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ScienceNews

MAGAZINE OF SOCIETY FOR SCIENCE ■ FEBRUARY 25, 2023

Messages from Mars

The Perseverance rover reveals a rocky surprise

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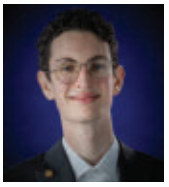

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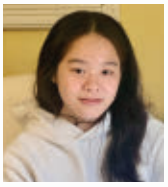

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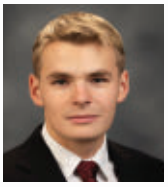

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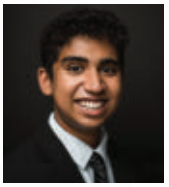

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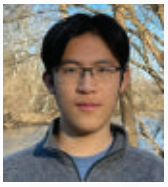

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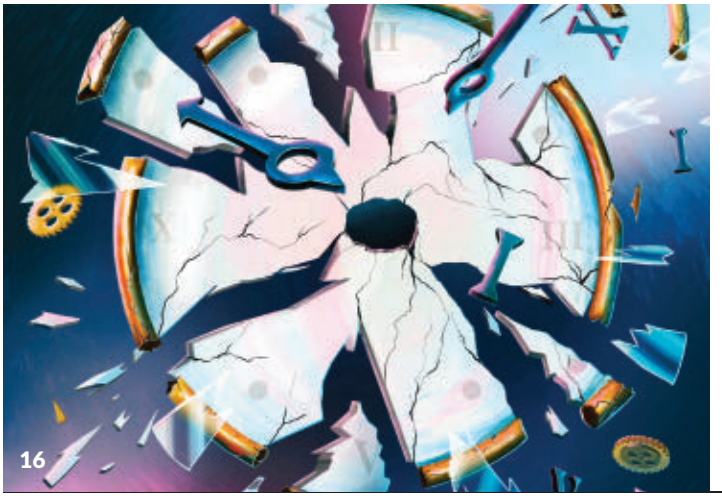
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COVER Perseverance took a selfie, a composite of dozens of images, over a rock named Rochette in September 2021. *JPL-Caltech/NASA, MSSS*

FROM TOP: KATTY HUERTAS; CINOBY/E+/GETTY IMAGES PLUS; JPL-CALTECH/NASA, SPACE SCIENCE INSTITUTE

How the science of rocks is like the science of humans

What field of science could be more solid than geology? Rocks are visible, tangible. You can bang on them with a hammer, drill them, compress them, zap them with X-rays, ultraviolet light and radar, analyze their chemistry, extract their secrets.

The study of human behavior, by contrast, is the story of science's struggle to identify the ineffable. Researchers have taken wildly different approaches to trying to figure out how people think and behave, from Sigmund Freud's notion of the Oedipus complex to making behavioral science more "scientific" through efforts such as the *Diagnostic and Statistical Manual of Mental Disorders* and fMRI brain scans. Human life is messy, and no hammer tap will reveal the brain's workings.

This issue of *Science News* articulates that duality in two features. Our cover story reports on the geology and chemistry of Mars, with NASA's Perseverance rover scouting the Red Planet for rocks that could reveal signs of past life (Page 22). In "Broken timelines," social sciences writer Sujata Gupta investigates efforts to understand how life crises can cause some people to lose their sense of self and vision of the future. Helping people restore that vision, some researchers believe, could be a balm for PTSD and suicidal thinking (Page 16).

As I read Gupta's article, I could sense the scientists' effort to quantify people's experiences through definitions — self-continuity, autobiographical reasoning. These terms were new to me, and I found myself having to read closely to be sure I understood what the scientists meant. I took comfort in Gupta's observation that philosophers have been wrestling with these questions for millennia. There are no easy answers.

When I turned to freelance writer Liz Kruesi's account of the first two years of the Perseverance mission, I thought, "Ah, easy." Find rocks, study rocks, confirm or reject hypotheses. NASA scientists directed the rover to the Jezero crater, the site of a dry lake bed that they presumed would be made of sedimentary rocks — the type of rock most likely to preserve evidence of ancient life. To their astonishment, the rover, affectionately known as Percy, instead found igneous rocks from past magmatic activity. The story was more complicated than most scientists thought.

Percy has since rolled on to a new location, the front of a dried-up delta, where it has found the sedimentary rocks the scientists were hoping for. The rover continues in its work as a robot geologist and astrobiologist, taking photos and collecting samples that are revealing the chemistry of the rocks. Bit by bit, that information will help scientists piece together the complex story of the planet's history. Someday, they may even be able to answer the big question of whether life once thrived on Mars.

So maybe rocks and humans aren't such different research subjects after all. Simple questions lead to complicated and contradictory data, with new discoveries challenging what we thought we knew to be true. As we learn, we rewrite the story of the past and get a clearer sense of what the future may hold. And so many questions remain to be answered. — *Nancy Shute, Editor in Chief*

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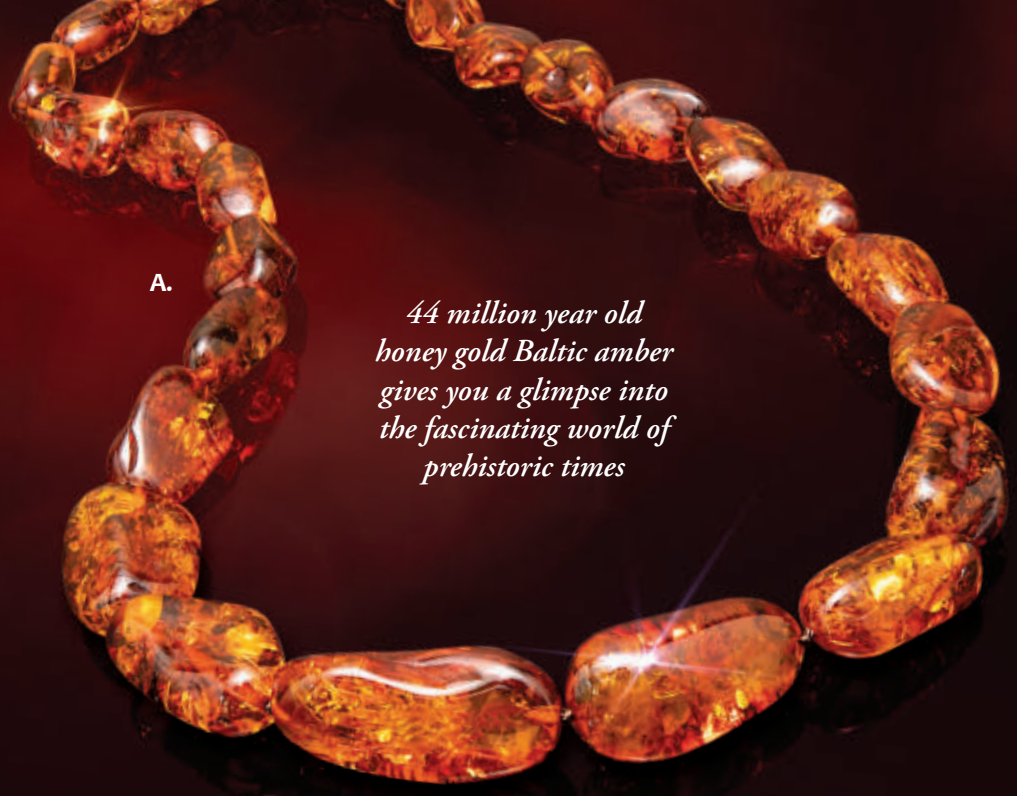
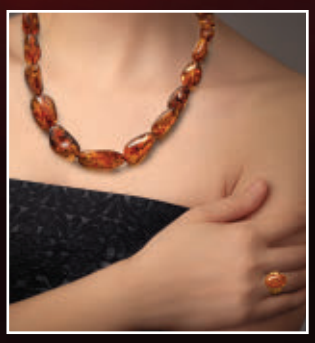


44 million year old honey gold Baltic amber gives you a glimpse into the fascinating world of prehistoric times



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Excerpt from the February 24, 1973 issue of *Science News*

50 YEARS AGO

The chances of contacting E.T.

The possibility of life … on other planets has stimulated many people's imaginations.... In the Feb. 9 *Nature*, James C. G. Walker of Yale University studies the possible parameters of such a search and comes to some pessimistic conclusions.

UPDATE: Walker estimated it could take 1,400 to 14 million years to contact E.T. with the available technology. That's way longer than researchers have spent listening for alien radio signals and scouring the sky with telescopes and satellites (*SN: 11/21/20, p. 18*).

Despite the silence, scientists have sent their own messages into the void. In 1974, Earth sent a string of binary code from the Arecibo Observatory in Puerto Rico. Years later, arguably the most famous message — the Golden Record — made its way to space aboard NASA spacecraft (*SN: 8/20/77, p. 124*).

If aliens ever reach out, they may send quantum dispatches, scientists say (*SN: 8/13/22, p. 5*). Even so, the aliens are likely so far from Earth that their civilization will have collapsed by the time we get the message (*SN: 4/14/18, p. 9*).

A new conservation metric that accounts for cultural connections between wildlife and humans suggests dugongs (juvenile shown) are endangered.

SOAPBOX

Scientists propose a new metric of extinction risk

In coastal waters of the Indian and Pacific oceans, a seagrass-eating cousin of the manatee is in trouble. Environmental strains like pollution and habitat loss pose a major threat to dugong (*Dugong dugon*) survival, so much so that the International Union for Conservation of Nature considers the species vulnerable to extinction.

In December, the IUCN upgraded the risk status of two populations to endangered and critically endangered. If that weren't bad enough, a third population is at risk of losing the protection of a group who has long looked after it: the Torres Strait Islanders.

These First Nations people of Australia historically have been stewards of the dugong population there, sustainably hunting the animals and monitoring their numbers. But the Torres Strait Islanders are also threatened, in part because rising sea levels are encroaching on their communities, and warmer air and sea temperatures are making it difficult for people to live in the region.

This situation isn't unique to dugongs. A global analysis of 385 plant and animal species found that 68 percent were both biologically vulnerable or endangered and at risk of losing their cultural protections, scientists report in the Jan. 10 *Proceedings of the National Academy of Sciences*.

The findings clearly illustrate that cultural factors should have a more prominent role in shaping conservation policy, says cultural anthropologist Victoria Reyes-García of the Catalan Institution for Research and Advanced Studies and the Autonomous University of Barcelona. When a culture dwindles, the species that are important to that culture may also be under threat. To be effective, more conservation efforts need to consider the vulnerability of both the species and the people that have historically cared about them, she says.

"A lot of the people in the conservation arena think we need to separate people from nature," Reyes-García says. But that tactic overlooks the caring relationship many cultures have with nature. One way to help shift conservation efforts is to give species a "biocultural status," which would provide a fuller picture of their vulnerability.

Reyes-García and colleagues used research on language vitality to determine a culture's risk of disappearing: The more a cultural group's language use declines, the more that culture is threatened and the more culturally vulnerable its important species are. The team then combined a species's cultural vulnerability with its biological vulnerablity as determined by the IUCN to arrive at its biocultural status. For the dugong species as a whole, its biocultural status is endangered, meaning the species is more at risk than its IUCN status suggests.

This approach can help species by involving the people who have cared for them and highlighting when stewards need support, Reyes-García says. She hopes it will spark more conservation efforts that lean into our connections with nature. —*Jude Coleman*

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SCIENCE STATS

Mysterious disease primarily affects older men

A disease first reported in 2020 may be to blame for severe, unexplained inflammation in older people. Now, scientists have their first good look at who VEXAS syndrome affects: roughly 1 in 4,000 men and about 1 in 26,000 women over 50 in the United States. Altogether, more than 15,000 people may have VEXAS, a disease tied to mutations in a gene called *UBA1* and that causes fever, anemia, inflammation and death. That's likely an underestimate, says geneticist David Beck of NYU Langone Health in New York City, whose group reported the findings January 24 in *JAMA*. The analysis is based on the electronic health records of over 160,000 people in Pennsylvania, most of whom are white. VEXAS is progressive, and the median survival time is 10 years from symptom onset. Genetic testing can help diagnose VEXAS, and steroids can ease symptoms. But what spurs the mutations and inflammatory frenzy is unclear. Researchers will learn more as more people are diagnosed, Beck says. —*Meghan Rosen*

~1 in 4,000

The prevalence of VEXAS syndrome in U.S. men over 50

FOR DAILY USE

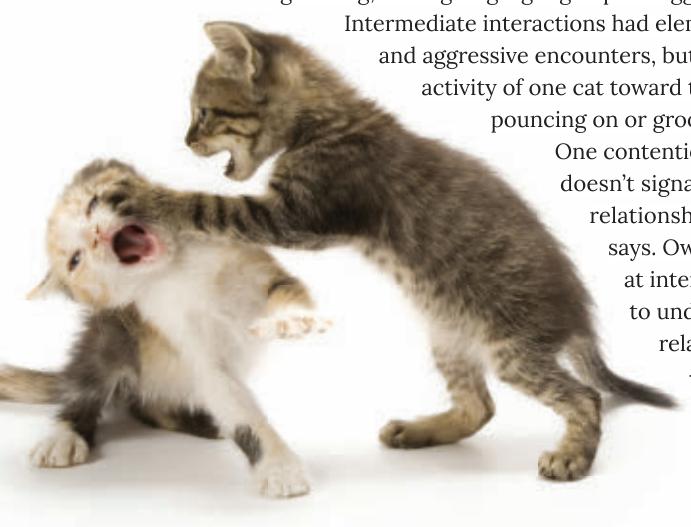
How to tell when cats are having fun or fighting

Are your cats play fighting or fighting fur real? Certain behaviors could be telltale signs that an interaction between domestic cats is friendly, aggressive or something in between, researchers report January 26 in *Scientific Reports*.

Studying feline social relationships is not new, but distinguishing whether two cats are playing or fighting is an overlooked area, says veterinarian Noema Gajdoš-Kmecová of the University of Veterinary Medicine and Pharmacy in Košice, Slovakia. The task is tricky, she notes, and misinterpretations of cat behavior can lead the animals to become stressed or ill, or even get rehomed.

To characterize interactions, she and colleagues watched 105 videos of pairs of cats. After viewing about a third of the videos, Gajdoš-Kmecová identified six types of behaviors, including wrestling and staying still. The team then watched all of the videos and noted how often and for how long each cat exhibited the specified behaviors. Statistical analyses of the data helped the researchers classify the behaviors as playful, aggressive or intermediate.

Clear connections emerged. Quiet wrestling suggested playtime. Chasing and growling, hissing or gurgling implied aggressive encounters. Intermediate interactions had elements of both playful and aggressive encounters, but included prolonged activity of one cat toward the other, such as pouncing on or grooming its fellow feline. One contentious encounter doesn't signal a cat-astrophic relationship, Gajdoš-Kmecová says. Owners should look at interactions over time to understand their cats' relationship. —*McKenzie Prillaman*



FROM TOP: ZHAO CHUANG; STEFAN1234/ISTOCK/GETTY IMAGES PLUS

An ancient bird with a dinosaur-like head may have used its raptorlike toes to catch prey, as illustrated here.

INTRODUCING

This bird had a *T. rex* head

A 120-million-year-old fossil bird could offer some new clues about how landbound dinosaurs evolved into today's flying birds. The dove-sized *Cratonavis zhui* sported a dinosaur-like head atop a body similar to those of today's birds, researchers report in the January *Nature Ecology & Evolution*.

The specimen came from the Jiufotang Formation, a hotbed for preserved feathered dinosaurs and archaic birds in northeastern China. CT scans showed that *C. zhui*'s skull is nearly identical (albeit smaller) to those of theropods like *Tyrannosaurus rex*, say paleontologist Li Zhiheng of the Chinese Academy of Sciences in Beijing and colleagues. *C. zhui* hadn't evolved the mobile upper jaw of modern birds.

However, *C. zhui* had a backward-facing toe on each foot, a lot like those of modern birds of prey. Given the ancient bird's small size, it would have probably hunted insects, lizards and perhaps small mammals.

The fossil's mishmash of features "is not unexpected," says paleontologist Luis Chiappe of the Natural History Museums of Los Angeles County. Most birds from the Age of Dinosaurs exhibited more primitive heads than today's birds, including having teeth. But the new find builds on scientists' understanding of this group of early birds. —*Aaron Tremper*

ARCHAEOLOGY

Egyptian mummy recipes revealed

Pots preserve ingredients from ancient embalming mixes

Vessels from an ancient Egyptian embalming workshop, including the ones shown, provided chemical clues to the ingredients used in mixtures for preparing the dead for mummification.

BY BRUCE BOWER

Scientists have unwrapped long-sought details of embalming practices that ancient Egyptians used to preserve dead bodies.

Mummification specialists concocted specific mixtures to embalm the head, wash the body, treat the liver and stomach, and prepare bandages that swathed the body, researchers report February 1 in *Nature*.

"Ancient Egyptian embalmers had extensive chemical knowledge and knew what substances to put on the skin to preserve it, even without knowing about bacteria and other microorganisms," Philipp Stockhammer, an archaeologist at Ludwig Maximilian University of Munich, said at a January 31 news conference.

The findings come courtesy of chemical residue inside 31 vessels found in the only known Egyptian embalming workshop and four vessels discovered in an adjacent pair of burial chambers. Writing on workshop vessels named embalming substances, provided instructions (such as "to put on his head") or both.

The artifacts — dating from Egypt's 26th dynasty, which rose to power between 664 B.C. and 525 B.C. — were excavated at a cemetery site called Saqqara in 2016. Archaeologist Ramadan Hussein, who died in 2022, led that project.

Five of the analyzed vessels had the label *antiu*. The substance was thought to have been a fragrant resin called myrrh. The *antiu* at Saqqara, however, consisted of oil or tar from cedar and juniper or cypress trees mixed with animal fats. Writing on these jars indicates that *antiu* could have been used alone or combined with another substance called *sefet*.

Three of the analyzed vessels from the embalming workshop bore the label *sefet*, which researchers have usually described as an unidentified oil. At Saqqara, *sefet* was a scented fat-based ointment with added ingredients from plants. Two *sefet* pots contained animal fats mixed with oil or tar from juniper or cypress trees. A third container held animal fats and elemi, a fragrant resin from tropical trees.

Clarification of the ingredients in *antiu* and *sefet* at Saqqara "takes mummification studies further than before," says Egyptologist Bob Brier of Long Island University in Brookville, N.Y., who was not part of the research.

Egyptians may have started mummifying the dead over 6,000 years ago (*SN: 9/20/14, p. 9*). Mummification procedures and rituals focused on keeping the body fresh so the deceased could enter what was believed to be an eternal afterlife.

Embalming and mummification procedures probably changed over time, says team member and biomolecular archaeologist Maxime Rageot, also at Ludwig Maximilian University. Embalmers' mixtures at Saqqara may not correspond, say, to those used around 700 years earlier for King Tutankhamun (*SN: 11/19/22, p. 14*).

Outside surfaces of other vessels from the workshop and burial chambers sported labels and, in some cases, instructions for treating the head, preparing linen mummy bandages, washing the body and treating the liver and stomach.

Chemical residue inside these pots consisted of mixtures specific to each embalming procedure. In addition to tree oils and animal fats, ingredients included pistachio resin, castor oil, heated beeswax, bitumen (a dense, oily substance), elemi and a resin called dammar.

Elemi and dammar resins have not previously been linked to ancient Egyptian embalming practices and are "highly unexpected," says Egyptologist Margaret Serpico of University College London, who did not participate in the new study.

Elemi was present in the workshop mixtures used to treat the head and the liver and for body bandages. Chemical signs of dammar appeared in a burial chamber vessel that included remnants of a range of substances, indicating that the container had been used to blend different mixtures, the researchers say. Specific properties of elemi and dammar that aided in preserving dead bodies have yet to be investigated, Stockhammer said.

Elemi resin reached Egypt from tropical parts of Africa or Southeast Asia, while dammar originated in Southeast Asia or Indonesia, Rageot says. Other embalming substances detected at Saqqara came from Southwest Asia and parts of southern Europe and northern Africa bordering the Mediterranean Sea. These findings provide the first evidence that ancient Egyptian embalmers depended on substances transported across vast trade networks.

It's no surprise that ancient Egyptians imported embalming ingredients from distant lands, Brier says. "They were great traders, had limited [local] wood products and really wanted these substances to achieve immortality." ■

EARTH

Earth's inner core may 'reverse' its spin

Such turnarounds aren't likely to have profound effects on life

BY NIKK OGASA

Our planet may have had a recent change of heart.

Earth's inner core might have temporarily stopped rotating relative to the mantle and surface, scientists report January 23 in *Nature Geoscience*. Now, the inner core's rotation may be slowing down even further, appearing to reverse its direction relative to the mantle and crust. This may be part of what could be a roughly 70-year-long cycle that may influence the length of a day and Earth's magnetic field.

"We see strong evidence that the inner core has been rotating faster than the surface, [but] by around 2009 it nearly stopped," says geophysicist Xiaodong Song of Peking University in Beijing. "Now it is gradually [moving] in the opposite direction."

Such a profound turnaround might sound bizarre, but Earth is volatile. Bore through the ever-shifting crust and you'll enter the mantle, where behemoth masses of rock flow, sometimes upwelling to breach the crust. Delve deeper still and you'll reach the liquid outer core. Here, circulating molten metals conjure our planet's magnetic field. And at the heart of that melt, you'll find the solid inner core—a metal ball that's about 70 percent as wide as the moon (SN: 3/2/19, p. 13).

Studies have suggested that Earth's solid heart rotates within the liquid outer core, compelled by the outer core's magnetic torque. Researchers have also argued that the mantle's immense gravitational pull applies a brake on the inner core's rotation, causing it to oscillate.

Evidence for the inner core's wayward rotation first emerged in 1996. Song and geophysicist Paul Richards, who were both at Columbia University's Lamont-Doherty Earth Observatory in Palisades, N.Y., at the time, reported that over a span of three decades, seismic waves from earthquakes took different amounts of time to traverse Earth's solid heart.

The pair inferred that the inner core rotates at a different speed than the mantle and crust, causing the time differences. The planet spins roughly 360 degrees in a day. Based on their calculations, Richards and Song estimated that the inner core was rotating about 1 degree per year faster on average than the mantle and crust.

But other scientists have questioned that conclusion. Some have suggested that the core spins slower than the mantle and crust, or that its spin doesn't differ at all.

In the new study, while analyzing global seismic data stretching back to the 1990s, Song and Peking University geophysicist Yi Yang made a surprising observation.

Before 2009, seismic waves from repeating earthquakes known as multiplets and doublets traveled at different rates through the inner core. This indicated the waves from recurring quakes were crossing different parts of the inner core, and that the inner core was rotating at a different pace than the rest of Earth, which aligned with Song's previous work.

Around 2009, the travel time differences vanished, suggesting the inner core had ceased rotating with respect to the mantle and crust. After 2009, the differences returned. This time, the waves traveled across specific sections of the inner core that suggested it had reversed the direction of its rotation relative to the mantle and crust, Song and Yang say.

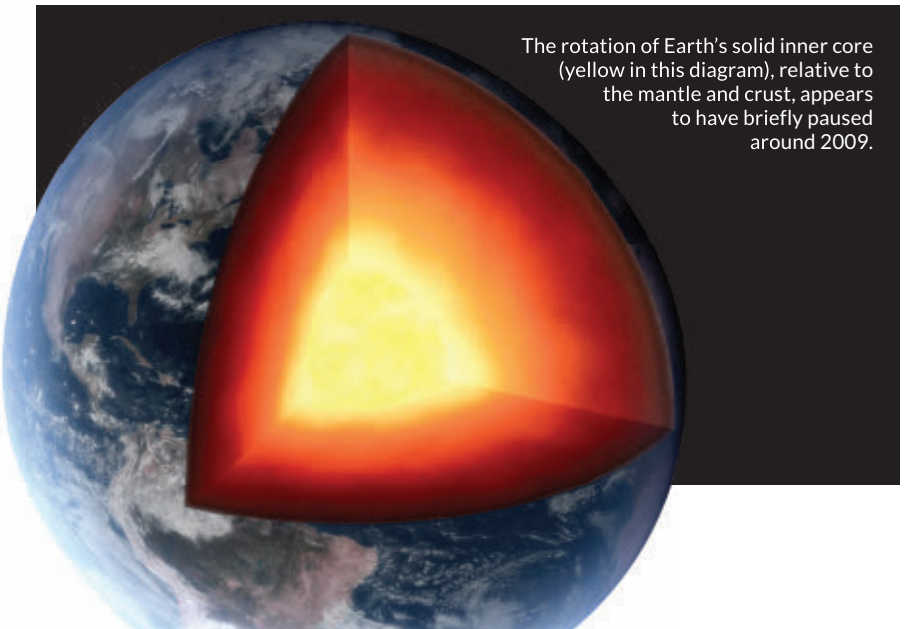
The pair pored over records of Alaskan earthquake doublets dating to 1964. While the inner core appeared to rotate steadily for most of that time, it seems to have made a reversal in the early 1970s.

Song and Yang think that the inner core may oscillate with a roughly 70-year periodicity, switching directions every 35 years or so. Because the inner core is gravitationally linked to the mantle and magnetically linked to the outer core, these oscillations could explain known 60- to 70-year variations in the length of Earth's days and the behavior of the planet's magnetic field, the researchers say.

The recent 10-year period of reduced activity that Yang and Song identified is "probably reliable," says geophysicist John Vidale of the University of Southern California in Los Angeles. But beyond that things get contentious, he says.

In 2022, Vidale and a colleague reported that the inner core may reverse its rotation every three years or so, based on an analysis of seismic waves from nuclear tests. Meanwhile, other scientists have proposed that the inner core is stationary relative to the mantle and crust. In that case, changes to the shape of the inner core's surface could explain the differences in wave travel times, those researchers say.

Future observations could help resolve the discrepancies, Vidale says. For now, he's unruffled by the purported standstill. "In all likelihood, it's irrelevant to life on the surface, but we don't actually know what's happening," he says. "It's incumbent on us to figure it out." ■



The rotation of Earth's solid inner core (yellow in this diagram), relative to the mantle and crust, appears to have briefly paused around 2009.

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MATERIALS SCIENCE

Device transforms from solid to liquid

Scientists control new phase-shifting material with magnetism

BY MCKENZIE PRILLAMAN

Shape-shifting liquid metal robots might not be limited to science fiction anymore.

Miniature machines can switch from solid to liquid and back again to squeeze into tight spaces and perform tasks like soldering a circuit board, researchers report January 25 in *Matter*.

This phase-shifting property, which can be controlled remotely with a magnetic field, is thanks to the metal gallium. Researchers embedded the metal with magnetic particles to direct the metal's movements with magnets. This new material could help scientists develop soft, flexible robots that can shimmy through narrow passages and be guided externally.

Scientists have been developing magnetically controlled soft robots for years. Most existing materials for these bots are made of either stretchy but solid materials, which can't pass through the narrowest of spaces, or magnetic liquids, which are fluid but unable to carry heavy objects (SN: 8/17/19, *p.* 13).

In the new study, researchers blended both approaches after finding inspiration from nature. Sea cucumbers, for instance, "can very rapidly and reversibly change their stiffness," says mechanical engineer Carmel Majidi of Carnegie Mellon University in Pittsburgh. "The challenge for us as engineers is to mimic that in the soft materials systems."

So Majidi and colleagues turned to gallium, a metal that melts at about 30° Celsius — slightly above room temperature. Rather than connecting a heater to a chunk of the metal to change its state, the researchers exposed it to a rapidly changing magnetic field to liquefy it. The alternating magnetic field generated electricity within the gallium, causing it to heat up and melt. The material resolidified when left to cool to room temperature.

Since magnetic particles are sprinkled throughout the gallium, a permanent magnet can drag it around. In solid form, the material can move via magnet at a speed of about 1.5 meters per second. The upgraded gallium can also carry about 10,000 times its weight.

External magnets can still manipulate the liquid form, making it stretch, split and merge. But controlling the fluid's movement in this way is more challenging because the particles in the gallium can freely rotate and have unaligned magnetic poles as a result of melting. That means the particles move in different directions in response to a magnet.

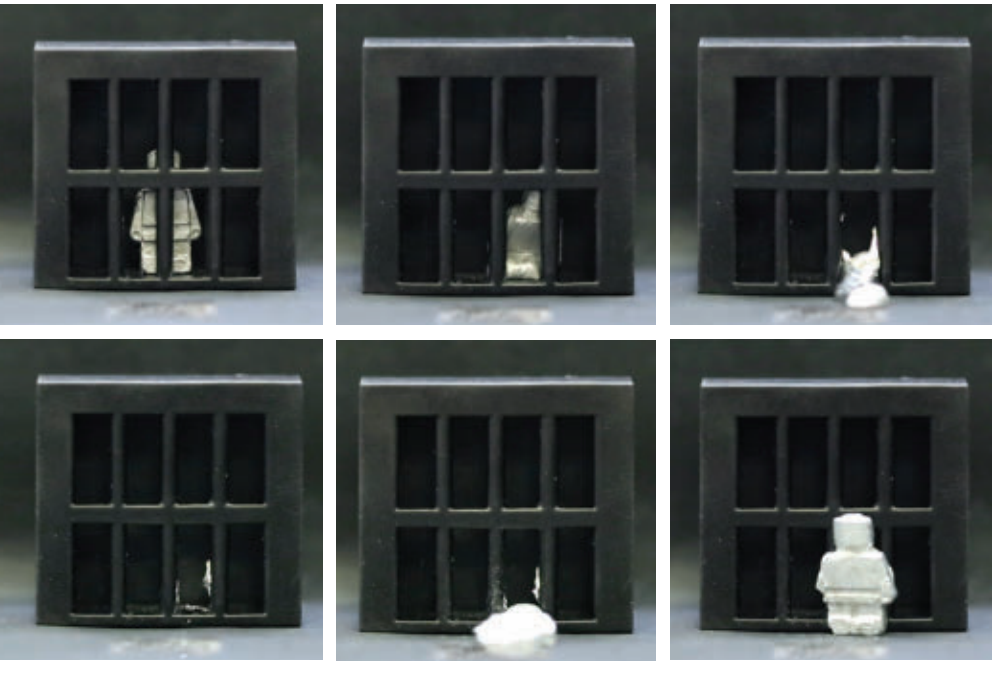
Majidi and colleagues tested their strategy in tiny machines that performed different tasks. In a demonstration straight out of the movie *Terminator 2*, a toy person escaped a jail cell by melting between the bars and resolidifying in its original form using a mold placed just outside the bars. In another demonstration, the material liquefied and rehardened to solder a circuit board.

The phase-shifting material might also be useful in biomedical settings. In one test, a machine removed a small ball from a model human stomach by melting slightly to wrap itself around the foreign object before exiting the organ. But gallium on its own would turn to goo inside a real human body, since the metal is a liquid at body temperature, about 37° C. Adding a few more metals, such as bismuth and tin, would raise the material's melting point, the scientists say.

Although this phase-shifting material is a big step forward in the field of soft robotics, questions remain about its biomedical applications, says Amir Jafari, a biomedical engineer at the University of North Texas in Denton, who was not involved in the work. One challenge, he says, is precisely controlling magnetic forces inside the human body that are generated from an external device.

Nicholas Bira, a robotics engineer at Harvard University who also was not involved in the work, agrees that this material surpasses those that came before it. But, he adds, scientists who study soft robotics are constantly creating new materials.

"The true innovation to come lies in combining these different innovative materials," Bira says. ■



This Lego-like figurine escaped from prison *Terminator 2*–style thanks to a new composite of gallium and magnetic particles, which liquefies in the presence of a changing magnetic field and moves under the guidance of a permanent magnet.

Q. WANG *ET AL*/*MATTER* 2023 (CC BY-SA)

Watch a video of a phase-shifting machine at **bit.ly/SN_LiquidRobot**

PLANETARY SCIENCE

Enceladus is buried in snow

Depth hints the moon's plume was more active in the past

BY LISA GROSSMAN

Saturn's moon Enceladus is shrouded in a thick layer of snow. In some places, the downy stuff is 700 meters deep, new research suggests.

"It's like Buffalo, but worse," says planetary scientist Emily Martin, referring to the famously snowy city in New York. The snow depth suggests that Enceladus' dramatic plume may have been more active in the past, Martin and colleagues report in the March 1 *Icarus*.

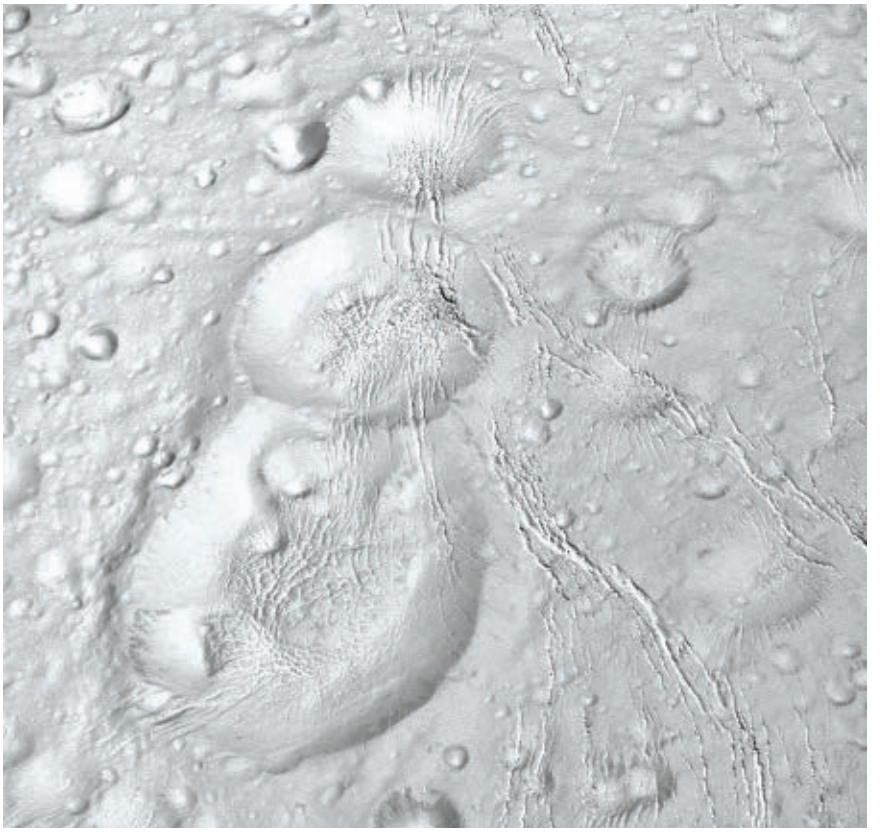
Planetary scientists have been fascinated by Enceladus' geysers, which spout water vapor and other ingredients that make up the plume, since the Cassini spacecraft spotted them in 2005. The spray probably comes from a salty ocean that's trapped beneath the moon's icy exterior shell.

Some of that water forms one of Saturn's rings (*SN: 5/6/06, p. 282*). But most of it falls back onto the moon's surface as snow, says Martin, of the National Air and Space Museum in Washington, D.C. Understanding the properties of that snow — its thickness and how dense and compact it is — could help reveal Enceladus' history and lay groundwork for future missions that could search for signs of life in the moon's plume and on its surface (*SN Online: 4/20/22*).

"If you're going to land a robot there, you need to understand what it's going to be landing into," Martin says.

To figure out how thick Enceladus' snow is, the team looked to Earth — specifically, Iceland. The island country hosts geologic features called pit chains, which are lines of pockmarks in the ground formed when loose rubble such as rocks, ice or snow falls into a crack underneath. Similar features show up all over the solar system, including on Enceladus.

Previous work suggested a way to use geometry and the angle at which sunlight hits the surface to measure the depth of such pits in the solar system. That measurement can then reveal the depth of the material the pits sit in. A few weeks of fieldwork in Iceland in 2017 and 2018 convinced Martin and colleagues that the technique would work on Enceladus.



This snowmanlike chain of craters on the surface of Enceladus is made from snow falling into fissures underneath. Scientists estimated the snow's thickness based on the craters' depths.

JPL-CALTECH/NASA, SPACE SCIENCE INSTITUTE

Using images from Cassini, the team estimated that the snow's thickness varies across Enceladus' surface, hundreds of meters deep in most places and 700 meters deep at its thickest.

It's hard to imagine how all that snow got there, though, Martin says. If the plume's spray was always what it is today, it would take 4.5 billion years — which is how long the solar system has existed — to deposit that much snow on the surface. Even then, the snow would have to be especially fluffy.

It's unlikely that the plume switched on the moment the moon formed and never changed, Martin says. Even if it did, later snow layers would have compressed the earlier ones, compacting the snow and making it shallower than it is today.

"It makes me think we don't have 4.5 billion years to do this," Martin says. Instead, the plume might have been much more active in the past. "We need to do it in a much shorter time frame. You need to crank up the volume on the plume."

The team's technique is clever, says Shannon MacKenzie, a planetary scientist at the Johns Hopkins University Applied Physics Laboratory in Laurel, Md. Without rovers or astronauts on Enceladus, there's no way to scoop up the snow and see how far down it goes. Instead, the researchers used "geology to be their rovers, to be their shovels."

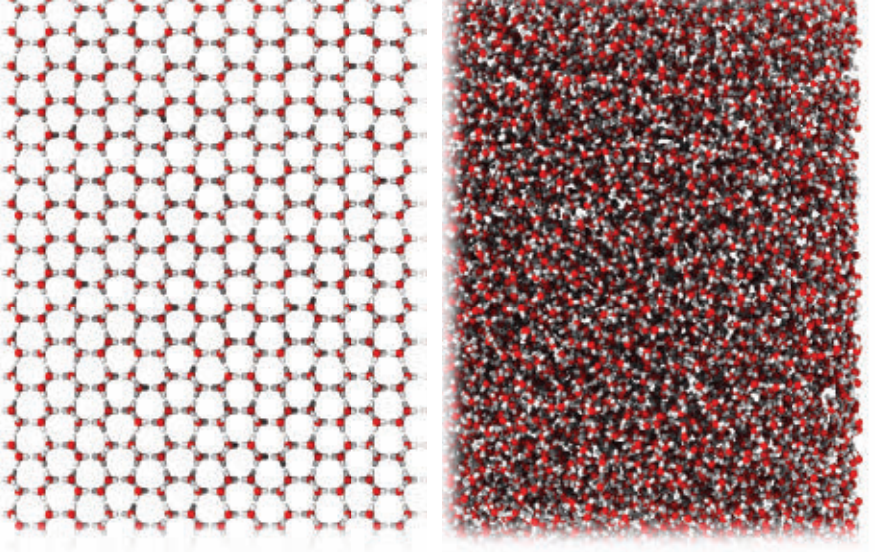
MacKenzie recently led a mission concept study for a NASA orbiter and lander that could one day visit Enceladus. A major question was where a lander could safely touch down on the moon. "Key to those discussions was, what do we expect the surface to be?" she says. The new study could help "identify the places that are too fluffy to land in." ■

PHYSICS

New ice may help demystify water

The amorphous ice and liquid water have similar densities

BY EMILY CONOVER



Simulations have revealed how the structure of crystalline ice (left) can change into a disorderly solid when the ice is shaken with stainless steel balls at low temperature. Ice layers shift randomly, rearranging water molecules (red and gray) into a jumbled scrum called an amorphous ice (right).

Ice cubes float in water because they're less dense than the liquid. But a newfound type of ice has a density nearly equal to what's in your water glass, researchers report in the Feb. 3 *Science*. If you could plop this ice in your cup without it melting immediately, it would bob around, neither floating nor sinking.

The new ice is a special type called an amorphous ice. That means the water molecules within it aren't arranged in a neat pattern like they are in crystalline ice. Other types of amorphous ices are already known, but they have densities either lower or higher than water's density under standard conditions. Some scientists hope that this newly made amorphous ice could help solve the scientific mysteries that swirl around water.

To generate the new ice, scientists used a surprisingly simple technique called ball milling, which involves shaking a container of ice and stainless steel balls cooled to 77 kelvins (nearly –200° Celsius). The researchers were motivated by curiosity; they didn't expect the technique to produce a new amorphous ice. "It was a sort of Friday-afternoon idea we had, to just give it a go and see what happens," says physical chemist Christoph Salzmann of University College London.

An analysis of how X-rays scattered from the frosty stuff suggested the team had created an amorphous ice. And computer simulations that mimicked the effects of ball milling revealed that a disordered structure could be produced by layers of ice sliding past one another in random directions, in response to the forces exerted by the balls.

Scientists created a new form of ice by shaking stainless steel balls together with standard ice (shown) at low temperature. The new ice has a density close to commonplace liquid water.

"You have to be open, as a scientist, for the unexpected," says Anders Nilsson, a chemical physicist at Stockholm University who was not involved with the research. The ball milling technique "was quite innovative to do," he says.

Since the material was made by mashing up normal ice, it's unclear whether the stuff can be produced directly by cooling liquid water. Not all amorphous ices share this connection with their liquid state.

But if the new ice does have this link to liquid water, the ice might help scientists better understand water's quirks. Water is puzzling because it flouts the norms for liquids. For example, whereas most liquids become denser upon cooling, water gets denser as it gets closer to 4° C, but becomes less dense as it is cooled further.

Many scientists suspect water's weirdness is connected to its behavior as a supercooled liquid. Pure water can remain a liquid at temperatures well below freezing. Under such conditions, liquid water is thought to exist in two different phases, a high-density liquid and a low-density one. That dual nature could explain water's behavior under more typical conditions (SN: 12/19/20 & 1/2/21, *p.* 8). But much remains uncertain about that idea.

Salzmann and colleagues suggest that the new ice could be a special form of water called a glass. Glasses can be made by cooling a liquid quickly enough that the molecules can't rearrange into a crystal structure. The glass in a windowpane is an example of this kind of material, made by cooling molten silica sand, but other substances can form glasses, too.

If the new ice is a glass state of water, scientists would need to work out how it fits into that dual-liquid picture. And that could help scientists tease out what's really going on at difficult-to-study supercooled conditions.

But some researchers are skeptical that the new material has any connection to the weird physics of liquid water. Physical chemist Thomas Loerting of the University of Innsbruck in Austria thinks that the ice is "closely related to very small, distorted ice crystals," rather than the liquid form.

Still, previous computer simulations have suggested that water could form glasses of a range of densities close to liquid water, says Nicolas Giovambattista, a computational physicist at Brooklyn College of the City University of New York. Those simulations produced structures similar to the ones seen in the computer simulation of ball milling ice, says Giovambattista, who was not involved in the work. "It opens doors for new questions. It's new, so what is it?" ■

FROM TOP: UNIV. OF CAMBRIDGE; C. SALZMANN

MICROBES

Bacteria backstab their aging algal pals

The finding could explain why some massive blooms peter out

BY ELISE CUTTS

A photosynthesizing plankton called *Emiliania huxleyi* has a dramatic relationship with its bacterial frenemies. The duplicitous microbes help *E. huxleyi* in exchange for nutrients. But the microbes kill and eat their phytoplankton host when it becomes more convenient. Now, scientists have figured out how the bacteria decide to turn from friend to foe.

One species appears to keep tabs on health-related chemicals that *E. huxleyi* produces, researchers report January 24 in *eLife*. The bacteria maintain their friendly demeanor until the plankton, a type of single-celled algae, age and weaken. The bacteria strike as soon as *E. huxleyi* can't afford to keep bribing them with nutrients. The finding could help explain how massive algal blooms come to an end.

The microbe is "establishing what we call the first handshake," says marine microbiologist Assaf Vardi of the Weizmann Institute of Science in Rehovot, Israel. "Then it will shift into a pathogen."

E. huxleyi's partnership with this bacterial species, which belongs to a group called *Roseobacter*, might be best described as a love-hate relationship. Since the alga can't make the B vitamins it needs, it offers up nutrients to lure *Roseobacter*, which can make the vitamins. The trade is win-win until the bacteria decide they'd be better off eating the algae rather than sticking around.

Sometimes called the Jekyll-and-Hyde trait, this kind of bacterial backstabbery shows up everywhere from animal guts to the open seas. But it wasn't clear how *Roseobacter* bacteria decide it's the right moment to kill *E. huxleyi*.

In lab experiments, Vardi's team exposed the *Roseobacter* species, which typically lives with *E. huxleyi*, to chemicals taken from algae that were either young and growing or old and stagnant. The team also introduced the bacteria to extra doses of a certain health-signaling algal chemical. Looking at which bacterial genes turned on in response to the various chemicals revealed how and why the microbes switch from friend to foe.

The bacteria kill their algal pals when exposed to high concentrations of a sulfur-containing chemical called DMSP, the scientists found. *E. huxleyi* leaks more and more DMSP as it ages, which cues the bacteria to go rogue. The microbes kill their hosts, and bacterial genes for nutrient-grabbing proteins and whiplike tails used to swim kick into overdrive.

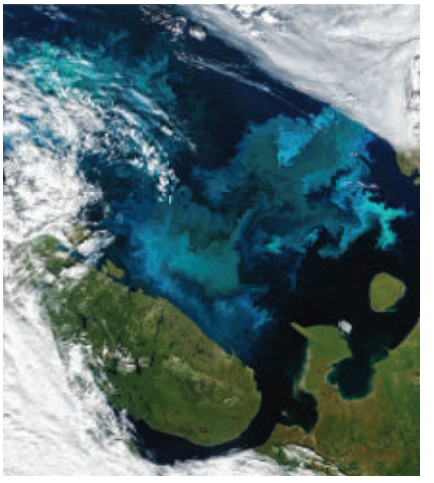
It's an "eat-and-run strategy," says Noa Barak-Gavish, a microbiologist at ETH Zurich. "You eat up whatever you can and then swim away to avoid competition… [and] find alternative hosts."

DMSP isn't the only figure in this chemical calculus. *E. huxleyi* can keep its companion friendly as long as old algae can provide bribes of benzoate, a nutrient that *Roseobacter* bacteria can use but many other types can't. The microbe turns deadly when the bribes stop and all it's left with is a flood of DMSP.

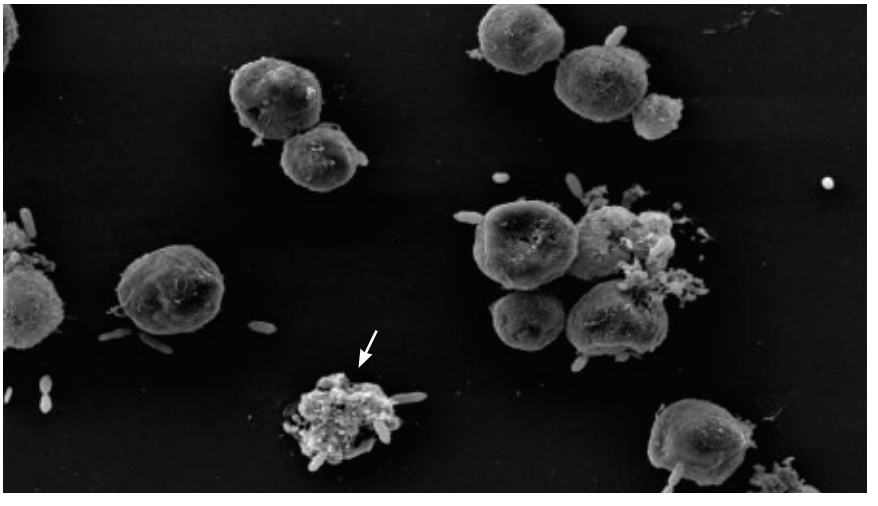
But how the *Roseobacter* species kills its algal host remains unclear. That's the next mystery that Vardi's team hopes to solve.

This kind of frenemies relationship, if it exists among other phytoplankton and bacteria, could be a key factor in controlling the boom and bust of massive algal blooms, says marine microbial ecologist Mary Ann Moran of the University of Georgia in Athens. Algal blooms can be toxic (SN: 9/29/18, p. 14), but they also convert, or "fix," enormous amounts of carbon dioxide into biomass and are a major source of carbon in the ocean.

"Phytoplankton fix half of all the carbon on the planet, and probably 20 percent to 50 percent of what they fix… actually goes right to bacteria," Moran says. If this kind of relationship controls how carbon flows through the ocean, "that is something that we would really like to understand." ■



Tiny marine phytoplankton can form giant blooms that are visible from space, like this one in the Barents Sea in 2021 that was spotted by a NASA satellite. Such blooms are a major source of carbon in the ocean and an important part of Earth's carbon cycle.



Round *Emiliania huxleyi* cells trade nutrients with rodlike bacteria. Once the algae get too old, the bacteria kill them — a fate that befell the *E. huxleyi* (arrow) in this microscope image.

FROM TOP: JOSHUA STEVENS, SUOMI NPP/NASA AND NOAA; N. BARAK-GAVISH *ET AL/SCIENCE ADVANCES* 2018

PALEONTOLOGY

Early primates lived in the Arctic

Two species moved north as the region warmed, fossils hint

BY FREDA KREIER

The Arctic today is a hostile place for most primates. But fossils suggest that wasn't always the case.

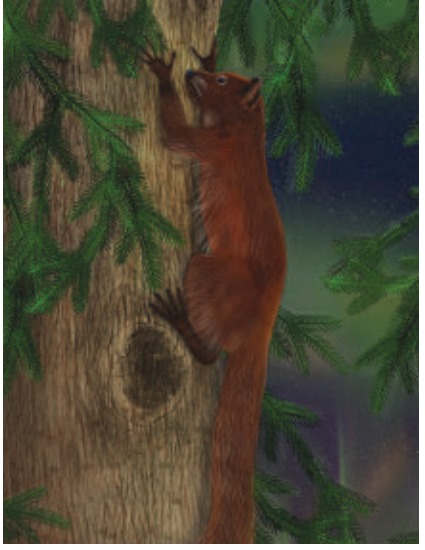
Dozens of fossilized teeth and jaw bones unearthed in Canada belonged to two species of early primates — or their close relatives — that lived in the Arctic about 52 million years ago, researchers report January 25 in *PLOS ONE*. These remains are the first primatelike fossils ever discovered above the Arctic Circle and tell of groundhog-sized animals that may have skittered across trees in a swampy Arctic.

The Arctic was a lot warmer during that time. But creatures still had to adapt to extreme conditions such as winter months without sunlight. These challenges make the presence of primatelike creatures in the Arctic "incredibly surprising," says paleontologist Chris Beard of the University of Kansas in Lawrence. "No other primate or primate relative has ever been found this far north."

Between frigid temperatures, limited plant growth and months of perpetual darkness, living in the modern Arctic isn't easy. This is especially true for primates, which evolved from small, tree-dwelling creatures that largely fed on fruit. Most modern primates tend to stick to tropical and subtropical forests, largely found around the equator.

But these forests haven't always been confined to their present location. During the early Eocene Epoch, which started around 56 million years ago, the planet underwent a period of intense warming that allowed forests and their residents to expand northward.

Scientists know about this early Arctic climate in part because of decades of research on Ellesmere Island in northern Canada. The area was once dominated by swamps similar to those found in the southeastern United States today. And a wide array of heat-loving animals, such as tapirs and crocodile relatives, called this ancient warm, wet environment home.



Evolving strong teeth and jaws to eat seeds and nuts may have helped two ancient species adapt to living in a warm, dark Arctic.

Beard and colleagues studied dozens of teeth and jaw fossils found in the area since the 1970s, concluding that they belong to two species of a now-extinct genus called *Ignacius* that was widespread across North America during the Eocene. The newfound species, *I. mckennai* and *I. dawsonae*, probably descended from *Ignacius* that moved north as the planet warmed and new habitat opened up near the North Pole.

Whether *Ignacius* can be considered a true primate or simply a close relative is still up for debate. Still, it's "really weird and unexpected" to find primates or their relatives in the area, says vertebrate paleontologist Mary Silcox of the University of Toronto Scarborough.

Ellesmere Island was already north of the Arctic Circle 52 million years ago. So while conditions there were warmer and wetter, the swamp was plunged into darkness during the winter. Newly arrived *Ignacius* would have had to adapt.

Unlike their southern kin, the Arctic *Ignacius* had unusually strong jaws and teeth suited to eating hard foods, Beard's team found. This may have helped the creatures eat nuts and seeds over the winter, when fruit was scarce.

Studying how plants and animals adapted to a warm Arctic could offer clues to how residents may do so in the future, Beard says. ■

QUANTUM PHYSICS

Store data with a quantum twist

Spiraling entangled photons make data-dense holograms

BY JAMES R. RIORDON

Particles of twisted light that have been entangled using quantum mechanics offer a new approach to dense and secure data storage.

Holograms that produce 3-D images and serve as security features on credit cards are usually made with patterns laid down with laser beams. In recent years, physicists have found ways to create holograms with entangled photons instead. Now there is, literally, a new twist to the technology.

Entangled photons that travel in corkscrew paths have resulted in holograms that offer the possibility of dense and ultrasecure data encryption, researchers report February 2 in *Physical Review Letters*.

Light can move in a variety of ways, including the up-and-down and side-to-side patterns of polarized light. But when it carries a type of rotation known as orbital angular momentum, it can also propagate in spirals resembling rotini pasta.

Like any other photons, the twisted versions can be entangled so that they essentially act as one entity. Something that affects one member of an entangled photon pair instantly affects the other, even if they are very far apart.

In previous experiments, researchers have sent data through the air in entangled pairs of twisted photons (SN: 9/5/15, *p.* 14). The approach should allow for high-speed data transmission because light can come with different twists, with each type of twist serving as a different channel of communication.

Now, physicists have used the twisty technique to record data in holograms. Instead of transmitting information on multiple twisted light channels, photon pairs with different amounts of twist create distinct sets of data in a single hologram. The more orbital angular

momentum states involved, each with different amounts of twist, the more data a hologram can store.

In addition to cramming more data into holograms, increasing the variety of twists used to record the data boosts security. Anyone who wants to read the information needs to know, or guess, how the light that recorded it was twisted.

For a hologram relying on two types of twist, a person would have to pick the right combination of the twists from about 80 possibilities to decode the data, says physicist Xiangdong Zhang of the Beijing Institute of Technology. Bumping that up to combinations of seven distinct twists leads to millions of possibilities. That "should be enough to ensure our quantum holographic encryption system has enough security level," he says.

Zhang and colleagues demonstrated their technique by encoding words and letters in holograms and reading the data back out again with twisted light. Although the team produced images from the holographic data, the storage itself should not be confused with holographic images, says physicist Hugo Defienne of the Paris Institute of Nanosciences.

Other quantum holography schemes, such as Defienne's efforts with polarized photons, produce direct images of objects, including microscopic structures.

That's quite different from Zhang and colleagues' approach. "They're using holography to store information," Defienne says, rather than creating the 3-D images typically associated with holograms.

The data storage that Zhang's team demonstrated is slow, requiring nearly 20 minutes to decode an image of the acronym BIT, for the Beijing Institute of Technology. And the security is still somewhat low because the tests included only up to six forms of twisted light. But Zhang is confident that technical improvements can overcome the limitations.

"We think that our technology has potential application in quantum information encryption," he says, "especially quantum image encryption. ■

PLANTS

How plant 'muscles' fold up a mimosa

Special motorlike cells close leaflets like books when touched

BY SUSAN MILIUS

AUSTIN, TEXAS — Call them plant motors. Or plant muscles. Tiny bulges of specialized cells in a mimosa plant can fold its feathery leaflets together in seconds, then relax — and do it again.

A new look at these bulges on the *Mimosa pudica* plant has revealed more details of how a leaf manages its unusually fast folding, says biomechanist David Sleboda of the University of California, Irvine. "I think that these particular organs are really cool because their motion is reversible," he says. "When people see plant motion that is reversible, it feels much more similar to animal motion."

Scientists have already worked out the basic chemistry that drives each little mimosa motor, or pulvinus. When a deer hoof or something else scary jostles a leaf, potassium and some other ions shift from one part of a pulvinus toward the other. Water follows the swoosh of ions. Cells that lose water deflate and sag while those on the other side bloat. Distortions in multiple pulvini make the halves of a feathery leaf fold toward each other, like an invisible hand gently closing a book.

Instead of chemistry, Sleboda and colleagues looked at structural details in pulvinus cells that help create such useful distortions, he said January 7 at the annual meeting of the Society for Integrative and Comparative Biology. The team reported its findings January 5 in *Current Biology*.

One feature that makes plant-muscle cells bloat more efficiently is reinforcement with microscopic fibrils. They work like corsets, keeping cells from bulging out in all directions. Instead, the corset directs much of the swelling along the axis that the leaf halves fold along.

Pulvinus cells that need to bulge fast have what look like wrinkles of easily expandable tissue for inrushing water, plus special highly porous zones called pit fields. The pits look as if water could sluice through easily in a tickled-leaf emergency. Cell arrangement itself looks specialized for expanding and shrinking. A pulvinus cross section reveals a pattern "like the bellows of a concertina," Sleboda said.

The widespread *M. pudica*, or sensitive plant, is one of the better-known leaf flexors. Yet clusters of other plants in the same family, the legumes, also move their leaves, says botanist Thainara Policarpo Mendes of Universidade Estadual Paulista in Botucatu, Brazil. Some relatives close fast like *M. pudica*, but many are slower. What she thinks about is why leaves close at all. People have proposed a variety of advantages: discouraging animals from grazing or helping a plant lose less heat during very cold nights.

Sleboda too can reel off hypotheses but remains skeptical of all of them. "There's not a ton of research," he says. That, however, is fine with him. "My favorite thing about sensitive plants' leaf closing is that we don't know why they do it." ■

When touched, *Mimosa pudica* shuts its leaves like a book thanks to musclelike cells. Now, scientists are looking at how structural details of the cells enhance the plant's folding abilities.

DEBU DURLAV/ISTOCK/GETTY IMAGES PLUS

HEALTH & MEDICINE

Procrastination may harm your health

Avoidance is linked to poor outcomes, but change is possible

BY MEGHAN ROSEN

The worst procrastinators probably won't be able to read this story. It'll remind them of what they're trying to avoid, psychologist Piers Steel says.

Maybe they're dragging their feet going to the gym. Maybe they haven't gotten around to their New Year's resolutions. Maybe they're waiting just one more day to study for that test.

Procrastination is "putting off to later what you know you should be doing now," even if you'll be worse off, says Steel, of the University of Calgary in Canada. But all those tasks pushed to tomorrow seem to wedge themselves into the mind — and it may be harming people's health.

In a study of thousands of university students, scientists linked procrastination to a panoply of poor outcomes, including depression, anxiety and even disabling arm pain. "I was surprised when I saw that one," says Fred Johansson, a clinical psychologist at Sophiahemmet University in Stockholm. His team reports the results January 4 in *JAMA Network Open*.

The study is one of the largest yet to tackle procrastination's ties to health. Its results echo findings from earlier studies that have gone largely ignored, says Fuschia Sirois, a behavioral scientist at Durham University in England.

For years, scientists didn't seem to view procrastination as something serious, she says. The new study could change that. "It's that kind of big splash that's ... going to get attention," says Sirois, who wasn't involved in the research. "I'm hoping that it will raise awareness of the physical health consequences of procrastination."

Bad for mind and body

Whether procrastination harms health can seem like a chicken-and-egg situation. It can be hard to tell if certain health problems make people more likely to procrastinate, or the other way around, Johansson says. (It may be a bit of both.) And controlled experiments on procrastination aren't easy to do: You can't just tell a study participant to become a procrastinator and wait and see if their health changes, he says.

Many previous studies have relied on self-reported surveys taken at a single time point. But a snapshot of someone makes it tricky to untangle cause and effect. The researchers in the new study enrolled about 3,500 students to follow over nine months, so the team could track whether procrastinating students later developed health issues.

On average, procrastinating students tended to fare worse over time than their prompter peers. Procrastinators were slightly more stressed, anxious, depressed and sleep-deprived, among other issues. "People who score higher on procrastination to begin with ... are at greater risk of developing both physical and psychological problems later on," says study coauthor Alexander Rozental, a clinical psychologist at Uppsala University in Sweden. "There is a relationship between procrastination at one time point and having these negative outcomes at the later point."

> "You made a mistake and procrastinated. It's not the end of the world. What can you do to move forward?"
>
> **FUSCHIA SIROIS**

The study was observational, so the team can't say for sure that procrastination causes poor health. But results from other researchers also seem to point in this direction. A 2021 study tied putting off going to bed and staying up late to depression. And a 2015 study from Sirois' lab linked procrastinating to poor heart health.

Stress may be to blame for procrastination's ill effects, data from Sirois' lab and other studies suggest. She thinks that the effects of chronic procrastinating could build up over time. And though procrastination alone may not cause disease, Sirois says, it could be "one extra factor that can tip the scales."

A behavioral pattern

Some 20 percent of adults are estimated to be chronic procrastinators. Everyone might put off a task or two, but chronic procrastinators make it their lifestyle, says Joseph Ferrari, a psychologist at DePaul University in Chicago who has been studying procrastination for decades. "They do it at home, at school, at work and in their relationships." These are the people, he says, who "you know are going to RSVP late."

Though procrastinators may think they perform better under pressure, Ferrari has reported the opposite. They actually work more slowly and make more errors than non-procrastinators, his experiments have shown. When deadlines are slippery, procrastinators tend to let their work slide, Steel's team reported last year in *Frontiers in Psychology*.

For years, researchers have focused on studying the personalities of people who procrastinate. Findings vary, but some scientists suggest procrastinators may be impulsive, be worriers and have trouble regulating their emotions. One thing procrastinators are not, Ferrari emphasizes, is lazy. They're actually "very busy doing other things than what they're supposed to be doing," he says.

In fact, Rozental adds, most research today suggests procrastination is a behavioral pattern. And if procrastination is a behavior, he says, that means it's something you can change.

End the dawdling

When people put off a tough task, they can feel good — in the moment.

Procrastinating is a way to sidestep the negative emotions linked to the task, Sirois says. "We're sort of hardwired to avoid anything painful or difficult," she says. "When you procrastinate, you get immediate relief." A backdrop of stressful circumstances — say, a pandemic — can strain people's ability to cope, making procrastinating even easier. But the relief it provides is only temporary.

Researchers have experimented with procrastination treatments that run the gamut from the practical to the psychological to help those who seek out ways to stop dawdling. What works best is still under investigation. Some scientists have reported success with time-management interventions. But the evidence for that "is all over the map," Sirois says. "Poor time management is a symptom, not a cause of procrastination."

For some procrastinators, seemingly obvious tips can work. In his clinical practice, Rozental advises students to simply put down their smartphones. Silencing notifications or studying in the library rather than at home can quash distractions and keep people on task. But that won't be enough for many people, he says.

Hard-core procrastinators may benefit from cognitive behavioral therapy. In a 2018 review of procrastination treatments, Rozental found that this type of therapy, which involves managing thoughts and emotions and trying to change behavior, seemed to be the most helpful. Still, not many studies have examined treatments, and there's room for improvement, he says.

Sirois also favors an emotion-centered approach. Procrastinators can fall into a shame spiral where they feel uneasy about a task, put the task off, feel ashamed for putting it off and then feel even worse than when they started. People need to short-circuit that loop, she says. Self-forgiveness may help, scientists suggested in one 2020 study.

Practicing mindfulness also could be effective. In a small trial of university students, eight weekly mindfulness sessions reduced procrastination, Sirois and colleagues report in the January *Learning and Individual Differences*. Students practiced focusing on the body, meditating during unpleasant activities, and discussed the best way to take care of themselves.

A little self-compassion may snap people out of their spiral, Sirois says. "You made a mistake and procrastinated. It's not the end of the world," she says. "What can you do to move forward?" ■

NASTACIA GOODWIN (CC BY-SA)

ANIMALS

Voles don't need oxytocin to bond

Lab rodents that can't detect the 'love hormone' still pair up

BY DARREN INCORVAIA

Prairie voles form male-female pair-bonds and stick with their partner for life.

Prairie voles have long been heralded as models of monogamy. But the "love hormone" once thought essential for their bonding—oxytocin—might not be so necessary after all, a new study finds.

Interest in the romantic lives of prairie voles (*Microtus ochrogaster*) was sparked more than 40 years ago. Biologists trying to capture voles would frequently catch two at a time. "What they were finding were these male-female pairs," says Devanand Manoli, a biologist at the University of California, San Francisco. Unlike many other rodents, prairie voles, it turned out, mate for life. Because of their relatively complex social lives, the animals have been a popular system for studying how social behavior evolves.

Pair-bonded prairie voles like to huddle together and prefer each other's company over a stranger's. Research has implicated a few hormones in the brain as vital for proper vole manners, most notably oxytocin, which is also important for social behavior in humans and other animals.

Manoli and colleagues thought the oxytocin receptor, the protein that detects and binds to oxytocin, would be the perfect test target for a new genetic engineering method based on CRISPR technology, which can selectively turn off genes. The researchers used the technique on vole embryos so that vole moms gave birth to pups without functioning oxytocin receptors. The team figured that these voles wouldn't be able to form pair-bonds—just like voles in past experiments whose oxytocin activity was blocked with drugs.

Instead, the voles had no problems pairing up, Manoli's team reports January 27 in *Neuron*.

"I was very surprised by their results," says Larry Young, a biologist at Emory University in Atlanta who has studied oxytocin in prairie voles for decades.

A key difference between the new study and past studies using drugs to block oxytocin is the timing of when the hormone's activity is turned off. With drugs, the voles are adults and have had exposure to oxytocin in their brains before the shutoff. With CRISPR, "these animals are born never experiencing oxytocin signaling in the brain," says Young, whose research group recently replicated Manoli's experiment and found the same result.

Pair-bonding may be controlled by a brain circuit that typically becomes dependent on oxytocin through exposure during development, like a symphony trained by a conductor. Remove that conductor, and the symphony will sound discordant. But a jazz band that's never practiced with a conductor fares just fine without one.

Manoli agrees that timing matters. Another reason for the disparity, he says, could be that the drugs meant to block oxytocin do other things in the brain that affect pair-bonding. Young disagrees. The drug "is very selective," he says, not even binding to the receptor of oxytocin's closest molecular relative, vasopressin.

Either way, the new study shows that oxytocin's role in pair-bonding isn't as clear-cut as once thought, Manoli says. It seems oxytocin plays a crucial role, but we're now left wondering, "What is that role?"

Manoli's group now hopes to look at how other hormones, like vasopressin, influence pair-bonding using the same CRISPR technique. The researchers are also looking more closely to be sure that the method didn't alter vole behavior in a way they haven't noticed yet.

In the game of vole "love," it looks like scientists are still trying to understand all the players. ■

Broken timelines

Life is a story, but trauma can shatter the plot

By Sujata Gupta

Trish Tran narrates her life in staccato notes.

"I remember carrying my little sister on my back because she's too tired and walking through the huge sunflower fields … and me feeling so tired I didn't think I could walk another step."

"I remember being in a taxi with my mother, coming back to the man who had been violently abusive to all of us.... Her words to me were, 'Just trust me, Trish. Just trust me.'"

"I'm waiting at a train station … to meet my mother who I haven't seen in many years.... Hours pass and eventually I try to call her … and she says to me, 'I'm sorry, Trish. My neighbor was upset, and I needed to stay back with them.' And her voice was slurring quite a lot, so I knew she had been drinking."

Tran, who lives in Perth, Australia, is dispassionate as she describes a difficult childhood. Her account lacks what are generally considered classic signs of trauma: She makes no mention of flashbacks, appears to have a generally positive outlook and speaks with relative ease about distressing events. Yet she narrates her life growing up and living in the Australian Outback as a series of disconnected events; her life story lacks connective glue.

That disjointed style is not how people, at least people in the West, tend to talk about themselves, says psychologist Christin Camia. Autobiographical accounts, like any good narrative, typically contain a curation of key past experiences, transitions linking those experiences and larger arcs about where life is headed. People use these stories to make sense of their lives, says Camia, of Zayed University's Abu Dhabi campus in the United Arab Emirates.

But a growing body of evidence from fields as wide-ranging as psychology, neuroscience, linguistics, philosophy and literary studies suggests that, as with Tran, trauma can shatter the narrative coherence of one's life. People lose the plot.

Life's crises can trigger an existential crisis, Camia says. People think: "I don't know who I am, and I don't know where I go from here."

One therapy now in testing aims to re-tether traumatized individuals to their mental timelines, or their sense of themselves as connected across past, present and future. The therapy focuses on the future, which once rife with possibilities now appears as a void. It asks: What would it take for someone like Tran, or anyone traumatized by war, abuse, mass shootings, the ongoing pandemic and other calamities, to flip their life script, to say that they know who they are and where they go from here?

The fixed self

In a nod to an established research approach, I have asked Tran to tell me her story in two parts. First, she should narrate seven snapshots of key moments in her life. Second, Tran, who is a lecturer on mental health recovery at Curtin University in Perth, should stitch those snapshots together to tell me how she became who she is today.

The first task comes easy. The second task eludes her. She switches to generalities. "I've always been a highly reflective person," she says. "I've had to rely on my brains to keep myself and my family alive."

I try to nudge her toward specifics, but her timeline disintegrates. She repeatedly attempted suicide. Her mother brought home many violent men.

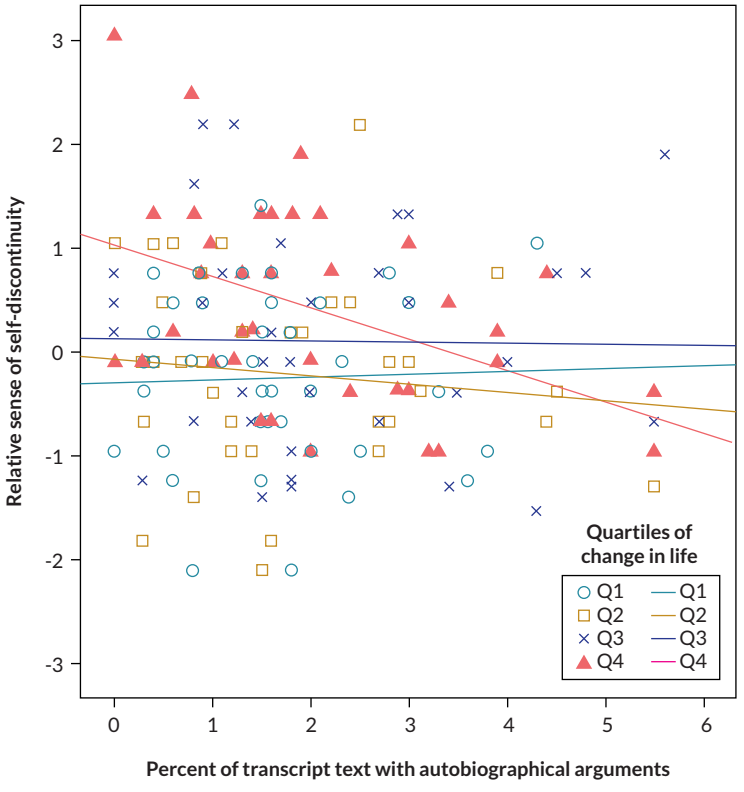
The developer of this two-question approach, psychologist Tilmann Habermas, wasn't focused on

OPPOSITE PAGE: KATTY HUERTAS

Examples of autobiographical arguments

Lessons learned	"After that I told myself, when I fall in love the next time, I must take care that school doesn't suffer."
Developmental status	"At the time I wasn't aware of any of that, after all, I was still too young for that."
Formative experience	"My burnout has led me to no longer attach so much importance to money today."

Autobiographical reasoning recorded in life narratives versus the sense of self as continuous over time



Life's plot

As part of a long-term study, participants shared their life stories in roughly 20-minute increments. Researchers analyzed those stories for autobiographical arguments — statements about how the past influences a person today (examples at top). Among those who experienced the most life changes (quartile 4 in the chart), more autobiographical reasoning correlated with a greater sense of self-continuity.

SOURCE: T. HABERMAS AND C. KÖBER/*MEMORY* 2015

people who had experienced trauma. Habermas, now at Goethe University Frankfurt, wanted to understand how adolescents develop a narrative identity and then sustain that sense of self over time.

In 2003, Habermas launched a study that would follow participants for up to 16 years. Participants came into the lab every four years and dictated their life story in roughly 20-minute increments, using the two-task format I tried with Tran. Habermas analyzed the resulting transcripts line by line, coding them for emotion, tense, transitions and other features.

With few psychologists at the time studying autobiography as a window into the mind, Habermas turned to theorists from other fields for guidance. "After I read psychology, I read narratology, literary theory, linguistics, social linguistics," he says. "I had to steal … all these concepts from the other areas."

One of Habermas' questions was how people retain their sense of self in the face of life's many disturbances, such as divorce, illness, job loss or moving to a new location.

Philosophers have been puzzling over this question for millennia. "Your body has changed. Your experiences have changed. Your knowledge has changed. And yet, people generally think of themselves as being the same person … in the past and future," says psychologist Yosef Sokol of Touro University in New York City. "That's a hard problem."

This general belief in self-continuity appears universal, even though how it is constructed may differ across cultures.

In the third wave of Habermas' long-term study, when 150 participants were ages 16, 20, 28, 44 and 69, Habermas and Camia, who joined Habermas' lab in 2009, also analyzed the transcripts for a type of thinking called autobiographical reasoning. This reasoning links the self across space and time.

"Autobiographical reasoning is this conscious reflection. How did my past impact me? How did I become the person I am today, and what does it mean for my future?" Camia says. Such reasoning tends to stem from change, she adds. "If there is perfect stability in life, you don't do a lot of autobiographical reasoning … it's the changes and the crises that compel meaning-making."

The researchers divvied such reasoning into eight categories, such as turning points, lessons learned, generalized insights and using an event to explain a change in personality.

Participants also filled out two surveys. One survey summed up the number of big life changes experienced over the previous four years. The other gauged self-continuity, with participants rating the truth of statements such as, "When I look at pictures of myself four years back, it feels a little unfamiliar" and "I have the feeling that at the core I am the same person I was four years ago."

Researchers then compared the three variables: autobiographical reasoning, levels of life change and sense of self-continuity. As expected, levels of autobiographical reasoning showed no discernible pattern among participants who experienced few changes in life, the team reported in 2015 in *Memory*.

But when the researchers zoomed in on the quarter of participants reporting the greatest level of change, more autobiographical reasoning came with higher levels of self-continuity. "Constructing continuity in the life story buffers against the effect of change in your life," Habermas says. Other teams have made similar findings.

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Most disruptions, however, do not rise to the level of trauma—such as that experienced by Tran. Several years later, Camia would study how traumatic events, notably being forced to flee one's home and the resulting isolation and bereavement, affect people's sense of self.

Out of sync

"What does war change first? One's sense of time, one's sense of space," said Ukrainian writer Serhiy Zhadan in an October speech translated to English in the online magazine LitHub.

Zhadan speaks from experience. But the idea that trauma disrupts time perception is also borne out by research. Researchers have found that emotions frequently dictate whether we experience time as passing fast or slow. And traumatic events, which come with intense emotions, can cause people to experience time in slow motion, researchers reported in 2012 in *Frontiers in Psychology*.

During a car accident, for instance, a person's whole body is ready to act, says Marc Wittmann, a psychologist with the Institute for Frontier Areas of Psychology and Mental Health in Freiburg, Germany. "Your inner workings, your processing, is speeded up. Relative to that, your outside slows down."

What's more, says health psychologist Alison Holman of the University of California, Irvine, in that moment or moments of crisis, you do not think about the past or future. All that matters is survival.

Zhadan speaks directly to this idea in his speech: "People in a war-torn space try not to plan for the future or think too much about what the world will be like tomorrow. What's happening to you here and now is all that matters, just the people and things that will be with you tomorrow morning—tops. That's if you survive and wake up."

That narrow focus can wreak havoc on mental health. "[When] that present moment is so intense that it sears into your mind…it may set up the likelihood that you will have a hard time moving past it," Holman says. "The past never passes."

Such breakdowns in time can show up in language, particularly among those most severely affected by trauma. For instance, Habermas and his team compared the speech patterns of 14 women diagnosed with post-traumatic stress disorder following a singular shocking event, such as physical or sexual abuse, and 14 women without such a diagnosis. The women with PTSD used more immersive language. They quoted people directly and spoke of the past as if it was ongoing, says Habermas, who reported the findings in 2014. "Instead of saying, 'He hit me,' they would say, 'He hits me.'"

This immersive language dominates Tran's narration. She is "carrying" her little sister. Her mother is "coming" back to the violent man. She is "walking many kilometers to school in the rain and then opening up my newspaper-wrapped wet and warm tomato sandwiches. They're so wet, but I'm so hungry that I know I have to eat them otherwise I'll never make the walk back."

And always there, her mother's voice: "Just trust me, Trish. Just trust me."

"I don't think I will ever forget those words," Tran says.

Traversing time

Tran remembers her mother's words exactly, but other details of the abuse she experienced as a child are fuzzier. That's common among people who experience trauma. People with trauma "have both an excess and depletion of memory," says cognitive neuroscientist Elisa Ciaramelli of the University of Bologna in Italy.

How memory changes among trauma survivors remains controversial, write the authors of a 2021 opinion piece in *Frontiers in Psychology*. But mounting evidence suggests that people tend to remember stressful memories in detail. As the mind fixates on those traumatic memories, memories unrelated to the trauma seem to fade, while new memories fail to register.

For example, when asked to describe memories associated with a specific word, such as "beach," people who do not have PTSD offer detailed reports, describing what they were wearing, what they said and who they were with, Ciaramelli says. People who have PTSD, on the other hand, typically provide general memories with little color.

Other memories can't find a foothold. In one study, researchers asked 52 participants—26 people

Trish Tran (seated with her father and the rest of her family in the photo at left) was physically and emotionally abused as a child. Today (at Graylands Hospital in Western Australia, right), she lectures on mental health recovery and provides support for people experiencing suicidal thoughts.

COURTESY OF T. TRAN

with PTSD and 26 people who had experienced trauma but not developed PTSD—to keep a diary recording their memories over the course of a week. Participants also responded to questions about the memory, such as whether or not it related to their trauma, how central it was to their current life and how far away in time the memory felt.

Participants without PTSD recorded an average of 21.4 memories across the week while participants with PTSD recorded an average of just 11 memories, the team reported in 2017 in *Clinical Psychological Science*. The PTSD participants had more trauma-related memories than the non-PTSD group.

Tran recognizes this paucity of detail in her own life story. "My memories are lightbulb memories," she says. "They are always attached to significant events like trauma or happy times. I may have 57 years of life, but you could truncate them into a chapter."

Everyone's memory has imprecision of course. That imprecision allows us to cut extraneous details and make sense of our story. The traumatized person's relative lack of memories, though, both in clarity and quantity, means they struggle to construct a cohesive narrative of their past and to envision themselves moving forward.

"Ten years ago, people have found that the same brain regions that are activated and are necessary for remembering the past are also necessary to imagine the future," Ciaramelli says. "We need memories to imagine the future."

Camia's work with refugees shows what can happen to the sense of self as people struggle and fail to reconcile a traumatic experience with the larger story of their life. Her central aim, which built on work with Habermas, was to see if the same autobiographical arguments people used to buffer against life's everyday changes could help those facing traumatic disruptions. She and Rida Zafar, a psychology student at New York University Abu Dhabi, recruited 31 refugees living in Germany and asked them to narrate their life stories, plus fill out the life change and self-continuity surveys used in the 2015 study.

Among the 16 refugees who experienced relatively less change since arriving in Germany, such as fewer upheavals in relationships and fewer moves, more autobiographical reasoning did correlate with higher self-continuity, the team reported in 2021 in *Frontiers in Psychology*. Refugees who experienced high change also used autobiographical reasoning, but their sense of self-continuity remained low.

These individuals cannot settle their trauma, Camia explains, so their reckoning with the past leads not to resolution but rumination. They are stuck.

21.4
Memories recorded per week in study participants without PTSD

11
Memories recorded per week in study participants with PTSD

SOURCE: S. SCHÖNFELD AND A. EHLERS/*CLIN. PSYCHOL. SCI.* 2017

The vivid future self

For most of her adult life, Tran grappled with that sense of stagnation. "My identity was rooted in the past, and I couldn't move forward," she says. "Time was this eternal loop. Every time a problem came up, it felt like a replication of a past problem. I couldn't see that I could change anything."

Over and over again, unable to envision a viable escape, Tran tried to kill herself.

Suicide attempts serve as the clearest signal that a person's future has gone blank, says Sokol, the psychologist at Touro University. The thinking here is intuitive. "If you think you have a meaningful life into the future, you're not going to kill yourself," he says.

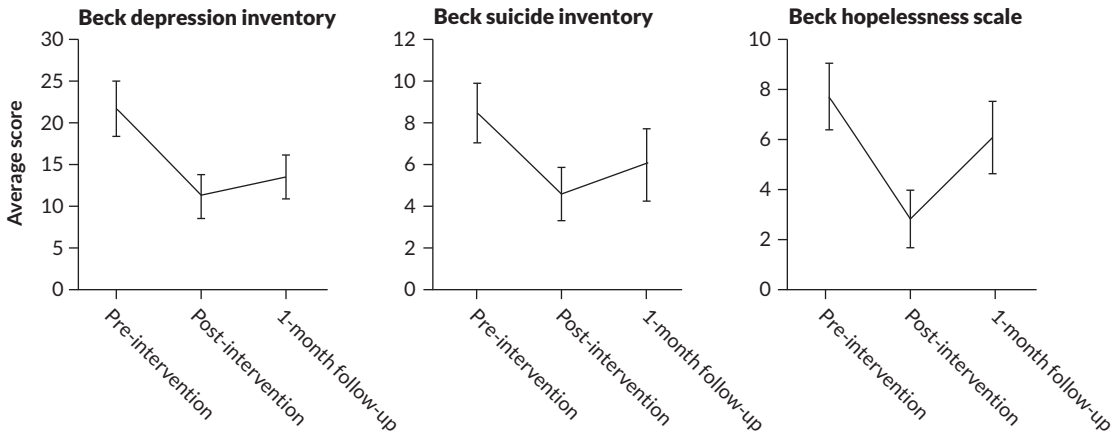
Conventional therapies for treating people struggling with suicidal thinking often fail to meet their needs because the therapies do not directly address people's future self, Sokol and his team wrote in 2021 in the *Journal of Cognitive Psychotherapy*. For instance, dialectical behavior therapy emphasizes focusing on the present to cope with stress and manage emotions. Narrative therapy likewise aims to help patients incorporate traumatic and other events into a continuous timeline, but focuses on linking past to present, not present to future.

So Sokol developed a therapy that incorporates elements of past- and present-oriented treatments but prioritizes future thinking. It's known as continuous identity cognitive therapy. His goal is to help military veterans struggling with mental illness re-create the plot in the mental timeline of their lives, to answer those foundational questions: Who am I? Where do I go from here?

Sokol tested an initial version of the therapy in a four-week pilot study with 17 veterans. The program contains many work-arounds for participants struggling to access or make sense of their memories. The specific memory is less important than the larger story, or the broader values contained within that memory, Sokol says. "I have all sorts of techniques to help people tap into something that they find important, meaningful."

In the first week, participants are asked to define their core values. The hope is that those values, rather than specific past events, will form the core of a person's life story. To get to that core, participants review negative and positive experiences from their past and identify choices they made.

Many veterans struggle with what are called moral injuries—choices they made that don't seem to align with who they wish to be, Sokol says. So veterans push those memories away. With the values approach, he hopes participants can start to see that they made the best choices they could



Thinking ahead
In a small pilot study with veterans, a new treatment for mental illness that focuses on future thinking, called continuous identity cognitive therapy, appeared to decrease levels of suicidal ideation and depression.
SOURCE: Y. SOKOL *ET AL/J. OF COGN. PSYCHOTHER.* 2021

under challenging circumstances. One way to access those values is to have participants identify people they admire, and the values those people embody. Participants can then use those people's experiences to identify their own core values.

The focus of the second week shifts to the future. Participants assemble possible futures by reflecting on how life might play out if they work with, or against, their stated values. Participants also actively construct self-continuity. For instance, they write letters to themselves across different time points, such as from their present self to their future self or vice versa.

In week three, participants learn to differentiate between external life stories, the series of events outside their control, and internal life stories made up of choices in line with their stated values. By week four, participants should be able to visualize their future self overcoming an issue that their present self faces.

Tran came across Sokol's research while embarking on her own journey to healing. That process began when Tran realized how her trauma was hurting the people she loved most. "I'm just causing my children and everybody near and dear trauma. I'm going to take [suicide] off the table," she eventually realized. "This is not my pathway anymore. If it's not my pathway, what am I going to do with the next 50 years of my life?"

Tran felt lost. So she dug into research on trauma survivors, eventually stumbling upon Sokol's project. She was moved by the idea that participants did not have to reconstruct the past to build a new future. "This is true. My soul knows this to be true," she remembers thinking.

Tran, who is also a trainer with DISCHARGED, a nonprofit organization that provides peer group support for people experiencing suicidal thoughts, and an occasional adviser to researchers writing about suicide, reached out to Sokol and offered to help him make the language used in his program more sensitive to people who have experienced trauma. For instance, she suggested changing references to "you" to "we" to give people a greater sense of belonging and agency. The two still work together.

Research on the therapy remains limited to Sokol's lab, but initial results are promising. The pilot study showed that the program decreased previously reported levels of suicidal ideation and depression. Those levels stayed low one month after completion. Now Sokol has received a five-year, $1.1 million grant from the U.S. Department of Veterans Affairs to scale up the program and eventually roll out a randomized controlled trial. In its newer iteration, the program will run for three months instead of one.

With input from Tran and veterans in the program, Sokol made another substantial modification to the pilot program. Participants will now identify how their own story intersects with the stories of other people in their lives. That addition makes sense to Tran, who has become engrossed in research showing the intergenerational nature of trauma. She now sees her life as part of a larger story with many characters, each on their own often troubled journey.

She says her story will always be truncated. But even without a clean narrative arc, she has managed to sever time's eternal loop. "You can change your relationship with your past experiences in a way that makes living a future possible," Tran says. ■

Explore more

- Constantine Sedikides, Emily K. Hong and Tim Wildschut. "Self-Continuity." *Annual Review of Psychology*. January 2023.

Editor's Note: If you or someone you know is facing a suicidal crisis or emotional distress, call or text the 988 Suicide & Crisis Lifeline at 988.

C. CHANG

Surprises
FROM THE JEZERO CRATER

Perseverance has found a dynamic environment. What does it mean for Martian life? **By Liz Kruesi**

In August 2021 on a lonely crater floor, the newest Mars rover dug into one of its first rocks.

The percussive drill attached to the arm of the Perseverance rover scraped the dust and top several millimeters off a rocky outcrop in a 5-centimeter-wide circle. From just above, one of the rover's cameras captured what looked like broken shards wedged against one another. The presence of interlocking crystal textures became obvious. Those textures were not what most of the scientists who had spent years preparing for the mission expected.

Then the scientists watched on a video conference as the rover's two spectrometers revealed the chemistry of those meshed textures. The visible shapes along with the chemical compositions showed that this rock, dubbed Rochette, was volcanic in origin. It was not made up of the layers of clay and silt that would be found at a former lake bed.

Nicknamed Percy, the rover arrived at the Jezero crater two years ago, on February 18, 2021, with its sidekick helicopter, Ingenuity. The most complex spacecraft to explore the Martian surface, Percy builds on the work of the Curiosity rover, which has been on Mars since 2012, the twin Spirit and Opportunity rovers, the Sojourner rover and other landers (SN: 8/13/22, p. 20).

But Perseverance's main purpose is different. While the earlier rovers focused on Martian geology and understanding the planet's environment, Percy is looking for signs of past life. Jezero was picked for the Mars 2020 mission because it appears from orbit to be a former lake environment where microbes could have thrived, and its large delta would likely preserve any signs of them. Drilling, scraping and collecting pieces of the Red Planet, the rover is using its seven science instruments to analyze the bits for any hint of ancient

JPL-CALTECH/NASA

Perseverance landed on Mars in February 2021. As of early February of this year, the rover had gathered 18 samples — and deposited half for a future potential return to Earth.

life. It's also collecting samples to return to Earth.

Since landing, "we've been able to start putting together the story of what has happened in Jezero, and it's pretty complex," says Briony Horgan, a planetary scientist at Purdue University in West Lafayette, Ind., who helps plan Percy's day-to-day and long-term operations.

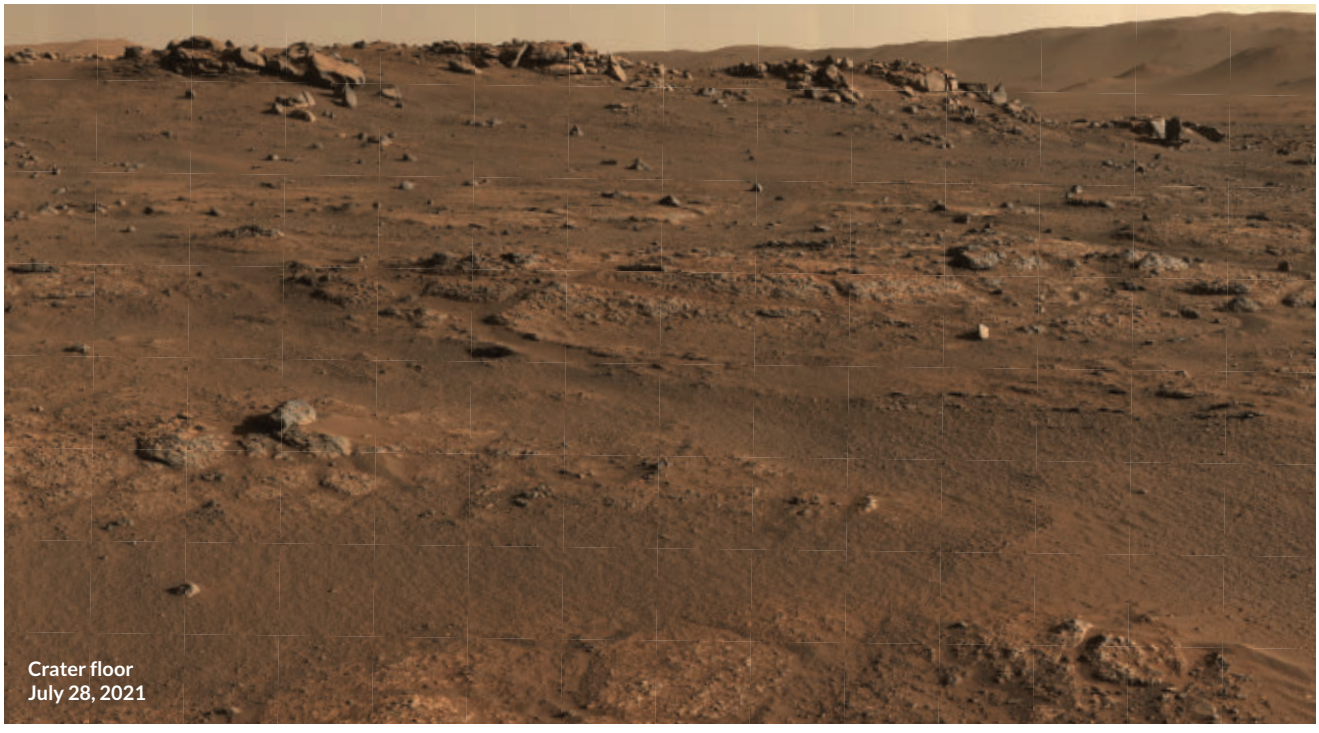
Volcanic rock is just one of the surprises the rover has uncovered (SN: 9/11/21, p. 32). Hundreds of researchers scouring the data Perseverance has sent back so far now have some clues to how the crater has evolved over time. This basin has witnessed flowing lava, at least one lake that lasted perhaps tens of thousands of years, running rivers that created a mud-and-sand delta and heavy flooding that brought rocks from faraway locales.

Jezero has a more dynamic past than scientists had anticipated. That volatility has slowed the search for sedimentary rocks, but it has also pointed to new alcoves where ancient life could have taken hold.

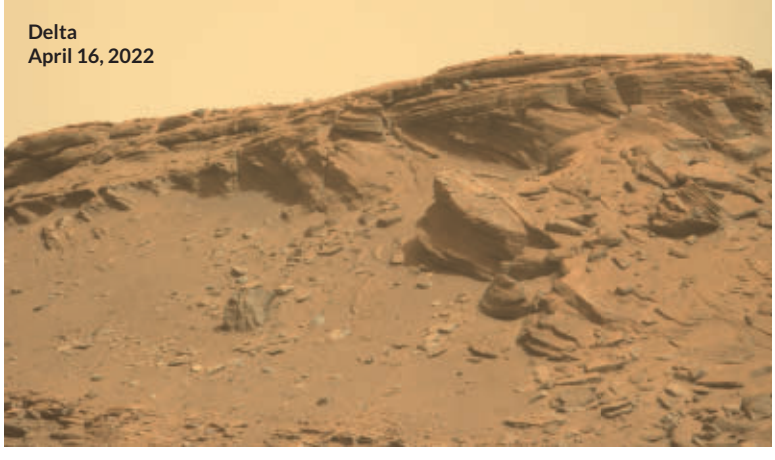
Perseverance has turned up carbon-bearing materials — the basis of life on Earth — in every sample it has abraded, Horgan says. "We're seeing that everywhere." And the rover still has much more to explore.

Surprises stirring

Jezero is a shallow impact crater about 45 kilometers in diameter just north of the planet's equator. The crater formed sometime between 3.7 billion and 4.1 billion years ago, in the solar system's first billion years. It sits in an older and much larger impact basin known as Isidis. At Jezero's western curve, an etched ancient riverbed gives way to a dried-out, fan-shaped delta on the crater floor. That delta "is like this flashing signpost beautifully visible from orbit that tells us there was a standing body of



Crater floor
July 28, 2021



Delta
April 16, 2022

On the floor of the Jezero crater (top), Perseverance found rocks that were volcanic in nature, not the sedimentary rocks that scientists expected from a dry lake bed. Sedimentary rocks made of layers of sand and silt did turn up in the delta front region (bottom), which the rover has been exploring since April of last year. Scientists hope to probe these rocks for signs of ancient life.

water here," says astrobiologist Ken Williford of Blue Marble Space Institute of Science in Seattle.

Perseverance landed on the crater floor about two kilometers from the front of the delta. Scientists thought they'd find compacted layers of soil and sand there, at the base of what they dubbed Lake Jezero. But the landscape immediately looked different than expected, says planetary geologist Kathryn Stack Morgan of NASA's Jet Propulsion Laboratory in Pasadena, Calif. Stack Morgan is deputy project scientist for Perseverance.

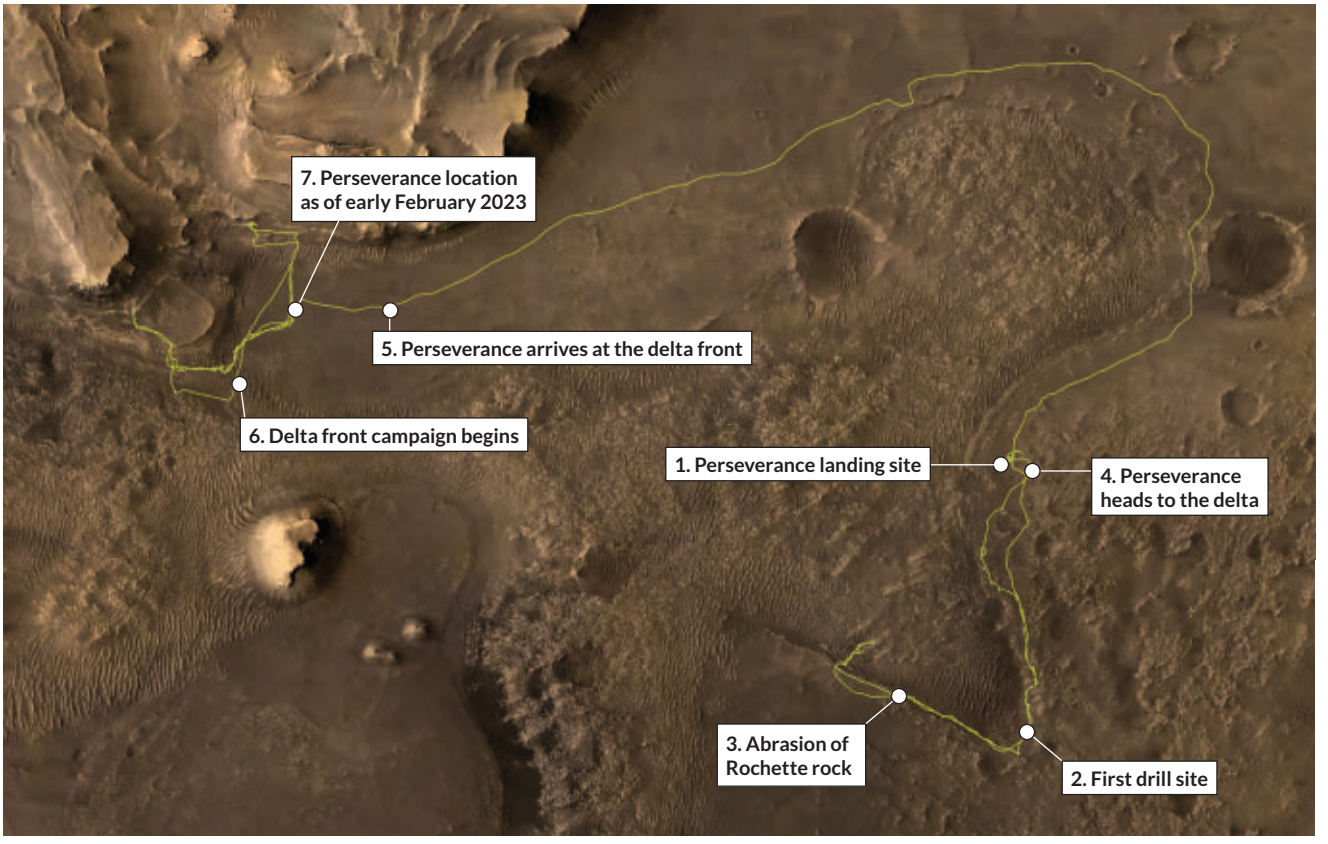
For the first several months after the landing, the Mars 2020 mission team tested the rover's movements and instruments, slowly, carefully. But from the first real science drilling near the landing location, researchers back on Earth realized what they had found. The texture of the rock, Stack Morgan says, was "a textbook igneous volcanic rock texture." It looked like volcanic lava flows.

Over the next six months, several more rocks on the crater floor revealed igneous texture. Some of the most exciting rocks, including Rochette, showed olivine crystals throughout. "The crystal fabric was obviously cooled from a melt, not transported grains," as would be the case if it were a sedimentary sample, says Abigail Allwood of the Jet Propulsion Lab. She leads the rover's PIXL instrument, which uses an X-ray beam to identify each sample's composition.

Mission scientists now think the crater floor is filled with igneous rocks from two separate events—both after the crater was created, so more recently than the 3.7 billion to 4.1 billion years ago time frame. In one, magma from deep within the planet pushed toward the surface, cooled and solidified, and was later exposed by erosion. In the other, smaller lava flows streamed at the surface.

Sometime after these events, water flowed from the nearby highlands into the crater to form a lake tens of meters deep and lasting tens of thousands of years at least, according to some team members. Percy's instruments have revealed the ways that water altered the igneous rocks: For example, scientists have found sulfates and other minerals that require water to form, and they've seen empty pits within the rocks' cracks, where water would have

FROM TOP: JPL-CALTECH/NASA, ASU, MSSS; JPL-CALTECH/NASA, ASU



After landing on the Red Planet, Perseverance tested its movements and instruments for several months before exploring the floor of the Jezero crater. Percy then journeyed to the delta, arriving in April 2022. The rover explored the delta front through December, before carefully depositing samples on the surface. Next, it's headed to the top of the delta.

HRSC: ESA, DLR, FU-BERLIN, CC BY-SA 3.0 IGO; CTX: JPL-CALTECH/NASA, MSSS; HIRISE: JPL-CALTECH/NASA, UNIV. OF ARIZONA; HIRISE DATASET: FERGASON *ET AL* 2020

washed away material. As that water flowed down the rivers into the lake, it deposited silt and mud, forming the delta. Flooding delivered 1.5-meter-wide boulders from that distant terrain. All of these events preceded the drying of the lake, which might have happened about 3 billion years ago.

Core samples, which Perseverance is collecting and storing on board for eventual return to Earth, could provide dates for when the igneous rocks formed, as well as when the Martian surface became parched. During the time between, Lake Jezero and other wet environments may have been stable enough for microbial life to start and survive.

"Nailing down the geologic time scale is of critical importance for us understanding Mars as a habitable world," Stack Morgan says. "And we can't do that without samples to date."

About a year after landing on Mars, Perseverance rolled several kilometers across the crater floor to the delta front—where it encountered a very different geology.

Preserving billions of years

Deltas mark standing, lasting bodies of water—stable locales that could support life. Plus, as a delta grows over time, it traps and preserves organic matter.

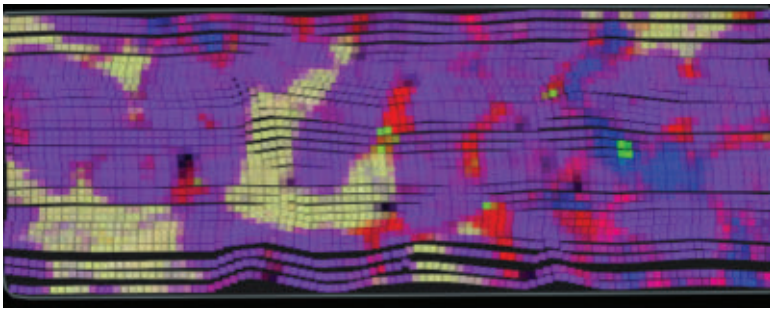
Sand and silt deposited where a river hits a lake get layered into sedimentary material, building up a fan-shaped delta. "If you have any biological material that is trapped between that sediment, it gets buried very quickly," says Mars geologist Eva Scheller of MIT, a researcher with the Percy team. "It creates this environment that is very, very good for preserving the organic matter."

While exploring the delta front between April 2022 and December 2022, Perseverance found some of the sedimentary rocks it was after.

Several of the rover's instruments zoomed in on the textures and shapes of the rocks, while other instruments collected detailed spectral information, revealing the elements present in those rocks. By combining the data, researchers can piece together what the rocks are made of and what processes might have changed them over the eons. It's this chemistry that could reveal signs of ancient Martian life—biosignatures. Scientists are still in the early stages of these analyses.

There won't be one clear-cut sign of life, Allwood says. Instead, the rover would more likely reveal "an assemblage of characteristics," with evidence slowly building that life once existed there.

Chemical characteristics suggestive of life are most likely to hide in sedimentary rocks, like those Perseverance has studied at the delta front.



Olivine
Pyroxene
Sulfate salts
Carbonate
Feldspar

Closeup images of an abraded rock from the crater floor (right) show a distinct crystalline structure. X-ray spectrometry of the same target rock (above) offers additional clues to its chemistry. Together, these types of data could help scientists find signs of ancient life.

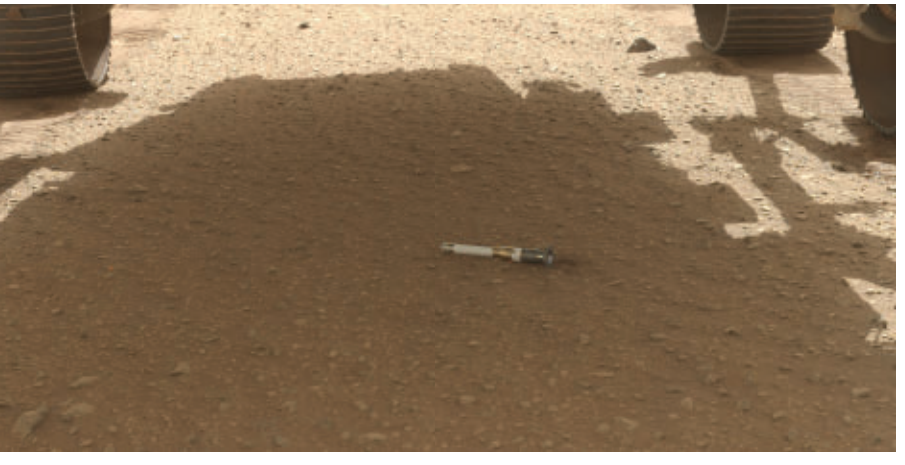
Especially interesting are rocks with extremely fine-grained mud. Such mud sediments, Horgan says, are where — in deltas on Earth, at least — organic matter is concentrated. So far, though, the rover hasn't found those muddy materials.

But the sedimentary rocks studied have revealed carbonates, sulfates and unexpected salts — all materials indicating interaction with water and important for life as we know it. Percy has found carbon-based matter in every rock it has abraded, Horgan says.

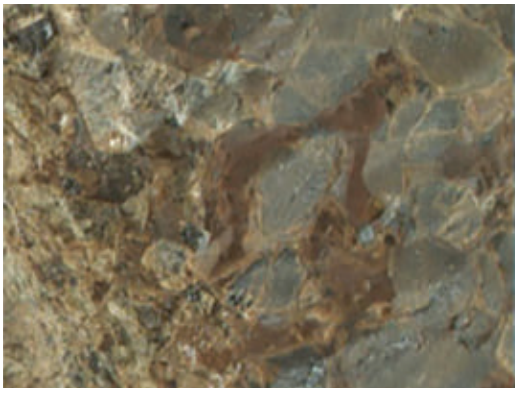
"We've had some really interesting results that we're pretty excited to share with the community," Horgan says about the exploration of the delta front. Some of those details may be revealed in March at the Lunar and Planetary Science Conference.

Martian treasures

As of early February, Perseverance has collected 18 samples, including bits of Mars debris and cores from rocks, and stored them on board in sealed capsules for eventual return to Earth. The samples come from the crater floor, delta front rocks and even the thin Martian atmosphere.



Perseverance deposited a cache of samples in the Three Forks region in December and January. If the rover isn't operable when a future mission arrives, the samples can still be collected and returned to Earth.



In the final weeks of 2022 and the first weeks of 2023, the rover dropped — or rather, carefully set down — half of the collected samples, as well as a tube that would reveal whether samples contained any earthly contaminants. These captured pieces of Mars are now sitting at the front of the delta, at a predetermined spot called the Three Forks region.

If Perseverance isn't functioning well enough to hand over its onboard samples when a future sample-return spacecraft arrives, that mission will collect these samples from the drop site to bring back to Earth.

Researchers are currently working on designs for a joint Mars mission between NASA and the European Space Agency that could retrieve the samples. Launching in the late 2020s, it would land near the Perseverance rover. Percy would transfer the samples to a small rocket to be launched from Mars and returned to Earth in the 2030s. Lab tests could then confirm what Perseverance is already uncovering and discover much more.

Meanwhile, Percy is climbing up the delta to explore its top, where muddy sedimentary rocks may still be found. The next target is the edge of the once-lake, where shallow water long ago stood. This is the site Williford is most excited about (SN: 11/24/18, p. 12). Much of what we know about the history of how life has evolved on Earth comes from environments with shallow water, he says. "That's where really rich, underwater ecosystems start to form," he says. "There's so much going on there chemically." ■

Explore more

- Follow the Mars Perseverance Rover Blog to find out the latest from the Mars 2020 mission: mars.nasa.gov/mars2020/mission/status/

Liz Kruesi is a freelance science journalist who focuses on astronomy. She is based in Colorado.

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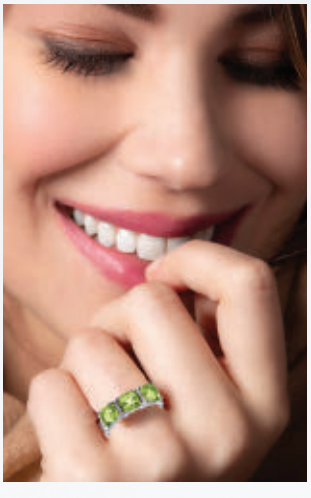

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Long overlooked, bioelectricity could spark medical advances

It took just a 9-volt battery and a little brain zapping to turn science writer Sally Adee into a stone-cold sharpshooter.

She had flown out to California to test an experimental DARPA technology that used electric jolts to speed soldiers' sniper training. When the juice was flowing, Adee could tell. In a desert simulation that pit her against virtual bad guys, she hit every one.

"Getting my neurons slapped around by an electric field instantly sharpened my ability to focus," Adee writes in her new book, *We Are Electric*. That brain-stimulating experience ignited her 10-year quest to understand how electricity and biology intertwine. And she's not just talking neurons.

Bioelectricity, Adee makes the case, is a shockingly underexplored area of science that spans all parts of the body. Its story is one of missed opportunity, scientific threads exposed and abandoned, tantalizing clues and claims, "electroquacks" and unproven medical devices — and frogs. Oh so many frogs.

Adee takes us back to the 18th century lab of Luigi Galvani, an Italian scientist hunting for what gives animals the spark of life. His gruesome experiments on twitching frog legs offered proof that animal bodies generate their own electricity, an idea that was hotly debated at the time. (So many scientists repeated Galvani's experiments, in fact, that Europe began to run out of frogs.)

But around the same time, Galvani critic Alessandro Volta, another Italian scientist, invented the electric battery. It was the kind of razzle-dazzle, history-shaking device that stole the spotlight from animal electricity, and the fledgling field fizzled. "The idea had been set," Adee writes. "Electricity was not for biology. It was for machines, and telegraphs, and chemical reactions."

It took decades for scientists to pick up Galvani's experimental threads and get the study of bioelectricity back on track. Since then, we've learned just how much electricity orchestrates our lives, and how much more remains to be discovered. Electricity zips through our neurons, makes our hearts tick and flows in every cell of the body. We're made up of 40 trillion tiny rechargeable batteries, Adee writes.

She describes how cells use ion channels to usher charged molecules in and out. One thing readers might not expect from a book that illustrates the intricacies of ion channels: It's surprisingly funny.

Chloride ions, for example, are "perpetually low-key ashamed" because they carry a measly -1 charge. Bogus medical contraptions (here's looking at you, electric penis belts) were "electro-foolery." In her acknowledgements, Adee jokes about the "life-saving powers of Voltron" and thanks people for enduring her caffeine jitters. That energy thrums through the book, charging her storytelling like a staticky balloon.

Luigi Galvani's 18th century experiments on frog legs offered proof that electricity flowed through the bodies of animals.

Adee is especially electrifying in a chapter about spinal nerve regeneration and why initial experiments juddered to a halt. Decades ago, scientists tried coaxing severed nerves to link up again by applying an electric field. The controversial technique sparked scientific drama, but the idea of using electricity to heal may have been ahead of its time. Fast-forward to 2020, and DARPA has awarded $16 million to researchers with a similar concept: a bioelectric bandage that speeds wound healing.

> "We are electrical machines whose full dimensions we have not even yet dreamed of."

Along with zingy Band-Aids of the future, Adee describes other sci-fi–sounding devices in the works. One day, for example, surgeons may sprinkle your brain with neurograins, neural lace or neural dust, tiny electronic implants that could help scientists monitor brain activity or even help people control robotic arms or other devices (SN: 9/3/16, p. 10).

Such implants bring many challenges — like how to marry electronics to living tissue — but Adee's book leaves readers with a sense of excitement. Not only could bioelectricity inspire new and improved medical devices, it could also reveal a current of unexpected truths about the body.

As Adee writes: "We are electrical machines whose full dimensions we have not even yet dreamed of." — *Meghan Rosen*

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WHY I VOLUNTEER AT SCIENCE FAIRS

Heather Hankamer
Nonprofit consultant, executive coach and president of the Dallas Regional Science and Engineering Fair

My involvement with the International Science and Engineering Fair (ISEF) started in 2017 when I joined the Dallas Regional Science and Engineering Fair organizing committee. Our regional fair is part of Society for Science's Affiliated Fair Network, and each year, nine projects from our fair can advance to Regeneron ISEF. I work with our finalists to help them prepare for ISEF. My first opportunity to attend ISEF in person was in 2022 in Atlanta.

I volunteer because of what science fairs teach students: to ask their own questions and find their own answers. Science fairs spark a curiosity that is not always taught in the classroom. The most fulfilling aspect of volunteering is watching students' experiences. They put so much work into their projects, and their excitement is contagious. The second-best part is hearing from the judges about their experiences. When the judging is over, they can't stop talking about how impressed they are by what they heard from the students.

My favorite ISEF memories will always be the ways the students support each other during the week and at the awards ceremony. Not everyone can win, but when we come together after the final awards there are cheers, high fives and celebrations for everyone.

I encourage others to get involved because Regeneron ISEF inspires our next generation of world changers. I especially love that this opportunity is about encouraging students. The whole process is about hearing their ideas and research, so students leave feeling heard and inspired.

Volunteer at Regeneron ISEF in Dallas this May!
www.societyforscience.org/isef/volunteers

The fossilized toe pads of the dinosaur *Microraptor* (one illustrated) suggest it used its feet to hunt like modern hawks do.

This dinosaur might have used its feet to snag prey in midair like modern hawks

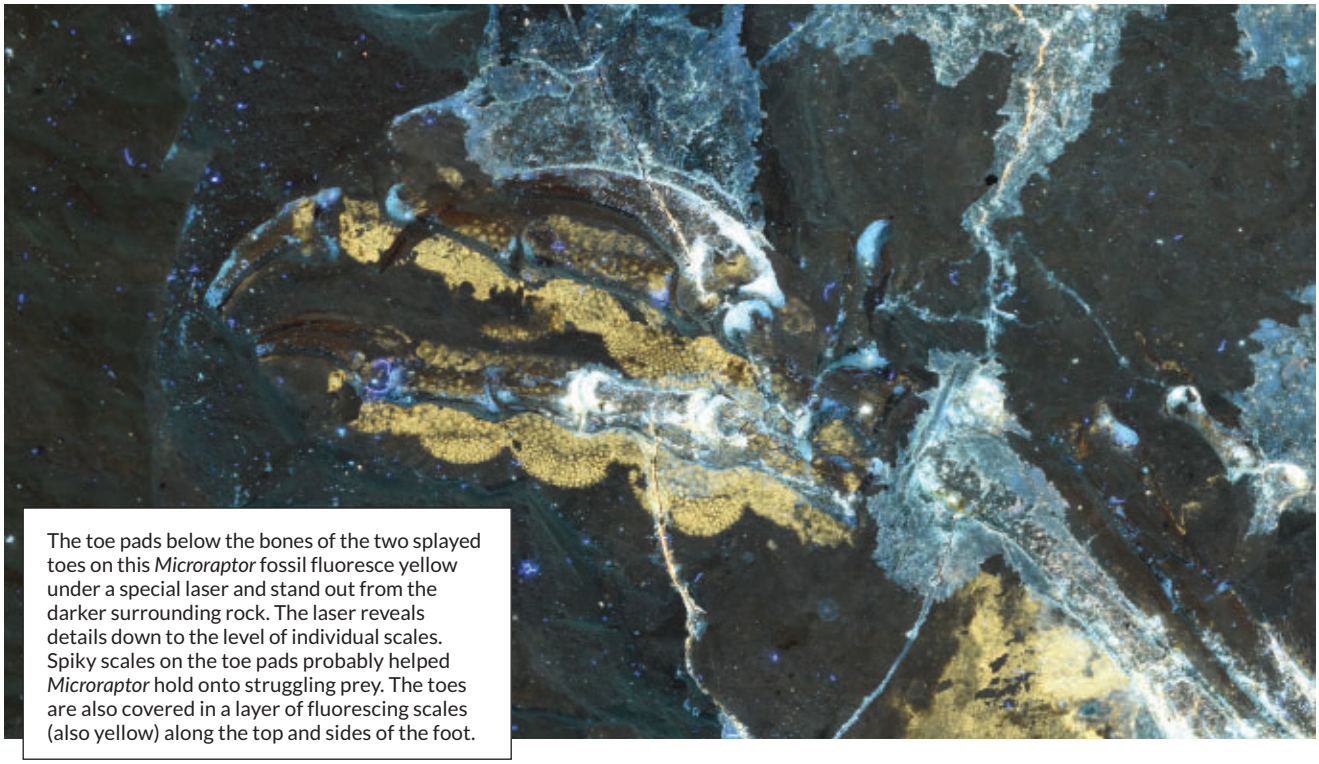
Modern birds evolved from dinosaurs, but it's not clear how well birds' ancient dinosaur ancestors could fly (SN: *11/26/16, p. 9*). A new look at the fossilized feet of one feathered nonavian dinosaur suggests it may have hunted on the wing, like some hawks today.

The crow-sized *Microraptor* (illustrated above) had toe pads like those of modern raptors that can hunt in the air, researchers report December 20 in *Nature Communications*. That means the feathered, four-winged dinosaur probably used its feet to catch flying prey too, paleobiologist Michael Pittman of the Chinese University of Hong Kong and colleagues say.

Other researchers caution that toe pads alone aren't enough to declare *Microraptor* an aerial hunter. But if the claim holds up, such a hunting style would reinforce a debated hypothesis that powered flight evolved multiple times among dinosaurs, a feat once attributed solely to birds.

Toe pads are bundles of scale-covered flesh on the undersides of dinosaur and modern bird feet, like "toe beans" on dogs and cats. Because they are points where the living animal interacted with surfaces, toe pads give paleontologists a "sense of where the rubber meets the road," says Alexander Dececchi, a paleontologist at Mount Marty University in Yankton, S.D., who was not involved in the new study.

These contact points can paint a clearer picture of an



The toe pads below the bones of the two splayed toes on this *Microraptor* fossil fluoresce yellow under a special laser and stand out from the darker surrounding rock. The laser reveals details down to the level of individual scales. Spiky scales on the toe pads probably helped *Microraptor* hold onto struggling prey. The toes are also covered in a layer of fluorescing scales (also yellow) along the top and sides of the foot.

FROM TOP: VITOR SILVA/STOCKTREK IMAGES/GETTY IMAGES; M. PITTMAN *ET AL/NATURE COMMUNICATIONS* 2022

animal's behavior by providing "details that the skeleton itself wouldn't show," says Thomas Holtz Jr., a dinosaur paleobiologist at the University of Maryland in College Park who was also not involved in the study.

To investigate dinosaur toe pads, Pittman and colleagues turned to the Shandong Tianyu Museum of Nature in Linyi, China. It "has arguably the largest collection of feathered dinosaurs in the world, and, importantly, they haven't been prepared extensively," Pittman says. Many of these dinosaur skeletons are still surrounded by rock, where soft tissues can be preserved. Such a specimen "gives us the best chance of finding this wonderful soft tissue information," he says. Using special lasers that cause the fossils' nearly invisible soft tissue to fluoresce, the team found 12 specimens with exceptionally well-preserved toe pads among the thousands examined.

The team compared the fossil toe pads with those of 36 types of modern birds, whose toe pads vary with their lifestyle. Predatory birds have protruding toe pads with spiky scales for grasping prey, while ground birds that spend their time walking and running have flatter toe pads. *Microraptor*'s feet (one shown at the bottom of the opposite page) had toe pads and other features, like the shape of the toe joints and claws, most like those of modern hawks. That similarity suggests that the dinosaur could hunt prey midair and on the ground like hawks do, the team says.

The feet of other dinosaurs, like those of the feathered *Anchiornis* (one below), had flatter toe pads and straighter claws, suggesting a terrestrial lifestyle. That's in line with ideas about this dinosaur being a poor flier, Pittman says.

The idea that *Microraptor* hunted like a hawk is consistent with other fossil evidence. One *Microraptor* fossil has been found with a bird in its stomach, and *Microraptor*'s skeletal and soft tissue anatomy suggest some powered flight ability.

There's still more work to do to figure out how well the dinosaur may have flown. "*Microraptor* is not a bird, but a close relative. Just because it has feet like a predatory bird doesn't necessarily mean it must be catching prey in the exact same way," Pittman says. But a hawklike lifestyle for *Microraptor* "is a strong possibility," he adds.

Flight could have been useful to *Microraptor* when hunting, even if it couldn't stack up to today's fliers. Dececchi speculates that *Microraptor*'s anatomy probably prevented it from outflying birds but may have helped it surprise otherwise out-of-reach prey, including flying and gliding animals.

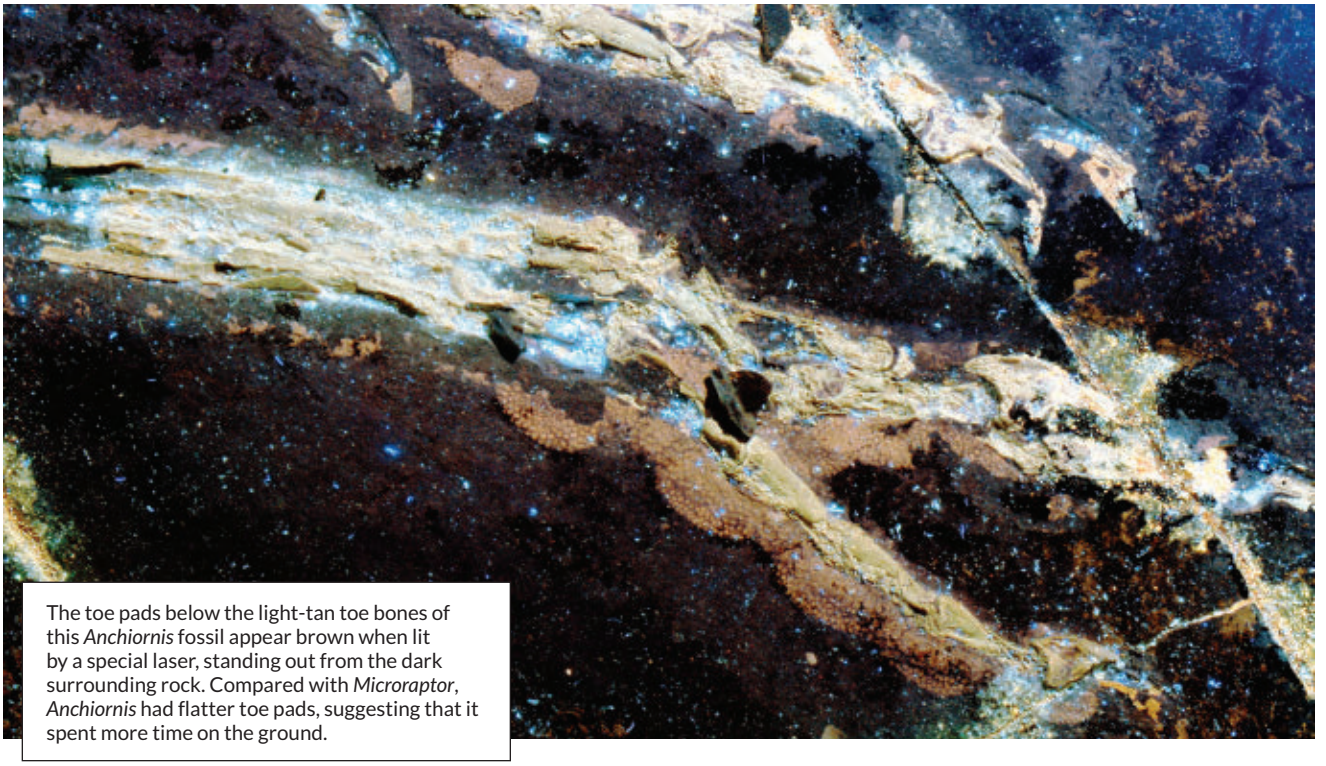
"You only have to be fast or aerobatic enough to catch other things in your environment," Holtz says. "So it's not improbable that [*Microraptor* was] catching things in the air on occasion."

Other paleontologists are more skeptical that *Microraptor* hunted in flight. "It would be a bit of a stretch to me to suggest that *Microraptor* was pursuing prey in an aerial context," says Albert Chen, a paleobiologist at the University of Cambridge. The new findings inform only "what the foot was used for."

Alternative hypotheses, such as a completely or partially terrestrial hunting style, could fit the data too, Holtz says, but the "feet are definitely playing a major role in their prey capture," whether on the ground or in the air.

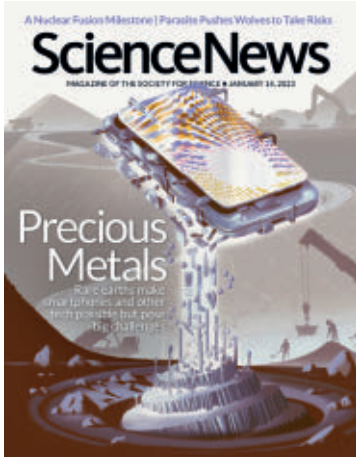
For now, the picture of *Microraptor*'s ecology remains fuzzy, but as lasers increase the picture's resolution, our understanding of dinosaur flight may reach new heights.

—Derek Smith



M. PITTMAN *ET AL*/*NATURE COMMUNICATIONS* 2022

The toe pads below the light-tan toe bones of this *Anchiornis* fossil appear brown when lit by a special laser, standing out from the dark surrounding rock. Compared with *Microraptor*, *Anchiornis* had flatter toe pads, suggesting that it spent more time on the ground.



JANUARY 14, 2023

Making a splash

Urinals designed with curves like those found in nautilus shells (below, second from the right) eliminate splash back, **James R. Riordon** reported in "How physics can improve the urinal" (*SN: 1/14/23, p. 5*). Reader **Yale Cohen** remarked: "How appropriate that this splashy pee research is being done at the University of Waterloo."

M. SHI AND Z. PAN/UNIV. OF WATERLOO

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Fungi Q&A

Three types of fungi — Histoplasma, Coccidioides *and* Blastomyces — *that cause serious lung infections were thought to be confined to certain regions of the United States. But now they are widespread in the country,* ***Tina Hesman Saey*** *reported in "Where fungal lung infections have spread" (*SN: 1/14/23, p. 32*).*
The story prompted so many questions from readers about the symptoms, treatments and testing for these fungal infections that **Saey** answered them in a follow-up article online, which you can read at bit.ly/SN_FungiQuestions. An abridged version appears below.

How do you get infected?
People generally get infected by inhaling fungal spores. Human activities such as farming, gardening and construction can disturb the soil where these fungi live, stirring up spores. Bird droppings and bat guano can also be sources of *Histoplasma*. Sweeping dried droppings increases the risk that spores will get kicked into the air and inhaled.

When cleaning up bird and bat droppings, it's best to first wet them with a hose. Wearing a mask can also help limit exposure.

What are the symptoms and treatments?
People with healthy immune systems may show no symptoms or may develop mild flulike symptoms, including fever, cough, fatigue, chills and body aches. Other symptoms may include chest pain or discomfort, weight loss, headache, muscle or joint pain, shortness of breath or night sweats.

People with coccidioidomycosis, also known as valley fever — the disease caused by *Coccidioides* — may also get a rash on their legs or upper body.

Symptoms can take time to appear. Those of histoplasmosis, the disease caused by *Histoplasma*, can develop between three and 17 days after exposure. Valley fever symptoms can appear between one and three weeks after exposure. For blastomycosis, the disease caused by *Blastomyces*, symptom onset can take anywhere from three weeks to three months.

Mild cases of all three infections usually clear up on their own in a few weeks to a few months. But some people may have lingering symptoms, especially if the infection becomes severe. Some people may develop severe or chronic pneumonia. And in a small number of people, the infections may spread to other parts of the body. For instance, *Histoplasma* tends to spread to the liver, spleen, bone marrow, adrenal glands and intestines. *Blastomyces* and *Coccidioides* often target joints. All three fungi can spread to the brain, where they may cause abscesses or meningitis — an inflammation of the membranes surrounding the brain and spinal cord.

Doctors can order blood or urine tests, chest X-rays or CT scans to help diagnose fungal infections. In some cases, doctors may need to test a small amount of body tissue or fluid from the spine or lungs.

Antifungal drugs and other medications can help treat infections and manage symptoms. If caught early, most people fully recover.

Who's at risk?
Infections and severe disease from all three fungi occur more often in men than in women, but the reason is unclear. People who are pregnant, living with HIV/AIDS or have weakened immune systems for other reasons are at higher risk of severe disease. So are older people and those with diabetes.

Visit mycoses.org to assess your risk for fungal disease based on where you live.

Editor's note

The study featured in "A newfound dinosaur had a flashy look" (SN: 1/16/21, p. 11) was withdrawn by *Cretaceous Research* in September 2021. In an email to *Science News*, journal publisher Lantice Brett stated that the withdrawal was due to ethical and legal concerns "regarding permissions for specimen export [which] remained unresolved nine months after [the study's] initial publication."

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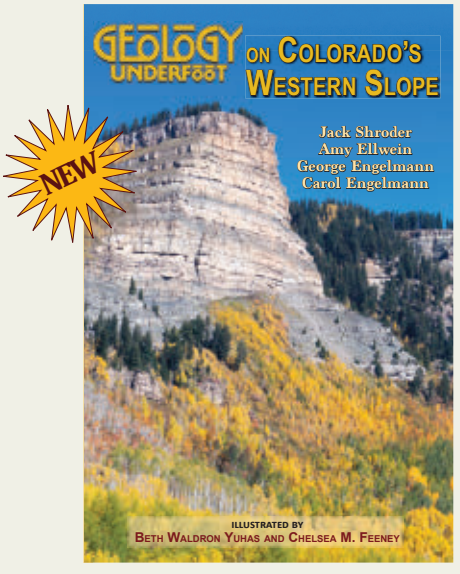

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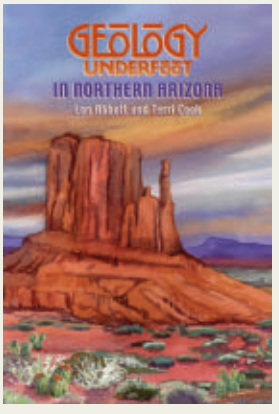

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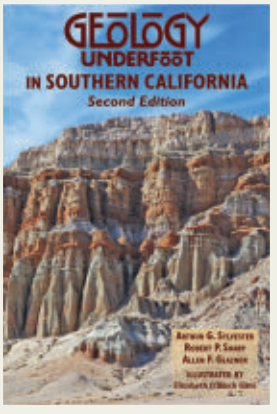

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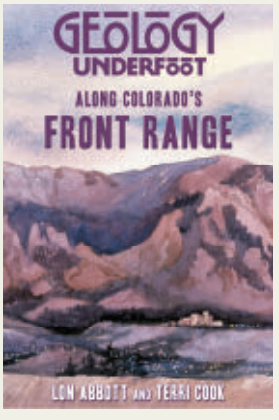

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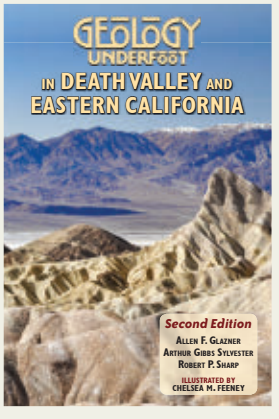

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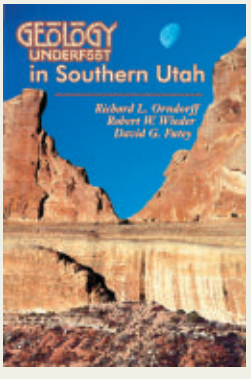

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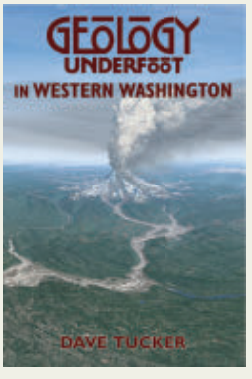

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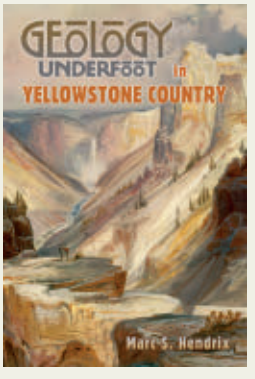

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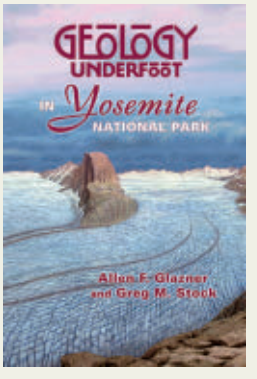

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