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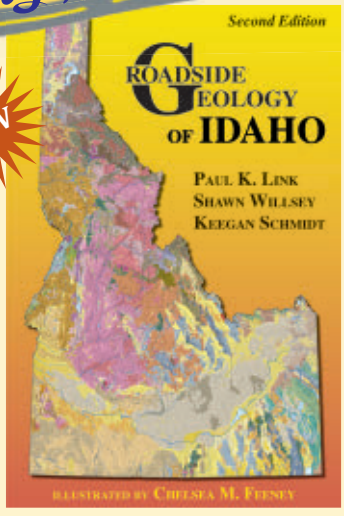

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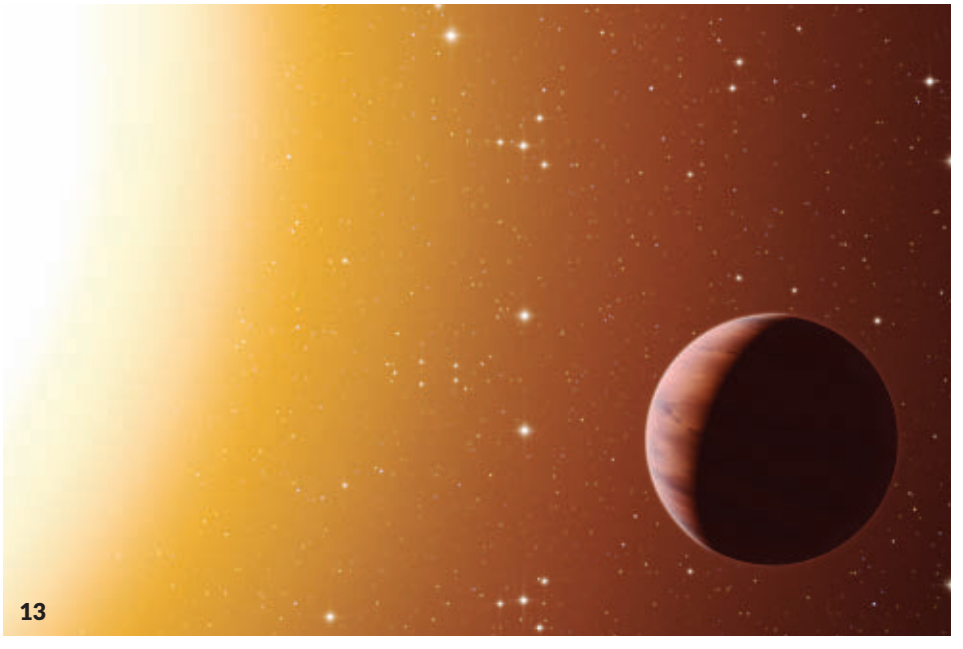
News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Departments

COVER People's heavy reliance on fossil fuels and the cutting down of carbon-storing forests have transformed global climate. *Sam Falconer*

FROM TOP: ABDULHAMID HOSBAS/ANADOLU AGENCY VIA GETTY IMAGES; APPLIED MATH LAB/NYU; L. CALÇADA/ESO

Why aren't we listening to what science is telling us?

Over the last 170 years, climate science has evolved from a collection of observations and hypotheses to as close as we've got to a crystal ball, revealing what lies ahead for Earth and those who dwell here.

In this issue's cover story, contributing correspondent Alexandra Witze details the remarkable story of scientists' efforts to learn how increasing the amount of carbon dioxide in Earth's atmosphere might affect our planet (Page 16). It's a saga that starts back in the 1850s, when Eunice Newton Foote, a women's rights activist and amateur scientist, devised an experiment showing that carbon dioxide heats up more quickly than regular air. As so often happens in science, other people were asking similar questions about the planet, climate and heat. But since our planet's climate systems are astonishingly intricate, these have not been easy questions to answer. It wasn't until 1938 that the burning of fossil fuels was linked to rising temperatures worldwide, and not until the late 1950s that scientists showed that atmospheric carbon dioxide is increasing, and that human activities, including fossil fuel burning and land use changes, are to blame.

Now the relatively new field of attribution science is showing us how climate change is fueling extreme weather, including the 2021 extreme heat wave in western North America. But as Witze notes, leaders in government and business worldwide have largely failed to act to prevent even more extreme consequences.

There's good reason to be furious at the fossil fuel companies and politicians who have invested vast effort into denying the legitimacy of climate science, thus delaying the coordinated efforts required to safeguard our future on Earth. But few of us are blameless.

My life is entwined with fossil fuels, from the gas stove I just used to make a cup of tea to the airplane I'll take to visit my dad next week. His life, I realize, mirrors a century of change. As a child in a Pennsylvania coal town, he traveled by horse and wagon and read by kerosene lamps. He took a bus to college, shipped off to the South Pacific in World War II and later flew worldwide for business and pleasure. Now retired in Oregon, he has had to evacuate due to wildfires, and he suffered through last summer's 115° Fahrenheit "heat dome."

Humans have been ingeniously adapting fossil fuels for millennia. The bricks in Mesopotamian ziggurats were set with bitumen from oil seeps, and people in China were drilling oil wells in the fourth century. It's time to apply the same ingenuity, industriousness and attention to inventing a world where we can flourish without having to rely on burning fossil fuels.

Last month we got a letter from 14-year-old Nico Santin. He had read an article in *Science News* on how seabirds are threatened by ocean heat waves (*SN: 2/26/22, p. 15*). Nico lives in Hawaii, and he writes eloquently on how essential seabirds are to his island home. "Most of Hawaii's native plants would not have been there without the help of birds," he writes. "It would be devastating if seabirds native to Hawaii would starve and possibly go extinct because of rising temperatures." It's time for us all, he says, to take practical steps to make sure that doesn't happen. I'm with Nico. —*Nancy Shute, Editor in Chief*

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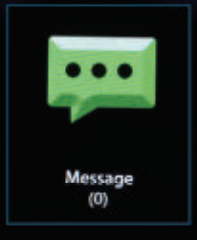
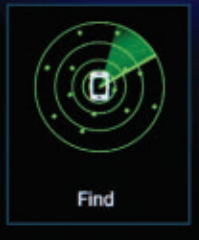


Emails and texts alerts



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Excerpt from the March 18, 1972 issue of *Science News*

50 YEARS AGO

Retaining older people's memory

In spite of the age-old yearning for the Fountain of Youth, there is a marked lack of research toward retaining vitality in later years. Nonetheless ... [researchers] have found they can reverse transient memory loss — or senility — in older patients by giving them periodic oxygen treatments in a hyperbaric chamber.

UPDATE: Studies still only hint that exposing patients to 100 percent oxygen at high pressures might give cognitive abilities a boost (*SN: 10/12/85, p. 236*). For instance, people with persistent symptoms after mild head trauma who underwent hyperbaric oxygen treatment outperformed untreated individuals on memory tests at least two months after the treatments, researchers reported in 2020. Exposure to high amounts of oxygen also has been shown to improve short-term memory in people who have had strokes and those with Alzheimer's disease. The treatments seem to work by dampening inflammation in the brain. The jury is still out on whether the method has a lasting effect on memory.

U.S. adults more often see faces in inanimate objects such as these as male rather than female, a study suggests. This bias may arise in childhood, scientists say.

HOW BIZARRE

Americans tend to assume imaginary faces are male

There may be a reason we see a man, rather than a maiden, in the moon. When Americans spot facelike patterns in inanimate objects, those faces are more likely to be perceived as male than female, scientists report in the Feb. 1 *Proceedings of the National Academy of Sciences*.

In experiments with more than 3,800 U.S. adults recruited online, participants reviewed about 250 photos of illusory faces — in objects from potatoes to suitcases — and labeled each one as male, female or neutral. Faces were deemed male about four times as often as they were female. Both male and female participants showed that bias. While about 80 percent of participants labeled more images male than female, only 3 percent judged more to be female.

In follow-up experiments, participants did not show the same bias toward images of the same kinds of objects without illusory faces. That finding helped rule out that participants viewed something about the underlying objects as masculine or feminine. Computer models that scoured the illusory face photos for stereotypically masculine or feminine elements — such as more angular or curved features — couldn't explain the bias, either.

Given the most basic facial pattern, "we're more likely to see it as male, and it requires additional features to see it as female," says cognitive neuroscientist Susan Wardle of the National Institutes of Health in Bethesda, Md. Wardle points to the fact that female emojis and Lego characters are often distinguished from their male counterparts by the addition of fuller lips, longer lashes or other feminizing features. It's not yet clear why basic facial structures are perceived as male by default, Wardle says. But in a recent study, her team found the same bias in children as young as about 5, suggesting it arises early in life.

Cognitive neuroscientist Sheng He of the Chinese Academy of Sciences in Beijing was surprised by the strength of the gender bias that Wardle's team found. He wonders whether people in matriarchal societies would show the same, or perhaps the opposite, bias. — *Maria Temming*

TOP ROW: S. WARDLE; CHRIS BAKER; PAUL DAVID GALVIN/MOMENT/GETTY IMAGES PLUS; BOTTOM ROW: S. WARDLE; CHRIS BAKER (LAST TWO)

SCIENCE STATS

Earth may be hiding thousands of tree species

Trillions of trees are growing on Earth, though how many kinds there are has been underestimated, a new study finds.

9,200
species
The estimated number of tree species that have yet to be discovered

Earth hosts roughly 64,100 known tree species. But there could be at least 73,300 — about 14 percent more than previously recorded — a global collaboration of scientists reports in the Feb. 8 *Proceedings of the National Academy of Sciences*.

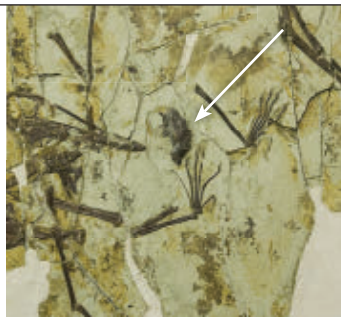
More than a third of the roughly 9,200 undiscovered species are probably rare and hiding out in South America's biodiversity hot spots, biologist Roberto Cazzolla Gatti of the University of Bologna in Italy and colleagues say.

To estimate the number of Earth's existing tree species, the team analyzed global forest data and used a statistical analysis to account for the number of rare, infrequent trees that could be overlooked, revealing the new difference between documented species and novel ones.

If more than 9,000 types of stationary, comparatively massive trees remain undetected, Cazzolla Gatti says, then the number of unknown smaller, mobile animal species must be even greater. The research could help target conservation efforts amid accelerating biodiversity loss worldwide (*SN: 8/1/20, p. 18*). In vulnerable places such as the Amazon, where deforestation and fires are quickly erasing habitat, many plants and animals could be wiped off the map before they are ever documented (*SN: 10/9/21 & 10/23/21, p. 12*). — *Jude Coleman*

FIRST

Pterosaurs regurgitated food like modern birds do



A fossilized gastric pellet (arrow) suggests that a pterosaur's stomach was similar to that of modern birds.

Picture it: Two hungry pterosaurs, one adult and one juvenile, dig in to a delicious lunch of fish. Down their gullets the fish go. A little later, back up come the scales and other indigestible fishy bits, expelled neatly as pellets several millimeters in size.

Scientists now have the first fossilized evidence that pterosaur dining included a final course of regurgitation. While studying two specimens of *Kunpengopterus sinensis*, a species that lived in what's now China between 165 million and 153 million years ago, researchers found a gastric pellet containing fossilized fish scales preserved alongside each of the pterosaurs, the team reports in the March 28 *Philosophical Transactions of the Royal Society B*.

That pterosaurs gave inedible bits the heave-ho isn't a surprise. The flying reptiles' family tree is full of gastric pellet–expelling species, from modern bird cousins such as owls and gulls to fossilized kin like ancient crocodilians and nonavian dinosaurs. But the study helps flesh out what little is known about pterosaur diet and digestion. Like modern birds, this pterosaur species probably had a stomach with an acid-secreting part to dissolve food and a gizzard to compact indigestible bits into a pellet. Based on the size of the scales in the pellet found next to the adult, the eaten fish was much larger than most fish fossils found at the site. Instead of scavenging fish that washed ashore, *K. sinensis* may have hunted the largest prey it could catch. — *Carolyn Gramling*

THE –EST

Pathogen has a long history of infecting kids

The death of a 6-year-old boy in early medieval England has given scientists the earliest direct clue to the history of the pathogen *Haemophilus influenzae* type b. Dated to about 550, it's the oldest case of this bacterial infection, called Hib, ever diagnosed, researchers report February 3 in *Genome Biology*.

The next confirmed case occurred more than 1,300 years later in 1892, when *H. influenzae* was first identified. Despite the similar name and symptoms to influenza, the bacterium (shown in a colorized microscope image, below) doesn't cause flu. But Hib can cause pneumonia and meningitis — especially in young children. Since the late 1980s, a Hib vaccine has largely sidelined the pathogen (*SN: 6/18/11, p. 10*).

Hib DNA in a tooth from the boy, who was buried in a plague cemetery near Cambridge, confirms the pathogen was infecting people at the same time as the first documented pandemic due to plague, caused by the bacterium *Yersinia pestis* (*SN: 1/18/20, p. 15*). The relationship between *H. influenzae* and humans, the pathogen's only host, is probably much older than that, says paleogeneticist Meriam Guellil of the University of Tartu in Estonia.

The boy's tooth also contained *Y. pestis* DNA. He probably contracted Hib first, Guellil and colleagues say. While respiratory infections rarely leave marks on bones, the boy's kneecaps had fused to his thighbones. Such damage can happen when Hib escapes the lungs and infects joints, which would have taken weeks. The boy was already quite ill when he caught *Y. pestis*, but "plague, probably, was what killed him," Guellil says. — *Amber Dance*

A woman cradles her baby in Malawi, which has one of the world's highest rates of preterm births. A study in Malawi suggests that chewing a sugar-free gum could lower that rate.

BODY & BRAIN

Sugar-free gum reduced preterm births

Study tested the link between poor oral health and early birth

BY AIMEE CUNNINGHAM

Chewing a sugar-free gum daily reduced preterm births in a large study in Malawi. The oral intervention was inspired by research linking poor oral health and preterm birth. The gum contains xylitol — a sweetener that can boost oral health — in place of regular sugar.

Among women who chewed the gum, 549 out of 4,349 pregnancies, or 12.6 percent, were preterm, researchers reported February 3 at the Society for Maternal-Fetal Medicine's Annual Pregnancy Meeting. That's a 24 percent reduction compared with the group that didn't get the gum. Among those women, 878 out of 5,321 pregnancies, or 16.5 percent, of the babies were born before 37 weeks.

The oral health of gum users also improved. About 4,000 of the women in the study had an initial dental exam and a later checkup. The women who chewed the gum had less periodontal disease, a condition in which the tissue surrounding the teeth becomes infected and inflamed, compared with those who didn't receive the chewing gum.

"The findings are very encouraging," says Kim Boggess, a maternal-fetal medicine specialist at the University of North Carolina School of Medicine in Chapel Hill. The researchers "are approaching a very complex problem in a low-resource area by trying to use a low-tech, easily applicable intervention." It would take more research to see if this could work in other settings, she says.

For the study, researchers enrolled about 10,000 women across eight health centers in the greater Lilongwe area of Malawi before the women were pregnant, or in early pregnancy. All of the women received tailored information on pregnancy, preventing preterm birth and improving oral health from community health workers. Roughly half of the women also received the gum.

The roughly six-year study was part of a decade-long project in the area surrounding Lilongwe, which has an estimated preterm birth rate of 19.3 percent, one of the highest globally. First, the research team talked with community members to learn what problems related to pregnancy the community was concerned about.

In the Chichewa language spoken in Malawi, preterm birth is *kuchila masika asankwane*, which means "born too soon." In focus groups conducted early in the project, "all participants knew of many women who had suffered 'born too soon,'" says team member Kjersti Aagaard, a maternal-fetal medicine specialist at the Baylor College of Medicine and Texas Children's Hospital in Houston. Babies born prematurely can have complications that impair their lungs, neurodevelopment and more, with long-term health risks, and they are more likely to die in their first year of life than babies born full term.

Along with learning about community perceptions of preterm birth, the researchers assessed the rate of cavities and gum disease among pregnant and postpartum women, which was in the 70 percent range. They also asked if chewing xylitol gum was "something that would be palatable — both truly palatable as well as acceptable," Aagaard says.

Studies finding a link between periodontal disease and preterm birth go back a couple of decades. The inflammatory disease has also been associated with atherosclerosis and other ailments (*SN: 4/16/16, p. 18*). The diversity and size of the microbial community in the mouth is second only to the gut. With periodontal disease, there is a shift in the composition of that oral microbial community, giving way to bacteria that cause inflammation and damage gum tissue. From there, the bacteria may enter the bloodstream to reach other organs, perhaps including the placenta.

Chewing xylitol gum appears to be a check on that shift in the oral microbial community. Previous studies have shown that chewing xylitol gum leads to fewer cavities and suggest it can reduce inflammation. Aagaard and colleagues plan to do more research on what's going on at the microbial level to understand how better oral health reduces preterm birth.

The team also wants to track the neurodevelopment of the children born early and those born on time in the study. "No matter how cost-effective an intervention may be, we still want to make sure you're making a difference in somebody's life," Aagaard says, "and the ultimate outcome is how do those kiddos do." ■

HUMANS & SOCIETY

Focus on nudges limits social science

Behavioral research is ignoring big societal questions, experts say

BY SUJATA GUPTA

Imagine removing a branch of the U.S. government, say, the Supreme Court. What are the myriad ways that such an upheaval might reshape people's lives?

Policy makers and researchers would want to have an idea of what those effects might be before erasing the highest court in the land. But "you can't test deep structural changes like that in an experiment" first, says David Gal, a behavioral decision–making expert at the University of Illinois Chicago.

Likewise, less wildly hypothetical but perhaps still far-reaching changes to society, such as expanding Social Security or providing universal parental leave, can't be tested with conventional studies that include control and experimental groups. As a result, many behavioral scientists today have turned to researching "nudges" — smaller interventions that operate within existing policies. Nudges can influence human behavior, research suggests, and be readily tested using experiments before being applied.

But an overreliance on nudges has stifled broader behavioral science research and insights into how to create a better society, Gal and marketing expert Derek Rucker of Northwestern University in Evanston, Ill., argue in a commentary in the January *Nature Reviews Psychology*.

In June 2021, a bar in Portland, Ore., offered people free alcohol if they got a COVID-19 vaccine. Such "nudges" have become a popular area of behavioral science research.

JOHN RUDOFF/SIPA USA/AP IMAGES

Nudges exploded in popularity in 2008 when economist Richard Thaler of the University of Chicago and law professor Cass Sunstein of Harvard University published a book on the topic. Nudge research inspired governments worldwide to set up nudge units to modify or create public policies (*SN: 3/18/17, p. 18*).

Examples of nudges include entering people in a lottery if they get a vaccine, sending text message reminders about a looming deadline, or automatically opting people into organ donation. For instance, researchers recently revamped a court summons form and sent text reminders to get more people to attend mandatory court appointments in New York City. The intervention decreased no-shows by up to 21 percent over previous years, the researchers estimated (*SN: 11/21/20, p. 14*).

But such nudges ignore thornier societal problems, such as overpolicing in low-income neighborhoods where these summons are typically issued, lawyer and sociologist Issa Kohler-Hausmann of Yale University wrote in a perspective piece about the research.

"Changing the approach to penal and welfare policy in our country will require interventions that are much more radical than cost-neutral behavioral nudges that everyone can agree on," she wrote.

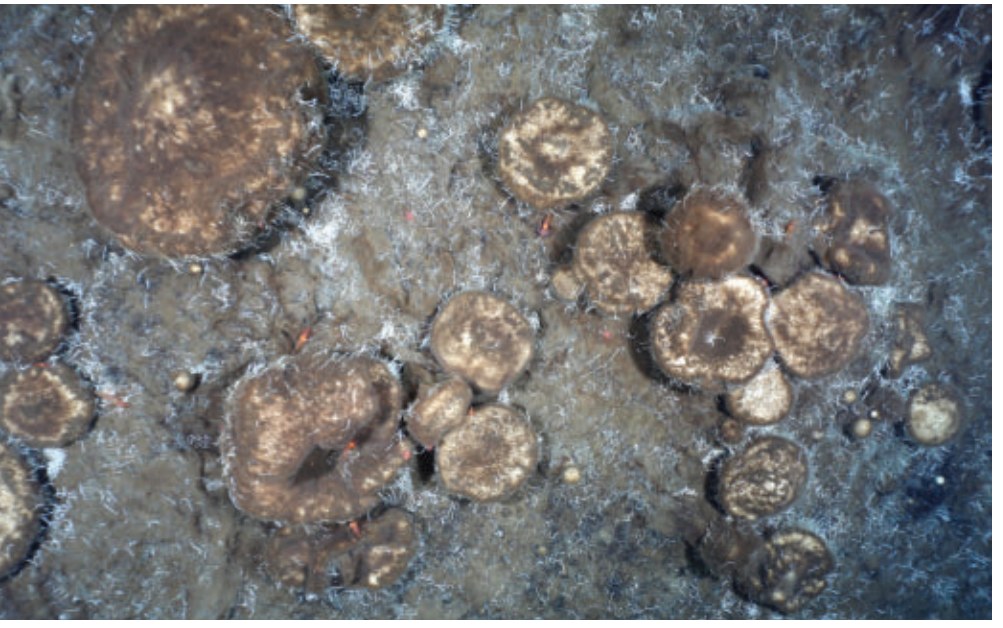
Gal and Rucker attribute nudges' popularity to behavioral scientists' desire to mimic the precision of other research fields. Medical researchers, for instance, can test pharmaceutical drugs using randomized controlled trials, comparing the outcomes of patients who received a drug versus a placebo. Nudge researchers can likewise generate a small change — their version of the drug — and compare the outcomes of those who experienced the change with those who did not. "We value experiments because they give us statistically precise estimates," Gal says.

But nudges that work in academic studies often fail in the real world, Gal and Rucker note. One analysis of 74 nudge experiments involving roughly half a million participants showed that nudges increased the desired behavior by an average of 8.7 percentage points, researchers reported in a 2020 working paper out of the National Bureau of Economic Research. But an analysis of 243 real-world studies of nudges involving over 23 million people showed that nudges increased the desired behavior by an average of just 1.4 percentage points.

Rather than chasing statistical precision, Gal would like to see behavioral scientists generate overarching theories that apply beyond a single narrow context. For instance, in the U.S. legal system, juries must reach a unanimous verdict to convict a defendant. But research into conformity suggests that people copy others as a result of social pressure. Unlike nudges, that research can generate insights into how human behavior interfaces with existing practices, Gal says, and raise crucial questions. In this case, is the push for unanimity preventing jurors from raising valid concerns during deliberations? "Even one dissenter can really reshape the debate and stop this tendency toward conformity," Gal says.

There's room for both theoretical and applied behavioral scientists in the field, counters data scientist Kevin Wilson of the Policy Lab, a policy research institute at Brown University in Providence, R.I. "We need people who think about theory, who are really synthesizing these lessons and, as they put it, extrapolating insights. But we also need people who are going to ... utilize these insights."

Right now, nudges are hogging all the attention, Kohler-Hausmann says. Like policy makers, funding agencies and editors of research journals seem to prefer the quantifiable results that nudges offer, she says, and that near singular focus has hindered transformational change. "The cost of a narrowly defined intervention is ruling out the study of more compound, complex interventions," she says. ■



These sponges, part of the densest known group of sponges in the Arctic, survive in the harsh conditions of the deep ocean by feeding on a layer of fossilized animals.

ALFRED-WEGENER-INSTITUT, PS101 AWI OFOS SYSTEM, ANTJE BOETIUS

LIFE & EVOLUTION

Arctic sponges feed on ancient fossils

Colony gets by in the deep ocean by foraging long-dead critters

BY RICHARD KEMENY

In the cold, dark depths of the Arctic Ocean, a feast of the dead is under way.

A vast community of sponges, the densest group of these animals ever found in the Arctic, is consuming the remains of an ancient ecosystem to survive, researchers report February 8 in *Nature Communications*.

The study highlights just how opportunistic sponges are, says Jasper de Goeij, a deep-sea ecologist at the University of Amsterdam who was not involved in the work. Evolutionarily speaking, sponges "are more than 600 million years old, and they inhabit all parts of our globe," he says. Scientists might not know about all of them because many places that sponges inhabit are really difficult to get to, he adds.

Sponges are predominantly filter feeders and are crucial to nutrient recycling throughout the oceans. The existence of this colony, discovered by a research ship in 2016, however, has been an enigma. Most of the sponges, which include the species *Geodia parva*, *G. hentscheli* and *Stelletta rhaphidiophora*, live between 700 and 1,000 meters deep in the central Arctic Ocean, where there are virtually no currents to bring in food, and sea ice covers the water year-round.

And though sponges are largely immobile, members of this colony move using microscopic skeletal structures called spicules, marine biologist Teresa Morganti of the Max Planck Institute for Marine Microbiology in Bremen, Germany, and colleagues reported in 2021. The sponges leave behind a thick brown trail of spicules in their wake.

In the new study, Morganti turned her attention to a matted layer of discarded spicules and blackened fossilized life — including empty worm tubes and mollusk shells — underneath the sponges. To see if the mat is a food source, she and colleagues analyzed samples of the sponges, the mat material, sediment and the surrounding water. The team also investigated the genetic makeup of the microbes that live within the sponge tissues.

The types of carbon and nitrogen atoms in the sponge tissues closely match those of the dead matter below, suggesting the animals consume the material. And the genetic signature of the microbes shows they have enzymes capable of breaking down the material, probably dissolving the dead organic matter into food for the sponges (*SN: 1/11/14, p. 14*).

The matted layer is as much as 15 centimeters thick in some places, the researchers found. Assuming that its average thickness is greater than 4 centimeters, the layer could provide almost five times as much carbon per year as the sponges would need to survive, the team calculates.

Because these sponges feed from below, they probably move to access more food, Morganti and colleagues say.

Radiocarbon dating suggests the adult sponges — spread across more than 15 square kilometers on an underwater volcanic mountain range — are 300 years old on average. Many of the sponges appear to be actively reproducing by budding, or breaking off parts to form new individuals, the team found.

The finding is "truly outstanding," says Paco Cárdenas, a sponge expert at Uppsala University in Sweden who was not involved with the new study. "We expected sponges to grow very slowly, but this had never been measured in the deep sea," he says.

The dead ecosystem beneath the colony is around 2,000 to 3,000 years older than the sponges. It had been a thriving community of animals that lived in the nutrient-rich conditions created when the volcanoes were last active, Morganti and colleagues suggest.

Sponges often appear to take advantage of the most abundant carbon sources in an area, and those sources may change as global warming alters the composition of the oceans, says ecologist Stephanie Archer of the Louisiana Universities Marine Consortium in Chauvin, who was not involved in the work. "One big question will be how flexible sponge-microbe associations are, and how quickly they change to take advantage of shifting carbon sources," she says. ■

HUMANS & SOCIETY

Homo sapiens' first foray into Europe revised

The hominids arrived long before Neandertals died out

BY BRUCE BOWER

Stone Age *Homo sapiens* began migrating into Europe much longer ago than has typically been assumed.

Discoveries at a rock-shelter in southern France put *H. sapiens* in Europe as early as 56,800 years ago, scientists report in the Feb. 11 *Science Advances*. That's about 10,000 years earlier than previously thought (*SN: 6/6/20, p. 14*).

The French site, called Grotte Mandrin, was alternately occupied by the *H. sapiens* newcomers and Neandertals native to Europe, replacing each other a couple of times before Neandertals died out roughly 40,000 years ago, the researchers say.

The finds from the rock-shelter, situated 225 meters above the middle Rhône River Valley, challenge a popular view that Neandertals died out within a few thousand years of *H. sapiens* reaching Europe, say archaeologist Ludovic Slimak of the University of Toulouse-Jean Jaurès in France and colleagues.

Slimak has directed excavations at Grotte Mandrin for the last 24 years. Nearly 60,000 stone artifacts and more than 70,000 bones of horses, bison and other animals have been unearthed from 12 sediment layers. Only nine isolated hominid teeth have been found in five of those layers. These teeth can be categorized as either Neandertal or *H. sapiens* based on their shapes and sizes, the researchers say. The oldest *H. sapiens* material in the rock-shelter includes a single tooth from a 2- to 6-year-old child, Slimak says.

Dating of each sediment layer relied on radiocarbon age estimates for bone artifacts, as well as calculations of the time elapsed since each set of finds was buried and certain stones were heated during toolmaking.

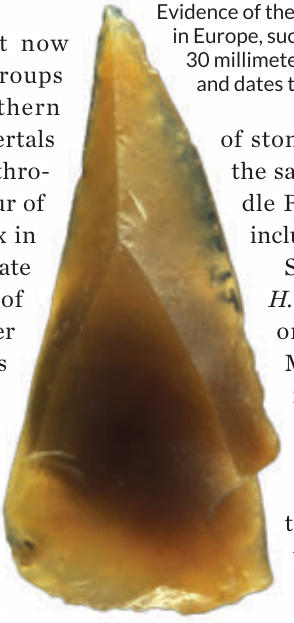
Given this evidence, it now appears that *H. sapiens* groups periodically entered southern Europe long before Neandertals went extinct, says paleoanthropologist Isabelle Crevecoeur of the University of Bordeaux in France, who did not participate in the work. "The arrival of *Homo sapiens* in Europe after the demise of Neandertals was probably the end of a long, sometimes unsuccessful, migration process."

The group of *H. sapiens* that first settled at Grotte Mandrin consisted of several dozen individuals or more, Slimak estimates. Archaeological evidence indicates that, between 56,800 and 51,700 years ago, those ancient people inhabited the site for some 40 years. "This was not a short-term hunter-gatherer camp but a tentative colonization of Europe," Slimak says.

Resident Neandertals and ancient *H. sapiens* migrants had at least brief contacts, Slimak says. Flint used by *H. sapiens* to make tools came from sources located within 100 kilometers of the rock-shelter in all directions, knowledge that could have been acquired only with the help of Neandertals already well-versed in the region's landscape, Slimak contends.

After *H. sapiens*' initial 40-year stay, Neandertals returned to the rock-shelter, where their earliest occupations date as far back as 120,000 years ago, the team found. *H. sapiens* reoccupied the site between about 44,100 and 41,500 years ago — roughly 14,000 years after their inaugural visit. After that, Neandertals left no signs of having come back.

In an unexpected twist, small stone points and blades made by *H. sapiens* at Grotte Mandrin as early as 56,800 years ago match those previously attributed to *H. sapiens* at a site in Lebanon dating to around 40,000 years ago. Archaeologists have struggled for over a century to figure out who made the same types of stone tools, dating to about the same time, at several middle Rhône River Valley sites, including Grotte Mandrin.



Evidence of the earliest known *Homo sapiens* in Europe, such as this stone point (less than 30 millimeters long), comes from France and dates to about 56,800 years ago.

L. SLIMAK

Slimak suspects that *H. sapiens* at Grotte Mandrin originally came from the Middle East, probably by navigating vessels some 3,000 kilometers along the Mediterranean coast. The Middle Easterners' toolmaking tradition was then passed down through many generations by groups living near the rock-shelter, he speculates.

No evidence exists of ancient sea trips from the Middle East to what's now southern France, but "it seems that *H. sapiens* arrived in Europe several times, and we cannot exclude that [they] arrived even earlier than 56,000 years ago," says paleoanthropologist Stefano Benazzi of the University of Bologna in Italy, who was not part of Slimak's team.

But the significance of the Grotte Mandrin finds, like the evolutionary relationship between *H. sapiens* and Neandertals (*SN: 12/18/21 & 1/1/22, p. 30*), is controversial. A single *H. sapiens* tooth deposited between 56,800 and 51,700 years ago can't conclusively demonstrate that *H. sapiens* but not Neandertals made tools found in that sediment layer, says evolutionary biologist Clive Finlayson of the Gibraltar National Museum.

Genetic evidence points to mating between Neandertals and *H. sapiens*, raising the possibility that hybrid offspring of those populations fashioned stone tools at the French site, says Finlayson.

To confirm the evolutionary identities of Grotte Mandrin's various Stone Age toolmakers, Slimak's team is now attempting to extract ancient DNA from hominid teeth and sediment at the site. ■

LIFE & EVOLUTION

Fossils reveal a case of the dino sniffles

Lesions may record oldest known lung infection in a dinosaur

BY SID PERKINS

The prehistoric world wasn't a paradise free of disease, but diagnosing ancient ailments is tricky: Germs usually don't fossilize well. Now, though, researchers have unearthed evidence of what appears to be the oldest known respiratory infection in a dinosaur.

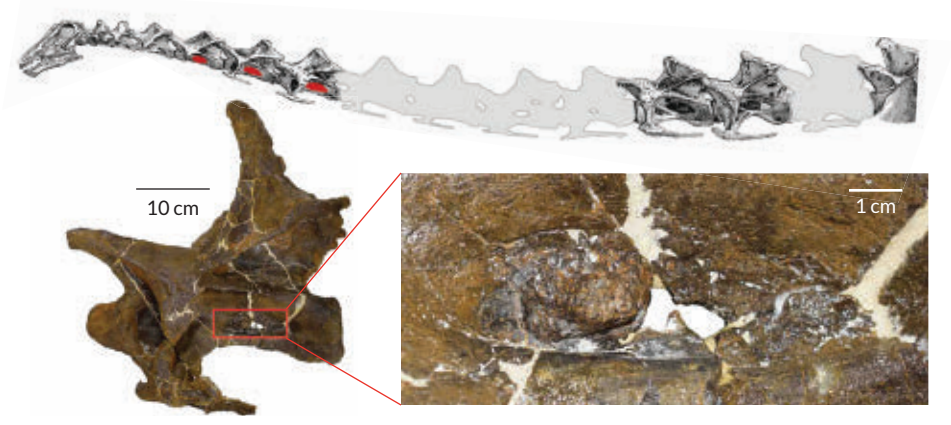
Lesions found in the vertebrae of a 150-million-year-old juvenile sauropod dubbed Dolly point to a lung infection that moved into the bones, vertebrate paleontologist Cary Woodruff and colleagues report February 10 in *Scientific Reports*. The case is at least 50 million years older than a respiratory infection reported from titanosaur fossils found in Brazil.

Discovered in southwestern Montana, Dolly, a long-necked dinosaur probably closely related to *Diplodocus*, was about 18 meters long and less than 20 years old at the time of its death, says Woodruff, of the Great Plains Dinosaur Museum in Malta, Mont.

Woodruff's team analyzed Dolly's skull and first seven neck vertebrae, which contained air sacs connected to the lungs and other parts of the respiratory system. The bones of many of today's birds, which are modern-day dinosaurs, have similar features.

The fifth through seventh vertebrae fossils have bone lesions where the air sacs would have intruded into the bone. The oddly shaped and textured bumps protrude from the bone as much as a centimeter, Woodruff says.

So many lesions turning up in similar spots are unlikely to be bone tumors, which are rare in birds anyway, says Woodruff. Instead, the lesions formed in response to a respiratory infection that



Lesions in the neck vertebrae (locations marked in red, top) of a dinosaur dubbed Dolly may have stemmed from an infection in those vertebrae's air sacs. The lesions show up as lumpy protrusions in the fossilized vertebrae (one shown, bottom).

D.C. WOODRUFF *ET AL/SCIENTIFIC REPORTS* 2022

MATTER & ENERGY

Quantum 'boomerang' effect observed

Jostled particles return to their starting points in some materials

BY EMILY CONOVER

Some quantum particles gotta get right back to where they started from.

Physicists have confirmed a theoretically predicted phenomenon called the quantum boomerang effect. An experiment reveals that, after being given a nudge, particles in certain materials return to their starting points, on average, researchers report February 23 in *Physical Review X*.

Particles can boomerang if they're in a material that has lots of disorder. Instead of a pristine material made up of orderly arranged atoms, the material must have many defects, such as atoms that are missing or misaligned, or other types of atoms sprinkled throughout.

In 1958, physicist Philip Anderson realized that with enough disorder, electrons in a material become localized: They get stuck in place, unable to travel very far from where they started. The pinned-down electrons prevent the material from conducting electricity, thereby turning what might otherwise be a metal into an insulator. That localization is also necessary for the boomerang effect.

To picture the boomerang in action, physicist David Weld of the University of California, Santa Barbara imagines shrinking down and slipping inside a disordered material. If he tries to fling away an electron, he says, "it will not only turn around and come straight back to me, it'll come right back to me and stop." (In this sense, he says, the electron is "more like a dog than a boomerang." The boomerang will keep going if you don't catch it, but a well-trained dog will sit by your side.)

Weld and colleagues demonstrated this effect using ultracold lithium atoms as stand-ins for the electrons. Instead of looking for atoms returning to their original position, the team studied the analogous situation for momentum, because that was relatively straightforward to create in the lab. The atoms were initially stationary, but after being given kicks from lasers to give them momenta, the atoms returned, on average, to standstill states, making a momentum boomerang.

The team also determined what's needed to break the boomerang. To work, the boomerang effect requires time-reversal symmetry — the particles should behave the same when time runs forward as they would on rewind. By changing the timing of the first kick so that the kicking pattern was off-kilter, the team broke time-reversal symmetry. As predicted,

spread to the air sacs, the team proposes.

Dolly's bone lesions wouldn't have been obvious to an ancient observer, but the dinosaur probably had a fever, cough, labored breathing and nasal discharge, the scientists suggest.

It's not clear whether the infection was bacterial, viral or fungal, or whether it's what killed Dolly. But the researchers note that many birds and reptiles today can suffer from a respiratory infection caused by the fungus *Aspergillus* that can in turn lead to bone infections.

For an infection in the neck vertebrae's air sacs to cause bony lesions, "you're looking at a chronic condition," says Cynthia Faux, a veterinarian at the University of Arizona in Tucson with a degree in vertebrate paleontology. She was not involved in the study.

While Dolly's respiratory infection seems to be the oldest known for a dinosaur, it's nowhere near the record for a respiratory infection discovered in an animal. In 2018, scientists described a tuberculosis-like infection in a fossilized marine reptile that lived about 245 million years ago. ■

the boomerang effect disappeared.

"I was so happy," says study coauthor Patrizia Vignolo, a theoretical physicist at Université Côte d'Azur who is based in Valbonne, France. "It was perfect agreement" with theoretical predictions.

Though Anderson made his discovery about localized particles over 60 years ago, the quantum boomerang effect is a newcomer to physics. "Nobody thought about it, apparently, probably because it's very counterintuitive," says physicist Dominique Delande of CNRS and Kastler Brossel Laboratory in Paris, who predicted the effect with colleagues in 2019.

The effect is the result of quantum physics. Quantum particles act like waves, with ripples that can add and subtract in complicated ways. Those waves combine to enhance the trajectory that returns a particle to its origin and cancel out paths that go off in other directions. "This is a pure quantum effect," Delande says, "so it has no equivalent in classical physics." ■

The Parker Solar Probe took visible-light images (one shown) of Venus' surface. Dark areas on the planet are highland regions. Streaks are caused by charged particles and dust striking the camera.

NASA, APL, NRL

ATOM & COSMOS

Scientists get a new view of Venus

Probe peers through clouds for a peek at the planet's terrain

BY NIKK OGASA

By serendipity, scientists have captured the first visible-light images of Venus' surface taken from space.

Though the planet's rocky body is concealed beneath a thick veil of clouds, telescopes aboard NASA's Parker Solar Probe managed to take the snapshots, researchers report in the Feb. 16 *Geophysical Research Letters*.

"We've never actually seen the surface through the clouds at these wavelengths before," Lori Glaze, director of NASA's Planetary Science Division, said February 10 during a live broadcast on Twitter.

The Parker Solar Probe was built to study the sun, but it makes regular flybys of Venus. The planet's gravity tugs on the probe, tightening its orbit around the sun. Those assists from Venus helped the spacecraft become the first probe to enter the sun's atmosphere (*SN: 1/29/22, p. 10*).

It was during two Venus flybys in July 2020 and February 2021 that the probe's WISPR telescopes captured the new images. Although Venus' dayside was too bright to image, WISPR could discern large-scale surface features, such as the vast highland region called Aphrodite Terra, through the clouds on the planet's nightside.

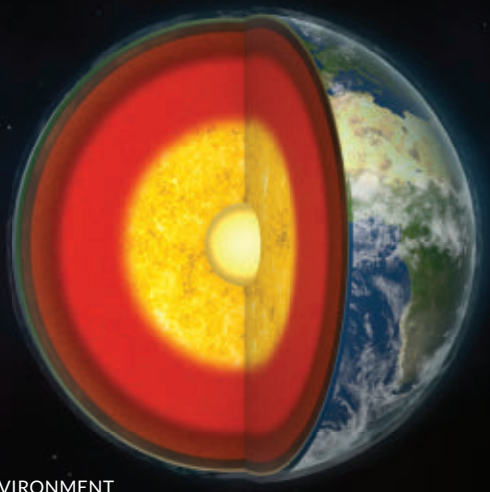
Clouds tend to scatter and absorb light. But some wavelengths of light get through, depending on the clouds' chemical makeup, says Paul Byrne, a planetary scientist at Washington University in St. Louis who was not involved in the study.

Though scientists knew such spectral windows exist in Venus' thick clouds of sulfuric acid, researchers didn't expect that light visible to human eyes would break through so intensely. WISPR's construction happens to allow it to detect this unanticipated light through Venus' clouds. "It's fortuitous that they happened to have an instrument that could see through the clouds," Byrne says.

The photographs show a planet so hot that it glows, much like red-hot iron, Brian Wood, an astrophysicist at the U.S. Naval Research Laboratory in Washington, D.C., and a coauthor of the paper, said during the social media event.

"The pattern of bright and dark that you see is basically a temperature map," he said — brighter regions are hotter and darker regions are cooler. This pattern correlates well with topographic maps previously produced from radar and infrared surveys of the planet. Highlands appear dark and lowlands appear bright, Wood said.

The images come as NASA prepares to launch two missions to Venus. The new photographs, Wood said, "may help in the interpretation of the observations taken in the future from these new missions." ■



Instead of being a normal solid, Earth's inner core (center in this illustration of the planet's layers) may be "superionic," a state of matter that has properties of both a solid and a liquid, new computer simulations show.

EARTH & ENVIRONMENT

Earth's inner core may be 'superionic'

Odd state of matter could solve mysteries of the planet's center

BY EMILY CONOVER

A quirky material that behaves like a mishmash of liquid and solid could be hidden deep in the Earth.

Computer simulations described in two studies suggest that the material in Earth's inner core, which includes iron and other, lighter elements, may be in a "superionic" state. That means that while the iron stays put, as in a solid, the lighter elements flow like a liquid.

The research gives a potential peek at the inner workings of an enigmatic, inaccessible realm of the planet. According to conventional scientific wisdom, Earth's core consists of a liquid outer core surrounding a solid inner core. But beyond knowing that the inner core is rich in iron, scientists don't know exactly which other elements are present, and in what quantities.

"The inner core is very difficult to scrutinize simply because it's so deep beneath our feet," says geophysicist Hrvoje Tkalčić of Australian National University in Canberra.

Seismic waves stirred up by earthquakes can plow through the inner core, providing clues to what's inside. But measurements of these waves have left researchers puzzled. The velocity of one type of wave, called a shear wave, is lower than expected for solid iron or for many types of iron alloys — mixtures of iron with other materials. "That is a mystery about the inner core," says geophysicist Yu He of the Chinese Academy of Sciences in Guiyang.

In one new study, He and colleagues simulated a group of 64 iron atoms, along with various types of lighter elements — hydrogen, carbon and oxygen — under pressures and temperatures expected for the inner core. In a normal solid, atoms arrange themselves in an orderly grid, holding fast to their positions. In a superionic material, some of the atoms arrange neatly, as in a solid, while others are liquidlike free spirits that slip right through the solid lattice.

In the simulation, the researchers found, the lighter elements moved about while the iron stayed in place. That superionic status slowed shear waves, the team reports in the Feb. 10 *Nature*, suggesting the weird phase of matter could explain the unexpected shear wave velocity measured in the inner core.

Shear waves, also known as secondary or S waves, jiggle the Earth perpendicular to their direction of travel, like the undulations that move along a jump rope that's wiggled up and down. Other waves, called primary or P waves, compress and expand the Earth in a direction parallel to their travel, like an accordion being squeezed.

To really explain the inner core, scientists must find a combination of chemical elements that keeps with everything known about the inner core, including its S wave velocity, P wave velocity and its density. "You have to match all three things, otherwise it doesn't work," says mineral physicist John Brodholt of University College London.

In a study published in August 2021 in *Earth and Planetary Science Letters*, Brodholt and colleagues did just that. A simulation of iron, silicon and hydrogen atoms reproduced the inner core's known characteristics. In that simulation, the material also was superionic: The iron and silicon stayed in position while the hydrogen flowed like a liquid.

But Brodholt notes that a superionic state is just one possible explanation for the inner core's properties. Brodholt and colleagues have previously found other combinations of elements that could explain the inner core without going superionic, he says, leaving unresolved the question of what lurks in Earth's deepest depths.

Another puzzle of Earth's heart is that the inner core's structure seems to change over time. This has previously been interpreted as evidence that the inner core rotates at a different rate than the rest of the Earth. But He and colleagues suggest that it could instead result from the motions of liquidlike light elements swirling inside the inner core and changing the distribution of elements over time. "This paper sort of offers an explanation for both of these phenomena" — the slow shear wave velocity and the shifting structure — says Tkalčić, who was not involved with either new study.

One thing missing is laboratory experiments showing how these combinations of elements behave under inner core conditions, says geophysicist Daniele Antonangeli of Sorbonne University in Paris, who was not involved with the new research. Such tests could help confirm whether the simulations are correct.

Previous experiments have found evidence that water ice can go superionic, perhaps under conditions found inside Uranus or Neptune. But researchers can't yet probe the behavior of superionic materials under the conditions thought to exist inside Earth's core. So scientists will have to keep pushing the tests to further extremes, Antonangeli says. "The experimentalist that is within me craves seeing experimental validation of this." ■

TUMEGGY/SCIENCE PHOTO LIBRARY/GETTY IMAGES PLUS

Hot Jupiters may be kicked into place

Celestial neighbors can send giant exoplanets toward their suns

BY KEN CROSWELL

Strange giant planets known as hot Jupiters, which orbit close to their suns, got kicked onto their peculiar paths by nearby planets and stars, a new study finds.

After analyzing the orbits of dozens of hot Jupiters, a team of astronomers found a way to catch giant planets in the process of getting uncomfortably close to their stars. The analysis, published in the Feb. 20 *Astrophysical Journal Letters*, pins the blame for the weird worlds on gravitational kicks from other massive objects orbiting the same star, many of which destroyed themselves in the process.

"It's a pretty dramatic way to create your hot Jupiters," says Malena Rice, an astrophysicist at Yale University.

Hot Jupiters have long been mysterious. They orbit very close to their stars, whirling around in a few days or less. In contrast, all the giant planets in our solar system lie at vast distances from the sun. To explain the odd planets, astronomers have proposed three main ideas (*SN: 4/28/18 & 5/12/18, p. 28*). Perhaps the hot Jupiters formed next to their stars and stayed put, or maybe they started off farther out and then slowly spiraled inward. In either of those cases, the planets should have circular orbits aligned with their stars' equators, because the worlds acquired their paths from the material in the protoplanetary disks that gave birth to them.

The new study, though, favors a third idea: Gravitational interactions with another giant planet or a companion star first hurl a Jupiter-sized planet onto a highly elliptical and inclined orbit that brings the planet close to its star. In some cases, the planet even revolves the wrong way around its star, opposite the way it spins.

Hot Jupiters orbit very close to their stars, whirling around in a few days or less.

In this scenario, every time the tossed planet sweeps past its sun, the star's gravity robs the planet of orbital energy. This shrinks the orbit, gradually making it more circular and less inclined, until the planet becomes a hot Jupiter on a small, circular orbit, realigned to be in the same plane as the star's equator.

Stars usually circularize a planet's orbit before they realign it, and cool stars realign an orbit faster than warm stars do. So Rice and colleagues looked for relationships between the shapes and tilts of the orbits of several dozen hot Jupiters that orbit stars of different temperatures.

Generally, the team found that the hot Jupiters around cool stars tend to be on well-aligned, circular orbits, whereas the hot Jupiters around warm stars are often on orbits that are elongated and off-kilter. Put another way, many of the orbits around warm stars haven't yet had time to settle down into their final size and orientation. These orbits still bear the marks of having been shaped by gravitational run-ins with neighboring bodies in the system, the team concludes.

It's a "simple, elegant argument," says astrophysicist David Martin of Ohio State University in Columbus. "They're presenting the evidence in a new way that helps strengthen" the idea that other massive objects in the same solar system produce hot Jupiters. Martin suspects this theory probably explains the majority of these planets.

But it means that innumerable giant worlds have suffered terrible fates. Some of the planets that hurled their brethren close to their stars ended up plunging into those same stars themselves, Rice says. And many other planets got ejected from their solar systems altogether, so today these wayward worlds wander the deep freeze of interstellar space, far from the light of any sun. ■

Circling close to its star, a type of planet known as a hot Jupiter (illustrated) can acquire its peculiar orbit after another planet or star catapults it inward.

L. CALÇADA/ESO

HUMANS & SOCIETY

How early trousers were designed

The oldest known pants stitched together Eurasian cultures

BY BRUCE BOWER

What little rain that falls on a gravelly desert in western China's Tarim Basin evaporates as it hits the blistering turf. Here, in this parched wasteland, lie the ancient remains of people who made one of the biggest fashion splashes of all time.

Herders and horse riders who buried their dead in the Tarim Basin's Yanghai graveyard pioneered pants making about 3,200 to 3,000 years ago. Their deft combination of weaving techniques and decorative patterns, displaying influences from societies across Eurasia, yielded a pair of stylish yet durable trousers now recognized as the oldest such garment ever known (*SN: 6/28/14, p. 16*).

Now, an international team of archaeologists, fashion designers, geoscientists, chemists and conservators has untangled how those trousers were made and painstakingly created a modern replica. The vintage slacks weave a tale not only of textile innovation, but also of how cultural practices fanned out across Asia, the researchers report in the March *Archaeological Research in Asia*.

"A diversity of textile techniques and patterns of different local origins, traditions and times merged into something new in this garment," says archaeologist Mayke Wagner of the German Archaeological Institute in Berlin. "Eastern Central Asia was a laboratory where people, plants, animals, knowledge and experiences from different directions and sources came ... and were transformed."

Fashion icon

One man brought the pants to scientists' attention without uttering a word. His naturally mummified body, as well as more than 500 other preserved bodies, was uncovered during excavations conducted by Chinese archaeologists since the early 1970s at the Yanghai cemetery.

The man sported an outfit that consisted of the trousers, a poncho belted at the waist, one pair of braided bands to fasten the trouser legs below the knees, another pair to fasten soft leather boots at the ankles and a wool headband with four bronze disks and two seashells sewn on it. A leather bridle, wooden horse bit and battle-ax in his grave indicated he had been a horse-riding warrior.

Researchers now call him Turfan Man because the Yanghai site lies about 43 kilometers southeast of Turfan, China.

Of all of Turfan Man's garments, his trousers stand out as truly special. Not only are they older than any other known pants by at least several centuries, but the Yanghai pants also boast a sophisticated, modern look. The pants feature leg pieces that gradually widen at the top, connected by a crotch piece that widens and bunches in the middle to increase leg mobility.

Within a few hundred years, mobile groups across Eurasia began wearing pants like Turfan Man's, other archaeological finds have shown. Woven leg covers connected by a flexible crotch piece eased the strain of riding horses bareback over long distances. Not surprisingly, mounted armies debuted around that time.

Today, people don denim jeans and dress slacks that incorporate the design and production principles of the ancient Yanghai trousers. In short, Turfan Man was the ultimate trendsetter.

Fancy pants

Despite being fashion-forward, the ancient Yanghai horseman left scientists wondering how his remarkable pants had been made. No traces of cutting appear on the fabric, so Wagner and colleagues suspected that the garment had been woven to fit its wearer.

Close examination of Turfan Man's trousers revealed a combination of three weaving techniques, the team reports. A re-created version of the find — fashioned by an expert weaver from the yarn of coarse-wooled sheep similar to those whose wool was used by ancient Yanghai weavers — confirmed that observation.

Much of the garment consists of twill weave, a major innovation in the history of textiles. Twill changes the character of woven wool from firm to elastic, providing enough "give" to let a person move freely in a pair of tight-fitting pants.

The fabric is created by using rods on a loom to weave a pattern of parallel, diagonal lines. Lengthwise warp threads are held in place so that a row of weft threads can be passed over and under them at regular intervals. The starting point of this weaving pattern shifts slightly to the right or left for each ensuing row so that a diagonal line forms.

Variations in the number and color of weft threads in the twill weave on Turfan Man's trousers were used to create pairs of brown stripes running up the off-white crotch piece, the team found.

Textile archaeologist Karina Grömer of the Natural History Museum Vienna says she recognized twill weave on Turfan Man's trousers when she examined them around five years ago. Grömer had previously reported that pieces of woven fabric found in Austria's Hallstatt salt mine display the oldest known twill weave. Radiocarbon dating indicates the Hallstatt textiles were made around 3,500 to 3,200 years ago, about 200 years before Turfan man sported his britches.

People in Europe and Central Asia may have independently invented twill weaving, says Grömer, who did not participate in the new work. But at the Yanghai site, weavers combined twill with other weaving techniques and innovative designs to create high-quality riding pants. "This is not a beginner's item," Grömer says. "It's like the Rolls-Royce of trousers."

Consider the ancient trousers' knees. A technique now known as tapestry weaving produced thick, protective fabric at these sections, the team found. A third weaving method used on the upper border of the pants created a thick waistband.

Other features of the trousers involve an unusual twining method, in which two differently colored weft threads were twisted around each other and laced through warp threads. This created a geometric pattern across the knees that

resembles leaning, interlocking T's. The method also produced zigzag stripes at the ankles and calves.

Yanghai artisans also showed their ingenuity in designing a formfitting crotch piece that is wider at its center than at its ends, Grömer says. Trousers dating to a few hundred years later than the Yanghai pants, found in several parts of Asia, often consist of woven legs connected by square fabric crotch pieces that resulted in a less flexible fit. In tests with a man riding a horse bareback while wearing a re-created version of Turfan Man's entire outfit, the trousers fit snugly yet allowed the legs to clamp firmly around the horse.

Today's denim jeans are made from one piece of twill material following some of the same design principles as those favored by Yanghai pants makers three millennia ago.

Ancient trousers from China's Tarim Basin display twill weaving that was used to produce alternating brown and off-white diagonal lines at the tops of the legs (right inset, top) and dark brown stripes on the crotch piece (second from top). Another technique for manipulating threads enabled artisans to create a geometric pattern at the knees (third from top) and zigzag stripes at the calves (bottom).

M. WAGNER ET AL/ARCHAEOLOGICAL RESEARCH IN ASIA 2022

Clothes connections

Perhaps most striking, Turfan Man's trousers tell a story of how ancient herding groups carried their cultural practices and knowledge across Asia, spreading seeds of innovation.

For instance, the decorative T pattern also appears on bronze vessels found in what's now China from around the same time, roughly 3,300 years ago, Wagner and colleagues say. The nearly simultaneous adoption of this geometric form in Central and East Asia coincides with the arrival in those regions of herders from western Eurasian grasslands riding horses that they domesticated 4,200 years ago or more (*SN: 11/20/21, p. 15*).

Pottery at those herders' home sites in western Siberia and Kazakhstan displays the T pattern as well. West Eurasian horse breeders probably spread the design across much of ancient Asia, the team suspects.

Similarly, a stepped pyramid pattern woven into the Yanghai pants appears on pottery from Central Asia's Petrovka culture, which dates to between about 3,900 and 3,750 years ago. The same pattern resembles architectural designs that are more than 4,000 years old from western and southwestern Asian and Middle Eastern societies, including Mesopotamian stepped pyramids, the team says. Tapestry weaving such as that observed on Turfan Man's trousers also originated in those societies.

It's no surprise that cultural influences from throughout Asia affected ancient people in the Tarim Basin, says Michael Frachetti, an anthropologist at Washington University in St. Louis who was not involved in the work. Yanghai people inhabited a region at a crossroads of seasonal migration routes followed by herding groups that ran from the Altai Mountains in Central and East Asia to southwestern Asia where Iran is located today (*SN: 4/15/17, p. 9*). Excavations at sites along those routes indicate that herders spread crops across much of Asia too (*SN: 5/3/14, p. 15*).

Cultural transitions in the Tarim Basin may have started even earlier. Ancient DNA suggests that western Asian herders, possibly in oxen-pulled wagons, moved through much of Europe and Asia around 5,000 years ago (*SN: 11/25/17, p. 16*).

By around 2,000 years ago, herders' migration paths formed part of a trade and travel network from China to Europe known as the Silk Road. Cultural mixing intensified as thousands of local routes across Eurasia formed this network.

Turfan Man's multicultural riding pants show that even in the Silk Road's early stages, migrating herders carried new practices to distant communities. "The Yanghai pants are an entry point for examining how the Silk Road transformed the world," Frachetti says.

Looming questions

How exactly Yanghai clothes makers transformed wool yarn into Turfan Man's trousers remains unclear. No remnants of ancient Yanghai looms have been found. A loom that could be operated while sitting may have made it possible to create intricate, twined patterns (*SN: 8/31/19, p. 16*). Experiments with different weaving devices are the next step in untangling how Turfan Man's trousers were made, Wagner says.

"We truly know so little about how clever the ancient weavers were," says Elizabeth Barber, an archaeologist at Occidental College in Los Angeles who was not involved in the work. But it's clear that the makers of Turfan Man's pants blended complex techniques into a revolutionary piece of apparel, she says.

Turfan Man may not have had time to ponder his clothes makers' prowess. With a pair of pants like that, he was ready to ride. ■

A Planetary Crisis

Scientific understanding of human-caused climate change underpins the need to act now

By Alexandra Witze

Even in a world increasingly battered by weather extremes, the summer 2021 heat wave in the Pacific Northwest stood out. For several days in late June, cities such as Vancouver, Portland and Seattle baked in record temperatures that killed hundreds of people. On June 29, Lytton, a village in British Columbia, set an all-time heat record for Canada, at 121° Fahrenheit (49.6° Celsius); the next day, the village was incinerated by a wildfire.

Within a week, an international group of scientists had analyzed this extreme heat and concluded it would have been virtually impossible without climate change caused by humans. The planet's average surface temperature has risen by at least 1.1 degrees Celsius since preindustrial levels of 1850–1900. The reason: People are loading the atmosphere with heat-trapping gases produced during the burning of fossil fuels, such as coal and gas, and from cutting down forests.

Heat waves and drought, made more extreme by human-caused climate change, led to the massive wildfires in British Columbia in 2021.

A little over 1 degree of warming may not sound like a lot. But it has already been enough to fundamentally transform how energy flows around the planet. The pace of change is accelerating, and the consequences are everywhere. Ice sheets in Greenland and Antarctica are melting, raising sea levels and flooding low-lying island nations and coastal cities. Drought is parching farmlands and the rivers that feed them. Wildfires are raging. Rains are becoming more intense, and weather patterns are shifting.

The roots of understanding this climate emergency trace back more than a century and a half. But it wasn't until the 1950s that scientists began the detailed measurements of atmospheric carbon dioxide that would prove how much carbon is pouring from human activities. Beginning in the 1960s, researchers started developing comprehensive computer models that now illuminate the severity of the changes ahead.

Today we know that climate change and its consequences are real, and we are responsible. The emissions that people have been putting into the air for centuries — the emissions that made long-distance travel, economic growth and our material lives possible — have put us squarely on a warming trajectory. Only drastic cuts in carbon emissions, backed by collective global will, can make a significant difference.

"What's happening to the planet is not routine," says Ralph Keeling, a geochemist at the Scripps Institution of Oceanography in La Jolla, Calif. "We're in a planetary crisis."

Setting the stage

One day in the 1850s, Eunice Newton Foote, an amateur scientist and a women's rights activist living in upstate New York, put two glass jars in sunlight. One contained regular air — a mix of nitrogen, oxygen and other gases including carbon dioxide — while the other contained just carbon dioxide. Both had thermometers in them. As the sun's rays beat down, Foote observed that the jar of CO_2 alone heated up more quickly, and was slower to cool down, than the one containing plain air.

The results prompted Foote to muse on the relationship between CO_2, the planet and heat. "An atmosphere of that gas would give to our earth a high temperature," she wrote in an 1856 paper summarizing her findings.

Three years later, working independently and apparently unaware of Foote's discovery, Irish physicist John Tyndall showed the same basic idea in more detail. With a set of pipes and devices to study the transmission of heat, he found that

ScienceNews 100

To celebrate our 100th anniversary, we're highlighting some of the biggest advances in science over the last century. To see more from the series, visit the Century of Science site at www.sciencenews.org/century

The village of Lytton in British Columbia was devastated by a wildfire on June 30, 2021, just after reaching the highest temperature ever recorded in Canada. Two people died in the conflagration.

CO_2 gas, as well as water vapor, absorbed more heat than air alone. He argued that such gases would trap heat in Earth's atmosphere, much as panes of glass trap heat in a greenhouse, and thus modulate climate.

Today Tyndall is widely credited with the discovery of how what we now call greenhouse gases heat the planet, earning him a prominent place in the history of climate science. Foote faded into relative obscurity — partly because of her gender, partly because her measurements were less sensitive. Yet their findings helped kick off broader scientific exploration of how the composition of gases in Earth's atmosphere affects global temperatures.

Carbon floods in

Humans began substantially affecting the atmosphere around the turn of the 19th century, when the Industrial Revolution took off in Britain. Factories burned tons of coal; fueled by fossil fuels, the steam engine revolutionized transportation and other industries. Since then, fossil fuels including oil and natural gas have been harnessed to drive a global economy. All these activities belch gases into the air.

Eunice Newton Foote observed in 1856 that an atmosphere of CO_2 would heat the planet.

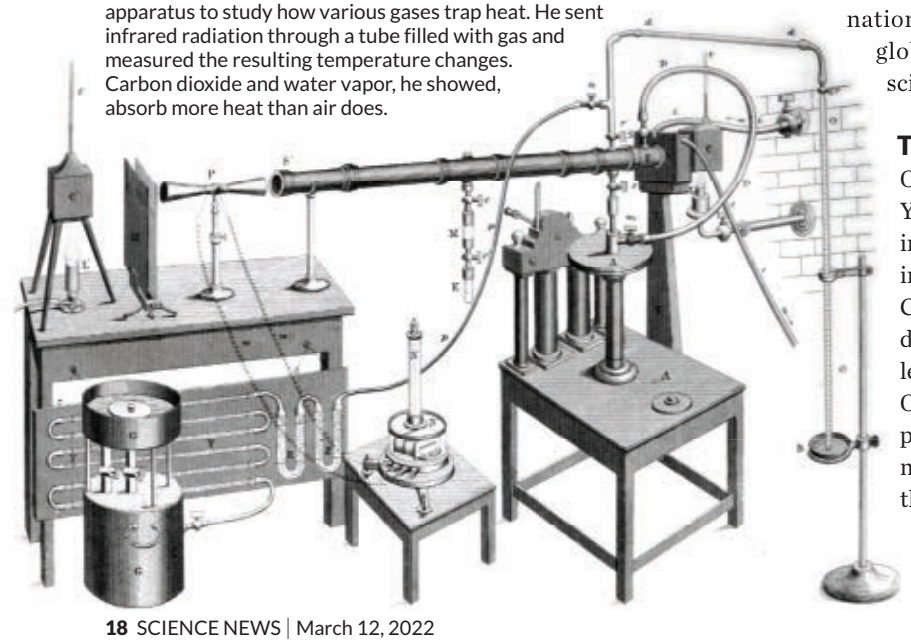
Yet Swedish physical chemist Svante Arrhenius wasn't worried about the Industrial Revolution when he began thinking in the late 1800s about changes in atmospheric CO_2 levels. He was instead curious about ice ages — including whether a decrease in volcanic eruptions, which can put carbon dioxide into the atmosphere, would lead to a future ice age. Bored and lonely in the wake of a divorce, Arrhenius set himself to months of laborious calculations involving moisture and heat transport in the atmosphere at different zones of latitude. In 1896, he reported that halving the amount of CO_2 in the atmosphere could indeed bring about an ice age — and that doubling CO_2 would raise global temperatures by around 5 to 6 degrees C.

It was a remarkably prescient finding for work that, out of necessity, had simplified Earth's complex climate system down to just a few variables. But Arrhenius' findings didn't gain much traction with other scientists at the time. The climate system seemed too large, complex and inert to change in any meaningful way on a timescale that would be relevant to human society. Geologic evidence showed, for instance, that ice ages took thousands of years to start and end. What was there to worry about?

One researcher, though, thought the idea was worth pursuing. Guy Stewart Callendar, a British engineer and amateur meteorologist, had tallied weather records over time, obsessively enough to determine that average temperatures were increasing at 147 weather stations around the globe. In a 1938 paper in a Royal Meteorological Society journal, he linked this temperature rise to the burning of fossil fuels. Callendar estimated that fossil fuel burning had put around 150 billion metric tons of CO_2 into the atmosphere since the late 19th century.

Like many of his day, Callendar didn't see global warming as a problem. Extra CO_2 would surely stimulate plants to grow and allow crops to be farmed in new regions. "In any case the return of the deadly glaciers should be delayed indefinitely," he wrote. But his work revived discussions tracing back to Tyndall and Arrhenius about how the planetary system responds to changing levels of gases in the atmosphere. And it began steering the conversation toward how human activities might drive those changes.

When World War II broke out the following year, the global conflict redrew the landscape for scientific research. Hugely important wartime technologies, such as radar and the atomic bomb, set the stage for "big science" studies that brought nations together to tackle high-stakes questions of global reach. And that allowed modern climate science to emerge.



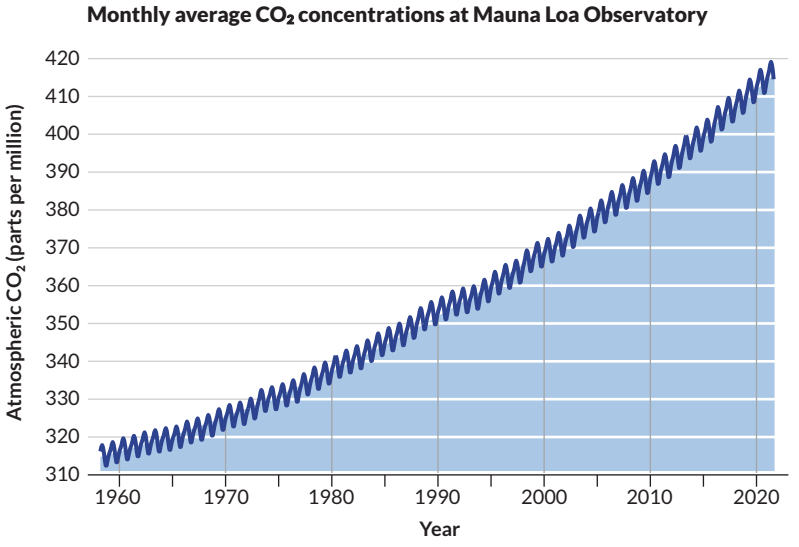
Heat-trapping gases In 1859, John Tyndall used this apparatus to study how various gases trap heat. He sent infrared radiation through a tube filled with gas and measured the resulting temperature changes. Carbon dioxide and water vapor, he showed, absorb more heat than air does.

The Keeling curve

One major effort was the International Geophysical Year, or IGY, an 18-month push in 1957–1958 that involved a wide array of scientific field campaigns including exploration in the Arctic and Antarctica. Climate change wasn't a high research priority during the IGY, but some scientists in California, led by Roger Revelle of the Scripps Institution of Oceanography, used the funding influx to begin a project they'd long wanted to do. The goal was to measure CO_2 levels at different locations around the world, accurately and consistently.

The job fell to geochemist Charles David Keeling, who put ultraprecise CO_2 monitors in Antarctica

FROM TOP: PICTORIAL PRESS LTD/ALAMY STOCK PHOTO; J. TYNDALL/WIKIMEDIA COMMONS



Steady rise In 1958, Charles David Keeling (pictured in 1988) began recording atmospheric carbon dioxide concentrations at Mauna Loa volcano in Hawaii. The measurements, collected continuously since, show the rise in CO_2 levels due to human activities (left). The visible sawtooth pattern is due to seasonal plant growth: Plants take up CO_2 in the growing seasons, then release it as they decompose in fall and winter.

and on the Hawaiian volcano of Mauna Loa. Funds soon ran out to maintain the Antarctic record, but the Mauna Loa measurements continued. Thus was born one of the most iconic datasets in all of science — the "Keeling curve," which tracks the rise of atmospheric CO_2.

When Keeling began his measurements in 1958, CO_2 made up 315 parts per million of the global atmosphere. Within just a few years it became clear that the number was increasing year by year. Because plants take up CO_2 as they grow in spring and summer and release it as they decompose in fall and winter, CO_2 concentrations rose and fell each year in a sawtooth pattern. But superimposed on that pattern was a steady march upward.

"The graph got flashed all over the place — it was just such a striking image," says Ralph Keeling, who is Keeling's son. Over the years, as the curve marched higher, "it had a really important role historically in waking people up to the problem of climate change." The Keeling curve has been featured in countless earth science textbooks, congressional hearings and in Al Gore's 2006 documentary on climate change, *An Inconvenient Truth*.

Each year the curve keeps going up: In 2016, it passed 400 ppm of CO_2 in the atmosphere as measured during its typical annual minimum in September. Today it is at 413 ppm. (Before the Industrial Revolution, CO_2 levels in the atmosphere had been stable for centuries at around 280 ppm.)

Around the time that Keeling's measurements were kicking off, Revelle also helped develop an important argument that the CO_2 from human activities was building up in Earth's atmosphere. In 1957, he and Hans Suess, also at Scripps at the time, published a paper that traced the flow of radioactive carbon through the oceans and the atmosphere. They showed that the oceans were not capable of taking up as much CO_2 as previously thought; the implication was that much of the gas must be going into the atmosphere instead.

"Human beings are now carrying out a large-scale geophysical experiment of a kind that could not have happened in the past nor be reproduced in the future," Revelle and Suess wrote in the paper. It's one of the most famous sentences in earth science history.

Here was the insight underlying modern climate science: Atmospheric carbon dioxide is increasing, and humans are causing the buildup. Revelle and Suess became the final piece in a puzzle dating back to Svante Arrhenius and John Tyndall. "I tell my students that to understand the basics of climate change, you need to have the cutting-edge science of the 1860s, the cutting-edge math of the 1890s and the cutting-edge chemistry of the 1950s," says Joshua Howe, an environmental historian at Reed College in Portland, Ore.

Evidence piles up

Observational data collected throughout the second half of the 20th century helped researchers gradually build their understanding of how human activities were transforming the planet.

Ice cores pulled from ice sheets, such as that atop Greenland, offer some of the most telling insights for understanding past climate change. Each year, snow falls atop the ice and compresses into a fresh layer of ice representing climate conditions at the time it formed. The abundance of certain forms, or isotopes, of oxygen and hydrogen in the ice allows scientists to calculate the temperature at which it formed, and air bubbles trapped within the ice reveal how much carbon dioxide and other greenhouse gases were in the atmosphere at that time. So drilling down into an ice sheet is like reading the pages of a history book that go back in time the deeper you go.

Scientists began reading these pages in the early 1960s, using ice cores drilled at a U.S. military base in northwest

FROM LEFT: SCRIPPS CO_2 PROGRAM; SIO PHOTOGRAPHIC LABORATORY RECORDS. SAC 0044. SPECIAL COLLECTIONS & ARCHIVES. UC SAN DIEGO

Geoffrey Hargreaves, curator at the National Science Foundation Ice Core Facility in Lakewood, Colo., holds a 1-meter-long section of an ice core. The facility houses more than 22,000 meters of ice cores from Antarctica, Greenland and North America — all records of past climates.

Greenland. Contrary to expectations that past climates were stable, the cores hinted that abrupt climate shifts had happened over the last 100,000 years. By 1979, an international group of researchers was pulling another deep ice core from a second location in Greenland — and it, too, showed that abrupt climate change had occurred in the past. In the late 1980s and early 1990s, a pair of European- and U.S.-led drilling projects retrieved even deeper cores from near the top of the ice sheet, pushing the record of past temperatures back a quarter of a million years.

Together with other sources of information, such as sediment cores drilled from the seafloor and molecules preserved in ancient rocks, the ice cores allowed scientists to reconstruct past temperature changes in extraordinary detail. Many of those changes happened alarmingly fast. For instance, the climate in Greenland warmed abruptly more than 20 times in the last 80,000 years, with the changes occurring in a matter of decades. More recently, a cold spell that set in around 13,000 years ago suddenly came to an end around 11,500 years ago — and temperatures in Greenland rose 10 degrees C in a decade.

Evidence for such dramatic climate shifts laid to rest any lingering ideas that global climate change would be slow and unlikely to occur on a timescale that humans should worry about. "It's an important reminder of how 'tippy' things can be," says Jessica Tierney, a paleoclimatologist at the University of Arizona in Tucson.

More evidence of global change came from Earth-observing satellites, which brought a new planet-wide perspective on global warming beginning in the 1960s. From their viewpoint in the sky, satellites have measured the rise in global sea level — currently 3.4 millimeters per year and accelerating, as warming water expands and as ice sheets melt — as well as the rapid decline in ice left floating on the Arctic Ocean each summer at the end of the melt season. Gravity-sensing satellites have "weighed" the Antarctic and Greenlandic ice sheets from above since 2002, reporting that more than 400 billion metric tons of ice are lost each year.

Temperature observations taken at weather stations around the world also confirm that we are living in the hottest years on record. The 10 warmest years since record keeping began in 1880 have all occurred since 2005. And nine of those 10 have come since 2010.

Worrisome predictions

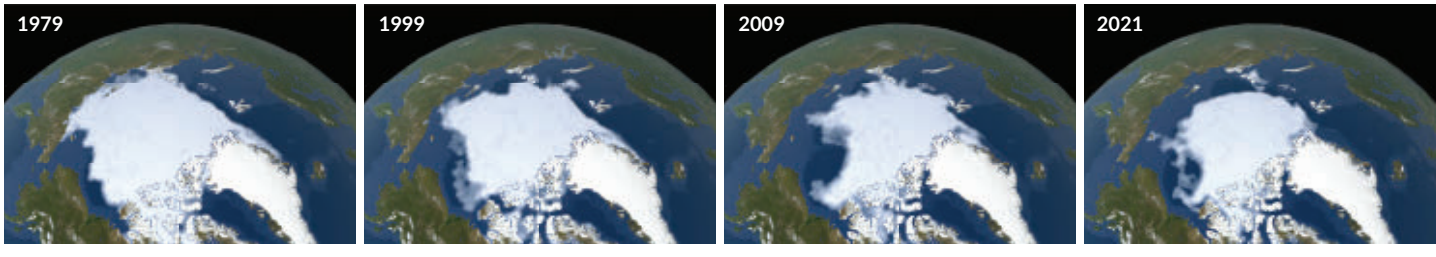
By the 1960s, there was no denying that the planet was warming. But understanding the consequences of those changes — including the threat to human health and well-being — would require more than observational data. Looking to the future depended on computer simulations: complex calculations of how energy flows through the planetary system.

A first step in building such climate models was to connect everyday observations of weather to the concept of forecasting future climate. During World War I, British mathematician Lewis Fry Richardson imagined tens of thousands of meteorologists, each calculating conditions for a small part of the atmosphere but collectively piecing together a global forecast.

But it wasn't until after World War II that computational power turned Richardson's dream into reality. In the wake of the Allied victory, which relied on accurate weather forecasts for everything from planning D-Day to figuring out when and where to drop the atomic bombs, leading U.S. mathematicians acquired funding from the federal government to improve

FROM TOP: JIM WEST/SCIENCE SOURCE; NASA'S SCIENTIFIC VISUALIZATION STUDIO

Arctic melting Arctic sea ice cover, which dips to its annual minimum in September, has declined in recent decades. In 1979, the minimum extent was 6.90 million square kilometers. By 2021, it had dropped to 4.72 million square kilometers.



predictions. In 1950, a team led by Jule Charney, a meteorologist at the Institute for Advanced Study in Princeton, N.J., used the ENIAC, the first U.S. programmable, electronic computer, to produce the first computer-driven regional weather forecast. The forecasting was slow and rudimentary, but it built on Richardson's ideas of dividing the atmosphere into squares, or cells, and computing the weather for each of those. The work set the stage for decades of climate modeling to follow.

By 1956, Norman Phillips, a member of Charney's team, had produced the world's first general circulation model, which captured how energy flows between the oceans, atmosphere and land. The field of climate modeling was born.

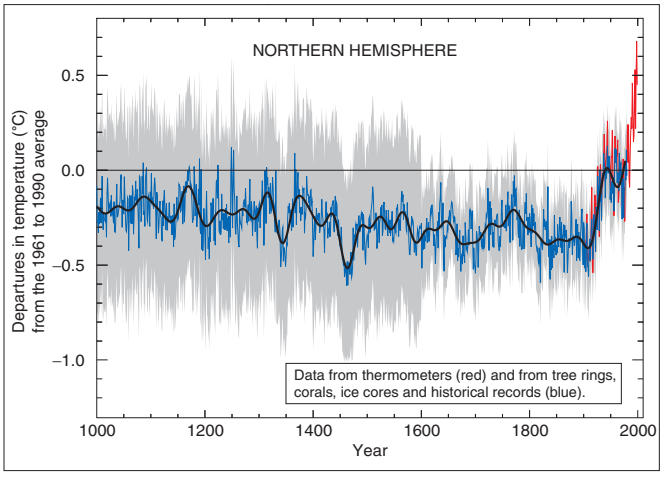
The work was basic at first because early computers simply didn't have much computational power to simulate all aspects of the planetary system.

An important breakthrough came in 1967, when meteorologists Syukuro Manabe and Richard Wetherald — both at the Geophysical Fluid Dynamics Laboratory in Princeton, a lab born from Charney's group — published a paper in the *Journal of the Atmospheric Sciences* that modeled connections between Earth's surface and atmosphere and calculated how changes in CO_2 would affect the planet's temperature. Manabe and Wetherald were the first to build a computer model that captured the relevant processes that drive climate, and to accurately simulate how the Earth responds to those processes.

The rise of climate modeling allowed scientists to more accurately envision the impacts of global warming. In 1979, Charney and other experts met in Woods Hole, Mass., to try to put together a scientific consensus on what increasing levels of CO_2 would mean for the planet. The resulting "Charney report" concluded that rising CO_2 in the atmosphere would lead to additional and significant climate change.

In the decades since, climate modeling has gotten increasingly sophisticated. And as climate science firmed up, climate change became a political issue.

The graph that launched climate skeptic attacks



The hockey stick This famous graph, produced by scientist Michael Mann and colleagues, and then reproduced in a 2001 report by the Intergovernmental Panel on Climate Change, dramatically captures temperature change over time. Climate change skeptics made it the center of an all-out attack on climate science.

Backlash

The rising public awareness of climate change, and battles over what to do about it, emerged alongside awareness of other environmental issues in the 1960s and '70s. Rachel Carson's 1962 book *Silent Spring*, which condemned the pesticide DDT for its ecological impacts, catalyzed environmental activism in the United States and led to the first Earth Day in 1970.

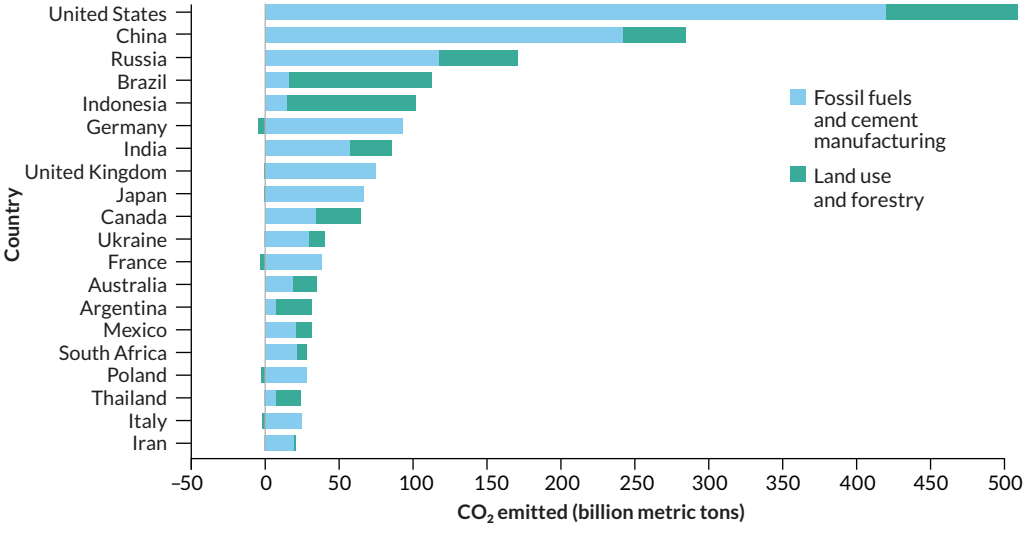
In 1974, scientists discovered another major global environmental threat — the Antarctic ozone hole, which had some important parallels to and differences from the climate change story. Chemists Mario Molina and F. Sherwood Rowland, of the University of California, Irvine, reported that chlorofluorocarbon chemicals, used in products such as spray cans and refrigerants, caused a chain of reactions that gnawed away at

Biggest footprint

These 20 nations have emitted the largest cumulative amounts of carbon dioxide since 1850. Emissions are shown in billions of metric tons and are broken down into subtotals from fossil fuel use and cement manufacturing (blue) and land use and forestry (green).

SOURCE: CARBON BRIEF ANALYSIS OF FIGURES FROM THE GLOBAL CARBON PROJECT, CDIAC, OUR WORLD IN DATA, CARBON MONITOR, HOUGHTON AND NASSIKAS (2017) AND HANSIS *ET AL* (2015)

Total carbon dioxide emissions by country, 1850–2021



FROM TOP: CLIMATE CHANGE 2001: THE SCIENTIFIC BASIS. CONTRIBUTION OF WORKING GROUP I TO THE THIRD ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE; E. OTWELL

the atmosphere's protective ozone layer. The resulting ozone hole, which forms over Antarctica every spring, allows more ultraviolet radiation from the sun to make it through Earth's atmosphere and reach the surface, where it can cause skin cancer and eye damage.

Governments worked under the auspices of the United Nations to craft the 1987 Montreal Protocol, which strictly limited the manufacture of chlorofluorocarbons. In the years following, the ozone hole began to heal. But fighting climate change is proving to be far more challenging. Transforming entire energy sectors to reduce or eliminate carbon emissions is much more difficult than replacing a set of industrial chemicals.

In 1980, though, researchers took an important step toward banding together to synthesize the scientific understanding of climate change and bring it to the attention of international policy makers. It started at a small scientific conference in Villach, Austria, on the seriousness of climate change. On the train ride home from the meeting, Swedish meteorologist Bert Bolin talked with other participants about how a broader, deeper and more international analysis was needed. In 1988, a United Nations body called the Intergovernmental Panel on Climate Change, the IPCC, was born. Bolin was its first chairperson.

The IPCC became a highly influential and unique body. It performs no original scientific research; instead, it synthesizes and summarizes the vast literature of climate science for policy makers to consider — primarily through massive reports issued every couple of years. The first IPCC report, in 1990, predicted that the planet's global mean temperature would rise more quickly in the following century than at any point in the last 10,000 years, due to increasing greenhouse gases in the atmosphere.

Climate change is increasingly impacting human life and is exacerbating extreme weather events. Clockwise from top: Displaced families line up for water in 2017 at a makeshift camp on the outskirts of Baidoa, Somalia, where hundreds of thousands fled drought. Beach erosion destroyed this home in Shishmaref, Alaska, shown in 2006; now the whole village must move because of sea level rise. In July 2021, severe rains and flash floods in Europe filled streets with debris in towns including Euskirchen, Germany (shown).

CLOCKWISE FROM TOP: TONY KARUMBA/AFP VIA GETTY IMAGES; GABRIEL BOUYS/AFP VIA GETTY IMAGES; ABDULHAMID HOSBAS/ANADOLU AGENCY VIA GETTY IMAGES

IPCC reports have played a key role in providing scientific information for nations discussing how to stabilize greenhouse gas concentrations. This process started with the Rio Earth Summit in 1992, which resulted in the U.N. Framework Convention on Climate Change. Annual U.N. meetings to tackle climate change led to the first international commitments to reduce emissions, the Kyoto Protocol of 1997. Under it, developed countries committed to reduce emissions of CO_2 and other greenhouse gases. By 2007, the IPCC declared the reality of climate warming is "unequivocal." The group received the Nobel Peace Prize that year, along with Al Gore, for their work on climate change.

The IPCC process ensured that policy makers had the best science at hand when they came to the table to discuss cutting emissions. Of course, nations did not have to abide by that science — and they often didn't. Throughout the 2000s and 2010s, international climate meetings discussed less hard-core science and more issues of equity. Countries such as China and India pointed out that they needed energy to develop their economies and that nations responsible for the bulk of emissions through history, such as the United States, needed to lead the way in cutting greenhouse gases.

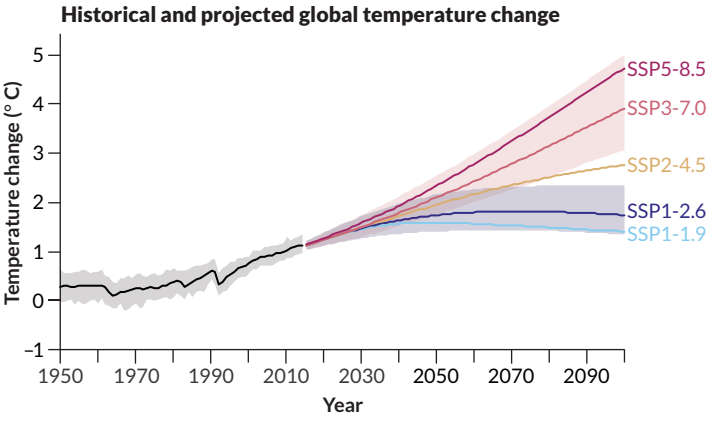
Meanwhile, residents of some of the most vulnerable nations, such as low-lying islands that are threatened by sea level rise, gained visibility and clout at international negotiating forums. "The issues around equity have always been very uniquely challenging in this collective action problem," says Rachel Cleetus, a climate policy expert with the Union of Concerned Scientists in Cambridge, Mass.

By 2015, the world's nations had made some progress on the emissions cuts laid out in the Kyoto Protocol, but it was still not enough to achieve substantial global reductions. That year, a key U.N. climate conference in Paris produced an international agreement to try to limit global warming to 2 degrees C, and preferably 1.5 degrees C, above preindustrial levels.

Every country has its own approach to the challenge of addressing climate change. In the United States, which gets approximately 80 percent of its energy from fossil fuels, sophisticated efforts to downplay and critique the science led to major delays in climate action. For decades, U.S. fossil fuel companies such as ExxonMobil worked to influence politicians to take as little action on emissions reductions as possible.

Such tactics undoubtedly succeeded in feeding politicians' delay on climate action in the United States, most of it from Republicans. President George W. Bush withdrew the country from the Kyoto Protocol in 2001; Donald Trump similarly rejected the Paris accord in 2017. As late as 2015, the chair of the Senate's environment committee, James Inhofe of Oklahoma, brought a snowball into Congress on a cold winter's day to argue that human-caused global warming is a "hoax."

In Australia, a similar mix of right-wing denialism and fossil fuel interests has kept climate change commitments in flux, as prime ministers are voted in and out over fierce debates about how the nation should act on climate.



Past and future Various scenarios for how greenhouse gas emissions might change going forward help scientists predict future climate change. This graph shows the simulated historical temperature trend along with future projections of rising temperatures based on five scenarios from the Intergovernmental Panel on Climate Change. Temperature change is the difference from the 1850–1900 average.
SOURCE: IPCC SIXTH ASSESSMENT REPORT 2021, CEDA/EDS/NERC

Yet other nations have moved forward. Some European countries such as Germany aggressively pursued renewable energies, including wind and solar, while activists such as Swedish teenager Greta Thunberg — the vanguard of a youth-action movement — pressured their governments for more.

In recent years, the developing economies of China and India have taken center stage in discussions about climate action. China, which is now the world's largest carbon emitter, declared several moderate steps in 2021 to reduce emissions, including that it would stop building coal-burning power plants overseas. India announced it would aim for net-zero emissions by 2070, the first time it has set a date for this goal.

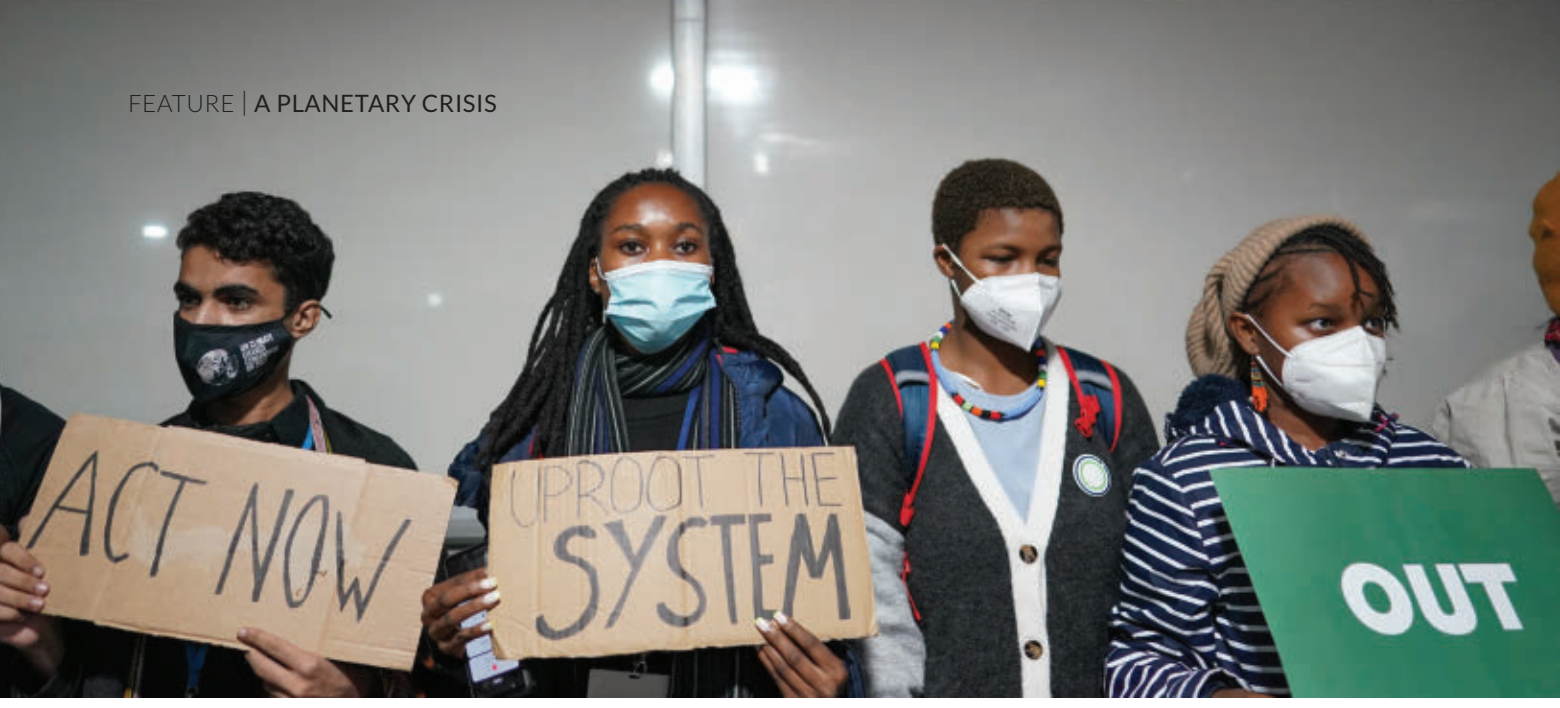
Yet such pledges continue to be criticized. At the 2021 U.N. Climate Change Conference in Glasgow, Scotland, India was globally criticized for not committing to a complete phaseout of coal — although the two top emitters, China and the United States, have not themselves committed to phasing out coal. "There is no equity in this," says Aayushi Awasthy, an energy economist at the University of East Anglia in England.

Facing the future

In many cases, changes are coming faster than scientists had envisioned a few decades ago. The oceans are becoming more acidic as they absorb CO_2, harming tiny marine organisms that build protective calcium carbonate shells and are the base of the marine food web. Warmer waters are bleaching coral reefs. Higher temperatures are driving animal and plant species into areas in which they previously did not live, increasing the risk of extinction for many.

No place on the planet is unaffected. In many areas, higher temperatures have led to major droughts, which dry out vegetation and provide additional fuel for wildfires such as those that have devastated Australia, the Mediterranean and

E. OTWELL



Young people's demands for action on climate have only intensified in recent years. At the 2021 United Nations Climate Change Conference in Glasgow, Scotland, youth activists called for climate meetings to include the people most affected by the warming climate.

western North America in recent years.

Then there's the Arctic, where temperatures are rising at more than twice the global average and communities are at the forefront of change. Permafrost is thawing, destabilizing buildings, pipelines and roads. Caribou and reindeer herders worry about the increased risk of parasites for the health of their animals. With less sea ice available to buffer the coast from storm erosion, the Inupiat village of Shishmaref, Alaska, risks crumbling into the sea. It will need to move from its sand-barrier island to the mainland.

"We know these changes are happening and that the Titanic is sinking," says Louise Farquharson, a geomorphologist at the University of Alaska Fairbanks who monitors permafrost and coastal change around Alaska. All around the planet, those who depend on intact ecosystems for their survival face the greatest threat from climate change. And those with the least resources to adapt to climate change are the ones who feel it first.

"We are going to warm," says Claudia Tebaldi, a climate scientist at Lawrence Berkeley National Laboratory in California. "There is no question about it. The only thing that we can hope to do is to warm a little more slowly."

That's one reason why the IPCC report released in 2021 focuses on anticipated levels of global warming. There is a big difference between the planet warming 1.5 degrees versus 2 degrees or 2.5 degrees. Each fraction of a degree of warming increases the risk of extreme events such as heat waves and heavy rains, leading to greater global devastation.

The future rests on how much nations are willing to commit to cutting emissions and whether they will stick to those commitments. It's a geopolitical balancing act the likes of which the world has never seen.

Science can and must play a role going forward. Improved climate models will illuminate what changes are expected at the regional scale, helping officials prepare. Governments and industry have crucial parts to play as well. They can invest in technologies, such as carbon sequestration, to help decarbonize the economy and shift society toward more renewable sources of energy.

Huge questions remain. Do voters have the will to demand significant energy transitions from their governments? How can business and military leaders play a bigger role in driving climate action? What should be the role of low-carbon energy sources that come with downsides, such as nuclear energy? How can developing nations achieve a better standard of living for their people while not becoming big greenhouse gas emitters? How can we keep the most vulnerable from being disproportionately harmed during extreme events, and incorporate environmental and social justice into our future?

These questions become more pressing each year, as carbon dioxide accumulates in our atmosphere. The planet is now at higher levels of CO_2 than at any time in the last 3 million years.

At the U.N. climate meeting in Glasgow in 2021, diplomats from around the world agreed to work more urgently to shift away from using fossil fuels. They did not, however, adopt targets strict enough to keep the world below a warming of 1.5 degrees.

It's been well over a century since chemist Svante Arrhenius recognized the consequences of putting extra carbon dioxide into the atmosphere. Yet the world has not pulled together to avoid the most dangerous consequences of climate change.

Time is running out. ■

Explore more

■ IPCC Sixth Assessment Report. Climate Change 2021: The Physical Science Basis. August 9, 2021. www.ipcc.ch/assessment-report/ar6/

IAN FORSYTH/GETTY IMAGES

As a step toward enabling animal-to-human organ transplants, doctors at NYU Langone Health in 2021 attached a genetically modified pig kidney to a person who was clinically brain-dead.

JOE CARROTTA FOR NYU LANGONE HEALTH

A High-Profile Transplant Milestone

Will the successful use of a pig heart in one dying man help others?

By Laura Beil

A 57-year-old Maryland man has now survived for weeks with the transplanted heart of a genetically engineered pig. His doctor has hailed the operation as a "breakthrough surgery" that could help solve the organ shortage crisis. But from a scientific standpoint, it's too early in the game to know how much this milestone will move the ball.

The use of animal organs for humans is an idea with a long, dramatic and often disappointing history. There's an old saying about xenotransplantation, as the field is known, says surgeon Joseph Leventhal, who heads the kidney transplant program at Northwestern University Feinberg School of Medicine in Chicago. "It's just around the corner. The problem is, it's a very, very, very long corner."

But a rash of new experiments, including three using pig kidneys for people being kept temporarily alive on ventilators, has provided tantalizing evidence that achieving the decades-old ambition may finally be in reach.

The recent animal-to-human operations come after an extensive effort to develop genetically altered pigs with organs that might avoid abrupt rejection, along with refinement of drugs that suppress the immune system and boost survival. That said, the Maryland heart operation was a Hail Mary rescue attempt and not part of a clinical trial — the kind of carefully designed study that is ultimately needed to show whether pig organs can function in humans, and do so safely.

One case can provide some valuable information about how the body responds to the organ, says Karen Maschke, a bioethics scholar at the Hastings Center in Garrison, N.Y., who is editor of the journal *Ethics & Human Research*. "You may find stuff that you didn't expect to find," she says.

But a single snapshot of data doesn't have enough context to draw conclusions, especially when it involves a gravely ill patient and brand-new technology. Without a study comparing several carefully selected patients, it's hard to know whether one individual's experience is typical.

Yet the latest flurry of pig-to-human transplant experiments could help open the door to the kinds of clinical trials that researchers want. That's the only way to significantly advance the science, says heart surgeon David Cooper of Massachusetts General Hospital in Boston, who has long researched the idea of xenotransplantation. "We'll learn much more if we are doing clinical cases than if we are staying in the laboratory."

High on the hog

If clinical trials ultimately prove successful, animals could help ease a critical shortage of donor organs. Of the more than 106,000 U.S. residents waiting for a transplant, about 90,000 need a kidney. Many will die before one is available.

Doctors have previously turned to animal organs in bold, headline-grabbing endeavors. Famed Houston heart surgeon Denton Cooley transplanted a sheep heart as a desperate move to save a dying man in the 1960s; the man's body quickly rejected the organ.

One of the most high-profile tries at xenotransplantation occurred in 1984, when doctors at Loma Linda University Medical Center in California sewed a baboon heart into a 2-week-old baby born with a fatal cardiac defect. Baby Fae, as she was known, lived for 20 days and her surgery left a wake of controversy. Some medical ethicists called the operation a

"beastly business" that lacked moral clarity. Scientists "beat a hasty retreat back to the laboratory," according to a 1995 report in *JAMA*.

More recently, scientists have focused on pigs, largely because porcine organs are about the size of adult human organs, and the animals are already raised on an industrial scale. Still, the feasibility of the idea was thrown into doubt with the discovery in the 1980s that pig cells are coated with a type of sugar molecule, called alpha-gal, that strongly triggers the human immune system to attack the unfamiliar intruders.

The field also experienced a setback with the discovery in the 1990s that the swine genome contains embedded viruses, snippets of viral genetic code woven into pigs' genetic instruction books. (It's not just a pig trait; these kinds of viral genes make up an estimated 8 percent of the human genome too.) The viruses, called porcine endogenous retroviruses, don't bother pigs but might cause problems after suddenly finding themselves in another species.

In the early 2000s, researchers reported the creation of genetically modified pigs lacking alpha-gal, making them theoretically more compatible with the human immune system than a hog straight from the farm. That feat set off attempts to raise alpha-gal–free animals, most notably in the United States by Revivicor, a company in Blacksburg, Va., owned by United Therapeutics. Then, in 2020, the possibility of pig-to-human transplants took a giant leap forward, when, for the first time, the U.S. Food and Drug Administration approved Revivicor's genetically altered pigs for human use.

Xenotransplantation also got a boost from CRISPR/Cas9 gene-editing technology and its remarkable ability to snip genes at will. Using CRISPR, scientists can trim the unwanted viral genes from pigs (*SN: 9/2/17, p. 15*). "Gene editing with CRISPR has just really helped accelerate [the field] in sort of a warp drive," Leventhal says.

In recent experiments, pig kidneys and hearts have been successfully transplanted into baboons. Though baboons died within days in early xenotransplantation attempts, researchers reported in 2018 that transplanted pig hearts kept beating in the chests of two baboons for about six months, a record at the time. Other similar experiments have replicated that survival time.

Then in October 2021, scientists at NYU Langone Health in New York City made the jump to humans. In a test, they grafted a Revivicor kidney onto a person who was clinically brain-dead and watched the organ function for 54 hours, considered long enough to detect any signs of immediate rejection (*SN: 11/20/21, p. 6*). Less than two months later, the same surgical team repeated the experiment. A third such transplant, by researchers at the University of Alabama at Birmingham, this time into the abdomen of a man kept temporarily alive by a ventilator following a motorcycle accident, was described January 20 in the *American Journal of Transplantation*.

None of those kidneys appeared to provoke immediate immune rejection, and the organs even began to produce urine, doctors reported. Given the overwhelming need for kidneys, and renal tests already done, most experts predicted that the first modern patient to get a xenotransplant would be given a kidney.

Then came the unexpected news of David Bennett.

'I want to live'

Bennett was suffering from acute heart failure and did not qualify for the human heart transplant list. On New Year's Eve, the FDA gave doctors at the University of Maryland Medical Center in Baltimore permission to transplant the pig heart through a special protocol, sometimes called compassionate use, that allows very sick people emergency access to experimental drugs or devices — either because the patient doesn't qualify for any relevant study or because no study exists. Bennett's new heart came from a Revivicor pig.

In a statement issued by the hospital, Bennett said he consented to the experimental surgery because he was simply out of options. He was bedridden, and no hospital would offer him a heart transplant, at least in part because he had a history of not following medical advice. "It was either die or do this transplant," he said. "I want to live." The eight-hour operation was performed on January 7.

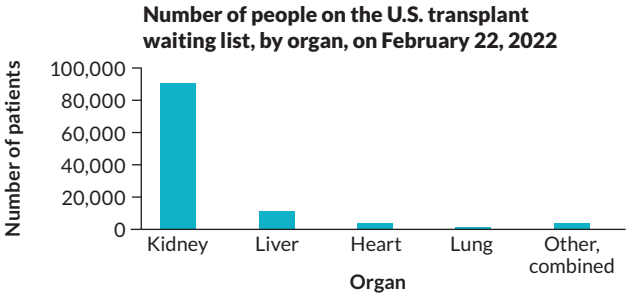
In a February 11 update, surgeon Muhammad Mohiuddin, said Bennett is making slow but steady progress. "The heart is contracting vigorously" and "it shows no signs of rejection." Bennett watched the Super Bowl with staff on the 13th.

"We are counting all these smaller wins and hope this heart will support him," says Mohiuddin, who directs the cardiac xenotransplantation program at the hospital and was part of the surgical team. The heart is strong enough that the doctors have had to dampen its power because it was too much for Bennett's body, weakened from lying in bed for weeks. "We put a Ferrari engine in a 1960 car," Mohiuddin says.

Still, Cooper, the heart surgeon at Massachusetts General, says he was surprised when he learned that the first living pig-to-human transplant patient received a heart, not a kidney. "What are they going to do if this graft slowly begins to fail?" he asks.

In a controversial 1984 surgery, "Baby Fae" received a baboon heart (left) but lived only 20 days. David Bennett (right, center) received a genetically modified pig heart in early 2022, raising ethical questions.

FROM LEFT: LOMA LINDA UNIVERSITY HEALTH; COURTESY OF DAVID BENNETT JR.



Unmet needs In the United States, the majority of people awaiting an organ transplant are in need of a kidney. SOURCE: THE ORGAN PROCUREMENT AND TRANSPLANTATION NETWORK

"I thought it would be the kidney first," Cooper says. "Because if that fails — say you get rejection that you didn't expect, or you get infection that you can't manage — you can take the kidney out, stop all the immunosuppressive therapy and put the patient back on dialysis." A heart transplant is not so reversible.

Last September, Cooper and surgeon Hidetaka Hara, both at the University of Alabama at Birmingham at the time, laid out a plan in *eBioMedicine*, suggesting that the first xenotransplant should be a step-by-step clinical trial with four patients waiting for a kidney. The trial would work like this: Three months after the first patient receives a transplant, perform the operation in a second patient if the first person isn't having complications. If those two are doing well, transplant a third pig kidney three months later, and a fourth three months after that. "So over the course of a year," Cooper says, "you've followed up four patients and you can see whether [they are] all doing well or are there complications."

Starting a clinical trial with kidneys also makes sense, Cooper says, because the need is so much greater. Around 83 percent of the people on the U.S. transplant waiting list need kidneys; 3 percent need a heart.

That's why eGenesis, a company in Cambridge, Mass., is focusing its research efforts on kidneys. "It's where the dominant need is," says Mike Curtis, the company's president of research and development. eGenesis, which is raising gene-edited, immune-compatible pigs, hopes to begin a clinical trial of six to 10 patients with transplanted pig kidneys around 2024.

Mohiuddin says that the reason he performed a heart operation is simple: He's a cardiac surgeon, and the patient was dying. "My 30-year interest has been only in hearts," he says. His research team has approached the FDA for permission to do a clinical trial, he says, but the agency wants more consistent data from baboon studies first. "We hope to get that permission," he says. "This was just to save Mr. Bennett's life."

One and not done

Should Bennett check out of the hospital and go home, that high-profile milestone may do more than allow him more time with his family: It could help persuade the FDA to green-light a larger, scientifically designed trial, Cooper says.

If Bennett continues doing well, doctors "may be able to get a handful of [heart] patients done over the next few months. And then they go back to the FDA and say, 'Look, these patients generally did well. Now can we do a proper series, where we take patients on our own waiting list and do the transplants?' "

Leventhal, the surgeon at Northwestern, has the same hope about approved clinical trials. "The only way that you're going to see whether these organs provide meaningful function over the long term in humans, in a way that would justify their use, is to transplant them into humans and follow them longer-term."

Still, it remains to be seen whether that will occur under compassionate use, as Bennett received, or in formal studies. The FDA's expanded access provision was designed to help people obtain drugs and procedures that they couldn't normally get. "Whether it should have been used in the case of an organ is an interesting ethical and regulatory and policy question," says Maschke, the bioethicist.

"One of the problems with going the route they did is that there are probably hundreds of heart patients in the country who are not on a waiting list because they're too sick," Maschke says. "Some of those folks may say, 'I'll never take an animal organ,' but some of them might say, 'Yes, I would take a pig heart. I want to do this too. Can you get me access?' "

But opening the floodgates could make it harder to find volunteers for clinical studies. And in some cases, it could backfire. That's what happened in the 1990s, when doctors started offering women with advanced breast cancer massive doses of chemotherapy followed by bone marrow transplantation to restore their collapsed immune systems. Thousands of women received the experimental treatment — so many that scientists had trouble recruiting for studies. And when the scientific trials were finally done, the treatment showed no benefit.

That's why there's often a concern about moving too fast, "because you don't want to derail the science — and the science is incremental," Maschke says.

For now, pig-to-human transplantation has logistical issues that will limit its use. For one, the painstakingly engineered pigs are hard to come by. In addition to their rare genetic pedigree, they must be raised in sterile environments so they don't pick up any microbes that might be transferred to humans. Another possible hurdle: Animal rights groups have decried the idea of pigs as spare parts for humans as "cruel and dangerous," a sentiment that society will need to square with the urgent medical need.

But first, doctors need to know if xenotransplantation is even possible, or if it will once again end in failure. "What we don't know is, how long and how well will these organs work in patients?" Leventhal says. "The only way we're going to assess that is through transplanting them." ■

Explore more

■ Paige M. Porrett *et al*. "First clinical-grade porcine kidney xenotransplant using a human decedent model." *American Journal of Transplantation*. January 20, 2022.

E. OTWELL

Fresh Banana Leaves
Jessica Hernandez
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BOOKSHELF

An Indigenous take on conservation

During the civil war in El Salvador that began in the 1970s, an injured Victor Hernandez hid from falling bombs beneath the fronds of a banana tree. The child soldier, a member of the Maya Ch'orti' Indigenous group, made a crutch from a branch of the tree and limped toward Guatemala, toward freedom. "I strongly believe that it was this banana tree that saved my life," he told his daughter, Jessica Hernandez, who shares the story in *Fresh Banana Leaves: Healing Indigenous Landscapes Through Indigenous Science*. "It is ironic because banana trees are not native to El Salvador," he said.

Jessica Hernandez, an environmental scientist, draws parallels between her father's story and that of the banana tree. The banana tree's journey from Southeast Asia via colonial ships forced the resilient plant to adapt to its new home in the Americas. Similarly, her father adjusted to being displaced, eventually settling in the United States, often experiencing less-than-warm welcomes along the way.

Hernandez uses her father's stories and other first-person accounts to frame a complex discussion on the interplay between colonialism, the displacement of Indigenous peoples, land degradation, and differences between how Western researchers and Indigenous people approach conservation. Western restoration can often focus on rooting out invasive species, Hernandez points out. But such a narrow focus, she contends, fails to understand that Indigenous people — the lands' original stewards — are integral parts of imperiled landscapes.

Some researchers are now taking a community-based approach to conservation, in which Indigenous people participate in project planning instead of serving as study subjects. But this still doesn't go far enough, Hernandez argues: In such studies, non-Indigenous people often end up speaking for Indigenous communities.

Science News spoke with Hernandez about what she sees as conservation's failures, Indigenous displacement and the connection between the two. The conversation has been edited for brevity and clarity. — *Alka Tripathy-Lang*

You write about how ecocolonialism — when "settlers" govern Indigenous lands without consulting Indigenous people — can exacerbate climate change and result in Indigenous displacement and ecological grief. What is ecological grief?
When I talk about ecological grief, I'm talking about the longing that many [displaced] Indigenous peoples have to return to their lands. Another way to look at that is the relationships that [Indigenous people] have with nature — especially with our plants, animals and nonliving relatives. When the impacts of climate change destroy them, there's a mourning that we all undergo as Indigenous peoples.

A lot of settlers have lost their relationships with nature. They view nature as commodities without understanding that some of these natural resources mean something else to many people, aside from economic value.

How does "helicopter research" affect Indigenous communities?
Helicopter research is when scientists come up with a question, but instead of building relationships with a community [whom the] question relates to, [they] just go to the community, collect the data and never come back.

Often, we see how even some [Indigenous] knowledge is stolen. The example I brought up in the book is how a white man went to the Aboriginal community [in Australia], learned about "permaculture" [a type of self-sustaining farming system that requires minimal input from people, unlike labor-intensive, single-crop agriculture] and came back and was deemed a "founder." Permaculture is something that you can get certified in, but not necessarily understand that it is Indigenous knowledge. Funds [from certification courses] are not going to the Indigenous communities whose knowledge system was co-opted.

Are Western conservation efforts that are rooted in good intentions insufficient?
I get a lot of pushback, especially when we are communities of color speaking up against conservation. We have to look at the impacts, and I think a lot of the impacts tend to be negative — tend to be oppressive — toward communities of color. [Conservationists] tend to make protected areas in other countries, when in reality, they're jeopardizing that local community's livelihood. We see that with marine protected areas, where people who rely on fishing for sustenance are not allowed to fish. It also sometimes displaces people because they have to leave their ancestral lands to find better economic opportunities.

Conservation is very linear, focused on one species, and doesn't necessarily look at the entire landscape. Look at why a species is declining, and sometimes it's not even that people are overharvesting — it's climate change and other environmental impacts we tend to ignore.

How can conservationists center Indigenous people in their approaches?
Invite them to the table or let them lead their own table. Indigenous peoples know their lands, know their environments, know some of the changes resulting from climate change. When you're connected to your environment, you know best how to approach it. Conservationists should include Indigenous peoples as stakeholders, as opposed to always focusing on governments as the stakeholders.

Who should read this book?
[Conservation] professionals. People take action once they reflect on how something that they uphold — like the field of conservation — can cause harm. ■

SOCIETY UPDATE

CELEBRATING WOMEN IN STEM

March is Women's History Month, a time that not only celebrates landmark contributions made by women but also encourages the potential of bright young women to significantly impact our future.

The Society for Science, publisher of *Science News*, is incredibly proud of the vital and lasting scientific achievements the alumnae of our student research competitions have made over the Society's 100-year history.

△

MARY JEANNE KREEK
Pioneering neurobiologist and physician whose research fundamentally shifted society's understanding of opioid addiction and treatment. Kreek competed in the 1954 STS and 1952–1953 ISEF.

△

MONIKA SCHLEIER-SMITH
MacArthur Fellow and professor of physics at Stanford University conducting groundbreaking research on many-particle quantum systems. Schleier-Smith competed in the 2001 STS.

△

SUSAN SOLOMON
Leading atmospheric chemist whose research helped identify the causes of the Antarctic ozone "hole." Solomon competed in the 1972 ISEF.

△

LISA SU
First female CEO of Advanced Micro Devices who also drove AMD's microchip technology, making the company an industry leader. Su competed in the 1986 STS.

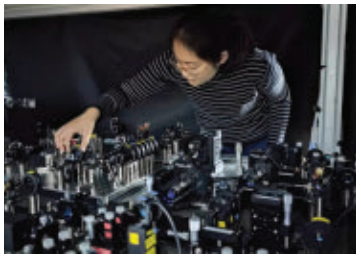
Join us in celebrating these extraordinary leaders and learn more about all of the notable alumni who competed in the Science Talent Search (STS) and International Science and Engineering Fair (ISEF) at **www.societyforscience.org/alumni/notable**.

JANUARY 29, 2022

SOCIAL MEDIA

Imagine this

Recent experiments (one shown below) suggest that a quantum physics theory based only on "real" numbers fails to explain the real world, **Emily Conover** reported in "Physics requires imaginary numbers" (*SN: 1/29/22, p. 14*). Twitter user **@DwightWebster45** mused on the findings: "The closer we look, the more complexity we find."



JINGYUN FAN

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Defining boundaries

NASA's Parker Solar Probe is the first spacecraft to enter the sun's atmosphere, crossing the boundary between interplanetary space and solar territory called the Alfvén critical surface, ***Lisa Grossman*** *reported in "NASA probe is the first to visit the sun"* (SN: 1/29/22, p. 10). The probe's solar visit allowed researchers to determine that the Alfvén critical surface lies about 13 million kilometers above the sun's surface, **Grossman** reported. Reader **Jeff Engel** wondered what is considered the sun's "surface," given that the star is made of plasma and doesn't have a distinct, solid surface.

In this context, the sun's "surface" refers to its photosphere, from which most of the sun's photons are emitted, **Grossman** says. The photosphere doesn't have a solid surface either. Instead, it consists of a layer of gas and plasma about a few hundred kilometers thick.

Rising seas

The ice shelf holding Antarctica's Thwaites Glacier back from the sea could collapse within five years, raising the risk of dramatic sea level rise, ***Carolyn Gramling*** *reported in "Ice shelf could collapse within 5 years"* (SN: 1/29/22, p. 12). **Gramling** wrote that if the whole glacier were to slide into the ocean, it would raise Earth's sea levels by 65 centimeters, or more than two feet. Reader **Jim Schmitz** wanted to know if water flowing into low-lying areas could possibly reduce the potential sea level rise.

Actual measurements of sea level rise do and will vary from place to place around the globe for various reasons, including expanding seawater, postglacial rebound, the rotation of Earth and sinking lands. The estimated sea level rise of 65 centimeters takes these factors into account, but none of them change the big picture, **Gramling** says.

As for already low-lying coastal areas, they won't be able to disperse the rising waters; they'll just become inundated themselves, **Gramling** says. "Melting of a major piece of an ice sheet will drown out everything else, pun intended."

Ancient landscapers

Neandertals' campfires, hunting and other activities may have helped transform an area in Europe from forest to open grassland around 125,000 years ago, making the hominids the first known to dramatically impact their environment, ***Bruce Bower*** *reported in "Neandertals shaped European terrain"* (SN: 1/29/22, p. 8). Reader **Morten Lindhard** asked how much of that European landscape was opened with Neandertal-made fire, rather than by wild grazing animals.

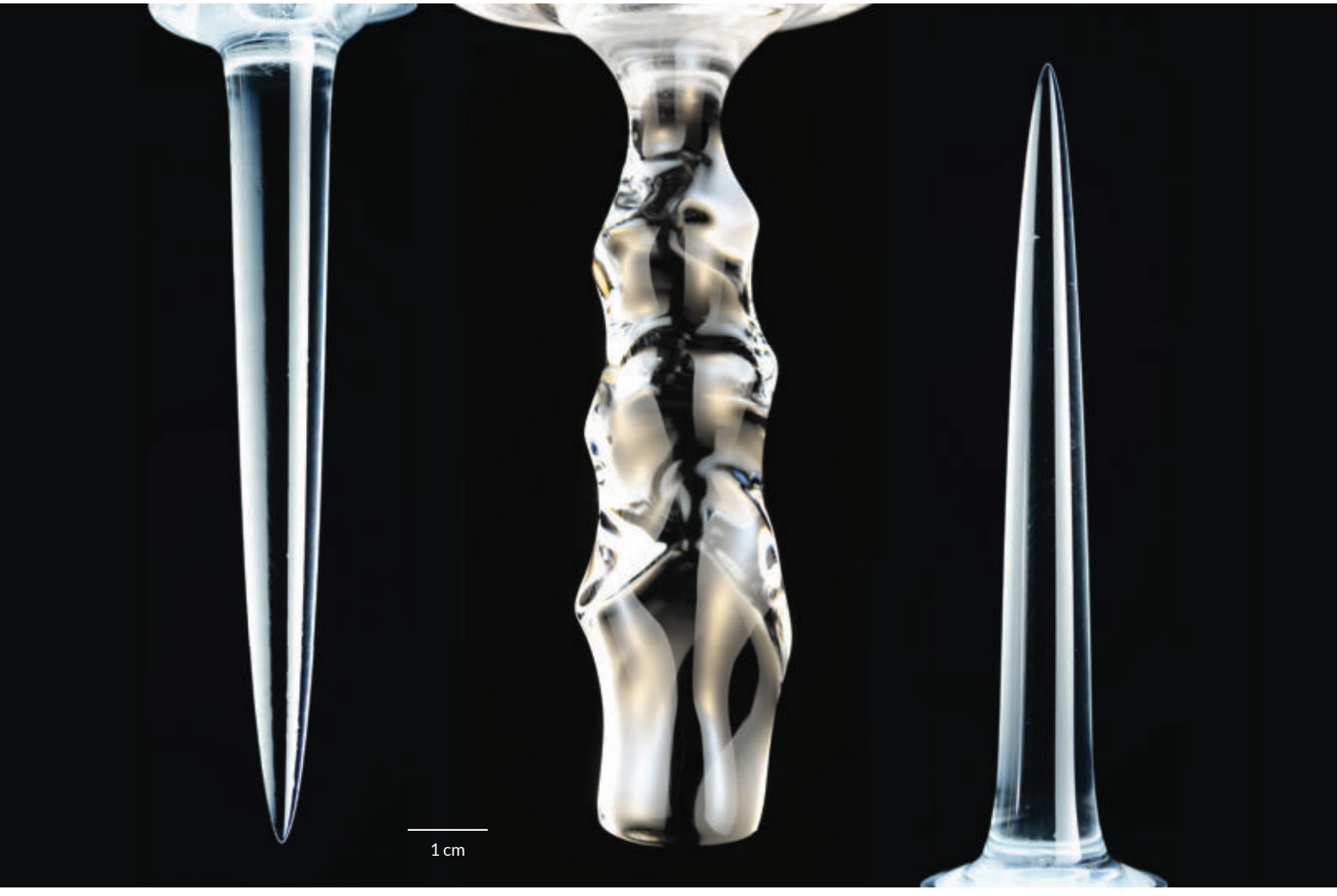
Researchers don't know for sure the percentage of the landscape transformed by fire, **Bower** says. A considerable area of the study site — which borders what is now a 24-hectare ancient lake basin and a nearby smaller basin in Germany — appears to have changed from forest to grassland. Extensive evidence suggests that ancient fires were the primary driver of this change, **Bower** says.

Several readers wondered if some of the Neandertal-made fires that cleared the forest may have been spread accidentally.

Scientists currently aren't able to distinguish archaeologically between one or a few large fires that spread accidentally or many smaller, controlled campfires, **Bower** says. Signs of numerous campfires at the study site over a period of around 2,000 years suggest the latter. But there is always some uncertainty when reconstructing ancient behavior from archaeological evidence, he says.

Correction

President Bill Clinton called the deciphering of the human genome a "stunning and humbling achievement" in 2000, not in 2003, as stated in "Reading our genes" (*SN: 2/12/22, p. 22*).



Freshwater ice can melt into scallops and spikes

Water's wacky density leads to strange effects that scientists are still uncovering.

Typically, liquids become denser and thus sink the more they cool. But freshwater is densest at 4° Celsius. As it cools below that temperature, the water becomes less dense and rises. As a result, ice columns submerged in liquid water can melt into distinct shapes, depending on the water's temperature, researchers report in the Jan. 28 *Physical Review Letters*.

Almost everything about the finding was surprising, says mathematician Leif Ristroph of New York University.

Ristroph and colleagues anchored ultrapure ice cylinders up to 30 centimeters long in place and submerged them in tanks of water at temperatures from 2° to 10° C.

If placed in water lower than about 5° C, a cylinder melted into a smooth, downward-pointing spike (above, left). Computer simulations showed "a strange thing," Ristroph says. The cold liquid water near the ice is actually buoyant due to being less dense than the rest of the water, which is warmer. That buoyancy creates an upward flow that draws warmer water closer to the bottom of the ice, causing it to melt faster than the top.

The opposite occurred in water above about 7° C; submerged ice formed an upward-pointing spike (right). That's because at this temperature, colder water near the ice is denser than the surrounding water and sinks, pulling in warmer water at the top of the ice and causing it to melt faster than the bottom, simulations showed. This matches "what your intuition would expect," Ristroph says.

Between about 5° to 7° C, the ice melted into a scalloped column (center). "Basically, the water is confused," Ristroph says, so it forms different layers — some tend to rise and some tend to sink, depending on their density. Ultimately, he says, the water organizes into "swirls or vortices of fluid that carve the weird ripples into the ice."

More work is needed to understand the complex interplay of factors that may generate these and other shapes in nature as ice melts. — *Rachel Crowell*

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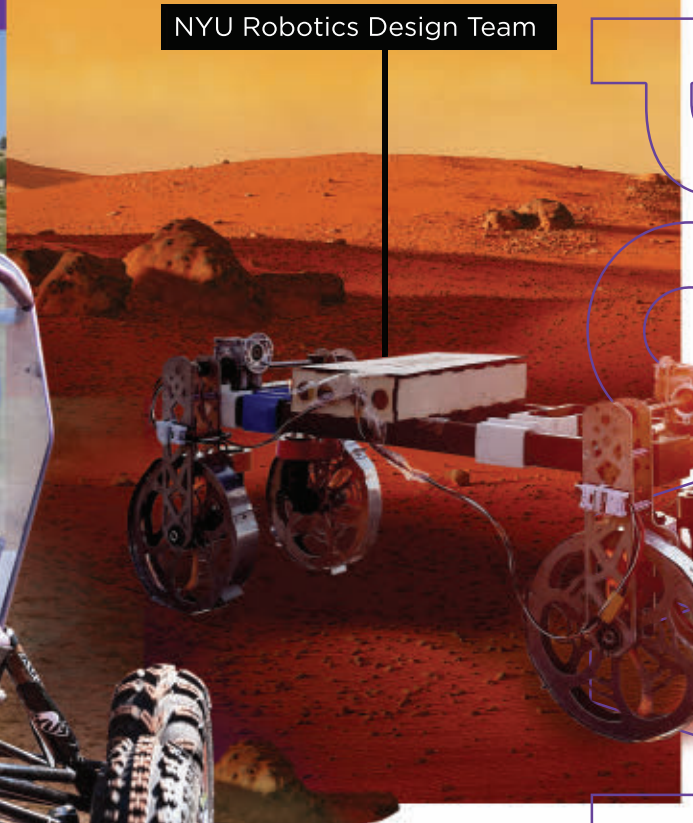

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