from two sites drilled in the North Atlantic and said, "Get to work." After completing my first project investigating the regolith hypothesis using radiogenic isotopes, I requested samples from the Bremen IODP core repository from the Scotia Sea in the Southern Ocean to study how ice sheets in opposing hemispheres evolved at the same time.

As someone who is very much a field scientist, I was itching to do fieldwork and was finally fortunate enough to sail for the first time on Expedition 403.

Sailing as an early-career scientist seemed somewhat counterproductive, however. On the one hand, I learned the intricacies of working both on the JR and within the realm of SciOD and connected with incredibly inspirational senior scientists. But at the same time, those skills won't be fully used due to the program being terminated.

Nonetheless, like many who have sailed on the JR, my experience was truly addictive. I would like to return to the same cabin—upper 'tween 4-14—and characterize sediment all day, but unlike those who have sailed in the past, my fellow 403ers and I will not get that chance.

Nicole: Although my involvement with the IODP began in 2019 at the start of my Ph.D., Expedition 403 was my first time sailing. In early 2020, I had secured funding to travel to the Oregon State University Marine and Geology Repository to collect sediment samples from Antarctic cores, an opportunity that I would not get to complete until years later due to the pandemic. This delay resulted in relying on published data and coding throughout the majority of my Ph.D., which was an amazing learning opportunity but not the field or lab work I had envisioned.

Sailing on Expedition 403 was my first opportunity for fieldwork and began less than a month after my graduation. I was driving to my grandparents' house in south Florida when I received the news that I was invited to sail and was immediately overwhelmed. With tears of excitement, as I knew I was finally going to step into the shoes that some of my role models, including my graduate adviser, John Jaeger, had filled on past expeditions.

Prior to Sailing

Nicole: As excited as I was to sail, I became so nervous prior to leaving for Amsterdam (our expedition's departure point) that I almost considered backing out. Life seemed

incredibly hectic at the time, having just graduated and knowing I was moving from Florida to California just weeks after returning from the expedition.

My partner convinced me I would forever regret not taking the leap, and I'm so glad I listened to him. As soon as I arrived at the airport and met up with my friend and shipmate Lindsey Monito, I could not have been more excited to get to the JR.

Gryphen: As someone who thoroughly enjoys physically collecting data to then process and analyze, I was very excited to sail into the Arctic. The idea of working 12-hour shifts while possibly seasick, however, wore on me in the days leading up to the expedition. In the end, the feelings of worry were far from necessary. There was no worry, just blissful excitement!

Adriane: I always get super nervous before an expedition, but this was the first expedition I participated in after being diagnosed with depression and anxiety. Being on medication to help manage both conditions was a game changer for me. The over-the-top presailing anxiety was minimal, and as such, excitement about the experience was at the forefront! I also knew this expedition would be heartbreaking, being the last.

Life Aboard the Final Expedition of the JR

Gryphen: The first challenge while sailing, and sailing on the JR specifically, is adjusting to 12-hour shifts and locking in a routine. For me, the gym was truly a lifesaver after midnight dinner. Sailing in the Arctic in 24-hour sunlight made this routine much more manageable.

Getting accustomed to wearing the same two to three outfits every day for 60 days and the slight unpleasantness of the desalinated water from the shower and sink were also a bit of a challenge.

Adriane: The main challenges for me while at sea are always getting to know everyone else (I'm an introvert) and fighting the urge to run to my room after shift instead of socializing.

But these weren't a huge deal on Expedition 403, as the team was *amazing* and I quickly became close friends with a lot of the other scientists! After friendships were formed, the biggest challenge was trying to not have too much fun so I could get my work done.

Nicole: If you ever wanted to conduct a social experiment to see 25 scientists slowly revert to childlike behavior over a 2-month period, the JR would be a great laboratory.

The sedimentology team huddles around one of the last sediment cores to be drilled by the JOIDES Resolution. *Clockwise from bottom left: Yusuke Suganuma, Catalina Gebhardt, Aruggoda K. Isuri U. Kapuge, Nicole Greco, Gryphen Goss, Adriane Lam, and Sijin K. A. Veedu. Credit: Adriane Lam/IODP*

If you've had the pleasure of sailing on an expedition, you know how mundane your days can become. No matter how much you love looking at gray mud or small wiggles of data on a screen, it's difficult to find ways to break up each shift.

The excitement of seeing whales, the midnight Sun, rainbows, or sea ice, of enjoying a new dessert in the mess hall, of having enough data to download a new playlist, or of taking part in an unexpected dance party—any of these incidents was enough to make us all jump up and down like we'd never experienced them before.

The Last Cores

Adriane: The day the JR drilled its last sediment core was honestly the worst day I've experienced while at sea. This was the last time the techs would work together to bring a core on deck, the last time the roughnecks would work the drill string, the last time the driller would be in the doghouse.

In a blog post for timescavengers.org I outlined my feelings during the last day of coring in a blog entry.

Gryphen: As the final sections of cores were brought aboard the JR, the overall atmosphere on the ship drastically shifted. Reality hit us like a drifting iceberg and the realization that 40+ years of scientific ocean drilling, science that shaped and molded our understanding of the Earth through time, were coming to a cold, hard end at 79°N.

What I found most unexpected was the emotions felt not just by the scientists but by the crew. I was so unaware of the community and relationships that came with being on the JR. Crew members who spent 6 months of every year together aboard the JR, truly a tight-knit family, were now being pulled apart by the expiration of a long-standing contract.

Nicole: There were only two times I cried while on the JR: when I was seasick in the North Sea and thought I might not survive the transit and watching the marine technicians hug after carrying in the final core to the onboard lab. Although it was impossible for the scientists to understand the emotions of the techs and crew—we were present only for a fraction of the time that they spent on board—the day was somber for everyone involved, and it felt like one big family mourning the loss of their home.

What the *JOIDES Resolution* and SciOD Mean to Us

Gryphen: The mission of the IODP itself—the decades of sheer determination required to explore the world's oceans every month of every year, to collect kilometers of sediment simply to aid in our understanding of the Earth system—is incredibly motivating.

The program has provided past and future generations with unlimited research potential through repositories filled to the brim with samples that can be delivered to your door. The IODP has made a once-expensive and relatively inaccessible sample collection accessible to any scientist from anywhere.

Nicole: I'll never forget the day I received the invitation to sail on Expedition 403. It was a once-in-a-lifetime opportunity.

As a glacial sedimentologist, I rely on marine sediment cores as the primary source for reconstructing glacial cyclicity and past climate in polar regions. Collecting new cores is crucial because legacy sediment cores from previous Arctic expeditions contain little or no material spanning the most important climatic periods (warm periods that are analogues to today's warming scenarios) because of the destructive analytical methods used on them and/or because of degradation with age.

Past ice sheets and the climatic conditions under which they existed can provide a vast amount of information that can be used to make predictions about the future of icy regions under a warming climate. In addition, due to the danger and remoteness of glacial regions, it is difficult and incredibly expensive to collect near-ice measurements that can tell us about the *current* stability of ice sheets.

Professional and scientific opportunities provided by the JR will be missed; many regions around the globe have yet to be explored and have the potential to hold key information on climate transitions and glacial changes throughout time, emphasizing the need for scientific ocean drilling to continue.

Adriane: Scientific ocean drilling meant, and still means, everything to my career. I mourn the loss of the IODP for the next generations of ocean scientists, who will never get the opportunity to sail on such an amazing ship.

It is mind-blowing that the United States, which has classified climate change as a national security threat, pulled funding from this singular program that has obtained data that are integral for understanding how Earth systems processes can change and operate under conditions of increased atmospheric carbon dioxide. These data can help identify regions that will be most affected by climate change in the future. The decision not to renew the contract between NSF and SEA1 Offshore is one of the most disheartening and shortsighted decision made by a U.S. funding agency.

The loss of the program is a huge loss for the United States, not just for the science community.

By **Adriane Lam** (alam@binghamton.edu), Binghamton University, Binghamton, N.Y.; also at Time Scavengers; **Gryphen Goss,** Yale University, New Haven, Conn.; and **Nicole Greco,** Arctic Data Center and Learning Hub, National Center for Ecological Analysis and Synthesis, University of California, Santa Barbara

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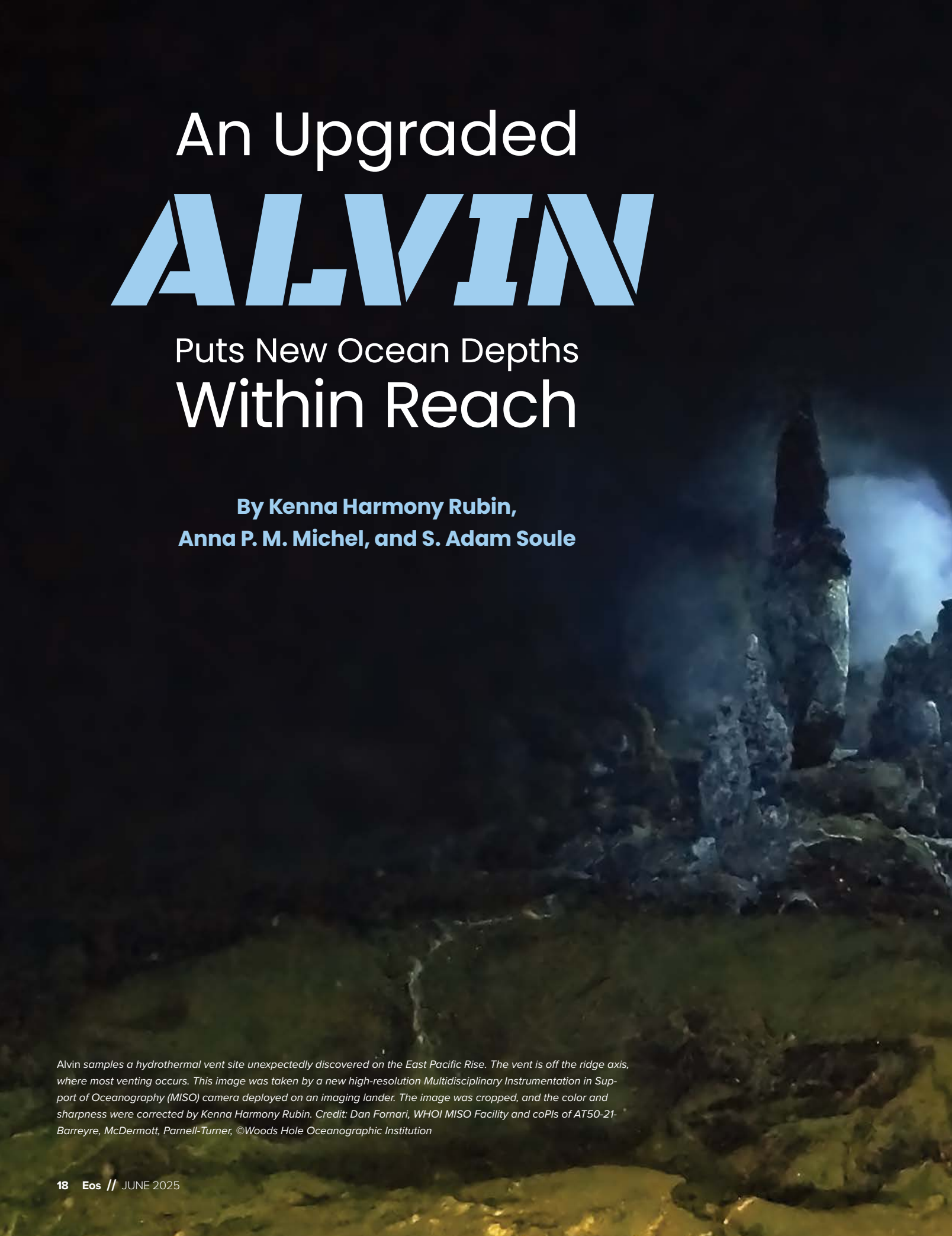
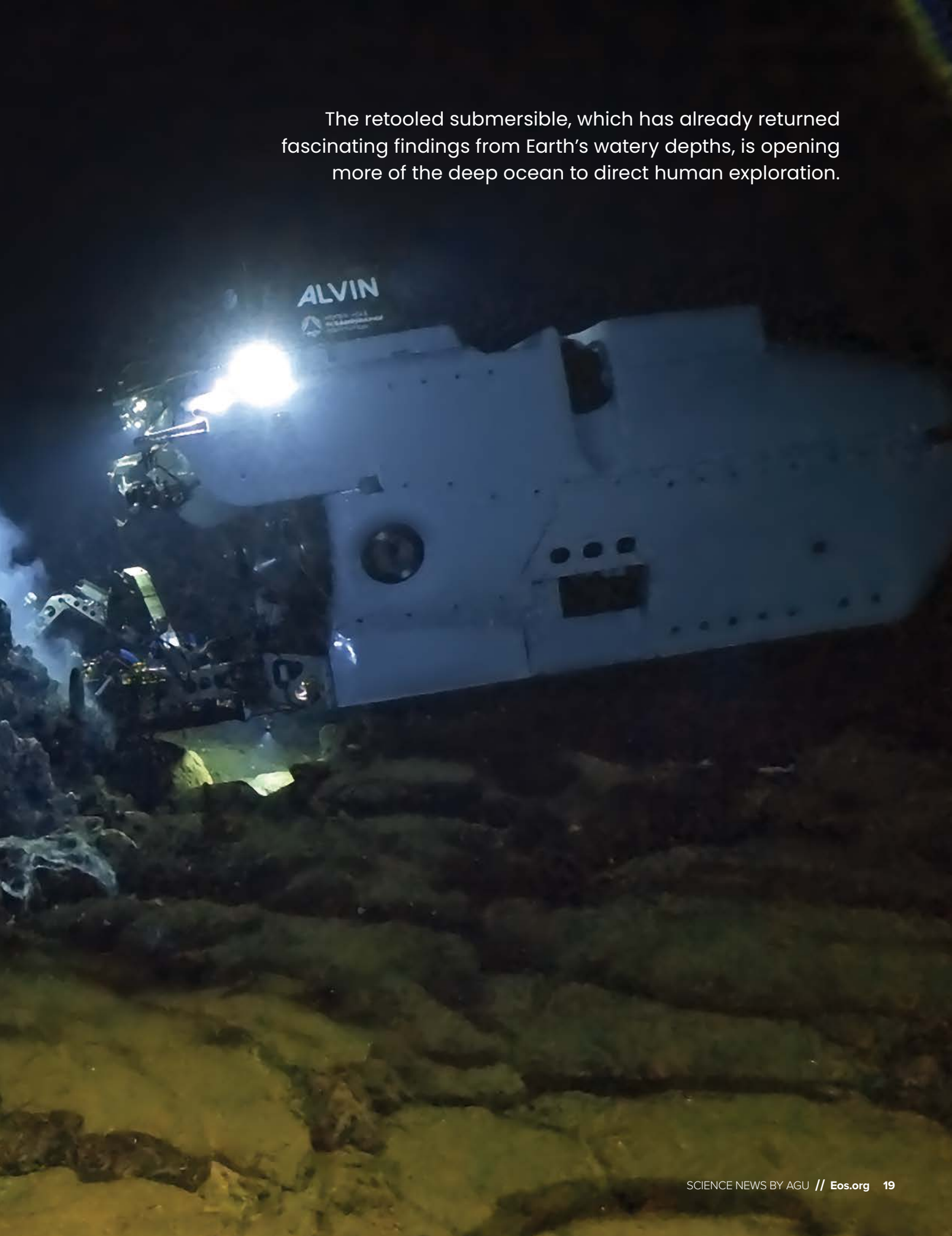
An Upgraded ALVIN Puts New Ocean Depths Within Reach

By Kenna Harmony Rubin, Anna P. M. Michel, and S. Adam Soule



Alvin *samples a hydrothermal vent site unexpectedly discovered on the East Pacific Rise. The vent is off the ridge axis, where most venting occurs. This image was taken by a new high-resolution Multidisciplinary Instrumentation in Support of Oceanography (MISO) camera deployed on an imaging lander. The image was cropped, and the color and sharpness were corrected by Kenna Harmony Rubin. Credit: Dan Fornari, WHOI MISO Facility and coPIs of AT50-21-Barreyre, McDermott, Parnell-Turner, ©Woods Hole Oceanographic Institution*

The retooled submersible, which has already returned fascinating findings from Earth's watery depths, is opening more of the deep ocean to direct human exploration.



Remotely operated and autonomous vehicles offer valuable access to these regions, but there is no substitute for direct human observation.

The deepest regions of Earth's oceans, known as the abyssal and hadal zones, lie at least as far under the water's surface as Mount Rainier's peak rises above the flat land surrounding it. These great depths of 4,000 or more meters make up one of Earth's least explored frontiers and are home to some of its most extreme environments and habitats.

The conditions in these regions—immense pressures, cold temperatures, and the total lack of sunlight—shape the physical, chemical, and geological phenomena that occur there in ways both predictable and surprising [e.g., *Marlow et al.*, 2021]. They also support unique life-forms that—far removed from the sunlit world above—thrive on alternative energy sources such as hydrothermal vents, seeps, and whale falls.

This part of the ocean remains largely unexplored because of the technical challenges of reaching such depths. However, potential discoveries within abyssal and hadal regions—such as dark oxygen, critical mineral resources, pressure-adapted extremophilic organisms, distinct ecosystems, archaeological sites (e.g., submerged human artifacts, including shipwrecks), and otherwise unknown landscapes—reinforce their allure. Remotely operated and autonomous vehicles offer valuable access to these regions, but there is no substitute for direct human observation: The situational awareness and targeted, delicate sampling that human-occupied vehicles (HOVs) enable are unique capabilities.

Yet the small number of vehicles capable of reaching abyssal and hadal depths—and the even smaller subset that can safely carry humans—limits the ability to explore them.

A key tool for this exploration is the deep submergence vehicle *Alvin*, the world's longest-operating and most productive human-occupied deep-sea submersible, with more than 5,000 dives completed in its 60 years of operation. *Alvin* recently underwent a significant upgrade, allowing it to reach depths of up to 6,500 meters, surpassing its previous limit of 4,500 meters.

The upgrade and a capstone science verification expedition (SVE) represent more than a decade of planning, scientific and engineering input, and technological development that have opened new possibilities for deep-sea research. With *Alvin*, researchers now have access to roughly 99% of the ocean floor (Figure 1), enabling in-person observations and data collection in regions that were previously unreachable by the submersible.

Exploring the Deep Ocean Directly

Direct exploration is crucial for understanding deep-ocean environments. Pilots and observers inside an HOV can see the area around them, intuitively perceive distances, and feel the movement of the thrusters and the robotic arms when they collect samples. These sensory inputs help them understand spatial relationships among features as well as water currents and the condition of specimens as they are being collected.

In addition, because a human-occupied submersible is not connected to a surface ship by a cable, it is a versatile and nimble exploration tool. An HOV can change direction more quickly than a remotely operated vehicle, without requiring a ship move, and it can explore steeper, more complex areas without encountering the constraints of a tether and a surface vessel, albeit usually with shorter dive times.

Such exploration is especially needed, for example, to provide baseline information that allows us to evaluate whether—and, if so, how—human-induced global changes are affecting deep ecosystems at different depths. Such effects are already pronounced in most ocean environments closer to the surface.

Alvin is owned by the U.S. Navy and certified under the Navy's Submarine Safety Program (SUBSAFE) protocol but is part of the National Science Foundation's National Deep Submergence Facility (NDSF) hosted at the Woods Hole Oceanographic Institution (WHOI). Operated by WHOI since its commissioning in 1964 and used by many research organizations, *Alvin* has long been at the forefront of deep-sea exploration. It can conduct a variety of logistical and scientific tasks, notably, transporting observers to study sites, conducting mapping and photographic surveys, and collecting samples using its robotic arms.

Throughout its lifetime, *Alvin* has undergone numerous upgrades to remain a state-of-the-art research platform. The most recent upgrade included outfitting it with a new, larger personnel sphere with better ergonomics and improved visibility, as well as improved thrusters and a more advanced command-and-control system.

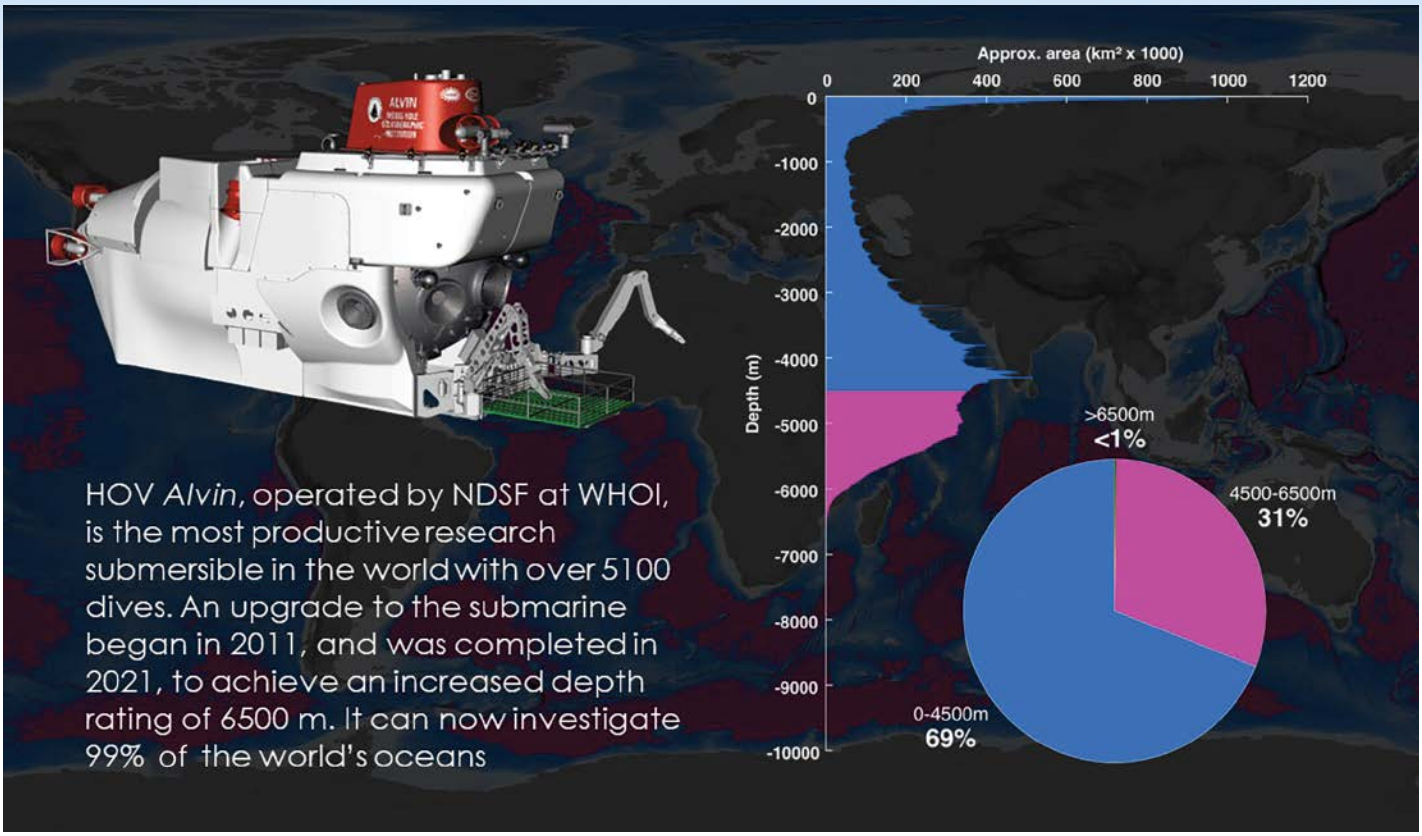


Fig. 1. Roughly 69% of the seafloor was accessible to Alvin *before (blue) its recent upgrade was completed. Following the upgrade (magenta), 99% of the seabed is now within the submersible's reach. Credit: Courtesy of S. Adam Soule, ©Woods Hole Oceanographic Institution*

New high-definition imaging systems and faster data acquisition capabilities were also installed, as were enhanced inertial navigation capabilities enabling very accurate tracking from the surface to the seafloor, even at great depth, and a new science interface that enables rapid integration of routine and novel sensors for in-sub viewing.

The 2022 Science Verification Expedition

In summer 2022, a diverse team of scientists—led in part by researchers from WHOI and the University of Rhode Island Graduate School of Oceanography (URI-GSO)—put *Alvin* and its upgraded systems to the test in real-world conditions during its first SVE following the upgrade [*Soule et al.*, 2022]. Team members represented a wide range of disciplines, career stages, and personal backgrounds, and the expedition included a major milestone in U.S. deep-sea science: *Alvin*'s first dives below 6,000 meters.

All told, the expedition involved six successful dives in the Puerto Rico Trench to nearly 6,400-meter depth and nine along the Mid-Cayman Rise to nearly 6,100-meter depth (Figure 2). These areas, chosen for their extreme depths and diverse conditions, provided rigorous proving grounds for *Alvin*'s new systems and offered opportunities to study underexplored regions.

During the dives, scientists explored various geological features, including fault lines, landslides, outcrops of ancient oceanic crust, young volcanic features, and active hydrothermal vent systems. The crew also deployed complementary tools, such as a CTD (conductivity, temperature, depth) profiler, as well as an autonomous sampling lander [*Muir et al.*, 2021] that enhanced *Alvin*'s observational and sampling capabilities down to 8,000-meter depth.

The 2022 expedition yielded several significant scientific observations that have contributed to our understanding of Earth's geological history and the processes that

***Alvin* has long been at the forefront of deep-sea exploration.**

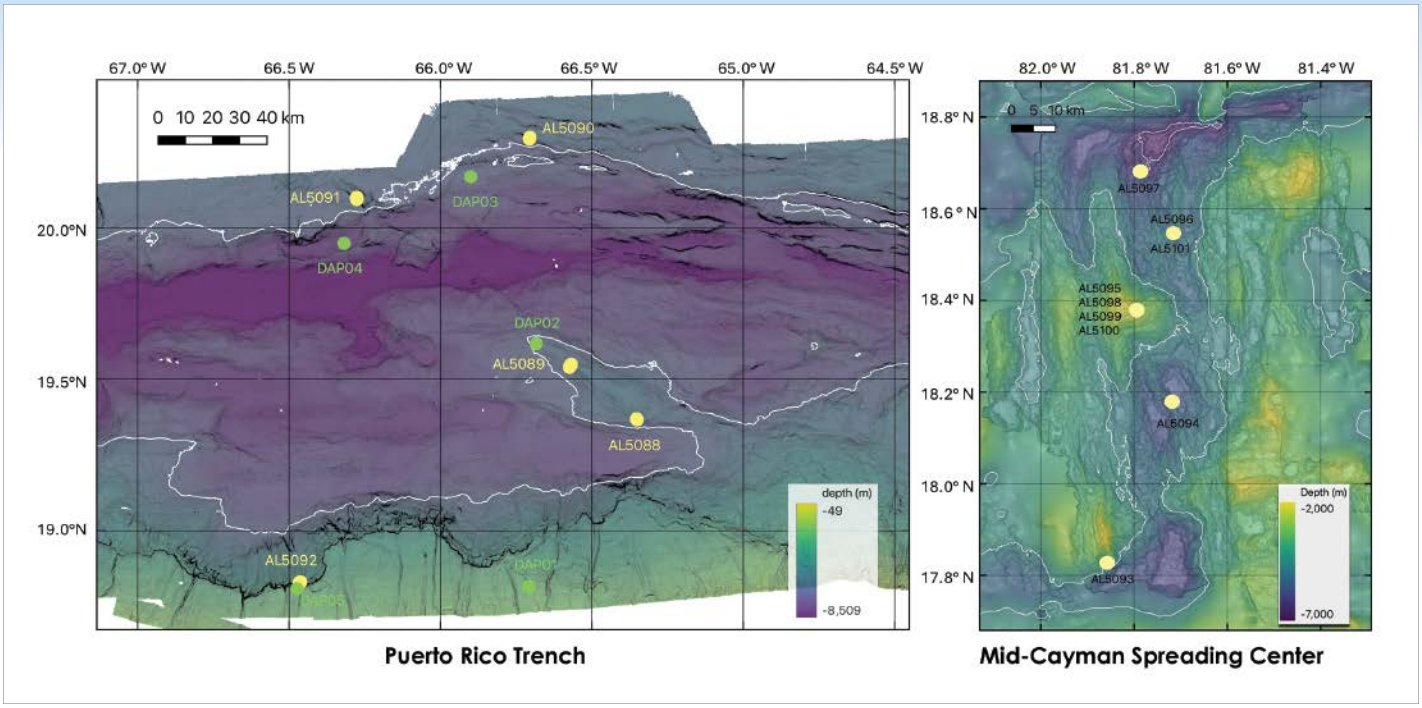


Fig. 2. Bathymetric maps of the science verification expedition (SVE) study locations near the Puerto Rico Trench (PRT; left) and Mid-Cayman Rise (MCR; right) display the locations and deployment identifiers of Alvin *at each site (yellow dots) and of the Deep Autonomous Profiler (DAP) at the PRT (green dots). Seabed depths are color coded from yellow (shallowest) to purple (deepest). White contours indicate depths of 6,500 meters (*Alvin*'s depth limit) at the PRT (left) and 3,000 meters and 6,500 meters at the MCR. The authors produced these maps using public domain bathymetric data.*

The 2022 Science Verification Expedition (SVE) yielded observations that contribute to our understanding of Earth's geological history and processes that shape the ocean floor.

shape the ocean floor. On the Mid-Cayman Rise, researchers aboard *Alvin* discovered the world's deepest-known very young (<1–2 decades) submarine volcanic eruption site at 6,000 meters deep [*Rubin et al.*, 2023]. This was an important finding for understanding the effect of high ambient pressure and low temperature on eruption mechanisms.

These researchers also characterized high-grade metamorphic rocks in multiple locations and collected samples at the Von Damm and Beebe active hydrothermal vents [*German et al.*, 2010], which have distinct faunal communities (Figure 3). In addition, the science team recovered the first samples of the active microbial communities living within the vent chimneys, offering insights into life in these extreme environments.

In the Puerto Rico Trench, *Alvin*'s dives uncovered well-preserved geological structures on steep rock faces, including samples of intrusive oceanic crust [e.g., *Rubin et al.*, 2022] thought to be as old as 100 million years [*Klein et al.*, 2017]. The site is well suited for systematic follow-on studies of spatiotemporal variations that occur during crustal accretion and alteration at the slow-spreading Mid-Atlantic Ridge.

The team also documented behavioral adaptations of deep-dwelling isopods in response to the recent appearance of *Sargassum* in the Caribbean Sea [*Peoples et al.*, 2024], a remarkable adaptation in the deep ocean to a modern ecological change in the surface waters.

The scientists and the *Alvin* operations team of pilots and engineers on the SVE, over the course of these dives, confirmed the upgraded *Alvin*'s readiness for abyssal and hadal explorations. Indeed, the submersible's new capabilities, including enhanced imaging, improved maneuverability, and upgraded navigational tracking, proved essential for the success of the mission.

Since the SVE, *Alvin* has returned to its regular operational cadence, completing more than 100 dives per year. These dives have included expeditions back to long-term study sites on the East Pacific Rise—where researchers, aided by the autonomous underwater vehicle *Sentry*, discovered a new off-axis hydrothermal vent site (D. Fornari, personal communication, 2024)—and in the Guaymas Basin, where scientists found dramatically changed

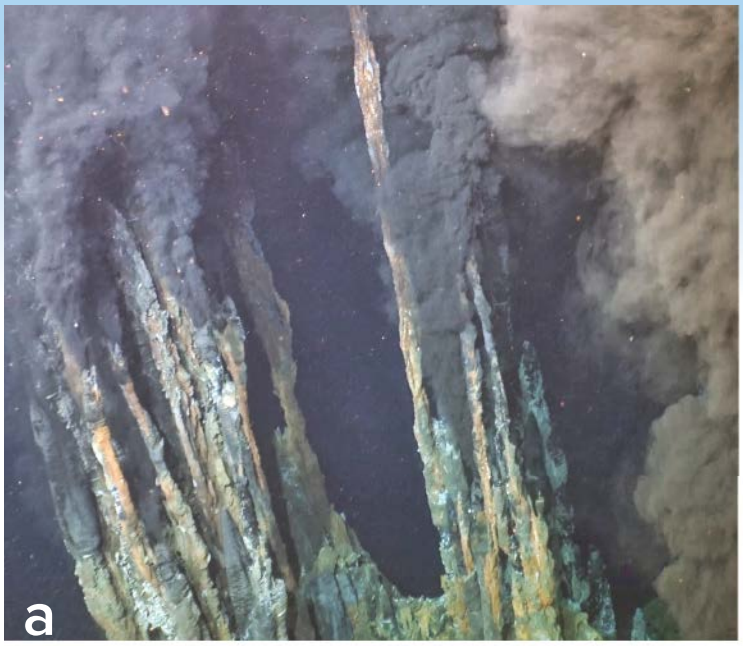


Fig. 3. These four views from Alvin*'s 2022 SVE show submarine features on the MCR at sites that were inaccessible to the submersible before its upgrade: (a) tall, thin black smoker chimneys at Earth's deepest-known hydrothermal vent field (~5,000-meter depth), alternatively referred to as the Piccard or Beebe field in the literature; (b) abundant* Rimicaris *shrimp populating slightly cooler active hydrothermal chimneys at Beebe; (c) anemones and filamentous microbial mats thriving amid diffuse hydrothermal flow at Beebe; and (d) a very young lava flow, with fresh glass and just 1–2 millimeters of sediment covering, sampled at 6,100-meter depth. These images were captured from 4K video, cropped, and color and sharpness corrected by K. H. R. Credit: Courtesy of S. Adam Soule and Anna P. M. Michel, WHOI/NSF/HOV Alvin/2022, ©Woods Hole Oceanographic Institution*

hydrothermal venting at a previously known site (M. Joye, personal communication, 2024). A subsequent series of deep science dives in 2024 reached nearly 5,000 meters in the Aleutian Trench, where polychaete-populated seeps were observed to provide habitat for a host of organisms such as hydroids, foraminifera, bacteria, and folliculinids, including possibly new species discoveries (L. Levin, personal communication, 2024).

Alvin's Legacy and Future

The deep ocean is a place where high hydrostatic pressure influences biological adaptation, geological processes like volcanism,

The continuing focus on inclusivity in future expeditions will help to foster a welcoming environment for the next generation of researchers using *Alvin*.

and chemical phenomena such as mineral and ore formation. Throughout its history, *Alvin*—the most active research submersible in the world and the only U.S. HOV capable of reaching such extreme depths—has contributed to numerous scientific discoveries related to these processes, as well as to explorations of shipwrecks and unknown deep-sea environs.

Alvin's notable contributions to deep-sea exploration include, among many others, the first discoveries of submarine hydrothermal vents (on the Galapagos Spreading Center in 1977) and black smokers (at 21°N on the East Pacific Rise in 1979), the discovery of methane seeps along the Florida Escarpment in 1984, Bob Ballard's famous 1986 dive to the *Titanic*, and the first exploration of the unique Lost City hydrothermal field in 2000.

Alvin has also supported U.S. leadership in deep-ocean exploration and motivated the work of more than 14,000 personnel. Continuing through the SVE in 2022, it has been a major part of each of our own dive histories, for example, contributing indelibly to our research and careers.

The SVE didn't involve only established scientists, however. As part of an emphasis on equity, diversity, and inclusion within the scientific community, it also included 11 early-career scientists, most of whom were diving in *Alvin* for the first time. These scientists offered their expertise in geology, biology, microbiology, hydrothermal activity, and resource mapping, and they hailed from oceanographic institutions, large research universities, and smaller teaching colleges, as well as from the Cayman Islands government.

The continuing focus on inclusivity in future expeditions will help to foster a welcoming environment for the next generation of researchers using *Alvin* to expand our understanding of deep-sea biological, geological, and chemical processes.

Alvin's upgraded capabilities will offer these scientists opportunities to study such processes in greater detail, contributing to knowledge of how life and Earth itself have evolved under extreme conditions. They will also help to provide vital understanding and insights into how human activities are increasingly affecting environments, including deep-ocean ecosystems, supporting comprehensive assessments of global change and how we might manage these regions.

As we continue to push the boundaries of human exploration ever deeper into the ocean, *Alvin* remains a critical tool and a symbol of enduring curiosity and commitment to understanding the world beneath the waves.

Acknowledgments

Alvin is a U.S. Navy–owned asset certified under the Navy's SUBSAFE protocol with support from the Naval Sea Systems Command (NAVSEA). The recent *Alvin* upgrade was supported primarily by the National Science Foundation with additional support from the Office of Naval Research. K.H.R. is the associate dean of research at URI-GSO and has completed more than 30 HOV dives. A.P.M.M. is an associate scientist at WHOI and the current chief scientist of deep submergence at NDSF. S.A.S. is a professor of oceanography at URI-GSO, director of the Ocean Exploration Cooperative Institute, and former NDSF chief scientist.

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Read the article at Eos.org

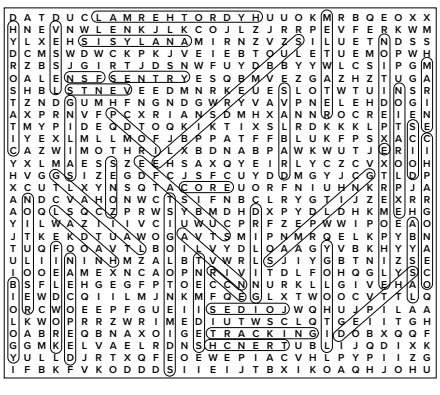
Food Insecurity Is Linked to Heart Disease and Diabetes in the United States

An estimated 13.5% of U.S. households experienced food insecurity in 2023. Factors such as limited income, unemployment, access to transportation issues, distance to grocery stores, high housing costs, widespread health-related disasters, natural hazards, and climate change can all contribute to inconsistent access to food. Poor diet can lead to health outcomes such as cardiovascular disease and diabetes.

Compiling datasets from the U.S. Department of Agriculture, Census Bureau, Centers for Disease Control and Prevention, and other agencies, *Joseph* used mixed-effects regression models to examine how the links between food insecurity and health vary geographically across the United States.

The author modeled diabetes incidence at the county level and cardiovascular disease at the state level. Overall, he found that higher levels of food insecurity correlated with increased rates of diabetes and heart disease. People living below the Federal Poverty Level had twice the incidence of diabetes as those with higher incomes. Combined food insecurity, diabetes, and cardiovascular health issues were highest in the southern United States, which has the highest poverty rate in the country.

The author also considered other demographic information from the datasets, such as ethnicity, education, and age. However, these factors were not included in the mixed-effects regression models because a consistent dataset for the whole country does not exist. Among the population examined, American Indian/Alaska Native adults were most affected by diabetes, but Black populations also experienced relatively high rates of food insecurity, cardiovascular disease, diabetes, and death from cardiovascular incidents. Lower education and lower income levels correlated with higher instances of cardiovascular disease, and children tended to experience higher food insecurity rates than adults. (*GeoHealth*, https://doi.org/10.1029/2024GH001198, 2025) **—Rebecca Owen,** *Science Writer*



Flooding from Below: The Unseen Risks of Sea Level Rise

Cars make their way down a street in South Dunedin, New Zealand, during June 2015 floods. Credit: John Cosgrove

As climate change continues to drive global sea level rise, many people living in coastal areas are already seeing its effects. Coastal erosion is accelerating and shifting coastlines inland, and storm surges are getting worse. Lurking beneath the surface is another major consequence that is thus far poorly understood: rising groundwater.

Evidence suggests that in some low-lying coastal regions with shallow groundwater, rising sea levels will drive a simultaneous rise in groundwater levels, with potentially serious risks for homes, businesses, and other infrastructure.

In a new paper focused on the coastal city of Dunedin, New Zealand, *Cox et al.* demonstrate a method for predicting how sea level rise might change groundwater levels and thereby increase inland flooding hazards. South Dunedin already experiences periodic flooding that will become even more challenging with sea level rise; the researchers describe the city as a poster child for New Zealand communities responding and adapting to climate change and rising seas.

The researchers used 2019–2023 data from a network of 35 groundwater sensors installed across Dunedin's low-lying coastal land, where much of the city's infrastructure is located. They compared the sensor data with data on tides, rainfall, and other factors to forecast rising sea level's future influence on groundwater.

The findings suggest that sea level rise will first drive a rise in groundwater that will reduce the land's ability to absorb rainfall. With further sea level rise, groundwater may rise even more and begin causing problems while still belowground, such as overwhelming wastewater systems, infiltrating basements, and destabilizing building foundations. Eventually, the groundwater may rise high enough to emerge as springs and cause flooding.

The researchers conclude that flood hazards resulting from rising groundwater can extend much farther inland than many people expect. In addition, assuming that the protective topography of Dunedin's sand dune barrier does not undergo significant change, these groundwater effects will occur sooner than any direct flooding from the rising sea.

The researchers note that their approach contains key assumptions and uncertainties—for instance, that groundwater and sea level will rise at the same rate and that the water table will maintain approximately the same shape—but add that the conservative predictions are valuable for planning and managing hazards in Dunedin. Because the method is relatively simple and inexpensive, it could also be applied in similar coastal regions around the world, they say. (*Earth's Future*, https://doi.org/10.1029/2024EF004977, 2025) **—Sarah Stanley,** *Science Writer*

Martian Dust Will Be a Health Hazard for Astronauts

During the Apollo missions to the Moon, astronauts encountered an unexpected hazard: lunar dust. It clung to their space suits; crept into lunar landers; and caused irritated throats, coughing fits, and watering eyes. Studies later determined that longer-term exposure to lunar dust has chronic health effects.

Now, scientists are concerned about how Martian dust could affect astronauts, too.

Wang et al. documented how Martian dust could harm the health of astronauts spending years on the planet and suggest strategies to mitigate dust exposure. On average, Martian dust is only 3 micrometers in diameter, or about 4% the width of a human hair. This fine dust could irritate astronauts' lungs, seep into their bloodstreams, and increase the risk of ailments such as lung diseases and cancers.

Martian dust contains compounds that can be toxic to humans, including perchlorates, iron oxides, silica, and gypsum. Perchlorates, for instance, can affect hormonal regulation, and inhaling just a few milligrams of Martian dust would surpass the recommended safe dose on Earth. Inhaling silica, a long standing risk in coal mining operations, increases the chances of lung cancer.

The dust also contains metals such as arsenic, chromium, and beryllium, although they may be in concentrations too small to affect human health. Iron oxides help make the dust magnetic and electrostatic, which means it could cling to space suits the same way lunar dust does. In addition, the high doses of radiation that astronauts receive make them more susceptible to pulmonary fibrosis, which exposure to Martian dust could exacerbate.

Without medical facilities on Mars and with Earth a long journey away, emergency treatment of such conditions would be difficult. So mitigating dust exposure in the first place should be prioritized, the researchers say. A combination of air filters, self-cleaning space suits, and electrostatic repulsion devices could help limit astronauts' exposure. (*GeoHealth*, https://doi.org/10.1029/2024GH001213, 2025) **—Rebecca Dzombak,** *Science Writer*

Trust in Evanston Tap Water Depends on Gender, Race, and Past Experiences

Most people in the United States have access to clean, affordable tap water. Yet many still choose to drink bottled water at home for reasons including the perception of contaminants, unpleasant taste or smell, and a distrust of institutions. The costs of drinking bottled water can be high for both consumers' pocketbooks and the environment, so knowing more about what people across the country think about their tap water is valuable.

O'Brien et al. used a community-based participatory science approach to learn more about the water habits and attitudes of residents of Evanston, Ill., a midsize city just north of Chicago on the shores of Lake Michigan. Unlike other research about trust in water in the United States, the authors chose a relatively high income setting for their study, probing how socioeconomic status could affect views of water quality. Using a survey that included both multiple-choice and open-ended questions, as well as follow-up interviews with selected participants, they looked into the reasons for trust, or the lack thereof, in different sources of water.

The researchers found that race and gender were the two most important predictors of trust in tap water. Black, Indigenous, and People of Color (BIPOC) respondents were 3.4 times more likely to distrust tap water than white respondents, and men were 44% less likely than women to distrust tap water. The researchers also found that 92.6% of respondents used tap water as their primary drinking water, and 55.6% treated it. More than 40% of Black respondents used bottled water compared with 5.4% of white respondents, and a third of unhoused respondents used bottled water versus 6.8% of those with some form of housing.

Concern about contamination was the chief reason for distrust in tap water, followed by worries about the taste, smell, or appearance of tap water and chemicals used in treatment. Follow-up interviews found that a general lack of trust in the government, as well as previous adverse experiences with water (including some indirectly related to drinking water quality, such as flooding, water shutoffs, and swimming), was also associated with lower trust levels.

Even in areas where residents have access to clean municipal water, households can have varying levels of trust in water quality and safety; some opt for alternatives. Credit: Vanessa Bly

To improve trust in tap water, the authors recommend solutions beyond engineering, including increasing access to at-home water testing and improving communication and education around water treatment procedures and water quality. (*Community Science*, https://doi.org/10.1029/2024CSJ000090, 2025) **—Nathaniel Scharping,** *Science Writer*

The Interplay of ENSO and Immunity in Infectious Disease Outbreaks

Variations in temperature, precipitation, and humidity can influence the spread of infectious diseases, including by altering the habitats of disease transmitters such as mosquitoes.

Extreme weather events can disrupt health care responses as well. Previous studies have shown that the El Niño–Southern Oscillation (ENSO), with its alternating warm (El Niño) and cold (La Niña) phases, contributes to extreme weather and may also influence the spread of infectious diseases, such as cholera, dengue, malaria, respiratory syncytial virus (RSV), and Rift Valley fever.

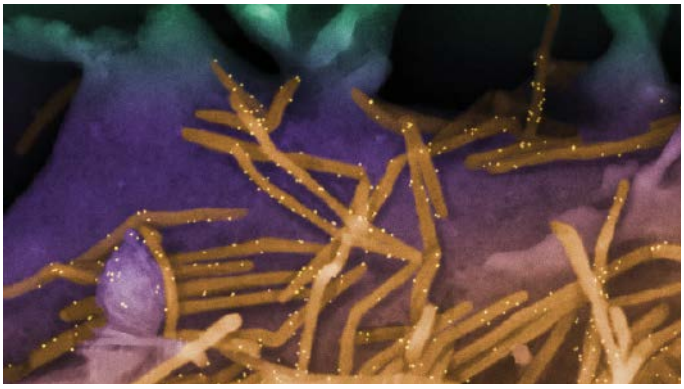
Though ENSO events can be forecast months in advance, few successful public health interventions, such as vaccine campaigns and vector control efforts, have resulted from these predictions.

Geographic variability, differences in timing between ENSO and disease cycles, and population immunity resulting from previous outbreaks are all factors that complicate linking ENSO events directly to disease outbreaks.

Chung et al. built upon previous locally focused and disease-specific studies to model longer-term interactions between ENSO cycles and various infectious diseases. They used two modeling approaches to investigate how ENSO's influence on disease outbreaks may change from year to year.

First, the team modeled how back-to-back ENSO events could directly and indirectly affect populations susceptible to disease outbreaks over multiple years for a generic seasonal disease. The second modeling effort focused on an airborne human coronavirus, HCoV-HKU1. Using global humidity data from 1981 to 2017, the researchers examined how humidity variations associated with ENSO influenced disease transmission.

When analyzing population data, the team repeatedly found that immune responses for infectious diseases lagged behind the initial El Niño and La Niña events, sometimes by more than a year. When ENSO events occurred in consecutive years, the effects could therefore lead to longer-lasting and larger disease effects a year or more later.



Extreme weather can influence the spread of infectious diseases such as respiratory syncytial virus, or RSV, seen here in a scanning electron micrograph. Credit: NIAID, CC BY 2.0 (bit.ly/ccby2-0)

The researchers suggest that on the basis of these findings, risk managers should consider how population immunity may be a predictor of ENSO's influence on the spread of infectious diseases. Further improving understanding of climate and disease interactions could mean planning interventions several months in advance and improving health outcomes, the authors say. (*GeoHealth*, https://doi.org/10.1029/2024GH001193, 2025) **—Sarah Derouin,** *Science Writer*

Massive Antarctic Icebergs May Calve at Random

Antarctica is losing ice quickly, in part because of climate change. Massive calving events, such as the one that formed the Delaware-sized (5,800 square kilometers, or 2,239 square miles) A-68 iceberg in 2017, can destabilize ice shelves and capture the public's attention. But the infrequency of extreme calving events makes it difficult for scientists to predict them and understand whether they are connected to climate change.

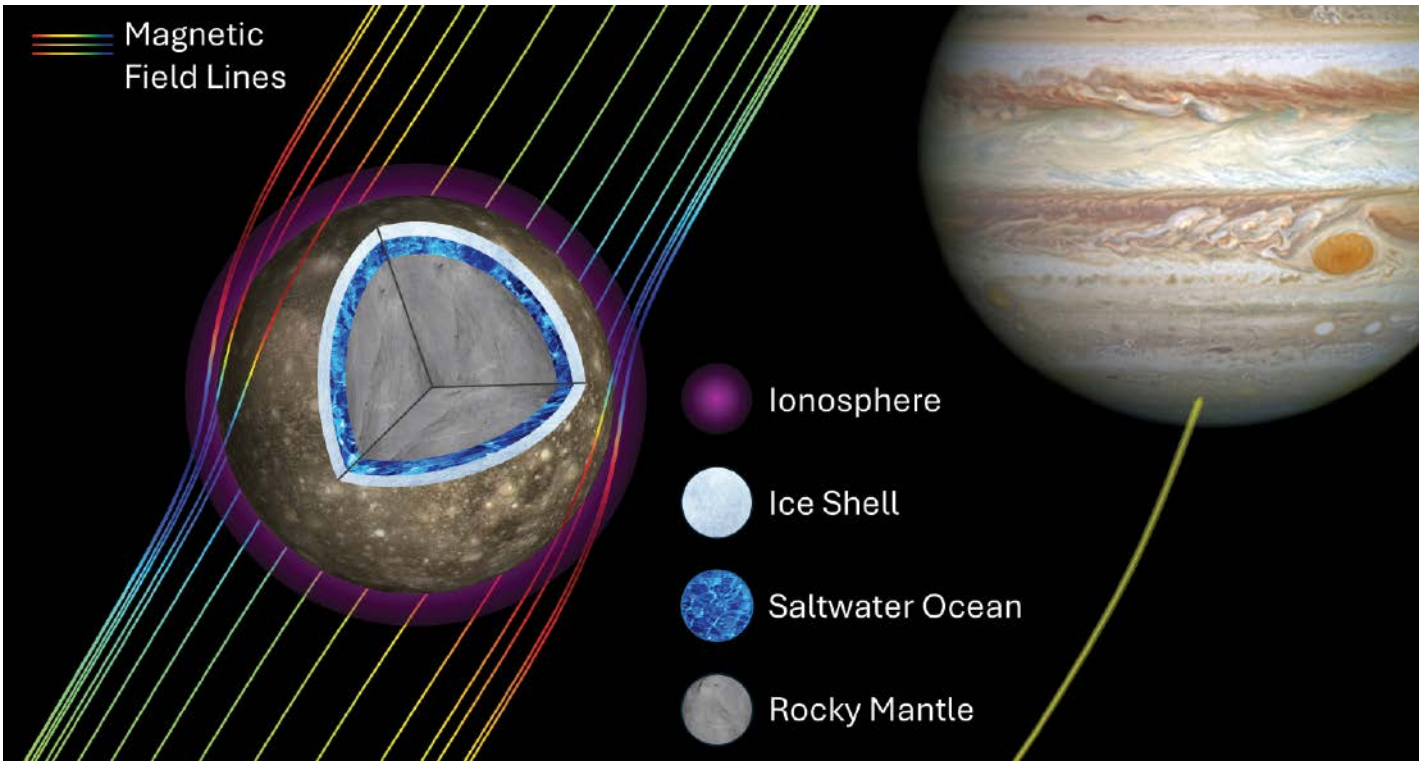
To explore potential connections between climate change and large iceberg formation in Antarctica, *MacKie et al.* carried out the first long-term analysis of the continent's biggest annual icebergs. Because such large calving events are rare and unevenly distributed, the researchers used statistical approaches specifically geared toward small datasets with long tails to look for changes in calving event frequency over time. They focused on the single largest iceberg to form each year from 1976 to 2023. These icebergs had surface areas of up to 11,000 square kilometers (4,247 square miles).

The study revealed that the surface area of the largest annual iceberg decreased slightly over time and that despite the growing influence of climate change, the risk of an extreme calving event did not increase. Because climate warmed over the study period but the largest iceberg area did not increase, the findings suggest that extreme calving events are not necessarily a direct consequence of climate change, the authors write.

However, the number of smaller calving events has increased over time, other work has found. This study highlights the role of these events in chipping away at Antarctic ice in a "death by a thousand cuts," the authors write. Though extreme calving events make dramatic headlines, more common, smaller iceberg formations are the main source of climate change–driven mass loss in Antarctica, they conclude.

The researchers also found that the biggest Antarctic iceberg may be yet to come. Although they do not predict an increase in the frequency of extreme calving events, their modeling suggests that a "once in a century" iceberg could be roughly the size of Switzerland (38,827 square kilometers, or 14,991 square miles). (*Geophysical Research Letters*, https://doi.org/10.1029/2024GL112235, 2024) **—Rebecca Dzombak,** *Science Writer*

Jupiter's Moon Callisto Is Very Likely an Ocean World



Observations acquired from the Galileo spacecraft indicate that Callisto (left) reacts inductively to Jupiter's time-varying magnetic field. New research suggests that this reaction and its results are indicative of the moon hosting a subsurface salty ocean. Credit: Corey J. Cochrane, NASA/JPL-Caltech

More pocked with craters than any other object in our solar system, Jupiter's outermost and second-biggest Galilean moon, Callisto, appears geologically unremarkable. In the 1990s, however, NASA's Galileo spacecraft captured magnetic measurements near Callisto that suggested that its ice shell surface—much like that of Europa, another moon of Jupiter—may encase a salty, liquid water ocean.

But evidence for Callisto's subsurface ocean remained inconclusive, as the moon has an intense ionosphere. Scientists thought this electrically conductive upper part of the moon's atmosphere might imitate the magnetic fingerprint of a salty, conductive ocean.

Now, *Cochrane et al.* have revisited the Galileo data in more detail. Unlike in prior studies, this team incorporated all available magnetic measurements from Galileo's eight close flybys of Callisto. Their expanded analysis much more strongly suggests that Callisto hosts a subsurface ocean.

In addition to reanalyzing the flyby data with advanced statistical techniques, they used computational models of Callisto's ionosphere and geophysical properties to examine whether a subsurface ocean is compatible with all available information.

They found that Callisto's ionosphere alone cannot explain all existing observations, but that a subsurface ocean in combination with the ionosphere can. Further exploring which scenarios best fit the data, the researchers predicted that the ocean is likely at least tens of kilometers thick, as measured from the top of the liquid ocean to its seafloor, and encased beneath a solid ice shell that itself could range from tens to hundreds of kilometers thick. Beneath the probable ocean lies a rocky interior.

These findings set the stage for spacecraft measurements that will be captured in the near future and should confirm, once and for all, whether Callisto is an ocean world. Close-up measurements are scheduled for NASA's Europa Clipper and the European Space Agency's JUICE (Jupiter Icy Moons Explorer) missions, both already launched. China's planned Tianwen-4 mission may also observe Callisto.

Callisto's crater-covered surface may be hiding a liquid water ocean. Credit: NASA/JPL-Caltech/Kevin M. Gill, CC BY 2.0 (bit.ly/ccby2-0)

Confirmation of Callisto's status as an ocean world would likely prompt further investigation into its potential to support life—just as the confirmation inspired research about Europa. (*AGU Advances*, https://doi.org/10.1029/2024AV001237, 2025)

—Sarah Stanley, *Science Writer*

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Hunter Enis Chair in Petroleum Geology and Director of Research for the Ralph Lowe Energy Institute

This full-time faculty position is on-campus and in-person.

The Department of Geological Sciences and the Ralph Lowe Energy Institute (RLEI) at Texas Christian University (TCU) is seeking an exceptional scholar to serve as the Hunter Enis Endowed Chair in Petroleum Geology and Director of Research at RLEI. This is a unique opportunity for a highly motivated researcher and visionary leader to shape the future of subsurface science and energy research at TCU and beyond.

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- A Ph.D. in Geosciences, or a closely related field.
- An internationally recognized record of excellence and publication in research in energy-related subsurface geoscience and its intersections with data-driven technologies and sustainability.
- An exceptional record of ongoing externally funded research
- A commitment to advancing subsurface research that addresses critical global needs in energy resilience and sustainability.
- A proven track record of academic leadership and the ability to establish interdisciplinary collaborations.
- Demonstrated excellence in teaching, mentorship, and engaging diverse student populations.

Applications should include:

- A cover letter outlining your vision for research, teaching, and leadership at TCU, specifically addressing departmental and institute goals in energy, sustainability, and resilience.
- A curriculum vitae detailing your academic and professional accomplishments.
- A statement of research interests and goals, including how your work aligns with the position's focus areas.
- A statement on teaching philosophy and mentorship.
- Contact information for three professional references.

Review of applications begin April 1, 2025. Applicants are encouraged to submit application materials by April 1st but the position will remain open until filled. For inquiries, please contact hrtalentaquisition@tcu.edu.

AMERICAN UNIVERSITY OF BEIRUT

TENURE-TRACK FACULTY IN PRECISION AGRICULTURE/SMART FARMING

ABOUT THE DEPARTMENT:
The Department of Agriculture is dedicated to advancing sustainable food systems through innovative research, education, and community engagement. We seek a dynamic scholar to drive interdisciplinary collaborations in Smart Agriculture, fostering transformative solutions for Lebanon and the MENA region. Our mission aligns with promoting entrepreneurship, practical innovation, and regional agricultural resilience.

FACILITIES & RESOURCES:
- Access to the **AUB Agricultural Research and Education Center (AREC)**, a 100-hectare facility in Lebanon's Bekaa Valley, equipped with advanced agricultural infrastructure.
- Opportunities to enhance existing resources and leverage them for cutting-edge research and teaching.

POSITION RESPONSIBILITIES:
1. Teaching
Deliver undergraduate and graduate courses in Precision/Smart Agriculture, such as:
- Autonomy in Agriculture
- Intensive Horticulture Systems
- Precision Fertilization and Variable-Rate Technologies
- Greenhouse Automation
- Site-Specific Crop Management
- Develop new courses integrating emerging technologies to align with departmental goals.
- Mentor students and supervise graduate research.

2. Research
- Pursue an innovative, externally funded research program in areas such as: Smart farming technologies (e.g., sensors, automation) Data-driven agronomic decision-making Sustainable resource optimization (water, fertilizer, energy)
- Collaborate with interdisciplinary teams across AUB and regional partners to address pressing agricultural challenges.

3. Service & Outreach
- Engage in departmental/university committees and academic program development. Conduct outreach activities at AREC, including partnerships stakeholders. Promote knowledge transfer and community-driven solutions.

QUALIFICATIONS & EXPECTATIONS:
- A Ph.D. in Precision Agriculture, Agricultural Engineering, Horticulture, or a related field.
- Demonstrated potential for excellence in teaching, research, and securing external funding. Commitment to advancing AREC's infrastructure and outreach impact. Ability to collaborate across disciplines and contribute to AUB's mission

APPLICATION INSTRUCTIONS:
Interested applicants must submit the following documents **electronically** to the FAFS Dean's Office at **fafs@aub.edu.lb** by **June 30, 2025:**
- Curriculum Vitae (CV) Research statement and Teaching philosophy List of relevant academic/professional qualifications and experiences Contact information for three professional references (name, position, institution, and email)

ADDITIONAL NOTES:
- Please do not include reference letters with your application. Referees must submit their letters directly to **fafs@aub.edu.lb**. Applications will be reviewed on a rolling basis until the position is filled. The selected candidate is expected to assume the position by **January 2026**.

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extremophile
fieldwork
glacial
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IODP
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marine
meltwater
NSF
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Resolution
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sampling
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