Meet the First True 'Einstein' | *T. rex* Gets Lippy

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ APRIL 22, 2023

BENEATH THE ICE

A massive cavern under an Antarctic glacier is an oasis of life

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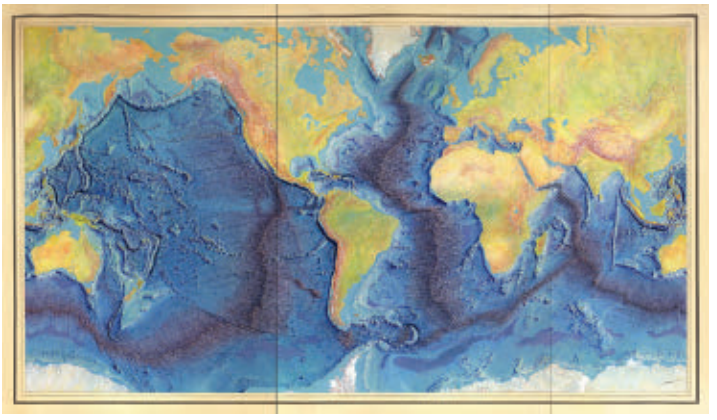
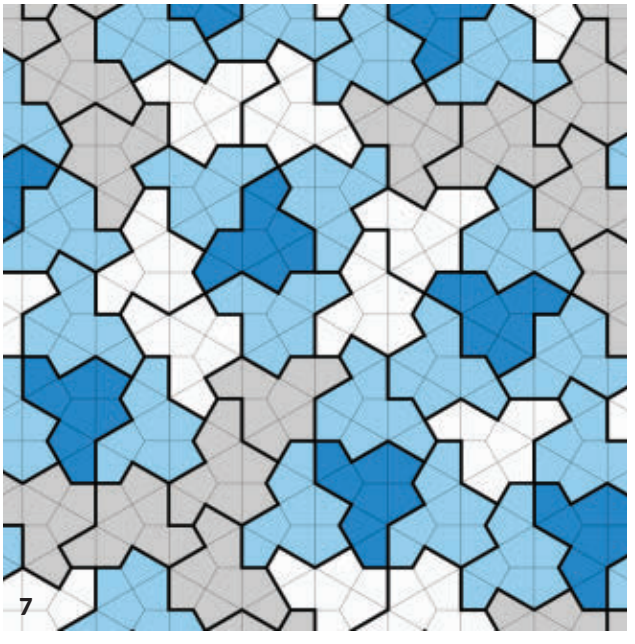


24

Features

News



7

32

Departments

COVER Researchers deploy instruments through a borehole into the water-filled cavern hidden beneath the Kamb Ice Stream. *H. Horgan*

The many challenges of exploring hidden realms

Imagine a young woman who sought to explore the oceans' depths but was barred from going to sea. From her desk in New York City in the 1950s, she used bits of data gathered by the ships she couldn't sail on to create maps that revolutionized our understanding of the seafloor and helped revise Earth's history. Her name was Marie Tharp.

Then imagine other scientists, many decades later. They traveled to Antarctica for mapping projects of their own. Like Tharp, the researchers faced obstacles: The river they sought lies under hundreds of meters of solid ice. So the team patched together clues, including a wrinkle on the surface of a glacier, which led to the discovery of a spectacular river-carved cavern beneath the ice that's almost as tall as the Empire State Building.

So many challenges in science revolve around exploring the invisible or inaccessible, whether the quarry is subatomic particles, distant galaxies or the genetic code of life. The desire to see, to measure, to reveal drives years of grueling, painstaking work and the invention of new tools for exploration.

In Tharp's case, technologies refined during World War II made it possible for ships to use soundings to accurately measure ocean depth. As freelance journalist Betsy Mason reports, Tharp used that limited acoustic information to plot two-dimensional vertical slices of seafloor topography, then carefully extrapolated that information to fill in the many blank spots on the map (Page 24). It was a cartographical tour de force—and one that helped scientists realize the reality of continental drift.

Present-day Antarctic researchers use World War II–era technologies including radar to peer under the ice, as well as bulky equipment to melt deep exploratory holes and then lower cameras down. It's tedious work, but the payoff can be thrilling, freelance journalist Douglas Fox describes in this issue's cover story (Page 18). He knows firsthand. Fox has traveled to Antarctica six times and was present in 2013 when scientists tapped into a subglacial lake and retrieved water and mud samples for the first time. He remembers the goose bumps he felt upon seeing the first glimpses of the lake's murky interior, likening it to "seeing the surface of Venus for the first time."

Scientists got their first view of the long-sought river at the end of 2021; they were astonished when the camera spied orange shrimplike creatures. The world those animals inhabit, almost 500 kilometers from daylight, is a new mystery to explore.

Marie Tharp's story is part of our Unsung Characters series, which tells the stories of scientists whose work has been underappreciated or little known. We launched this series online as part of our Century of Science project (www.sciencenews.org/century). The profiles proved so popular that we're bringing them to our print readers and extending the series to elevate the work of both past and present-day scientists.

Is there a scientist whose work you think deserves more attention? We welcome your nominations for potential profile subjects. Email your suggestions to us at editors@sciencenews.org. —*Nancy Shute, Editor in Chief*

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SOCIETY FOR SCIENCE

For the Man Who Gives Everything and Expects Nothing

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Excerpt from the April 28, 1973 issue of *Science News*

50 YEARS AGO

First successful enzyme therapy

Fabry's disease … [is caused by] a faulty fat-metabolizing enzyme called alpha-galactosidase. Because the abnormal enzyme does not break down lipids in the blood as it should, they accumulate in the body. [Researchers] tried to purify the enzyme in its normal form from human placental tissue. Four months ago they got enough of the enzyme to inject into two patients…. The results look promising.

UPDATE: Though the trial showed that enzyme replacement therapy could work, it took decades before such treatments were cleared for use by the U.S. Food and Drug Administration. In 1991, an injection to treat a different rare inherited disorder called Gaucher disease became the first to gain approval (*SN: 5/25/91, p. 327*). Approval for an enzyme replacement therapy for Fabry's disease followed in 2003. Scientists are still developing enzyme therapies. Last year, researchers reported treating a developing fetus for Pompe disease, which causes severe heart and muscle defects (*SN: 12/17/22 & 12/31/22, p. 6*).

James Wilson (left) and Rodger Kram (right) carry a log using head straps to show how ancient people may have transported heavy timber to Chaco Canyon in New Mexico.

THE SCIENCE LIFE

Ancient people of Chaco Canyon may have hauled logs with their noggins

As the morning sun peeked through the trees, Rodger Kram readied himself for the coming marathon. But not the running kind.

Kram, a physiologist at the University of Colorado Boulder, stood next to undergrad James Wilson at the end of a rural dirt road. Each donned a strap of nylon webbing onto his head. Attached to the bottom of their straps — called tumplines — a log rested horizontally across the duo's lower backs.

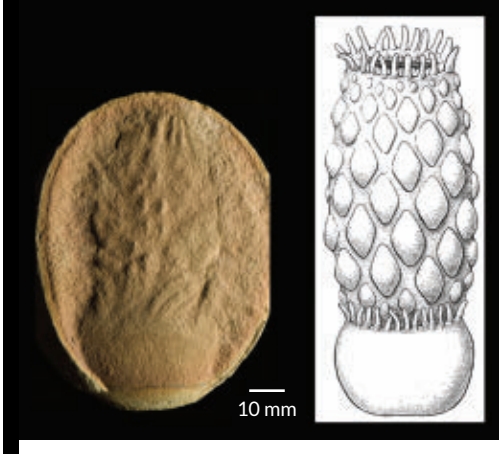
The men were about to embark on a 25-kilometer trek to replicate how the

RETHINK

These fossil blobs might not be jellyfish after all

What do you get when you flip a fossilized "jellyfish" upside down? The answer, it turns out, might be an anemone. Fossil blobs once thought to be ancient jellyfish were actually a type of burrowing sea anemone, scientists propose March 8 in *Papers in Palaeontology*.

From a certain angle, the fossils' features include what look like a bell shape, perhaps with tentacles hanging beneath — like a jellyfish. And for decades, that's what many scientists thought the animals, dubbed *Essexella asherae*, were. But for paleontologist Roy Plotnick, something seemed fishy. One fossil feature had long been interpreted as a curtain around the jellies' tentacles. "No jellyfish has that," says Plotnick, of the University of Illinois Chicago. "How would it swim?"



Essexella asherae (fossil shown, left) resembles some modern sea anemones. In the stylized reconstruction (right), the upper body and tentacles protrude from the smooth lower body.

While looking over fossils at Chicago's Field Museum, Plotnick had a realization. Rotated 180 degrees, the fossils resemble some modern anemones. The bell might be an anemone's body and the tentacles might be its protruding barrel. So Plotnick's team gathered more clues from thousands of fossils. Bands running through them match anemone musculature, and nubs look like tentacles. Plus, the Illinois site where *Essexella* lived 310 million years ago was near a shoreline, just the kind of place anemones may have called home. — *Meghan Rosen*

FROM TOP: PATRICK CAMPBELL/CU BOULDER; R.E. PLOTNICK *ET AL*/ *PAPERS IN PALAEONTOLOGY* 2023, MARJORIE LEGGITT

ancient people of Chaco Canyon may have transported timber about 1,000 years ago (SN: 5/27/17, p. 16). By the day's end, the pair's successful journey suggested that it would have taken just a few days for three people with tumplines to carry a full-size timber to Chaco, the researchers report in the April *Journal of Archaeological Science: Reports*.

Chaco Canyon is home to grand structures built between the years 850 and 1200 in what is now New Mexico. Multistory stone buildings called great houses had roofs with timber beams about 5 meters long by 22 centimeters wide. The site contained at least 200,000 such timbers.

The wood came from forests at least 75 kilometers away. But load-pulling animals and wheels weren't there at the time, and the timbers don't appear to have been dragged. Scientists are puzzled by how the ancient people, ancestors of modern-day Diné and Pueblo peoples, moved the wood.

Ancient people transported timbers a long way to build houses (ruins shown) in Chaco Canyon.

A 1986 study suggested that each beam weighed 275 kilograms. But Kram suspected this number was off. In 2016, he cut a section of ponderosa pine outside of his house, the same species used in Chaco, and weighed it on his bathroom scale. He then extrapolated that a 5-meter-long timber would be closer to 90 kilograms. This led Kram and colleagues to recalculate the Chaco timbers' masses as between 85 and 140 kilograms.

"As soon as we figured out that the weight was reasonable, I wanted to carry them," Kram says.

He and Wilson propose that tumplines could have been used to transport the timbers. These straps, placed on the crown of the head with the attached cargo resting on the small of the back, have been found on every continent except Antarctica, and are thought to have been used since at least 2,000 years ago. While there's no evidence that the people of Chaco used tumplines to haul logs, there is proof that they used them to transport items like water vessels.

Kram and Wilson's 25-kilometer trek, which they spent three months training for in 2020, took nearly 10 hours. Though the ponderosa pine weighed 60 kilograms and measured 2.5 meters long and 24 centimeters wide, it only slightly slowed their pace. "I felt happy at the end that it was proved feasible," Wilson says. "I never really doubted that we could do it." —*McKenzie Prillaman*

MYSTERY SOLVED

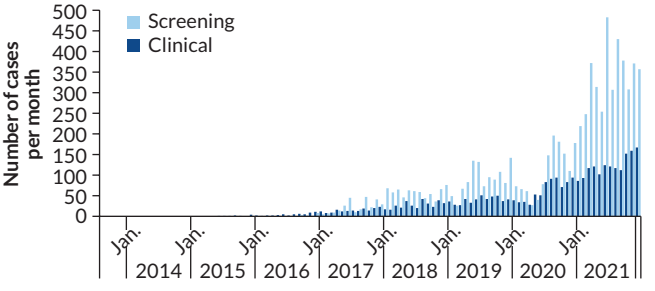
Why Huygens made fuzzy scopes

Dutch scientist Christiaan Huygens set his sights on faraway Saturn, but he may have been nearsighted.

Huygens is known for discovering Saturn's largest moon in 1655 and deducing the shape of the planet's rings. But by some accounts, his telescopes produced fuzzier views than others of the time despite having well-crafted lenses. That may be because Huygens needed glasses, astronomer Alexander Pietrow proposes March 1 in *Notes and Records: the Royal Society Journal of the History of Science*.

Huygens' telescopes combined two lenses, an objective and an eyepiece. He experimented with different lenses to find combinations that, to his eye, created a sharp image, and recorded which combos to use to obtain a given magnification. But when compared with modern knowledge of optics, Huygens' calculations were a bit off, says Pietrow, of the Leibniz Institute for Astrophysics Potsdam in Germany. One explanation: Huygens selected lenses based on his flawed vision. Records indicate that Huygens' father was nearsighted, so it wouldn't be surprising if the scientist also had the often-hereditary condition. Assuming that's the reason, Pietrow calculates that Huygens had 20/70 vision: What someone with normal vision could read from 70 feet away, Huygens could read from 20 feet. That may be why his telescopes never reached their full potential. —*Emily Conover*

Reported U.S. *Candida auris* cases, 2013–2021



SCIENCE STATS

Candida auris cases are on the rise

A deadly fungus that recently evolved to infect humans is spreading rapidly in health care facilities, the U.S. Centers for Disease Control and Prevention says. Since *Candida auris* infections were first detected in the United States, the number of people infected has risen dramatically each year (see graph, above). In 2016, *C. auris* sickened 53 people (dark blue). In 2021, it sickened 1,471 people, nearly twice the cases from 2020. What's more, tests of people at high risk of infection found 4,041 individuals who carried the fungus but were not sick at the time (light blue), CDC researchers report March 21 in *Annals of Internal Medicine*. A small percentage of carriers may later get sick from the fungus. —*Tina Hesman Saey*

FROM TOP: JOHN ELK III/THE IMAGE BANK/GETTY IMAGES PLUS; M. LYMAN *ET AL/ANNALS OF INTERNAL MEDICINE* 2023

PALEONTOLOGY

T. rex may have sported lizardlike lips

The dinosaur kept its teeth covered, skeletal analyses hint

BY JAKE BUEHLER

In movies and TV shows, *Tyrannosaurus rex* often has a fleet of big, sharp teeth that are almost always on display. But the dinosaurs and their kin may have kept their pearly whites mostly tucked behind lizardlike lips.

Similar to modern Komodo dragons, these dinosaurs had ample soft tissue around the mouth that would have functioned as lips, an analysis of fossilized and modern reptile skulls and teeth finds. The research, described in the March 31 *Science*, challenges traditional reconstructions of how these top predators appeared in life.

"This is a nice, concise answer to a question that has been asked for a long time by dinosaur paleontologists," says Emily Lessner, a vertebrate paleontologist at the Denver Museum of Nature & Science who wasn't involved in the study.

In studies of dinosaurs, soft tissue is often not included in analyses of feeding biomechanics, she says. Acknowledging the potential presence of lips in these tests could change how we think some dinosaurs ate.

It's "not an unfair argument" to suggest that nonavian theropods, the dinosaur group that includes *T. rex*, might have had their chompers constantly exposed, says paleontologist Thomas Cullen of Auburn University in Alabama. Their sharp teeth tended to be large, potentially too big to fit fully in the mouth. And crocodiles and their ilk—theropods' closest living relatives that have teeth—lack lips.

But almost all modern land vertebrates have liplike coverings, Cullen says. Why should *T. rex* and other nonbird theropods be different?

Cullen and colleagues analyzed fossilized theropod skulls and teeth alongside those of some living and extinct reptiles. The analysis included an examination of the pattern of foramina, small passageways through bone, in the jaw.

Foramina route blood vessels and nerves to the soft tissue around the mouth. In crocodilians, foramina are scattered across the jaw. But in lipped reptiles such as lizards, the little holes are arranged in a line along the edge of the jaw near the teeth. Theropods like *T. rex* share this row of jaw pores, the analysis showed.

Enamel in theropod and crocodilian teeth also yielded clues. When enamel dries out, it wears down more easily. The side of alligator teeth that is continuously exposed to air erodes more than the wetter side facing the inside of the mouth, the team found. Theropods have a more even wear pattern, suggesting the teeth were kept covered and moist.

And monitor lizards, which have proportionally long, serrated teeth much like theropods did, don't decrease their lip coverage with increasing tooth and skull size, the researchers found. Because tooth length and skull size scale similarly in monitor lizards and theropods, the team says, it's possible that theropods could fit their teeth fully in their mouths too.

Scientists developed several reconstructions of a *T. rex* head (from top): a skeletal reconstruction, crocodilian-like without lips, lizardlike with lips and an illustration of how lips could have extended past the teeth.

MARK P. WITTON

What's more, the analysis revealed a neat row of jaw foramina in *Hesperosuchus*, a very early cousin of crocodilians. That finding suggests that lips may have been present in the earliest archosaurs—the group of reptiles that gave rise to both dinosaurs (including birds) and crocodilians. If true, birds and crocodilian lineages that survived to the modern day may have lost their lips in separate processes.

But paleontologist Thomas Carr is not persuaded by the results. The study "can be summed up in two words: completely unconvincing," says Carr, of Carthage College in Kenosha, Wis.

In 2017, he and colleagues showed that tyrannosaur jawbones had a rough, wrinkled surface texture and that crocodilians have this same bone texture underlying the lipless, scaly margins of their jaws (SN: 4/29/17, p. 5).

"In many cases," Carr says, "the soft tissues leave signatures on bone." Those signatures can tell you what sat on top of the bone in cases when skin or scales haven't been preserved, he says. The new research "completely disregards ... the texture of the facial bones, which unambiguously shows that [tyrannosaurs] had flat scales, like in crocodilians, all the way down to the edges of the jaws."

This bone roughness isn't a consistent feature in theropods, Cullen says. Young tyrannosaurs and smaller theropod species had smooth bones similar to a lizard's. It's possible that these animals had lips and then lost them over their life, but "I don't think there is really any modern example of that kind of thing happening," he says.

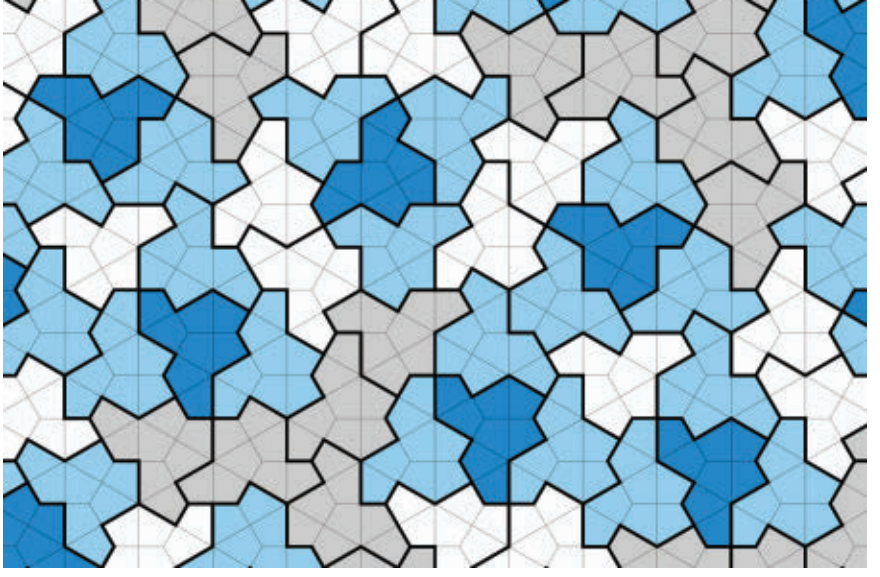
Something like the discovery of a mummified dinosaur carcass with preserved facial tissues could settle the matter of who had lips and who didn't, Carr says. ■

MATH

Elusive 'einstein' tile finally found

The 13-sided shape forms a pattern that never repeats

BY EMILY CONOVER



A 13-sided tile called "the hat" forms a pattern (shown, colors represent tile clusters) that covers an infinite plane yet cannot repeat, making it a long-sought shape known as an "einstein."

A 13-sided shape known as "the hat" has mathematicians tipping their caps.

It's the first true example of an "einstein," a single shape that forms a special tiling of a plane: Like bathroom floor tile, it can cover an entire surface with no gaps or overlaps, but only with a pattern that never repeats.

"Everybody is astonished and is delighted, both," says mathematician Marjorie Senechal of Smith College in Northampton, Mass., who was not involved with the discovery. Mathematicians had been searching for such a shape for half a century. "It wasn't even clear that such a thing could exist," Senechal says.

Although the name "einstein" conjures up the iconic physicist, it comes from the German *ein Stein*, meaning "one stone," referring to the single tile. The einstein sits in a weird purgatory between order and disorder. Though the tiles fit neatly together and can cover an infinite plane, they are aperiodic, meaning they can't form a pattern that repeats.

With a periodic pattern, it's possible to shift the tiles over and have them match up perfectly with their previous arrangement. An infinite checkerboard, for example, looks just the same if you slide the rows over by two. While it's possible to arrange other single tiles in patterns that are not periodic, the hat is special because there's no way it can create a periodic pattern.

The hat is a polykite, a bunch of smaller kite shapes stuck together. It was identified by David Smith, a nonprofessional mathematician who describes himself as an "imaginative tinkerer of shapes," and reported in a paper posted March 20 at arXiv.org. Polykites hadn't been studied closely in the search for einsteins, says Chaim Goodman-Strauss of the National Museum of Mathematics in New York City, one of a group of trained researchers Smith teamed up with to study the hat.

It's a surprisingly simple polygon. Before this work, if you'd asked what an einstein would look like, Goodman-Strauss says, "I would've drawn some crazy, squiggly, nasty thing."

Mathematicians previously knew of nonrepeating tilings that involved multiple tiles of different shapes. In the 1970s, mathematician Roger Penrose discovered that just two different shapes formed a tiling that isn't periodic. From there, "it was natural to wonder, could there be a single tile that does this?" says mathematician Casey Mann of the University of Washington Bothell, who was not involved with the research. That one has finally been found, "it's huge."

Other shapes have come close. Taylor-Socolar tiles are aperiodic, but they are a jumble of multiple disconnected pieces — not what most people think of as a single tile. "This is the first solution without asterisks," says mathematician Michaël Rao of CNRS and École Normale Supérieure de Lyon in France.

Smith and colleagues proved that the tile was an einstein in two ways. One came from noticing that the hats arrange themselves into larger clusters, called metatiles. Those metatiles then arrange into even larger supertiles, and so on indefinitely, in a type of hierarchical structure that is common for tilings that aren't periodic. This approach revealed that the hat tiling could fill an entire infinite plane, and that its pattern would not repeat.

The second proof relied on the fact that the hat is part of a continuum of shapes: By gradually changing the relative lengths of the sides of the hat, the mathematicians were able to form a family of tiles that can take on the same nonrepeating pattern. By considering the relative sizes and shapes of the tiles at the extremes of that family — one shaped like a chevron and the other reminiscent of a comet — the team again showed that the hat couldn't be arranged in a periodic pattern.

While the paper has yet to be peer-reviewed, the experts interviewed for this article agree that the result seems likely to hold up to detailed scrutiny.

Nonrepeating patterns can have real-world connections. Materials scientist Dan Shechtman won the 2011 Nobel Prize in chemistry for his discovery of quasicrystals, materials with atoms arranged in an orderly structure that never repeats, often described as analogs to Penrose's tilings (SN: 10/22/11, *p.* 13). The new aperiodic tile could spark further investigations in materials science, Senechal says.

Similar tilings have inspired artists, and the hat appears to be no exception. Already the tiling has been rendered as a jumble of shirts and hats. Presumably it's only a matter of time before someone puts hat tiles on a hat.

Researchers should continue the hunt for more einsteins, says coauthor Craig Kaplan, a computer scientist at the University of Waterloo in Canada. "Now that we've unlocked the door, hopefully other new shapes will come along." ■

NEUROSCIENCE

Native language shapes the brain

Wiring patterns reflect grammatical characteristics

BY ELISE CUTTS

The language you learn growing up seems to leave a lasting, biological imprint on the brain.

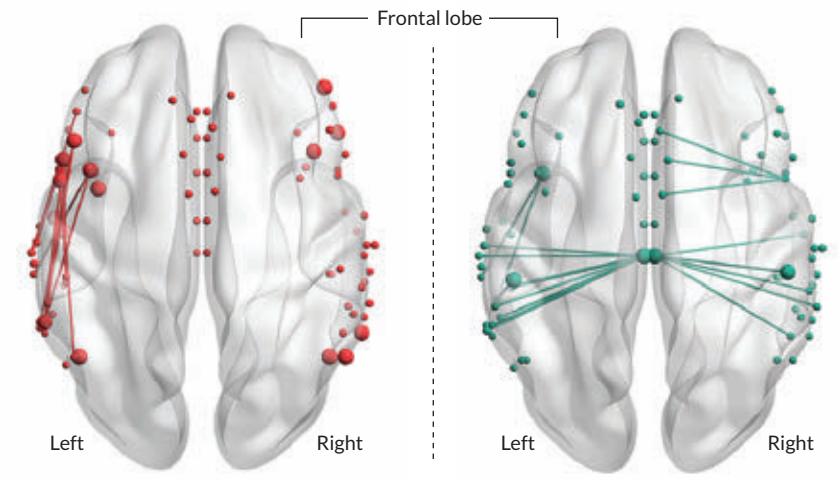
German and Arabic native speakers have different connection strengths in specific parts of the brain's language circuit, researchers report in the April 15 *NeuroImage*, hinting that the cognitive demands of a person's native language physically shape the brain. The study, based on nearly 100 brain scans, is one of the first to identify these kinds of structural wiring differences in a large group of monolingual adults.

"The specific difficulties [of each language] leave distinct traces in the brain," says neuroscientist Alfred Anwander of the Max Planck Institute for Human Cognitive and Brain Sciences in Leipzig, Germany. "So we are not the same if we learn to speak one language, or if we learn another."

Every language expresses itself using a different set of tricks. Some use rich systems of suffixes and prefixes to build enormous, dense words. Others change how words sound or how they are arranged within phrases to create meaning. Our brains process these tricks in a constellation of regions connected by white matter. This tissue routes long, cablelike nerve cells from one part of the brain to another and speeds up communication between them. Wiring regions together this way is part of how we learn: The more often we use a connection, the more robust it becomes.

Different parts of the brain's language circuit have different jobs. The large-scale structure of this circuit is universal, but every language has "its own difficulties," which might result in different white matter networks, Anwander says.

His team recruited 94 healthy volunteers who spoke one of two unrelated native languages — German or Levantine Arabic — for structural MRI brain scans.



Wired up MRI scans revealed differences in the brains of native German (left) and native Arabic (right) speakers. The colored spheres represent different parts of the brain's language circuit. Lines show connections between nodes that are strong in one group of speakers relative to the other.

The Arabic speakers had arrived recently in Germany as refugees and didn't yet speak German. They tended to have stronger connections across their left and right hemispheres, the scans revealed, whereas the German speakers had a denser network of connections within the left hemisphere. "This corresponds to the specific difficulties in the respective languages," Anwander says.

For instance, the complexity of Arabic's root system — trios or quartets of consonants that buddy up with vowel patterns to produce words — might demand extra effort from parts of the brain involved in parsing sounds and words, which are found in both hemispheres. A common example is the root *k-t-b*, which forms words related to writing like *kitaab* (book), *taktub* (you or she writes) and *maktab* (office). Arabic text is also written right to left, which the researchers speculate might demand more communication between the hemispheres than text, like German, that's written left to right.

German, for its part, has a complex and flexible word order that allows the language to create subtle shades of meaning just by shuffling around words within a phrase. While an English speaker can't rearrange the words *woman*, *ball* and *dog* in the sentence "The woman gave the dog a ball" without garbling the core meaning, it's possible to do exactly that in German. This could explain the German speakers' denser white matter networks within parts of the left hemisphere that parse word order.

Still, it's possible that the Arabic speakers, who had been in Germany for six to eight months, could have tweaked their white matter networks too, says Zhenghan Qi, a cognitive neuroscientist at Northeastern University in Boston.

Just one month of learning a new language, she says, can lead to more engagement of the brain's right hemisphere and greater interaction between the two hemispheres. Examining MRI scans of Arabic speakers living in their home countries or tracking brain changes as people learn new languages would help separate the effects of language learning from those of native language, Qi says.

While the study focused just on the language circuit, parts of that circuit handle more than just language, Qi says. And language learning "might also change nonlinguistic regions of the brain," so it's possible that people with different language experiences might process nonlanguage information differently too, she says.

It's still controversial whether language-associated white matter rewiring affects more than just language, Anwander says. But at least within the language circuit, the new results hint that our mother tongues are far more than just the words we happened to grow up with — they are quite literally a part of us. ■

X. WEI ET AL/NEUROIMAGE 2023

Paxlovid may cut risk of long COVID

The drug lowered the odds of 10 of 13 long-term health issues

BY TINA HESMAN SAEY

The antiviral medication Paxlovid seems to reduce the chance of developing long COVID, researchers report.

In a large study of veterans' medical records, Paxlovid lowered a person's chance of landing in the hospital or dying from all causes in the six months after a COVID-19 infection. And the drug reduced the risk of developing 10 of 13 long-term health problems, researchers report March 23 in *JAMA Internal Medicine*.

On average, the drug lowered the relative risk of developing the conditions by 26 percent, says Ziyad Al-Aly, a clinical epidemiologist at Washington University School of Medicine in St. Louis. That's a reduction from nearly 18 of every 100 untreated people developing post–COVID-19 conditions to about 13 of every 100 people in the Paxlovid group.

The antiviral drug provided protection against some heart problems, blood clots, kidney damage, muscle pain, fatigue, shortness of breath and two neurological conditions. But it did not lessen the chance of developing liver disease, cough or diabetes after a COVID-19 infection.

Paxlovid, made by the pharmaceutical company Pfizer, has previously been shown to reduce the chance that susceptible people will be hospitalized or die from COVID-19. To assess the drug's longer-term effects, Al-Aly and colleagues examined medical records from the U.S. Department of Veterans Affairs' health care system. The team found more than 280,000 patients who had a positive COVID-19 test in 2022 and at least one risk factor for developing severe illness. Of those people, nearly 36,000 got Paxlovid within five days of their positive test result.

The team then compared the health outcomes of those who took Paxlovid with those who did not. Since omicron and its subvariants were circulating in 2022, the researchers compared people in the Paxlovid group only with people in the untreated group who were infected at the same time and in the same geographic region, Al-Aly says.

Paxlovid takers had a reduced risk of post–COVID-19 conditions regardless of whether the infection was their first or if they'd had bouts with earlier variants. The drug also lowered long COVID risk for unvaccinated people, for those who were vaccinated with one or two doses, and for people who had at least one booster shot.

But some researchers dispute whether the study fully captures what long COVID is. The condition is notoriously hard to define. "Even in research studies in which we have hours to ask questions, figuring out who has long COVID and who does not is challenging," says Steven Deeks, a long COVID researcher at the University of California, San Francisco. "These electronic medical record reviews are helpful, but they lack specificity for long COVID. They are great for studying other long-term consequences [of COVID], including cardiovascular events and strokes."

For instance, many people with long COVID experience postexertional malaise, or extreme tiredness after exercise, says Monica Verduzco-Gutierrez, director of the post–COVID-19 recovery clinic at the University of Texas Health Science Center at San Antonio. But there isn't a medical code for that condition, she says, "so it's hard to pull out of a medical record review."

Still, the study was able to identify some of the conditions that affect many people with long COVID, including dysautonomia, in which the nervous system has trouble regulating heart rate, blood pressure and breathing.

And the large number of people in the study allows researchers to see effects they might not be able to uncover in smaller randomized control trials, Deeks says. "You can overcome bad data with huge numbers," he says. In such large studies, "when you do see something, it tends to be real."

One limitation of the study is that most patients in the VA system are white males, whereas long COVID patients tend to be female, says Al-Aly, who is also the chief of research and development at the VA St. Louis Healthcare System. But he defends the study's relevance to multiple populations. The study has "literally tens of thousands of women," he says. "Is it true that the majority are male? It's true, but you cannot deny the experience of tens of thousands of people just because they're the minority."

Paxlovid — as well as other antiviral drugs, vaccination and perhaps a diabetes drug called metformin — might all help protect against long COVID, but plenty of patients who have taken Paxlovid are still showing up in long COVID clinics.

"We know it's not this panacea. It's not going to be a miracle cure for long COVID," Verduzco-Gutierrez says. "It may be one of the things that can help, or that can decrease the risk, but it's not going to take it away completely." ■

Paxlovid, an antiviral drug that stops the coronavirus from replicating, might protect against long COVID.

JOE RAEDLE/GETTY IMAGES NEWS

PLANETARY SCIENCE

Did a crash trigger plate tectonics?

Moon-forming impact set off subduction, scientists propose

BY NIKK OGASA

Vestiges of a moon-forming cataclysm could have kick-started plate tectonics on Earth.

The leading explanation for the origin of the moon proposes that a Mars-sized planet, dubbed Theia, struck the nascent Earth about 4.5 billion years ago, ejecting a cloud of debris into space that later coalesced into a satellite. New computer simulations suggest that purported remains of Theia now deep inside Earth could have triggered the onset of global subduction, geodynamicist Qian Yuan of Caltech reported March 13 at the Lunar and Planetary Science Conference. Subduction, a process in which one tectonic plate slides under another, is a hallmark of modern plate tectonics.

The story could offer a cohesive explanation for how Earth gained both its moon and its moving tectonic plates, and it could aid in the search for other Earth-like worlds. But other researchers caution that it's much too early to say that this is, in fact, what happened.

Of all the worlds yet discovered, ours is the only one confirmed to have plate tectonics. For billions of years, Earth's creeping plates have spread, collided and plunged beneath one another, birthing and splitting up continents, uplifting mountain ranges and widening oceans (SN: 6/6/20, p. 10; SN: 1/21/17, p. 18). But all this reshaping has also erased most of the clues to the planet's early history, including how and when plate tectonics began.

For their simulations, Yuan and colleagues focused on two continent-sized blobs of material in Earth's lower mantle known as large low-shear velocity provinces (SN: 6/11/16, p. 13). These are regions through which seismic waves move anomalously slow. Researchers had previously proposed that these regions could have formed from old, subducted plates. But in 2021, Yuan and colleagues proposed that the mysterious masses could instead be the dense, sunken remnants of Theia.

Building off that previous work, the researchers simulated how Theia's impact, and its lingering remains, might have affected the flow of rock inside Earth.

Once these hot alien blocks had sunk to the bottom of the mantle, they could have compelled large plumes of warm rock to upwell and wedge into Earth's rigid outer layer, the simulations suggest. As upwelling continued to feed into the risen plumes, the plumes would have ballooned and pushed slabs of Earth's surface beneath them, triggering subduction about 200 million years after the moon formed.

While the simulations suggest that the large low-shear velocity provinces could have had a hand in starting subduction, it's not yet clear whether these masses came from Theia. "The features… are a fairly recent discovery," says geodynamicist Laurent Montési of the University of Maryland in College Park. "This material down there is something special," he says. "But whether it has to be originally extraterrestrial, I don't think the case is made." As such, he says, it's too early to say that Theia triggered plate tectonics.

If confirmed, though, the explanation could have implications that reach beyond our solar system. Any rocky exoplanet with a relatively large moon was probably struck by a large impactor, which could have initiated plate tectonics, Yuan said at the meeting. Scientists have yet to confirm the discovery of any such exomoons (SN *Online*: 4/30/19; SN: 8/19/17, p. 15). But keeping an eye out, Yuan said, could help us uncover another world as tectonically active as our own. ■

MEETING NOTE

Martian soil contains the right stuff for growing rice

Dirt on Mars may have all the necessary nutrients for growing rice, planetary scientist Abhilash Ramachandran reported March 13 at the Lunar and Planetary Science Conference. But the plant may need a bit of help to survive amid perchlorate, a chemical that has been detected on Mars' surface and can be toxic to plants.

"We want to send humans to Mars… but we cannot take everything there. It's going to be expensive," says Ramachandran, of the University of Arkansas in Fayetteville. Growing rice there would be ideal, because it's easy to prepare, he says. "You just peel off the husk and start boiling."

Ramachandran and colleagues grew rice plants in a Martian soil simulant made of Mojave Desert basalt. They also grew rice in pure potting mix, as well as several mixtures of the potting mix and soil simulant.

Rice plants grew in the synthetic Mars dirt but developed shorter, thinner shoots and wispier roots than the plants that sprouted from the potting mix or hybrid soils. Even replacing just 25 percent of the simulant with potting mix helped heaps, the team found.

The researchers also tried growing rice in soil with added perchlorate. They sourced one wild rice variety and two cultivars genetically modified for resilience against environmental stressors like drought and grew rice in Mars-like dirt with and without perchlorate.

No rice plants grew amid a concentration of 3 grams of perchlorate per kilogram of soil. But when the concentration was just 1 gram per kilogram, a seed from one of the modified lines grew both a shoot and a root, while a seed from the wild variety managed to grow a root.

By tinkering with the successful rice's modified gene, *SnRK1a*, humans might be able to develop a rice cultivar suitable for Mars. — *Nikk Ogasa*

PLANETARY SCIENCE

Earth-sized planet is surprisingly hot

The finding suggests that TRAPPIST-1b lacks an atmosphere

BY SID PERKINS

A rocky planet that circles a small star nearly 40 light-years from Earth is hot and has little or no atmosphere, a new study suggests. The finding raises questions about the possibility of atmospheres on the other orbs in the planetary system.

At the center of the system is the red dwarf star dubbed TRAPPIST-1. It hosts seven known planets with masses ranging from 0.3 to 1.4 times that of Earth. That a few of the planets might hold liquid water and thus be habitable has driven scientists to learn more about the system since it was discovered in 2017 (SN: 3/18/17, *p.* 6).

The largest planet, TRAPPIST-1b, is the closest to the parent star and receives about four times the radiation that Earth gets from the sun, says astrophysicist Thomas Greene of NASA's Ames Research Center in Mountain View, Calif. Like all other planets in the system, TRAPPIST-1b is tidally locked, meaning that one side of the planet always faces the star and one side looks away. Calculations suggest that if the stellar energy falling on TRAPPIST-1b were distributed around the planet—by an atmosphere, for example—and reradiated equally in all directions, the planet's dayside surface temperature would be about 120° Celsius.

But the planet's dayside temperature is actually about 230° C, Greene and colleagues report March 27 in *Nature*. That suggests there's little or no atmosphere to carry heat from the sunlit side to the dark side, the researchers contend.

Greene's team used the James Webb Space Telescope to observe the planet in a narrow band of infrared wavelengths five times in 2022. The observations were made just before and after TRAPPIST-1b dodged behind its parent star, revealing the planet's fully lit face.

Greene and colleagues' work is "the first deep-dive look at this planet," says astrophysicist Knicole Colón of NASA's Goddard Space Flight Center in Greenbelt, Md. "With every observation, we expect to learn something new."

Astronomers have long suggested that planets close to red dwarf stars might not hold onto their atmospheres, largely because frequent and high-energy flares from such stars would blast away any gaseous shroud the orbs might have during their early years. Yet some scenarios posit that flares could heat up a planet's surface and drive volcanism that, in turn, produces atmosphere-forming gases.

Many more measurements are needed "to be totally sure" that TRAPPIST-1b has no atmosphere, says astrophysicist Michaël Gillon of the University of Liège in Belgium. When observed at a wider variety of wavelengths and from other angles, the planet might show signs of a gaseous shroud that hints at volcanism.

Either way, says astronomer Laura Kreidberg of the Max Planck Institute for Astronomy in Heidelberg, Germany, the new result motivates detailed study of the system's cooler, potentially habitable planets, "to see if the same is true of them." ■

PLANETARY SCIENCE

Asteroid hosts an ingredient for life

Scientists extract uracil from samples of space rock Ryugu

BY ALLISON GASPARINI

Uracil, a building block of life, has been found on the asteroid Ryugu.

Yasuhiro Oba and colleagues discovered the nucleobase in a sample brought to Earth by Japan's Hayabusa2 spacecraft, the team reports March 21 in *Nature Communications*. The finding bolsters the idea that life's key ingredients exist elsewhere in space and that space rocks delivered them to Earth.

Detecting uracil in the Ryugu sample "is very important to clearly demonstrate that it is really present in extraterrestrial environments," says Oba, an astrochemist at Hokkaido University in Sapporo, Japan.

Uracil is one of four nucleobases that form the structure of RNA, an essential component of living cells. Some scientists think RNA drove the chemical reactions associated with early life on Earth. All four nucleobases had been previously detected in meteorites (SN: 6/4/22, *p.* 7). But since those space rocks landed on Earth, there's a chance they had been contaminated by the planet's inhabitants.

The Ryugu sample was collected in space, so it's the purest bit of the solar system scientists have studied to date. That means Oba and colleagues could rule out terrestrial contamination. The team extracted organic material from the Ryugu sample with hot water, then used acid to separate out uracil.

It's possible that the uracil was separated from longer chains of molecules in the process, says prebiotic chemist Laura Rodriguez of the Lunar and Planetary Institute in Houston. Nucleobases can bond to create complex structures, she says, which may eventually form RNA. "My question is, are those more complex structures also forming in the asteroids?"

Oba says his team plans to analyze samples from NASA's OSIRIS-REx mission, which grabbed a bit of asteroid Bennu in 2020 and will bring it to Earth this fall (SN: 11/21/20, *p.* 5). ■

The asteroid Ryugu, shown in this photo taken in 2018 by the Hayabusa2 spacecraft, carries the RNA building block uracil, scientists say.

HAYABUSA2/JAXA

ASTRONOMY

Crashing stars may lob fast radio bursts

A burst trailed gravitational waves from a neutron star merger

BY LISA GROSSMAN

A neutron star pileup may have emitted two different kinds of cosmic signals: ripples in spacetime known as gravitational waves and a brief blip of energy called a fast radio burst.

One of the three detectors that make up the gravitational wave observatories LIGO and Virgo picked up a signal from a cosmic collision on April 25, 2019. About 2½ hours later, a fast radio burst detector picked up a signal from the same region of sky, researchers report March 27 in *Nature Astronomy*.

If strengthened by further observations, the finding could bolster the theory that mysterious fast radio bursts have multiple origins — and neutron star mergers are one of them.

"We're 99.5 percent sure" both signals came from the same event, says astrophysicist Alexandra Moroianu, who spotted the merger and its aftermath while she was at the University of Western Australia in Perth. "We want to be 99.999 percent sure."

Unfortunately, Virgo's detector and one of LIGO's two detectors didn't pick up the signal, so it's impossible to precisely triangulate its location. "Even though it's not a concrete, bang-on observation for something that's been theorized for a decade, it's the first evidence we've got," Moroianu says. If confirmed, "it's going to be a big boom in fast radio burst science."

Astronomers have spotted over 600 fast radio bursts, or FRBs, since they were discovered in 2007. Despite their frequency, their source remains an open question. One leading candidate is a highly magnetized neutron star called a magnetar, which might shoot off FRBs as it spins and its magnetic field interacts with surrounding material (SN: 7/4/20 & 7/18/20, *p.* 12). But since some FRBs appear to repeat while others are apparent one-off events, there's probably more than one way to produce the bursts (SN: 2/29/20, *p.* 14).

Theorists have wondered whether a collision between two neutron stars could spark a singular FRB, before the wreckage produces a black hole. Such a smashup should also emit gravitational waves (SN: 11/11/17, *p.* 6).

Moroianu and colleagues searched archived data from LIGO and the Canadian Hydrogen Intensity Mapping Experiment, a fast radio burst detector in British Columbia, to see if any of their signals lined up. The team found one candidate pairing: GW190425 and FRB20190425A.

Even though just one LIGO detector caught the gravitational waves, the team spotted other suggestive signs that the FRB and gravitational wave signals were related. Both came from the same distance, about 370 million light-years from Earth. The gravitational waves were from the only neutron star merger LIGO spotted in that observing run, and the FRB was particularly bright. Satellite data indicate there may even have been a simultaneous burst of gamma rays — another aftereffect of a neutron star merger.

"Everything points at this being a very interesting combination of signals," Moroianu says. She says it's like watching a crime drama on TV: "You have so much evidence that anyone watching the TV show would be like, 'Oh, I think he did it.' But it's not enough to convince the court."

The finding has exciting implications despite the uncertainty, says astrophysicist Alessandra Corsi of Texas Tech University in Lubbock. One is the possibility that two neutron stars might merge into a single, extra-massive neutron star without immediately collapsing into a black hole. "There's this fuzzy dividing line between what's a neutron star and what's a black hole," Corsi says.

In 2013, astrophysicist Bing Zhang of the University of Nevada, Las Vegas suggested that a neutron star smashup could create an extra-massive neutron star that wobbles on the edge of stability for up to a few hours before collapsing into a black hole. In that case, the resulting FRB would be delayed — just like in the 2019 case.

The most massive neutron star yet observed is 2.35 times the mass of the sun, but theorists think that neutron stars could grow to be around three times the mass of the sun without collapsing immediately. The neutron star that might have resulted from the collision in 2019 would have been 3.4 solar masses, Moroianu and colleagues calculate.

"Something like this, especially if it's confirmed with more observations, it would definitely tell us something about how neutron matter behaves," Corsi says. "The nice thing about this is we have hopes of testing this in the future."

The next LIGO run is expected to start in May. Corsi is optimistic that more coincidences between gravitational waves and FRBs will show up, now that researchers know to look for them. "There should be a bright future ahead of us," she says. ■

Merging neutron stars (illustrated) produced gravitational waves that were soon followed by a burst of bright radio waves, evidence that colliding neutron stars may be a source of some such bursts.

DANA BERRY, SWIFT/NASA

PLANTS

Parched plants make ultrasonic clicks

The sounds might offer a new way to detect thirsty crops

BY MEGHAN ROSEN

Listen carefully, and a plant may tell you it's thirsty.

Dry tomato and tobacco plants emit distinct ultrasonic clicks, scientists report in the March 30 *Cell*. The noises, when brought into the range of human hearing, sound something like a kid stomping on Bubble Wrap. They also popped off when scientists snipped the plants' stems.

When evolutionary biologist Lilach Hadany talks about the findings, she says, people tell her, "'You cut the tomato and it screams.'" But that's a conclusion her team has yet to reach. "Screaming" assumes the noise is intentional, says Hadany, of Tel Aviv University. "We've shown only that plants emit informative sounds."

Still, detecting those sounds could offer a new way to monitor water stress in crops, Hadany and colleagues propose. If microphones in fields or greenhouses picked up certain clicks, farmers would know their crops were drying out.

Previous work had suggested that some plants produce ultrasonic emissions. Those experiments used sensors connected directly to plants, says Alexandre Ponomarenko, a physicist at the biotech company NETRI in Lyon, France.

Hadany's team wanted to know whether such sounds are airborne. So the researchers set up microphones beside living plants. Horticultural hiccups were first detected in plants on lab tables. To rule out other sources, the team placed plants in sound-dampening boxes and tucked them in a relatively quiet basement.

Tomato plants that hadn't been watered in four to six days emitted about 35 clicks per hour. Those cut at the stem were slightly less noisy, and tobacco plants clicked even less. Plants not water-stressed or chopped kept mostly quiet. Clicks were about as loud as a conversation, but too high-pitched for humans to hear (though dogs' ears might perk up).

Each species had a recognizable "voice." A machine learning algorithm could not only tell the difference between tomato- and tobacco-plant clicks, but it could also tell thirsty plants from hydrated ones. The algorithm even differentiated tomato plants in a greenhouse filled with sounds of people talking and nearby construction.

It's unclear what causes the clicks. Perhaps bubbles form and pop within plants' water-carrying tissues, Hadany suggests.

Tomato and tobacco aren't the only plants that prattle, the team found. Wheat, corn, grapevines and pincushion cactus do too. "It seems like this is not a random thing," says plant developmental biologist Ravishankar Palanivelu of the University of Arizona in Tucson. Palanivelu doesn't know if the clicks have evolutionary significance, but, he says, the findings will certainly generate some noise. ■

ANIMALS

Barn owls turn red on volcanic islands

Scientists link sulfur-rich environments with more florid feathers

BY JAKE BUEHLER

Life on a volcanic isle appears to give barn owls a blush of red-brown plumage.

The high-sulfur environment on such islands influences the birds' coloration, scientists report March 13 in the *Journal of Biogeography*. Darker feathers might also detoxify harmful sulfur-based chemicals or help the owls blend in with the islands' shadowy forest backdrop. The findings are among the first evidence that environmental sources of sulfur such as soil can influence feather color.

Barn owls (*Tyto alba*) are found on most continents and many islands. The color of their plumage varies considerably, with bellies ranging from almost completely white to a much darker copper depending on location, says evolutionary ecologist Andrea Romano of the University of Milan.

In 2021, he and colleagues discovered that barn owls on some islands are paler than mainland populations. But that difference "disappears on small and remote islands and archipelagos," Romano says. "In some cases, owls are darker than the continental ones." The researchers wondered if sulfur could be behind the reversal.

The pale belly plumage of barn owls like this one tends to be redder in sulfur-rich environs.

Many of the smaller, more isolated islands have volcanoes that load the air and soil with sulfur dioxide. Sulfur has a crucial role in the development of pigments such as pheomelanin, which imparts a reddish hue in vertebrate soft tissues. A few previous studies have linked sulfur-rich diets or sulfur pollution to plumage color, Romano says. So the team hypothesized that a volcanic environment full of sulfur might lead the owls to produce more pheomelanin, thus making plumage darker.

The team examined more than 2,000 preserved barn owl specimens from dozens of islands, scoring the redness of belly plumage to find an average color for each geographic location. Owls from volcanic islands such as Sulawesi in Indonesia or the Canary Islands off the coast of northwestern Africa had darker, redder plumage than owls from nonvolcanic islands such as Tasmania in Australia. But volcanic sulfur's influence explains less than 10 percent of the color variation, the team estimates.

Genetics also plays a role in plumage color, says ecoevolutionary biologist Thomas Kvalnes of the Norwegian Institute for Nature Research in Trondheim. The gene *MC1R* is responsible for as much as 70 percent of the color variation seen in barn owls, he says. The remaining portion "is where different environmental factors need to be taken into account."

If and how the owls take up volcanic sulfur is unclear, but it might provide some benefits. Darker feathers may help the predators blend into thick vegetation, Romano speculates. Making more pheomelanin might also be a way for the owls to use up sulfur and avoid toxic effects.

The connection between plumage color and volcanic sulfur may extend to other types of birds. Several species in Iceland get a pheomelanin boost from environmental sulfur, another group reported February 25 in the *Journal of Ornithology*. But some of these birds are migratory, which weakens the link between place and pigmentation, Kvalnes says. ■

EARTH

'Hidden' tornado track spotted

Satellite data reveal a twister's path across a barren landscape

BY KATHERINE KORNEI

When a strong tornado roars through a city, it often leaves behind demolished buildings, broken tree limbs and trails of debris. But damage from a similarly powerful storm touching down over barren land can be much harder to spot.

Now, satellite imagery has revealed a 60-kilometer-long track of moist earth in Arkansas that was invisible to human eyes. The feature was presumably excavated by a tornado when it stripped away the uppermost layer of the soil, researchers report in the March 28 *Geophysical Research Letters*.

Tornado tracks can help reveal a twister's strength, path and number of vortices. This new method of looking for "hidden" tracks is particularly valuable for better understanding tornadoes that strike in the winter, when there's less vegetation, the researchers suggest. Recent research has shown that wintertime storms will probably increase in intensity as the climate warms (*SN Online: 12/16/21*).

More than 1,000 tornadoes strike the United States each year, according to the National Weather Service. But not all tornadoes are equally likely to be studied, says Darrel Kingfield, a meteorologist at the National Oceanic and Atmospheric Administration in Boulder, Colo., who was not involved in the work.

For starters, storms that pass over populated areas are more apt to be analyzed. "There's historically been a pretty big population bias," Kingfield says. Storms that occur over vegetated regions also tend to be well studied, simply because they leave obvious scars on the landscape in the form of ripped-up grasses or downed trees.

Spring and summer are peak storm seasons in the United States — more than 70 percent of tornadoes strike from March through September. But on

ZAHOOR SALMI/MOMENT/GETTY IMAGES PLUS

Not all tornadoes leave prominent scars like the one shown cutting across Tuscaloosa, Ala., in this 2011 satellite image. Soil moisture could help scientists track a storm's path across barren lands.

GOOGLE EARTH, GEOEYE

December 10, 2021, a cluster of storms started racing across the central and southern United States. Those twisters, which killed more than 80 people, swept across cities and farmland that had been mostly harvested.

Jingyu Wang, a physical geographer at Nanyang Technological University in Singapore, and colleagues set out to detect the signatures of those deadly storms in unpopulated, barren landscapes.

Swirling winds, even relatively weak ones, can suck up several centimeters of soil. And since deeper layers of the ground tend to be wetter, a tornado ought to leave behind a telltale signature: a long swath of moister-than-usual soil. Two properties linked with soil moisture level — texture and temperature — in turn impact how much infrared light the soil reflects.

Wang's team analyzed infrared data collected by NASA's Terra and Aqua satellites, looking for changes in soil moisture consistent with a passing tornado.

A signal in northeastern Arkansas stood out in data obtained shortly after the 2021 storm outbreak. The feature was consistent with a track of wet soil stretching roughly 60 kilometers. Tornadoes had been previously reported in that area so it's likely a powerful storm created the feature, the team concludes.

That conclusion makes sense, Kingfield says, and observations like these can reveal tornado signatures that scientists might otherwise miss. But the technique works best with clay-rich soils that retain water, he says, which make up only about 2 percent of the United States' surface area.

Still, a new tool for understanding storms is useful, especially since many go unexamined because of where and when they occur, Kingfield says. "Now we have this new ground truth." ■

HEALTH & MEDICINE

Hormone shot sobers up drunk mice

The finding hints at a possible treatment for alcohol poisoning

BY FREDA KREIER

The only cure for drunkenness is to wait it out. But that might not always be the case: Injecting drunk mice with a naturally occurring hormone helped them sober up more quickly than they otherwise would have, a new study shows.

Mice that received a shot of FGF21 — a hormone made by mouse and human livers — woke up from a drunken stupor roughly twice as fast as those that didn't get the shot, scientists report in the March 7 *Cell Metabolism*.

The finding could lead to treatments for alcohol poisoning, a sometimes-deadly side effect of heavy drinking that lands millions of people in emergency rooms every year, says David Mangelsdorf, a molecular endocrinologist at the University of Texas Southwestern Medical Center in Dallas.

The sobering effect of FGF21 isn't the first time the hormone has been linked to drinking. Scientists have previously shown that the liver ramps up production of the hormone when alcohol floods the bloodstream. While FGF21 doesn't help break down alcohol, it can help protect the liver from the toxic effects of liquor while dampening the desire to drink, studies in mice and monkeys have shown.

Mangelsdorf and colleagues were curious whether FGF21 also plays a role in recovering from too much alcohol. The team gave mice alcohol until the rodents became unconscious and waited to see how long it took for them to wake up.

Mice that were genetically altered so that they couldn't make their own FGF21 took about an hour and a half longer to wake up than normal mice, which took nearly four hours. And normal mice given an extra dose of FGF21 woke up twice as fast as those that hadn't received a boost. Drunk mice that were injected with FGF21 also balanced on a slowly rotating platform for longer than their drunken peers.

FGF21 probably activates nerve cells in a part of the brain involved with stimulating wakefulness, the researchers say. If the hormone works in a similar way in people, it could be used to nudge individuals with alcohol poisoning back into wakefulness, Mangelsdorf says.

That ability could be useful in cases when doctors need people with alcohol poisoning to wake up before addressing symptoms. "There is no drug for treating alcohol poisoning," Mangelsdorf says. A drug that could help people wake up — much the way that Narcan prods consciousness along in opioid overdoses — would improve treatment for people rushed to the hospital, he says.

Researchers have found ways to sober up rodents before, but these treatments didn't work well in people (SN: 11/19/22, p. 4). FGF21 might be a different story, Mangelsdorf says, based on the previous research in monkeys.

Drugs derived from FGF21 might also be useful for treating liver disease and alcohol addiction, says Lorenzo Leggio, a Baltimore-based physician-scientist with the National Institutes of Health. In the meantime, Leggio says, this study adds "an important piece to the puzzle" for understanding the role of FGF21. ■

GENETICS

Beethoven's hair hints at why he died

Combing through DNA reveals liver disease risk and hepatitis B

BY FREDA KREIER

DNA from strands of Beethoven's hair is helping to uncover what may have caused his death, researchers say.

The composer was plagued with health issues for most of his life. On March 26, 1827, he succumbed at age 56 to what many historians suspect was liver failure while in his apartment in Vienna. Now, an analysis of several locks of hair passed down through families and gathered by collectors shows that Beethoven carried a slew of genetic risk factors for liver disease, scientists report March 22 in *Current Biology*.

This elevated risk, paired with a potential liver infection and the composer's alleged drinking habits, may have hastened Beethoven's premature death, says biological anthropologist Tristan Begg of the University of Cambridge.

It's well-known that Ludwig van Beethoven's storied career was hampered by progressive hearing loss that rendered the composer completely deaf by age 45. Beethoven also suffered from gastrointestinal issues and a deteriorating liver. That faulty organ is thought to be responsible for the composer's skin reportedly turning yellow in 1821.

The root cause of Beethoven's plethora of health issues has been a source of fascination to many. But working out what ailed a man that lived two centuries ago is no easy task. Researchers have had to rely on notes from the composer's autopsy, two physical examinations performed after his body was exhumed in 1863 and again in 1888, and other historical documents.

Scientists have wondered if clues hide in Beethoven's DNA. Such a genetic treasure trove would offer information that "no anatomical examination, after 200 years, could provide," says Carles Lalueza-Fox, a paleogeneticist at the Institute of Evolutionary Biology in Barcelona, who was not involved in the study.

Only a few historical figures—such as Richard III (*SN: 3/9/13, p. 14*; *SN Online: 12/2/14*)—have had their DNA analyzed. In 2014, Begg and colleagues set out to reconstruct Beethoven's genetic instruction book, or genome.

First, the team needed a piece of the composer himself. Around 30 separate locks of hair attributed to Beethoven have survived in the possession of collectors and the descendants of people who first received the hair in the 19th century. Begg partnered with Beethoven enthusiasts to ask the owners to part with a few strands. The team gathered samples from eight locks said to have been snipped from 1821 to around 1827.

One lock didn't yield enough DNA for analysis. And two locks could not have come from the composer; one belonged to a woman with probable Ashkenazi Jewish ancestry, the team found. The remaining five locks, which came from various sources, clearly belonged to a single individual with Central European ancestry, which Beethoven would have had. The natural degradation of DNA over time in these locks was also consistent with the hair dating to the early 19th century.

Those common features, along with a clear record of who owned these separate locks of hair over the centuries, Begg says, make him "extremely confident" that the five locks are Beethoven's.

That's a reasonable conclusion, Lalueza-Fox says. The team provides "compelling evidence of five samples being from the composer," he says.

Begg and colleagues used the best-preserved lock to reconstruct Beethoven's genome. The analysis didn't uncover any genetic markers for deafness or intestinal issues, but it did turn up several risk factors for liver disease. Notably, the team found a variant of the gene *PNPLA3* that would have tripled the composer's risk of developing liver issues in his lifetime.

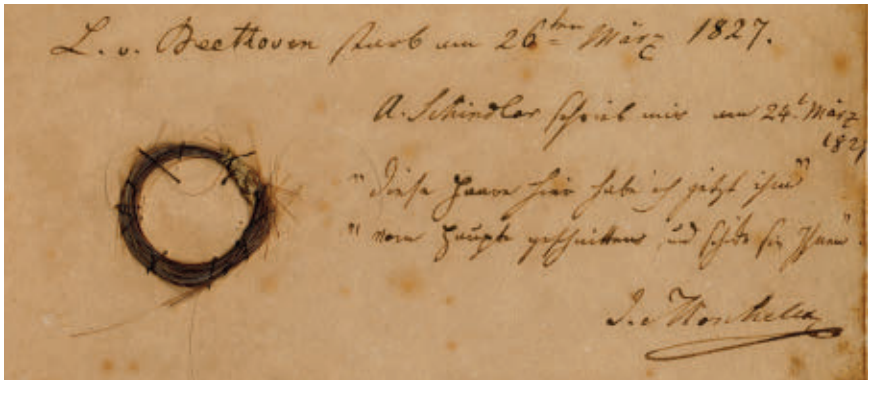
Those risk factors alone shouldn't have doomed Beethoven to an early death. But the scientists also found traces of the hepatitis B virus in his genome. The risk to the liver from a hepatitis B infection would have been compounded by regular alcohol use, the researchers say. Some contemporaries claimed that Beethoven was drinking heavily by the end of his life.

While the exact combination of factors that killed Beethoven remains unclear, "this is a fascinating detective story," says hepatologist Ian Gilmore of the Royal Liverpool University Hospital in England.

It's also a fascinating story with a new twist: Beethoven's Y chromosome doesn't match those of living relatives with whom he shares a 16th century ancestor. (Beethoven had no known children.)

This could be a sign that the hair is inauthentic. More likely, Begg says, is that somewhere in the seven generations between this common ancestor and Beethoven, a woman on his father's side had a son with a man who wasn't her husband, and Beethoven is a descendant of that liaison. ■

Hair collected from Ludwig van Beethoven during his lifetime helped scientists reconstruct the composer's genome. The lock shown here was taken from Beethoven in 1827, the year he died.



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Surveys conducted in 2016 at West Antarctica's lower Kamb Ice Stream revealed a cavern hidden far beneath the surface. At the end of 2021, researchers drilled into it.

H. HORGAN

Journey under the ice

Researchers get their first look at a massive ice cavern within a West Antarctic glacier

By Douglas Fox

The coastal plain of the Kamb Ice Stream, a West Antarctic glacier, hardly seems like a coast at all. Stand in this place, 800 kilometers from the South Pole, and you see nothing but flat ice extending in every direction. The ice is some 700 meters thick and stretches for hundreds of kilometers off the coastline, floating on the water. On clear summer days, the ice reflects the sunlight with such ferocity that it inflicts sunburn in the insides of your nostrils. It might seem hard to believe, but hidden beneath this ice is a muddy tidal marsh, where a burbling river wends its way into the ocean.

Until recently, no human had ever glimpsed that secret landscape. Scientists had merely inferred its existence from the faint reflections of radar and seismic waves. But in the closing days of 2021, a team of scientists from New Zealand melted a narrow hole through the glacier's ice and lowered in a camera. They had hoped that their hole would intersect with the river, which they believed had melted a channel up into the ice — a vast water-filled cavity, nearly tall enough to hold the Empire State Building and half as long as Manhattan. On December 29, Craig Stevens finally got his first look inside. It is a moment that he will always remember.

Stevens is a physical oceanographer with New Zealand's National Institute of Water and Atmospheric Research in Wellington. He spent 90 anxious minutes that day in Antarctica with his head buried ostrich-style under a thick down jacket to block the sunlight that would otherwise obscure his computer monitor. There, he watched live video from the camera as it descended into the hole. Icy circular walls scrolled past, reminiscent of a cosmic wormhole. Suddenly, at a depth of 502 meters, the walls widened out.

Stevens shouted for a colleague to halt the winch lowering the camera. He stared at the screen as the camera rotated idly on its cable. Its floodlights raked across a ceiling of glacial ice — a startling sight — scalloped into delicate crests and waves.

It resembled the dreamy undulations that might take millennia to form in a limestone cavern.

"The interior of a cathedral," says Stevens. A cathedral not only in beauty, but also in size. As the winch restarted, the camera journeyed downward for another half hour, through 242 meters of sunless water. Bits of reflective silt stirred up by currents streamed back down like snowflakes through the black void.

Stevens and his colleagues spent the next two weeks lowering instruments into the void. Their observations revealed that this coastal river has melted a massive, steep-walled cavern cutting as far as 350 meters up into the overlying ice. The cavern extends for at least 10 kilometers and appears to be boring inland, farther upstream, into the ice sheet with each passing year.

This cavity offers researchers a window into the network of subglacial rivers and lakes that extends hundreds of kilometers inland in this part of West Antarctica. It's an otherworldly environment that humans have barely explored and is laden with evidence of Antarctica's warm, distant past, when it was still inhabited by a few stunted trees.

One of the biggest surprises came as the camera reached bottom that day. Stevens gazed in disbelief as dozens of orange blurs swam and darted on his monitor—evidence that this place, roughly 500 kilometers from the open, sunlit ocean, is nonetheless bustling with marine animals.

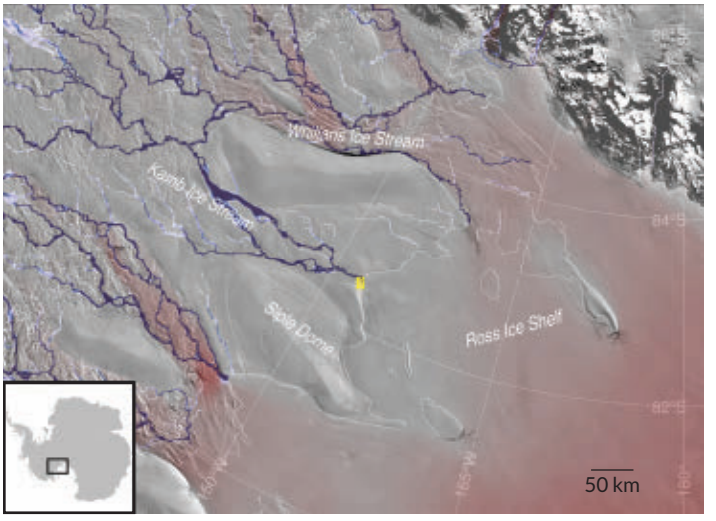
Seeing them was "just complete shock," says Huw Horgan, a glaciologist formerly at the Victoria University of Wellington who led the drilling expedition.

Horgan, who recently moved to ETH Zurich, wants to know how much water is flowing through the cavern and how its growth will impact the Kamb Ice Stream over time. Kamb is unlikely to fall apart anytime soon; this part of West Antarctica is not immediately threatened by climate change. But the cavern might still offer clues to how subglacial water could affect more vulnerable glaciers.

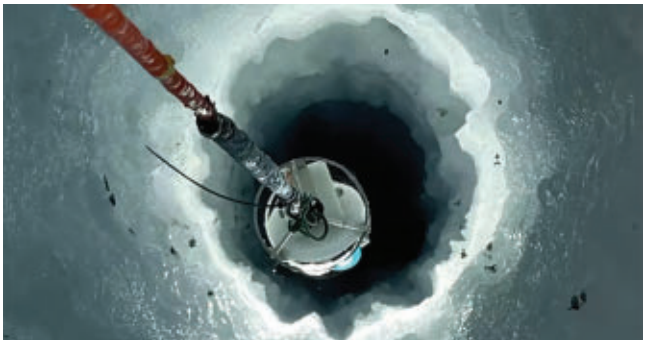
Mapping the unknown

Scientists have long surmised that a veneer of liquid water sits beneath much of the ice sheet covering Antarctica. This water forms as the bottom of the ice slowly melts, several pennythicknesses per year, due to heat seeping from the Earth's interior. In 2007, Helen Amanda Fricker, a glaciologist at the Scripps Institution of Oceanography in La Jolla, Calif., reported evidence that this water pools into large lakes beneath the ice and can flood quickly from one lake to another (SN: 6/17/06, p. 382).

Fricker was looking at data from NASA's Ice, Cloud and Land Elevation Satellite, or ICESat, which measures the height of the ice surface by reflecting a laser off of it. The surface at several spots in West Antarctica seemed to bob up and down, rising and falling by as much as nine meters over a couple of years. She interpreted these active spots as subglacial lakes. As they filled and then spilled out their water, the overlying ice rose and fell. Fricker's team and several others eventually found over 350 of these lakes scattered around Antarctica, including a couple dozen beneath Kamb and its neighboring glacier, the Whillans Ice Stream.



The Kamb Ice Stream is located on the coast of West Antarctica and flows into the Ross Ice Shelf, a slab of floating ice hundreds of meters thick. The site of the newly discovered cavern is shown as a yellow box.



Researchers got their first glimpse into the hidden landscape in late 2021, when they drilled through 500 meters of ice and lowered in instruments to observe the cavern below (borehole shown).

The lakes provoked great interest because they were expected to harbor life and might provide insights about what sorts of organisms could survive on other worlds—deep within the ice-covered moons of Jupiter and Saturn, for instance. The layers of sediment in Antarctica's lakes might also offer glimpses into the continent's ancient climate, ecosystems and ice cover. Teams funded by Russia, the United Kingdom and the United States attempted to drill into subglacial lakes. In 2013, the U.S.-led team succeeded, melting through 800 meters of ice and tapping into a reservoir called Subglacial Lake Whillans. It was teeming with microbes, 130,000 cells per milliliter of lake water (SN: 9/20/14, p. 10).

Horgan helped map Lake Whillans before drilling began. But by the time the lake was breached, he and others were becoming intrigued with another facet of the subglacial landscape—the rivers thought to carry water from one lake to another, and eventually to the ocean.

Finding these hidden rivers requires complicated guesswork. Their flow paths are influenced not only by the subglacial topography, but also by differences in the thickness of the overlying

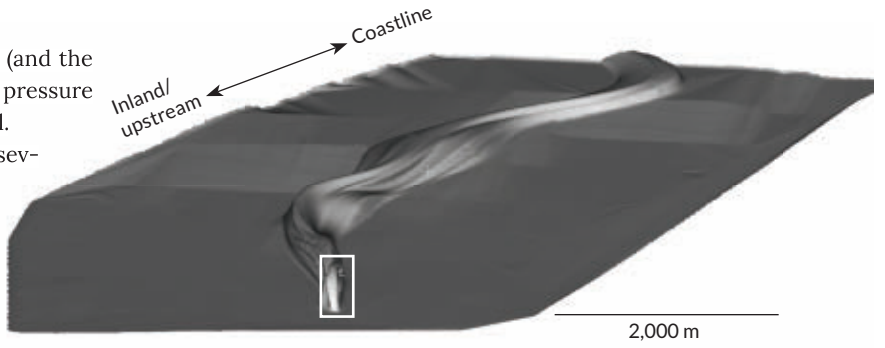
FROM TOP: A. WHITEFORD ET AL/ JOURNAL OF GEOPHYSICAL RESEARCH: EARTH SURFACE 2022; C. STEVENS/NIWA (CC BY-ND)

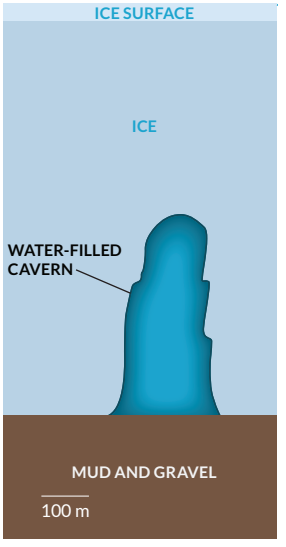
ice. Water moves from places where the ice is thick (and the pressure high) to places where it is thinner (and the pressure lower) — meaning that rivers can sometimes run uphill.

By 2015, scientists had mapped the likely paths of several dozen subglacial rivers. But drilling into them still seemed farfetched. The rivers are narrow targets and their exact locations often uncertain. But around that time, Horgan got a lucky break.

While examining a satellite photo of the Kamb Ice Stream, he noticed a wrinkle in the pixelated tapestry of the image. The wrinkle resembled a long, shallow trough in the surface of the ice, as if the ice had sagged from melting beneath. The trough sat several kilometers from the hypothetical path of one subglacial river. Horgan believed that it marked the spot where that river flowed over the coastal plain and spilled into the ice-covered sea.

In 2016, while visiting the area for an unrelated research project, Horgan and his companions detoured briefly to the surface trough to take radar measurements. Sure enough, they found a void under the ice, filled with liquid water. Horgan began making plans to study it more closely. He would return twice in the next few years, once to map the river in detail and a second time to drill into it. What he found greatly exceeded his expectations.





A cathedral in ice The 3-D rendering above shows the shape of the cavern, based on radar traces. Scientists think it is being carved back from the coastline as a river flowing beneath the ice meets the ocean and stirs up the water there. The illustration at left shows what a rough cross section at one point might look like, with ice above and ground beneath.

A river runs through

Horgan and graduate student Arran Whiteford of the Victoria University of Wellington visited the lower Kamb Ice Stream to map the river in December 2019.

After weeks on the Antarctic ice sheet, they'd grown accustomed to its monotonous flat landscape, their perception sensitized to even tiny ups and downs. In this context, the surface trough "looked like this massive chasm," Whiteford says, "like an amphitheater" — even though it slanted no more dramatically than a rolling cornfield in Iowa.

It was a week of scientific drudgery, towing the ice-penetrating radar behind a snowmobile along a series of straight, parallel lines that crisscrossed the trough to map the shape of the river channel under the ice.

Horgan and Whiteford worked up to 12 hours per day, occasionally trading positions. One person drove the snowmobile, straining his thumb on the throttle to maintain a constant 8 kilometers per hour. Two sleds hissed along behind. One held a transmitter that fired radar waves into the glacier below; the other held an antenna that received the signal reflected back off the bottom of the ice. The second person rode on the sled with the antenna, his eyes on a bouncing laptop screen making sure that the radar was functioning.

Each evening they huddled in their tent, reviewing their radar traces. The river channel appeared far more dramatic than the gentle dip atop the ice suggested. Below their boots sat a vast water-filled cavern with steep sides like a train tunnel, 200 meters to a kilometer wide and cutting as much as 50 percent of the way up through the glacier. The more they looked, the more it resembled a river. "It kind of meanders downstream," Whiteford says.

All told, Whiteford made two weeklong visits to the trough, snowmobiling over from another camp 50 kilometers away. The first time he was accompanied by Horgan, and the second time by another graduate student, Martin Forbes.

After returning home to New Zealand in January 2020, Whiteford examined a series of old satellite images. They showed that the surface trough — and hence, the cavern — had begun forming at least 35 years before, starting with a blip at the very mouth of the river, where it ran into the ocean. That blip had gradually lengthened, reaching progressively farther inland, or upstream. Whiteford and Horgan reported the observations in late 2022 in the *Journal of Geophysical Research: Earth Surface* — along with their theory about how the cavern formed.

In other parts of Antarctica where the ice sheet protrudes off the coastline, scientists have found that the ice's underside is often insulated from the ocean heat by a buoyant layer of colder, fresher meltwater. That protective layer is sometimes only a couple of meters thick. But Horgan and Whiteford suspect that the turbulence of the subglacial river flowing into the ocean stirs up that protective layer, causing seawater — a few tenths of a degree warmer than the subglacial water — to swirl up into contact with the ice. This causes an area of concentrated melt right at the river's mouth, creating a small cavity where warm seawater can intrude further.

In this way, says Horgan, the focal point of melting is "stepping back over time." And the cavern gradually burrows farther upstream into the ice.

Whiteford used a different set of satellite measurements — which measured the rate at which the ice's surface sank over time — to determine how quickly the ice was melting in the cavern below. Based on this, he estimated that in the upstream end

FROM TOP: A. WHITEFORD *ET AL/JOURNAL OF GEOPHYSICAL RESEARCH: EARTH SURFACE* 2022; E. OTWELL

of the cavern, the ice (currently 350 to 500 meters thick over the channel) was melting and thinning 35 meters per year. That's an astronomical rate. It's 135 times what has been measured 50 kilometers southwest of the cavern, where the ice floats on the ocean. The water temperature is probably similar at both locations. But the turbulence caused by the river transfers the water's heat far more efficiently into the ice.

Horgan thinks that the cavern at Kamb also owes its dramatic height to another factor. Glaciers in this part of West Antarctica generally flow several hundred meters per year. So the melt caused by a flowing river beneath, over years or decades, would normally be spread out over a long swath of ice. This would erode a shallow channel rather than a deep cleft. But Kamb is an oddball. Around 150 years ago, it stopped moving almost entirely due to the cyclical interplay of melting and freezing at its base. It now creeps forward only about 10 meters per year. The melting is thus concentrated, year after year, in almost the same spot.

Back in 2020, all of this was still conjecture. But if Horgan and his colleagues could return, drill into the cavern and lower instruments into it, they could confirm how it formed. By studying the water, sediment and microbes flowing out of it, they could also learn a lot about Antarctica's vast subglacial landscape.

The West Antarctic Ice Sheet covers an area three times the size of the Colorado River drainage basin, which sprawls across Arizona, Utah, Colorado and parts of four other states. To date, humans have observed only a tiny swath of this underworld, smaller than a basketball court — represented by several dozen narrow boreholes scattered across the region, where scientists have grabbed a bit of mud from the bottom or sometimes lowered in a camera.

Horgan was eager to explore more. With New Zealand already melting boreholes through ice floating on the ocean, drilling into this coastal river seemed like a natural next step.

Looking to the lakes

On December 4, 2021, a pair of caterpillar-tracked PistenBullys arrived at the place where Horgan and Whiteford had visited two years before. The tractors had traveled for 16 days from New Zealand's Scott Base on the edge of the continent, growling across a thousand kilometers of floating ice as they towed a convoy of sleds packed with 90 metric tons of food, fuel and scientific gear. The convoy lumbered around to the upstream end of the valley and stopped.

Workers erected a tent the size of a small aircraft hangar, and inside it, assembled a series of water heaters, pumps and a kilometer of hose — a machine called a hot water drill. Using shovels and a small mechanized scooper, they dumped 54 tons of snow into a tank and melted it. The workers then jetted that hot water through the hose, using it to melt a narrow hole, no wider than a dinner plate, through 500 meters of ice — and down through the domed ceiling of the cavern.

The sight of animals inside the cavern generated instant excitement among Horgan, Stevens and the other people at camp. But those first images were blurry, leaving people unsure of what the orange, bumblebee-sized critters actually were.

Workers next lowered an instrument down the borehole to measure the water temperature and salinity inside the cavern. They found the top 50 meters of water colder and fresher than what lay below — confirming that seawater was flowing in along the bottom and a more buoyant mixture of saltwater and freshwater was flowing out along the top. The cavern, says Stevens, "is operating quite like an estuary."

But those measurements also presented a mystery: The water in the top of the cavern was only about 1 percent less salty than the seawater in its bottom, suggesting that the amount of freshwater flowing in through the river was "quite small," says Stevens. It's akin to a shallow creek that a young kid might splash around in. He and Horgan doubted that the turbulence caused by this small flow, even over 35 years, could melt the entire cavern — roughly a cubic kilometer of ice.

A likely answer came from a set of samples collected from the floor of the cavern. Gavin Dunbar, a sedimentologist at the Victoria University of Wellington, lowered a hollow plastic cylinder down the hole in hopes of retrieving a core. As he and graduate student Linda Balfoort hoisted the cylinder back up, they found it streaked and filled with chocolaty mud — a strange sight in this world of pure white, where not a speck of rock or dirt can be seen for hundreds of kilometers.

As Dunbar and Balfoort X-rayed and analyzed the cores months later, back in New Zealand, their peculiarities became obvious: They were unlike anything that Dunbar had ever encountered in this part of the world.

Every core that Dunbar had ever seen from the seafloors near this part of Antarctica consisted of a chaotic jumble of sand, silt and gravel — a material called diamict, formed as the ice sheet advances and retreats over the seafloor, plowing and mixing it like a rototiller. But in these cores, Dunbar and Balfoort saw distinct layers. Bands of coarse, gravely material were interspersed with layers of fine, silty mud.

That alternating pattern resembled samples from steep seafloor canyons off the coast of New Zealand, where earthquakes sometimes trigger underwater landslides that sweep for many kilometers downhill. Each flood deposits a single layer of chunky material.

Dunbar believes that something similar happened under the Kamb Ice Stream, possibly in the last few decades. A series of fast-moving torrents gushed through the river channel carrying big gravelly chunks from somewhere upstream that later settled on the cavern floor. "Each of these [coarse layers] represents minutes to hours of sediment deposition" that occurred during a single flood, he says. And the fine, silty layers would have been laid down over years or decades in between the floods, when the river flowed languidly along.

These subglacial floods could explain how this small river carved such a large cavern, Stevens says. Those floods could have been 100 to 1,000 times as large as the flow rates that were measured during the 2021–22 field season.

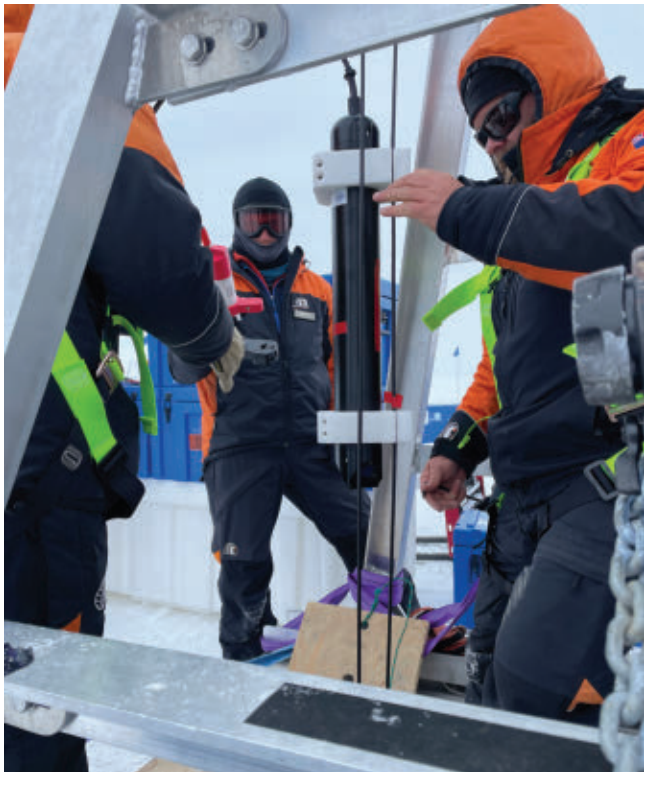
No one knows when those events happened, but scientists using satellites to study subglacial lakes have spotted at least one candidate. In 2013, a lake 20 kilometers upstream from the cavern, called KT3, disgorged an estimated 60 million cubic meters of water—enough to fill 24,000 Olympic-sized swimming pools.

Scientists would love to know whether that flood actually passed through this cavern. "Connecting this upstream to the lake system would be extremely cool," says Matthew Siegfried, a glaciologist at the Colorado School of Mines in Golden, who coauthored one of the reports documenting the 2013 flood.

Studying the outflow of this river could also answer other questions about the subglacial landscape upstream. "The vast majority of our knowledge of subglacial lakes comes from surface observations from space," Siegfried says. But those satellite records, of ice bobbing up and down, permit only indirect estimates of how much water is flowing through. It's possible, for example, that a lot of water passes through the lakes even when the ice above isn't moving.

Scientists could also learn about the subglacial landscape by studying the sediment washed downstream. When Dunbar and his colleagues examined the coarse material from their cores, they found it full of microscopic fossils: glassy shells of marine diatoms, needly spicules of sea sponges, and notched and spiky pollen grains of southern beech trees. These fossils represent the remains of a warmer world, 15 million to 20 million years ago, when a few stands of stunted, shrubby trees still clung to parts of Antarctica. Back then, the West Antarctic basin held a sea rather than an ice sheet, and this detritus settled on its muddy bottom. These old marine deposits underlie much of the West Antarctic Ice Sheet, and the few boreholes drilled so far suggest that the mix of fossils differs from one place to another. Those mixes could provide clues to how the flow of rivers changes over time.

At the end of the trip, scientists including Craig Stewart (right) and Andrew Mullen (center) lowered instruments (a current meter is shown) into the cavern so they could continue monitoring it from afar.



C. STEVENS/NIWA

To uncover the nuance of what's happening in the cavern "is mind-blowingly cool," says Christina Hulbe, a glaciologist at the University of Otago in Dunedin, New Zealand, who has studied this region of Antarctica for nearly 30 years. "That's the outlet for a massively big river system, if you think about it."

By studying the water, scientists could estimate the amount of organic carbon and other nutrients flowing out of the river into the ice-covered ocean. The landscape beneath the ice sheet appears to be rich in nutrients that might sustain oases of life in an otherwise famished biological desert.

An oasis of life

Even as the cavern penetrates farther into the Kamb Ice Stream, it does not necessarily threaten the glacier's stability. This part of the West Antarctic coastline is not considered vulnerable, because its shallow bed shields it from the deep, warm ocean currents that are causing rapid ice loss in other regions. But subglacial rivers pour out at many other points along the coastline, including some—like Thwaites Glacier, roughly 1,100 kilometers northeast of Kamb—where the ice is retreating rapidly (SN: 3/11/23, p. 8).

Thwaites and nearby glaciers have collectively shed over 2,000 cubic kilometers of ice since 1992. They could eventually raise global sea levels by 2.3 meters if they collapse. Remote sensing studies have documented over a dozen low, squat shield volcanoes beneath this part of the ice sheet. The elevated geothermal heat flow, even from inactive volcanoes, is thought to cause high levels of melting under the ice sheet. That melting produces large amounts of subglacial water, which could render these glaciers even more vulnerable to human-caused climate change.

Horgan believes that what scientists learn at Kamb could improve our understanding of how subglacial rivers impact those other, rapidly changing coastlines of Antarctica.

But the most evocative discovery made at Kamb—in purely human terms—may be the blurry, orangish animals seen swarming near the bottom of the cavern. Stevens captured some clearer images a few days later and tentatively identified them as shrimp-like marine crustaceans called amphipods. To see so many of them here, Stevens says, "we really hadn't expected that."

Microbes like those previously found under the ice sheet in Subglacial Lake Whillans are known to eke out a living even in harsh conditions. But animals are a different matter. The deepest seafloors on Earth sit only 10 or 11 kilometers from sunlight, and animal life in those places is generally scarce. But the animals in the cavern are thriving 500 kilometers from the nearest daylight, cut off from the photosynthesis that fuels most life on Earth.

The amphipods and their supporting ecosystem must be subsisting on some other food source. But what? Observations in

the Kamb ice cavern, combined with those at two other remote boreholes drilled in recent years, offer some tantalizing hints.

In 2015, researchers pierced the ice at another site 250 kilometers from the cavern, where the Whillans Ice Stream lifts off its bed and floats. In that location, a thin sliver of seawater, just 10 meters deep, sits beneath 760 meters of ice. A remotely operated vehicle, or ROV, sent down the hole captured images of fish and amphipods.

John Priscu, a microbial ecologist at Montana State University in Bozeman who was involved in the drilling at the site, believes that the glacier itself is sustaining this ecosystem. The bottom 10 meters of ice is packed with mud that had frozen onto the belly of the glacier many kilometers upstream. The mud had been dragged to its present location as the glacier oozed forward, 400 meters per year. As the ROV navigated about, bits of that muddy debris constantly rained down, released as the ice's underside slowly melted. That debris is rich in organic matter — the rotting remains of diatoms and other phytoplankton that sank to the bottom millions of years ago when the world was warmer.

"Those amphipods are swarming to the particulate matter," Priscu says. "They're sensing the organic matter falling out of that basal ice." Or perhaps they may be eating the bacteria that live on those organics.

Because the Kamb Ice Stream is barely moving, the supply of dirty ice moving toward the sea is small. But the river flowing into the ice cavern may deliver the same subglacial nutrients that are found in dirty ice. After all, the water's journey through a series of subglacial lakes down to the river's mouth may take years or decades. Throughout that time, the river absorbs nutrients from the organic-rich subglacial sediments.

Indeed, when scientists drilled into Subglacial Lake Whillans in 2013, they found its water honey-colored — chock-full of life-sustaining iron, ammonium and organics. "What these lakes are pumping out may be a concentrated source of nutrients" for ecosystems along the dark coastline, says Trista Vick-Majors, a microbial ecologist at Michigan Technological University in Houghton who was involved in the drilling at Lake Whillans. She has estimated that the subglacial rivers flowing out from under Kamb and its neighboring glaciers may deliver 56,000 tons of organic carbon and other nutrients to this section of the coastline every year.

More recently, in December 2019, a team from New Zealand led by Horgan and Hulbe drilled through the ice just 50 kilometers from the Kamb cavern, in a place where the Kamb Ice Stream floats on the ocean. There's no dirty ice there and no nearby river outlets. The area resembled a famished seafloor desert; it was populated by single-celled microbes with little to eat, and few signs of animals were seen — only a few burrowing traces on the muddy bottom. Priscu sees this location as an exception that proves the point: Subglacial nutrients are the crucial energy source in this dark world under the floating ice, whether they are dragged forward on the undersides of glaciers or spilled out through subglacial rivers.

The mud and water samples collected from the Kamb ice cavern may provide a new opportunity to test that theory. Craig Cary, a microbial ecologist at the University of Waikato in New Zealand, is analyzing DNA from those samples. He hopes to determine whether the microbes in the cavern belong to taxonomic groups that are known to subsist on ammonium, methane, hydrogen or other sources of chemical energy that originate from the subglacial sediments. That might reveal whether such sources support enough microbial growth to feed the animals observed there.

C. STEVENS/NIWA

The video feed from the camera lowered into the cavern showed animals, perhaps amphipods, swimming about. They may subsist in part on subglacial nutrients transported to this location by the river.

The team also needs to measure the flow rate of the subglacial river that spills into the cavern, since that determines the nutrient supply. Stevens continues to monitor this thanks to a set of instruments left behind in the cavern.

As people were packing up camp on January 11, 2022, workers pumped more hot water into the borehole, widening it to more than 35 centimeters — and creating a dangerous pitfall. Stevens and his colleagues donned climbing harnesses, clipped into safety ropes and approached the hole one last time. They lowered a series of cylinders the size of caulking guns down the hole. These devices continue to measure the temperature, salinity and water currents inside the cavern, sending the data 500 meters up a cable to a transmitter that beams it home via satellite once a day. That data will reveal how the river's flow changes over time. With luck, the instruments might even detect a subglacial flood gushing through.

"That would just be outstanding," Horgan says. For many years, he had to content himself with seeing these rivers and lakes dimly, through the outlines of water on radar and satellite images. This is "one of the first times we've got to stand at a river mouth and observe it." ■

Explore more

- Stephen J. Livingstone *et al.* "Subglacial lakes and their changing role in a warming climate." *Nature Reviews Earth & Environment*. February 2022.

Douglas Fox is a freelance journalist based in northern California.

Barred from ocean expeditions for much of her career, Marie Tharp poured all of her energy into mapping the seafloor — creating the most comprehensive views available.

Marie Tharp brought us the ocean floor

Her deep understanding of geology made for valuable insights and gorgeous views

By Betsy Mason

Walk the halls of an academic earth science department, and you'll likely find displayed on a wall somewhere a strikingly beautiful map of the world's ocean floor. Completed in 1977, the map represents the culmination of the unlikely, and underappreciated, career of Marie Tharp. Her three decades of work as a geologist and cartographer at Columbia University gave scientists and the public alike their first glimpse of what the seafloor looks like.

In the middle of the 20th century, when many American scientists were in revolt against continental drift — the then-controversial idea that the continents are not fixed in place — Tharp's groundbreaking maps helped tilt the scientific view toward acceptance and clear a path for the emerging theory of plate tectonics (*SN: 1/16/21, p. 16*).

Tharp was the right person in the right place at the right time to make the first detailed maps of the seafloor. Specifically, she was the right woman. Her gender meant certain professional avenues were essentially off-limits. But she was able to take advantage of doors cracked open by historical circumstances, becoming uniquely qualified to make significant contributions to both science and cartography. Without her, the maps may never have come to be.

"It was a once-in-a-lifetime — a once-in-the-history-of-the-world — opportunity for anyone, but especially for a woman in the 1940s," Tharp recalled in a 1999 perspective. "The nature of the times, the state of the science, and events large and small, logical and illogical, combined to make it all happen."

Tharp's cartographic roots ran deep. She was born in Michigan in 1920 and as a young girl would accompany her father on field trips to survey land and make maps for the U.S. Department of Agriculture's Bureau of Soils, a job that kept the family on the move. "By the time I finished high school I had attended nearly two dozen schools and I had seen a lot of different landscapes," Tharp recalled. "I guess I had mapmaking in my blood, though I hadn't planned to follow in my father's footsteps."

Tharp was a student at the University of Ohio in 1941 when the attack on Pearl Harbor emptied campuses of young men, who were joining the military in droves. This sudden scarcity of male students prompted the University of Michigan's geology department to open its doors to women. Tharp had taken a couple of geology classes and jumped at the opportunity.

"There were 10 or 12 of us that appeared from all over the United States, girls. With a sense of adventure," she recalled in an oral history interview in 1994. Tharp earned a master's degree in 1943, completing a summer field course in geologic mapping and working as a part-time draftsperson for the U.S. Geological Survey along the way. Upon graduating, she took a job with an oil company in Oklahoma but was bored by work that involved neither fieldwork nor research. So she enrolled in night classes to earn a second master's degree in mathematics from the University of Tulsa.

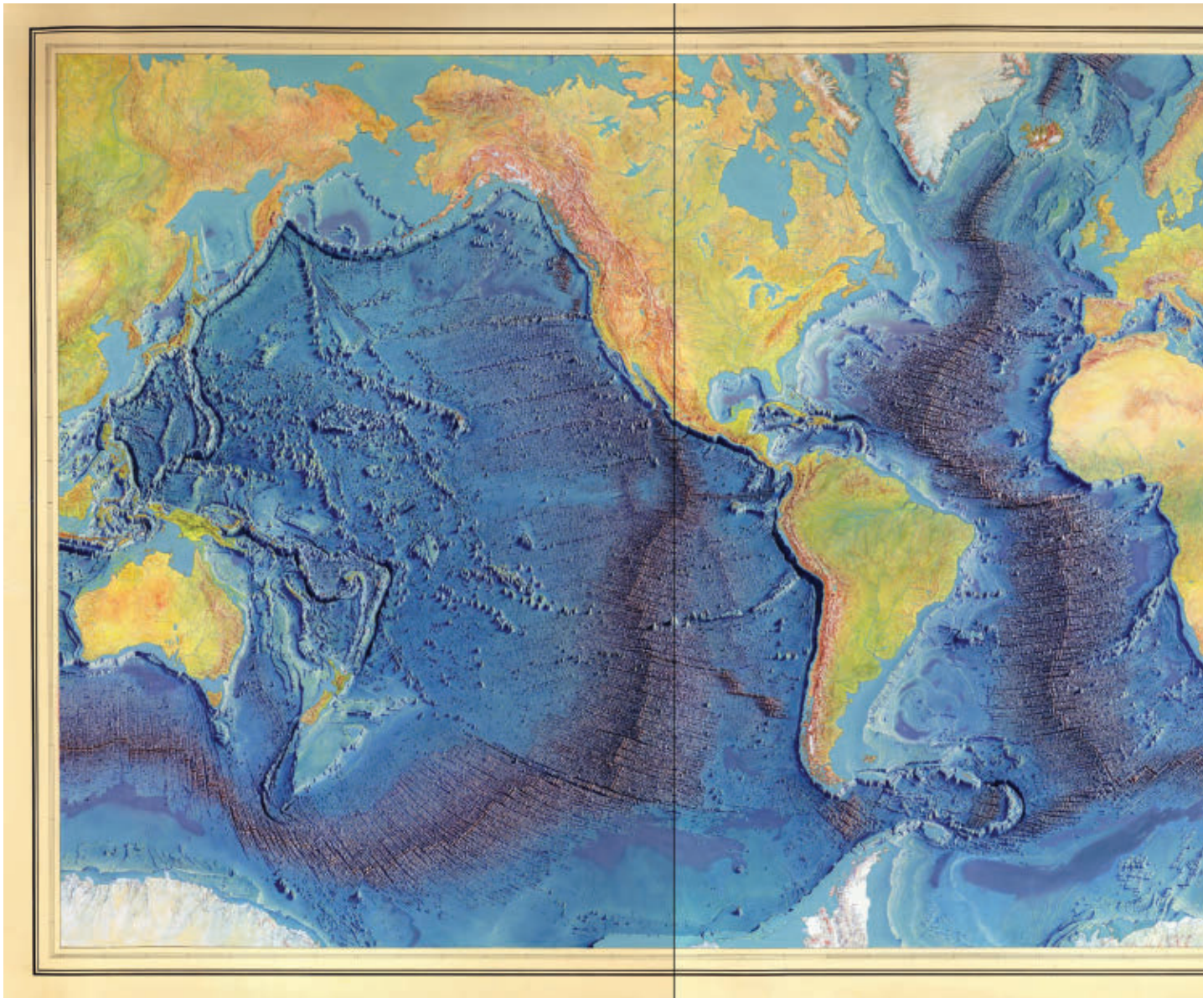
Looking for more excitement, she moved to New York City in 1948. When she walked into the Columbia University geology department looking for a job, her advanced degrees got her an interview, but the only position available to a woman was that of a draftsperson assisting male graduate students working toward a degree in geology that she had already earned. Still, it seemed more promising than the other job she had inquired about — studying fossils at the American Museum of Natural History — so she took it.

The following year Tharp became one of the first women employed by Columbia's newly founded

UNSUNG CHARACTERS

This article is part of a *Science News* series highlighting people of science — past and present — who we believe should be better known. Watch for more of these stories and send your ideas to editors@sciencenews.org

OPPOSITE PAGE: GRANGER COLLECTION



With funding from the U.S. Navy, Marie Tharp and Bruce Heezen produced this 1977 map with Austrian painter Heinrich Berann. It has become iconic among cartographers and earth scientists.

Lamont Geological Observatory and soon was working exclusively with geologist Bruce Heezen, a newly minted Ph.D. Like many of the male scientists at Lamont, Heezen was primarily occupied with collecting ocean data, which Tharp would then analyze, plot and map — work she was more than qualified to do.

"These men considered it glamorous and pleasurable to go to sea, far more so than staying at home to analyze [the data]," writes science historian Naomi Oreskes of Harvard University in *Science on a Mission: How Military Funding Shaped What We Do and Don't Know About the Ocean* (SN: 4/10/21, p. 28). "This is one reason data analysis was often left to women." In fact, women often weren't allowed on the research ships at all.

Initially barred from ocean expeditions, Tharp poured all of her energy into mapping the seafloor starting with the North Atlantic, work that would lead to two important discoveries. To make a map, she first translated the echo soundings gathered by ships crossing the ocean into depths and then created two-dimensional vertical slices of the terrain beneath the ships' tracks. These ocean-floor profiles showed a broad ridge running down the middle of the Atlantic.

Though the feature had been roughly mapped in the 19th century, Tharp noticed a notch near the top of the ridge in each of the profiles. She believed the notches represented a continuous, deep valley running down the center of the mid-ocean ridge. If she was right, the valley might be a rift where

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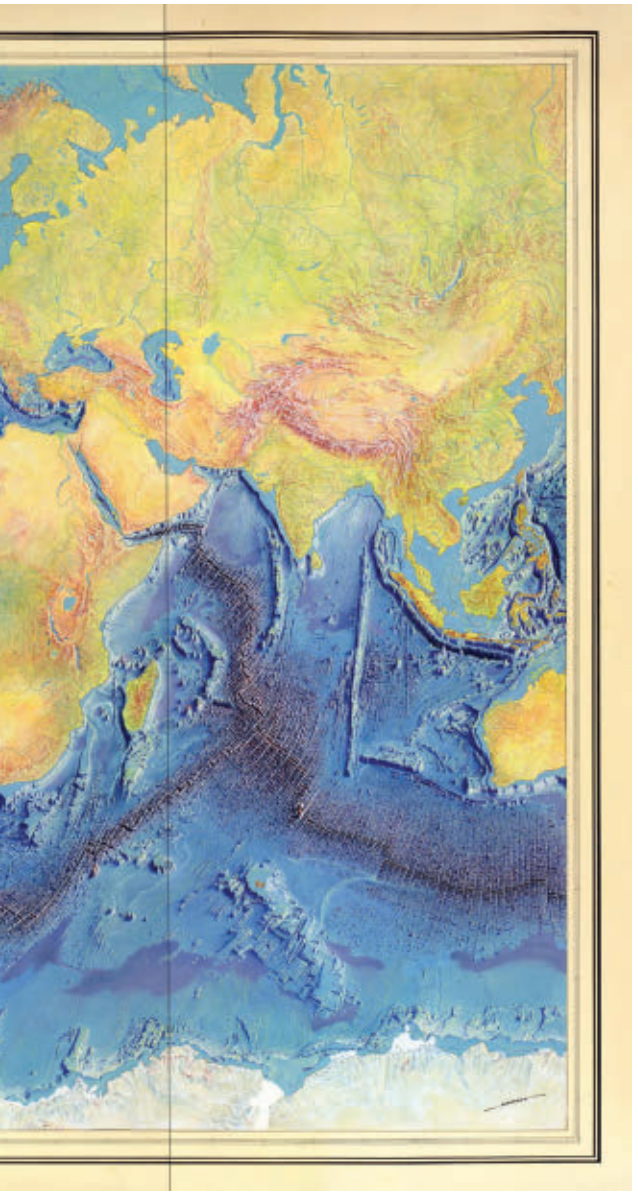


RIGHT: B.C. HEEZEN, M. THARP AND M. EWING/LAMONT-DOHERTY EARTH OBSERVATORY/GEOLOGICAL SOCIETY OF AMERICA SPECIAL PAPER 1965

molten material came up from below, forming new crust and pushing the ocean floor apart—evidence that could support continental drift.

The idea that the continents were not fixed in place had gained traction in Europe, but Heezen, like most U.S. scientists at the time, "considered it to be almost a form of scientific heresy," Tharp later wrote in *Natural History* magazine. It took her a year or so to convince Heezen that the rift was real, and it took the two several more years to finish their first map of the North Atlantic, in 1957.

To publish that first map and share their work with other scientists, Tharp and Heezen had to get around the U.S. Navy's Cold War–inspired decision to classify detailed topographic maps that used contour lines to indicate depths. This was one of the reasons the pair chose to adapt a relatively new cartographic style known as a physiographic diagram, a sort of three-dimensional sketch of terrain as if seen from an airplane window. To do this, Tharp had to rely on her training as a geologist and experience with mapping on land—knowledge and skills that a typical research assistant or draftsperson wouldn't have had.

Physiographic maps had previously been used to represent continental landforms with standardized symbols. Each type of mountain, valley, plain and desert was sketched in a specific way. Tharp and Heezen were the first to use the technique to show what unknown, unseeable terrain might look like. Tharp first sketched a strip of seafloor along each profile, deciphering what type of landform each bump and dip was likely to be. Then she identified patterns to fill in the blank spaces between the profiles.

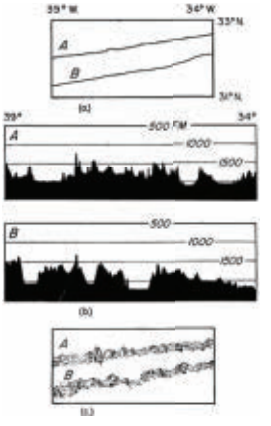
"The amount of work involved in taking it from just those soundings and being able to create that is just amazing," says historian Judith Tyner, author of *Women in American Cartography*.

As Tharp was creating her map, an unrelated project was taking shape on the drafting table next to hers. Heezen had hired a recent art school graduate to plot thousands of earthquake epicenters in the Atlantic Ocean to help Bell Labs find the safest places to lay transoceanic cables. The epicenters he was plotting lined up with Tharp's rift valley. The correlation lent weight to the idea that the rift was where the crust was pulling apart and gave Tharp a way to accurately locate the rift between the ship tracks.

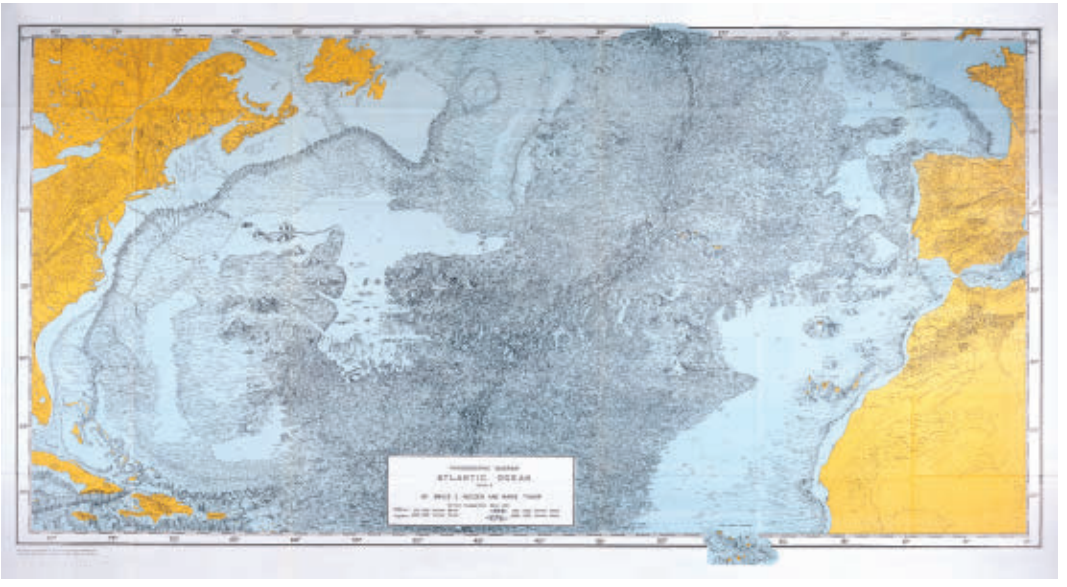
Heezen and Tharp's 1957 diagram of the North Atlantic Ocean was by far the most exhaustive seafloor map ever produced. "The marvelous thing about that map is how comprehensive it looked on rather limited data," says science historian Ronald Doel of Florida State University in Tallahassee. "But the earthquake data also helped to make clear just where the ridges are oriented and where the associated geological features are."

The American scientific community was initially skeptical, wary of the speculative nature of the map. But as the pair continued mapping the rest of the Atlantic and moved on to other oceans, evidence accumulated for a continuous ridge, with a rift valley at its center, stretching for some 60,000 kilometers across the globe.

Tharp and Heezen's innovative use of the physiographic method gave scientists a compelling visual comparison to continental landforms they understood. This helped convince them that just as the



To generate the detailed seafloor maps, Marie Tharp started with two-dimensional ocean profiles (top three) and then used her extensive geologic knowledge to decipher landforms and fill in the blank spaces (bottom).



Bruce Heezen and Marie Tharp's physiographic maps, this one of the North Atlantic first published in 1957 and again in 1959, gave scientists a compelling visual comparison to continental landforms they understood.

East African Rift was splitting that continent, the submarine rift valley marked where the continents on either side of the Atlantic had pulled away from each other.

"That's why her map is so powerful," says David Spanagel, a historian of geology at Worcester Polytechnic Institute in Massachusetts. "It allows people to see the bottom of the ocean as if it were a piece of land, and then reason about it. That's a transformative thing that she's able to accomplish."

National Geographic also took notice of the maps and invited Heezen and Tharp to collaborate on some ocean illustrations with the Austrian painter Heinrich Berann, who would become famous for his mountain panoramas. The gorgeous ocean-floor depictions were included as poster-sized supplements in issues of *National Geographic* magazine between 1967 and 1971. At the time, the magazine had a circulation of 6 million or 7 million, giving a sizable swath of the public a window into the ocean.

> "That's why her map is so powerful. It allows people to see the bottom of the ocean as if it were a piece of land...."
>
> **DAVID SPANAGEL**

Half a century ago this year, in 1973, Heezen and Tharp received a grant from the U.S. Navy to work with Berann on a complete map of the world's ocean floor. It took the trio four years to create the iconic cartographic masterpiece, an unparalleled, panoramic visualization that continues to shape how scientists and the public think about the seafloor.

The map was finished just weeks before Heezen died of a heart attack at age 53, while in a submarine exploring the mid-ocean ridge near Iceland. His death left Tharp without a source of funding and data, essentially ending her remarkable career.

It would be decades before her contributions were fully recognized. But unlike many other unsung figures in the history of science, the accolades began rolling in before she died of cancer in 2006. During the last decade of her life, Tharp received prestigious awards from several institutions including Lamont — now known as the Lamont-Doherty Earth Observatory — and the Library of Congress, which named her one of the four greatest cartographers of the 20th century.

"Can you imagine what heights she would have risen to in her profession," Tyner asks, "if she'd been a man?"

Though hers was always the second name, after Heezen's, on the maps they made, and doesn't appear at all on many of the papers her work contributed to, Tharp never expressed any regrets about her path. "I thought I was lucky to have a job that was so interesting," she recalled in 1999. "Establishing the rift valley and the mid-ocean ridge that went all the way around the world for 40,000 miles — that was something important.... You can't find anything bigger than that, at least on this planet." ■

Explore more

■ Judith Tyner. *Women in American Cartography: An Invisible Social History*. Lexington Books, 2019.

Betsy Mason is a freelance science journalist based in the San Francisco Bay Area. She is coauthor of All Over the Map: A Cartographic Odyssey.

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NEXT GENERATION OF STEM LEADERS

Congratulations to the Regeneron Science Talent Search top winners

On March 14, Society for Science and Regeneron announced the top winners of the Regeneron Science Talent Search (STS), the most prestigious science and math competition in the United States for high school seniors. Launched in 1942 as the Westinghouse Science Talent Search, Regeneron STS recognizes and empowers our nation's most promising young scientists who are developing ideas that could solve society's most urgent challenges.

Neel Moudgal (center), 17, of Saline, Mich., won first place and $250,000 for creating a computer model that can rapidly and reliably predict the structure of RNA molecules using only easily accessible data. The model might prove useful for diagnosing or treating diseases.

Second place and $175,000 went to **Emily Ocasio** (left), 18, of Fairfax, Va., who used artificial intelligence to determine how the *Boston Globe* used language when reporting on homicide victims between 1976 and 1984. She found that Black victims received less humanizing coverage than white victims.

Third place and $150,000 went to **Ellen Xu** (right), 17, of San Diego, Calif., for developing an algorithm that uses a smartphone photo of a patient to help diagnose Kawasaki disease, the leading cause of acquired heart disease in children between the ages of 1 and 5 years old.

In the "Lights Out" exhibition, a film shows how different cultures have explained the origin of the Pleiades star cluster.

BRITTANY M. HANCE, JAMES D. TILLER, PHILLIP R. LEE AND JAMES DI LORETO/SMITHSONIAN INSTITUTION

EXHIBIT

What's at stake as artificial light pollutes the night sky

Bright, artificial lights are drowning out the night sky's natural glow. Now, an exhibition is highlighting some of the consequences of a fading starry night—and how people can help restore it.

"Lights Out," open through 2025 at the Smithsonian National Museum of Natural History in Washington, D.C., illuminates how light pollution is affecting astronomy, natural ecosystems and human cultures around the world. "We want people to understand that it's a global problem, and it's having broad impact," says Jill Johnson, an exhibit developer at the museum.

Upon entering the exhibition, the dimly lit space resets the mood for nighttime exploration. The exhibition spans a long hallway that can be entered from either end. One entrance quickly draws in visitors with a personal connection. An interactive display invites you to experience your own night sky, whether in a city, suburb or remote location. Three tactile panels feature raised elements, including dots representing light pollution and crosses indicating visible stars. The more populated a place, the more dots are smattered across the panel. Visitors can also listen to the artificial light and starlight in each sky through data that have been translated into sound. The multisensory experience is especially engaging for visitors who may not be able to experience the exhibition visually.

Lights Out
THROUGH DECEMBER 2025
SMITHSONIAN NATIONAL MUSEUM OF NATURAL HISTORY | *Washington, D.C.*

The other entrance offers a more didactic introduction to the exhibition. A timeline presents a brief history of human-made light, from fire-lit torches to today's LEDs, and then segues to astronomy. Space scientists rely on light, both visible and not, to understand celestial bodies. And their views of the universe have become increasingly obstructed by artificial light.

"Astronomers were some of the first folks to sound the alarm on light pollution," says Ryan Lavery, a public affairs specialist at the museum.

Astronomers aren't the only scientists who have noticed the repercussions. Biologists have observed light pollution's toll on plants and animals, whether harming corals' moonlight-triggered reproduction or bats' ability to pollinate flowers.

Here, much of the evidence on display is visual. Photographs and specimens demonstrate the variety of critters that are active at night, while a glass case of preserved birds presents the grim consequences of light pollution. All of these birds died from striking buildings in Washington, D.C., or Baltimore after being disoriented by the bright cityscapes.

Losing dark, starry nights also affects human cultures. Another area of the exhibition presents people's ancient and modern-day connections to the night sky through photographs, stories and cultural items. A glistening beadwork depicting the Milky Way was crafted specially for "Lights Out" by Gwich'in artist Margaret Nazon, who grew up staring at the stars in Canada's Northwest Territories.

Our connections under a shared sky are emphasized in the exhibition's small central theater. It replicates a starry night over Coudersport, Pa., through speckled lighting and walls bearing illustrations of trees and hills. A short film describes the star cluster Messier 45, also known as the Pleiades, and explains the stars' origins according to tales from three cultures—the ancient Greeks, the Ainu in Japan and the Māori in New Zealand.

"Cultures all over the world have a deep relationship to the night sky," says Stephen Loring, cocurator of the exhibition and an archaeologist at the museum. "If we lose the night sky, we lose an avenue to our understanding of what it is to be a human being."

But the exhibition isn't all bleak. Sprinkled throughout it are success stories of how people are reducing light pollution, from France's outdoor lighting curfews to beach communities that have altered their lighting systems to avoid drawing hatchling sea turtles away from the ocean. And visitors may be heartened to learn about simple but meaningful actions that they can take, such as aiming outdoor lights downward and using the dimmest settings.

Overall, "Lights Out" instills a sense of hope and a desire to reconnect with the night sky. "This is an optimistic exhibition," Loring says. "We can solve this problem." —*McKenzie Prillaman*

MARCH 11, 2023

SOCIAL MEDIA

Take a look at fish

Bluestreak cleaner wrasses (one shown below) recognize themselves in mirrors and photos, suggesting that the animals may be self-aware, **Betsy Mason** reported in "Fish recognize themselves in photos" (*SN: 3/11/23, p. 13*). Many readers were not surprised to learn of the fish's possible self-awareness. Twitter user **@amphimanifesto** wrote: "I've long thought animal self-awareness is probably far more widespread than we think. Our current [underestimation] of its breadth is due to the limits of our current methods of 'testing' for it and interpreting the results."

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Sizing up rings

The dwarf planet Quaoar sports a ring that lies outside the orb's Roche limit, an invisible line beyond which rings aren't thought to be stable, ***Lisa Grossman*** *reported in "This dwarf planet hosts an odd ring"* (SN: 3/11/23, p. 11).

Reader **Henry Leonard** wondered if it's possible the ring isn't so unusual, that perhaps Quaoar simply has an unexpectedly large mass, resulting in a large Roche limit.

Astronomer **Bruno Morgado** of the Federal University of Rio de Janeiro is certain that the dwarf planet's ring is an oddball. **Morgado's** team used the orbital motion of Quaoar's satellite, Weywot, to determine the dwarf planet's mass. That revealed that the ring is way outside its Roche limit, **Morgado** says.

Down the drain

Fifty years ago, scientists discovered that Earth's oceans slowly drain into the mantle. Today, it's known that some water cycles back into the oceans, but just how much remains unclear, ***Erin Garcia de Jesús*** *reported in "Oceans may be shrinking"* (SN: 3/11/23, p. 4).

Reader **Karen Schaffer** wondered how this phenomenon influences sea level rise due to climate change.

The oceans are draining into Earth's interior via plate tectonics at a much slower rate than they are rising due to modern climate change, says **Clint Conrad**, a geophysicist at the University of Oslo. About 280 million metric tons of ocean water leaks into the mantle every year, **Conrad** says. This seems like a lot, but it represents only a tiny fraction of a millimeter of sea level drop per year, he says. In comparison, Greenland and Antarctica together shed about 420 billion tons of ice into the oceans annually, which contributes an average of roughly a millimeter each year to global sea level rise (*SN Online: 8/17/18*).

At the current rate, the ice sheets will completely melt within about 50,000 years, **Conrad** says. But the slow and steady loss of ocean water to the mantle will continue for much of Earth's lifetime. With that said, "the rapid sea level rise occurring right now is, of course, much more important for human society because it produces notable changes during human lifetimes," he says.

Reader **Rashad Blount** asked what might happen if the mantle reaches its capacity to hold ocean water. Could that contribute to underwater earthquakes or cracks in Earth's core?

Setting aside processes that cycle water from Earth's interior back into the oceans, the mantle and core could probably store all of the seawater on the surface, **Conrad** says. Doing so would affect the planet's geology. But rather than cause quakes or cracks, it would most likely boost volcanism, he says. Water tends to decrease the melting point of minerals. So "a more hydrated Earth should have more melted rocks — more magma — and thus more volcanism," **Conrad** says. Indeed, the amount of volcanism the planet experiences today might be different if the oceans were not leaking into the planet's interior, he says.

Tastemaker

Some farmers in the western United States are forgoing irrigation, saving on water and producing more flavorful fruits and vegetables, ***Katherine Kornei*** *reported in "Betting on dry farming"* (SN: 3/11/23, p. 16).

Reader **Bill Taylor**, a former gardener who sold dry-farmed tomatoes and apples, advocated for the quality of dry-farmed produce. Though such fruits and vegetables are often smaller than ones grown with typical irrigation, "the flavor is more enjoyable," **Taylor** wrote. Their size may even be a perk. "On a mountain above Redwood Valley, Calif., [I grew] a dry-farmed apple.... These small apples sold well as 'lunch box apples' for kids to take to school."

Online, the story inspired Twitter user **@Rickdalgetty1** to share their experience eating dry-farmed produce: "The [tomatoes] I purchased from a farmer that were grown with minimal water had such concentrated flavor. It was incredible."

The fruit fly brain in exquisite detail

The wiring of one insect's brain no longer contains much uncharted territory. All of the nerve cells — and virtually every connection between them — have now been mapped in a larval fruit fly brain, researchers report in the March 10 *Science*. It's the most complex wiring diagram of a whole brain yet created.

Previously, just three organisms — a sea squirt and two types of worm — had their brain circuitry fully diagrammed to such a high resolution. But those creatures have at most about 1,500 neurons in their entire body. The scientists who conducted the new study wanted to understand much more complex animals, whose brains alone contain thousands of neurons. So they turned to a 6-hour-old fruit fly.

Fruit flies (*Drosophila melanogaster*) share many behaviors with humans, such as learning and combining information from many senses. Larvae perform nearly all the same actions as adult flies — except for some, like flying and mating — but have smaller brains, making the scientists' data collection job much easier (*SN*: 8/18/18 & 9/1/18, *p.* 36).

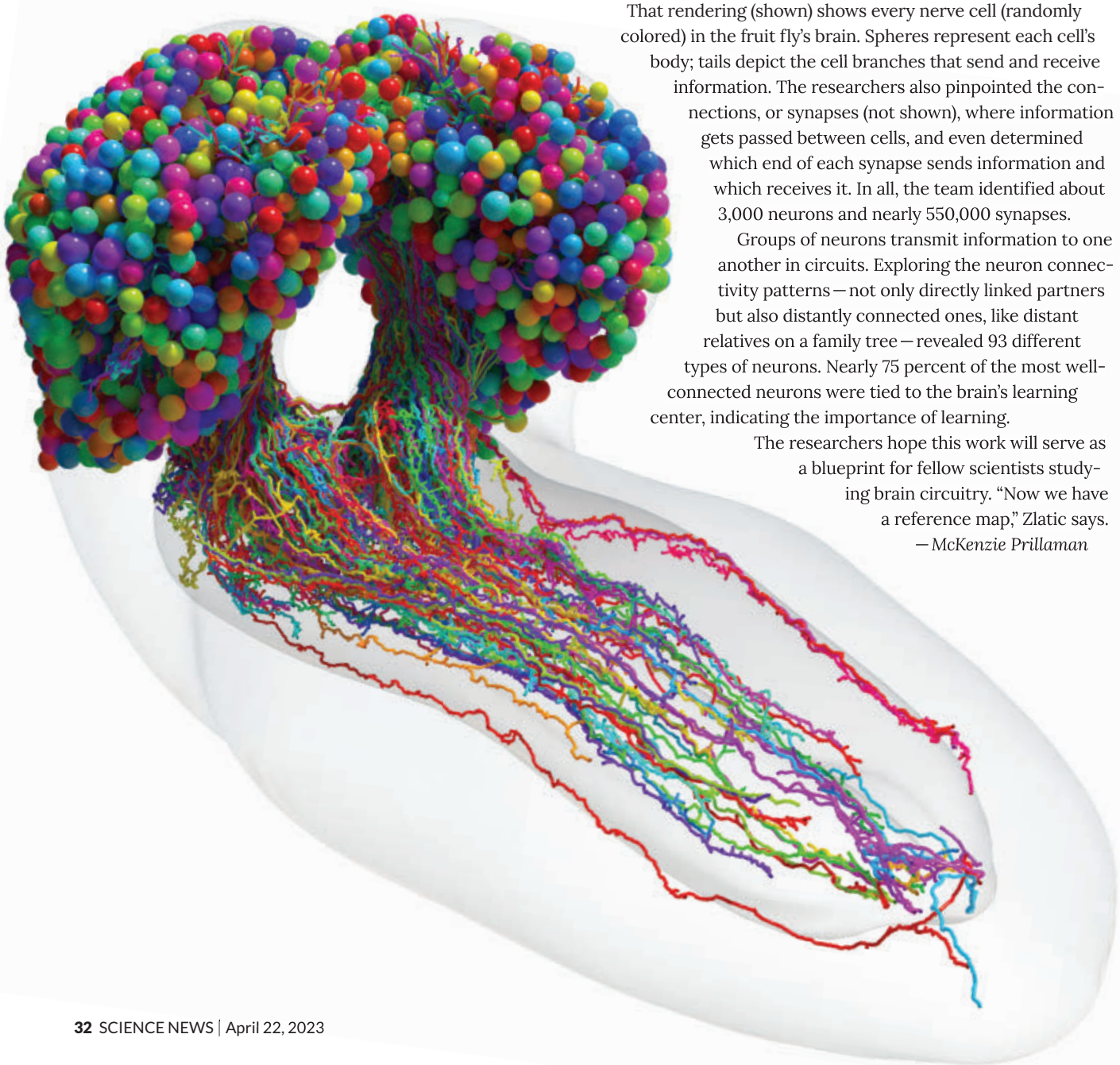
The idea for this project came 12 years ago, says Marta Zlatic, a neuroscientist at the MRC Laboratory of Molecular Biology in Cambridge, England. Back then, she and her colleagues began capturing electron microscope images of an entire larval fruit fly brain. Using a computer, the team then stitched those images together and manually traced each neuron to create a 3-D rendering of the cells.

That rendering (shown) shows every nerve cell (randomly colored) in the fruit fly's brain. Spheres represent each cell's body; tails depict the cell branches that send and receive information. The researchers also pinpointed the connections, or synapses (not shown), where information gets passed between cells, and even determined which end of each synapse sends information and which receives it. In all, the team identified about 3,000 neurons and nearly 550,000 synapses.

Groups of neurons transmit information to one another in circuits. Exploring the neuron connectivity patterns — not only directly linked partners but also distantly connected ones, like distant relatives on a family tree — revealed 93 different types of neurons. Nearly 75 percent of the most well-connected neurons were tied to the brain's learning center, indicating the importance of learning.

The researchers hope this work will serve as a blueprint for fellow scientists studying brain circuitry. "Now we have a reference map," Zlatic says.

— *McKenzie Prillaman*



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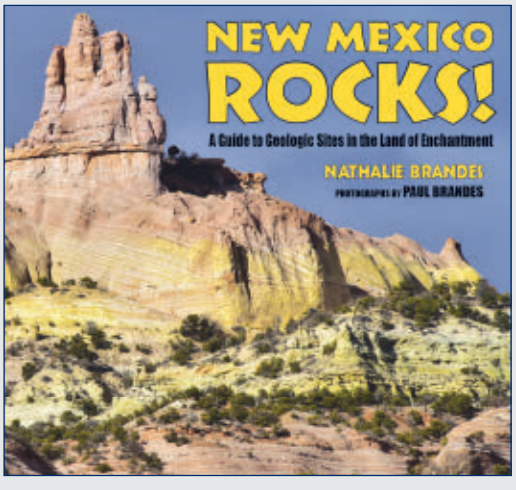

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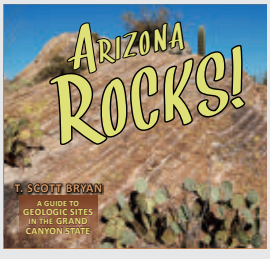

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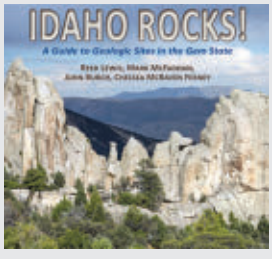

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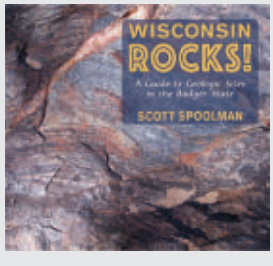

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