Eos

SCIENCE NEWS BY AGU

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Whither the Anthropocene?

The Source of Swift Quakes

Tatooine, Trisolaris, and Thessia, Oh My!

ALL ROADS LEAD TO...

Seatbelt Rock
the Order of the Red Nose
luna firma
$13,000 worth of missing acid
Teletubby training
beanbag sampling
cruise hands
stickers and geotags
penguins

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Scientists are lowered from the deck of R/V *Nathaniel B. Palmer* to the sea ice of the Southern Ocean as part of a GEOTRACES research cruise. Credit: Sofia Moutino

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Janice Lachance, Interim Executive Director/CEO

Swift Quakes Caused by Stomping Feet, Not Booming Beat

Taylor Swift performs to a stadium full of fans in Arlington, Texas. Credit: Ronald Woan/Flickr, CC BY-SA 2.0 (bit.ly/ccbysa2-0)

When 70,000 fans bounced up and down at a Taylor Swift concert last year, the ground pulsed with them, making distinct spikes in seismic signals that many referred to as Swift quakes. Scientists have now analyzed the tremors to learn about their source.

Researchers have long debated what causes these types of seismic signals at large events, said Gabrielle Tepp, a seismologist at the California Institute of Technology in Pasadena. Some argued that it's crowd motion, whether that be dancing at a rave or jumping out of your seat at a football game. Others suspected that the blaring music itself is the cause.

Tepp and her colleagues took advantage of a series of three August 2023 Taylor Swift concerts in Inglewood, Calif., to investigate. The team deployed seismic sensors in and near SoFi Stadium, where Swift performed, and gathered data from the regional seismic monitoring network.

In the basement of their university building on a Sunday morning, when few people were around to be bothered, they cranked up Swift songs.

For one of the concerts, the team plotted the intensity of the seismic signal over time and a range of frequencies on what's known as a spectrogram. A natural earthquake produces a continuous range of frequencies on a spectrogram and typically begins sharply, then tapers off in intensity. That was not the pattern at the Swift concert, whose spectrogram instead contained segments of fairly uniform intensity at characteristic frequencies.

The researchers matched that pattern to the set list based on tunes' start times, durations, and beat rates. Each songs seismic frequency typically synced up with its beat rate and harmonics, whose frequencies are multiples of the beat rate.

To investigate the origin of the harmonics, Tepp and her colleagues experimented with the potential factors at play: music and human motions. In the basement of their university building on a Sunday morning, when few people were around to be bothered, they cranked up Swift songs. They played one of her bouncier songs, "Love Story," with a seismic sensor next to the speaker. That didn't produce the characteristic spectrogram.

Then Tepp jumped up and down next to the sensor and the speaker. "It gave a very nice harmonic signal," she said, suggesting that the motion of jumping fans produced the curious seismic signals. The researchers published their findings in *Seismological Research Letters* (bit.ly/quake-it-off).

Quake It Off

The concert data also revealed that the most intense seismic signals came during Swift hits "Shake It Off," "You Belong with Me," and "Love Story."

Compared with Metallica, Morgan Wallen, and Beyoncé concerts, which were also recorded by seismic sensors near SoFi Stadium, Swift's concerts had the most intense seismic signals. Tepp said she suspects the differences may stem from how danceable the music is. Beyoncé's show started with ballads, to which concertgoers may have swayed rather than jumped. Likewise, the typical motions of Metallica's metal fans may not make steady, repeating vibrations like the ones made by pop fans.

People are often curious about the magnitude of this type of ground shaking and how it might compare with earthquakes, said Jackie Caplan-Auerbach, a seismologist at Western Washington University in Bellingham who wasn't involved with the study. But "in no way, shape, or form is this the kind of thing we normally consider when we talk about earthquake magnitude," she said. "The concept of magnitude is very much wrapped up in the physics of how earthquakes shake the ground." Crowd motion doesn't happen underground or on a fault. Nor does it break the rock or make it slip.

Some measures of an earthquake's effect would be tricky to translate to swaying or dancing Swifties, but the researchers reasoned that both types of events release energy into the ground. On the basis of the spectrograms, they determined the energy released by concertgoers and used this to calculate an equivalent magnitude for each song. The greatest of these was 0.85.

With a motion sensor inside the stadium, the team also observed the intensity of shaking. The strongest shaking was between II and III on the Modified Mercalli Intensity Scale. "It's not going to be super strong, but you would definitely feel it," Tepp said.

The magnitude calculation is a "unique contribution" to the field, Caplan-Auerbach said. She and her colleagues published a separate study in *GSA Today* in March analyzing several of Swift's concerts in the Seattle area (bit.ly/Swift-quake-Seattle). The group compared seismic signals from preconcert sound checks; concerts when fans were jumping; and Swift's acoustic sets during which the band didn't play. Their findings largely echo the study by Tepp and her colleagues. "The strongest ground shaking is definitively caused by the crowd," Caplan-Auerbach said.

The seismic spikes caused by jumping fans resemble the repetitive trembles of earthquake swarms, Tepp said. And volcanic systems often have harmonic signals associated with gases or magma traveling through a conduit. Studying harmonics from crowds could provide clues for seismologists figuring out how to identify these unusual signals in seismic data.

"The strongest ground shaking is definitively caused by the crowd."

By **Carolyn Wilke** (@CarolynMWilke), Science Writer

What's Next for the Anthropocene?

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In late March, the International Union of Geological Sciences (IUGS) issued a statement: The process that a few weeks earlier had rejected identifying the Anthropocene as a formal geological epoch was settled, and the downvote was valid. The statement came after a heated discussion about the vote's validity and whether the Subcommission on Quaternary Stratigraphy (SQS) had followed the statutes of the International Commission on Stratigraphy (ICS).

Despite IUGS's formal acknowledgment of the vote, "some uncomfortable facts will not go away," said Martin Head, a vice-chair of SQS and a palynologist and stratigrapher at Brock University in Ontario, Canada. Head suggested that there were breaches in the decisionmaking process.

"The Anthropocene Working Group was not allowed to revise its proposal after discussions within SQS had been brought to a halt, even though this is customary. This meant that important results that had recently become available were excluded from consideration," Head explained. "Even worse," he continued, "there were several statutory violations that call the validity of the vote into question."

Last year, the Anthropocene Working Group (AWG) proposed that the IUGS designate a new geological epoch, the Anthropocene, as having started in the mid-20th century. Radionuclides such as plutonium (emitted by nuclear tests) were put forth as physical markers of the new epoch. The team chose Crawford Lake in southern Canada as the reference site for the globally synchronous event that would mark the end of the Holocene.

Philip Gibbard, an SQS voting member and Quaternary geologist at the University of Cambridge in the United Kingdom, said that even if the subcommission had approved the proposal, the ICS probably would not have let it move forward. "The 'epoch-division' is too large scale when compared to other epochs such as Oligocene or Miocene—which are characterized by a whole series of elements" as opposed to the single set of radionuclide markers, he said.

"The marker is not the issue."

For Fernanda Quaglio, a paleontologist at the Universidade Federal de São Paulo in Brazil, "the marker is not the issue." To her, markers of the Anthropocene could be plastics or other proxies.

"The point," she explained, "is the temporal scale. Eighty years is a drop in the ocean in geological terms."

"It might be too early to define the Anthropocene as a new epoch, but it's also too early to end the debate."

"But that does not invalidate the discussion at all," she continued. Quaglio is worried that the downvote may have put a premature end to discussion of the Anthropocene. "It might be too early to define the Anthropocene as a new epoch, but it's also too early to end the debate.... We have to keep the conversation going," she said.

Renato de Almeida, a sedimentary geologist at the Universidade de São Paulo, has a similar view. "The issue is what the marker is signaling. Is it the beginning of a new epoch? We are at the margin of error of that limit," he said. Epochs are large geological intervals marked by patterns associated with events such as extinctions, he explained, and "the Holocene clearly hasn't ended, as its fauna and flora are still here."

"Everything we say about the human impact over the planet is true," Almeida stressed. "The problem is calling it an epoch."

To Almeida, the problem in defining an epoch stems mainly from the fact that geologists cannot know for certain what planetary changes will come after the new epoch is defined. All the epochal language of current geology is made in retrospect.

"Geologists don't deal with the future," Gibbard said, "just the past."

Event or Epoch

Gibbard and a group of colleagues defend the Anthropocene not as an epoch but as a geological "event" (bit.ly/event-not-epoch), a term that is used for occurrences such as the Great Ordovician Biodiversification Event, which took place more than 400 million years ago (bit.ly/GOBE). During this pivotal time in Earth's history, changes in tectonic activity and an uptick in marine oxygen are thought to have contributed to a radical increase in marine biodiversity—but it is not an epoch.

To Head, however, "the Anthropocene is not an event...and it's not strictly geological, as it combines social criteria. It is in fact interdisciplinary, local to regional in scale, and always subject to reinterpretation." The most substantial signals of the Anthropocene, he said, include a significant increase in human population, energy consumption, and greenhouse gas emissions.

To Simon Turner, a geographer at University College London and AWG secretary, conditions now are "very much post-Holocene." He said the recent downvote "makes Quaternary geology look further out of sync with other sciences concerned with climate change and other destructive impacts of recent human activity to our planet."

According to Almeida, it ultimately doesn't matter whether the Anthropocene is an event or an epoch. "The term is larger than stratigraphy, and it gave the discipline a visibility it never had before," he said. "Nomenclature doesn't change its importance.... People in geology and other disciplines will keep on using" the term, he said.

"The term is larger than stratigraphy, and it gave the discipline a visibility it never had before."

Almeida pointed out that something very similar happened when stratigraphers grappled with Quaternary nomenclature (bit.ly/Quaternary-period). "It was only officially approved as a period in 2009, but people were already using the term in that way decades before it happened" he said. "The ICS sort of adjusted to a change that had happened already."

By **Meghie Rodrigues** (@meghier), Science Writer

Holes in Ross Sea Ice Grow and Shrink in an Unexpected Cycle

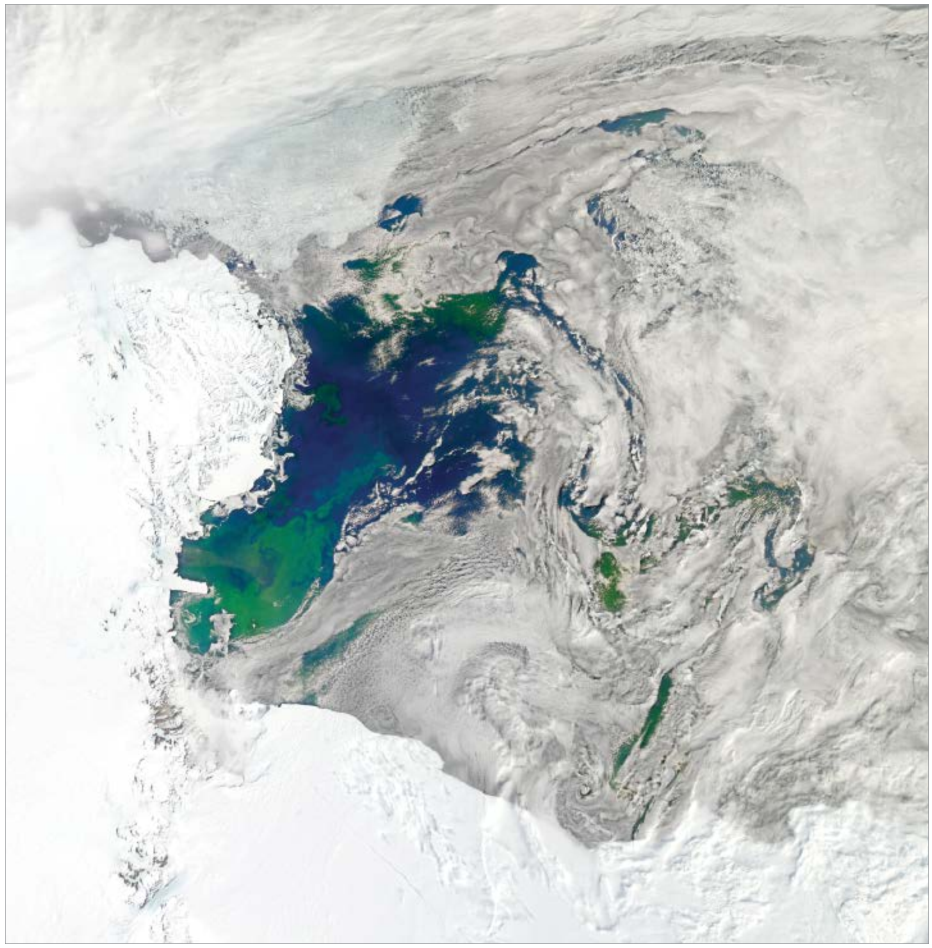
When sea ice breaks apart or is pushed away from the coast by wind, what's left behind are pockets of open water surrounded by ice, known as polynyas. The polynyas that form around Antarctica can be identified and measured using satellite data going back to 1979.

In the Ross Sea region, the size of polynyas appears to fluctuate on a 16-year cycle.

"It's quite remarkable," said Kent Moore, a climate scientist at the University of Toronto Mississauga in Canada who was not involved in the study. "I haven't seen such periodicity in polynya area before."

The discovery comes at a time when Antarctic sea ice is declining overall. But the changes in polynya area do not consistently mirror sea ice changes, said Ceridwen Fraser, a biologist at the University of Otago in New Zealand. She and colleagues published their findings in *Proceedings of the National Academy of Sciences of the United States of America* (bit.ly/Antarctic-polynyas).

For the past several years, Fraser said, "we've seen really dramatic and terrifying lows in Antarctic sea ice." She expects 2024 will see another record low. "But what people haven't really looked at quite as much is where the holes in the sea ice occur."



Open areas of water surrounded by ice, or polynyas, can be seen in this 22 January 2011 satellite image. Credit: NASA

"If there are big polynyas butting up against the coast, then there is ice-free coastline that could potentially be colonized by these coastal species that we know we're getting in from further north."

Climate-Driven Colonization

Various marine species typically found in lower latitudes, such as kelp, are moving poleward in search of more hospitable habitats, something Fraser is exploring in her research. Polynyas could represent a new path forward for them.

"If there are big polynyas butting up against the coast, then there is ice-free coastline that could potentially be colonized by these coastal species that we know we're getting in from further north," Fraser said.

One of Fraser's Otago colleagues, ecologist Grant Duffy, used daily satellite observations to identify polynyas and calculate changes in their size.

Under current conditions, most of the species that survive the journey won't find suitable habitats. But warming temperatures could allow new species to gain a foothold in Antarctica, Fraser said.

"That is bad news for Antarctic ecosystems, because these things will probably outcompete a lot of slow growing Antarctic species," she said. "But I guess you can also look at it as good news for those species that are able to reach somewhere where they can grow in the future."

Although polynya area and sea ice concentration are related, the former hasn't always changed in sync with the latter. This study suggested that the 16-year cycle in the Ross Sea shows a further decoupling of the two.

Temperature Records Offer a Clue

The polynya modeling was initially a bit of a sideline to Fraser's research into the potential for new plants and animals to stake claims in

Antarctica. Identifying the periodicity surprised the researchers and led to questions about what creates these recurring holes. Coauthor Ariaan Purich, a climate scientist at Monash University in Australia, said there is another data set with a similar cycle length.

"Examining the longer 68-year record for meteorological stations, a 16-year periodicity has been observed in winter air temperature on the Antarctic Peninsula," she said.

Purich also thinks the Amundsen Sea Low, a low-pressure system off the coast of Antarctica in the Pacific sector, could affect both temperature and polynya area.

"We can physically understand how it might influence both the temperature at stations on the peninsula, as well as the polynya area in the Ross Sea," she said. "That, I guess, is a bit of a hint that it could be the atmosphere forcing this rather than the ocean."

Purich is looking at ways the Southern Annular Mode, a circumpolar wind pattern, interacts with the Amundsen Sea Low.

But, of course, the atmosphere and the ocean constantly interact, and Purich said the ability to gather relevant ocean information at the resolution needed to study a 16-year cycle remains elusive.

"They're on the right track by looking for an atmospheric component," Moore said. "The challenge is that 16 years is an odd cycle in the atmosphere." The El Niño–Southern Oscillation, for example, has a periodicity of 3–5 years.

Both Moore and Purich said further study of the deep-ocean formation and water mass circulation could enhance understanding of the findings. Moore said he would start by investigating the extent of the polynyas.

"They're on the right track by looking for an atmospheric component."

With a limited data set and a 16-year cycle, finding answers could be slow going.

"We're not 100% sure that it's a long, long-term pattern," Fraser said. "And so looking at that into the future will be really interesting. But that's going to be something that happens over decades, not years."

By **Amy Mayer** (@amyhmayer), Science Writer

Tatooine, Trisolaris, Thessia: Sci-Fi Exoplanets Reflect Real-Life Discoveries

Tatooine familiarized people with the idea of circumbinary planets long before the first one was discovered in 2005. Credit: Journal of Science Communication – JCOM

Astronomers have identified more than 5,000 extrasolar planets since the first—51 Pegasi b—was found in 1995. As the discoveries started pouring in, they quickly realized that few exoplanets resembled anything in the solar system. Instead, they found chunks of rocks orbiting dead stars, balls of evaporating gas, planets raining rubies, and super-puffs no denser than cotton candy.

But worlds beyond our solar system captured public imagination long before 1995. They have been the settings for science fiction (sci-fi) for more than a century.

"Sci-fi already introduces the general public to lots of scientific concepts—many people probably first encounter exoplanets through science fiction," said Emma Puranen, a doctoral student at St Andrews Centre for Exoplanet Science in Scotland.

A new study led by Puranen examined how the discovery of real exoplanets has influenced portrayals of fictional ones. The researchers showed that as scientists discovered that real-life exoplanets rarely resembled Earth, sci-fi exoplanets became less Earth-like, too.

"Science fiction and popular culture are key to engaging the general public and nonscientists in current scientific discoveries," said Erin Macdonald, an astrophysicist and science consultant for the *Star Trek* franchise who was not involved with the new research. "Seeing an interesting planet in science fiction can pique curiosity and allow scientists to share the similarities and differences with actual discoveries using common ground."

Strange New Worlds

Science and science fiction have long had a circular relationship, Macdonald said. "Many science fiction writers may have a science background or a deep interest in science which then influences their work as new discoveries are made." Likewise, "scientists are often inspired to become scientists because

As scientists discovered that real-life exoplanets rarely resembled Earth, sci-fi exoplanets became less Earth-like, too.

of what they see in media and science fiction."

Puranen is a sci-fi fan herself. ("Huge fan of Mr. Spock!" she said, as well as of Becky Chambers's *Wayfarers* series and Andy Weir's *Project Hail Mary*.) She said that case studies and anecdotal evidence have suggested that science and sci-fi influence each other, but few studies quantify how the two are linked.

"The portrayal of exoplanet science in science fiction is the perfect area in which to investigate this [link] because exoplanets have long featured in sci-fi stories, but our scientific knowledge of them has completely changed since they were first discovered," Puranen said.

To quantify how science may have influenced sci-fi, the researchers crowdsourced examples of fictional exoplanets from social media groups, sci-fi conventions, and team members. These sci-fi planets originated in books, films, TV shows, video games, and podcasts and included stories told before and after 1995.

The researchers categorized planets by whether they orbited a real star, orbited in the habitable zone, were gaseous, had human-breathable air, had a biosphere, had intelligent native life, or had an established colony of non-native humans. They used a Bayesian network analysis to explore connections between these characteristics and identify trends that shifted with the discovery of 51 Pegasi b.

The analysis showed that "fictional exoplanets from after the real-life discovery of exoplanets were less likely to have intelligent native life and less likely to have established populations of non-native humans," Puranen said. Sci-fi exoplanets became less Earth-like and more likely to feature nonintelligent native life. These results were published in the *Journal of Science Communication* (bit.ly/scifi-exoplanets).

"We've known for a long time that there's a two-way influence between science and sci-fi, but it's really interesting to see it quantified and represented in this way," said Moiya McTier, an astrophysicist, folklorist, and author who was not involved with the research. "These [categorizations] are exactly the exoplanet questions people are interested in exploring."

However, McTier didn't necessarily agree that creatives were evolving with the science. "The discovery of non-Earth-like planets opened the door to new possibilities," she said, "but a lot of sci-fi creators ended up making less realistic worlds because they tend to know even less about the science of gas giants than they do about physics here on Earth." In other words, sci-fi may have started to depict more gas giants than it did before 1995, but those planets do not approximate how exoplanets actually work.

"That's fine, though," McTier added, "because I think sci-fi should be inspired by science and not beholden to it."

As real exoplanets were revealed to be unlike Earth, fictional exoplanets also became less Earth-like. Credit: britaseifert/AdobeStock

"I think sci-fi should be inspired by science and not beholden to it."

Teaching Tatooine

This research included a few long-running franchises, including *Star Trek* and *Star Wars*. Macdonald said that she would like to have seen more discussion on how exoplanet trends within individual franchises have evolved, too. "The exoplanets we see in *Star Trek* in 1966 versus the ones we see in current shows [like] *Star Trek: Prodigy* and *Strange New Worlds*, particularly, have definitely expanded based on our knowledge of what is possible out there and the desire to tell unique stories," she said.

Stories of fictional worlds can inspire scientists as they interpret obscure signals from new worlds and communicate their discoveries to broader audiences. *Star Wars* familiarized folks with Tatooine decades before the 2005 discovery of HD 202206 c, the first known exoplanet orbiting two Sun-like stars. Now, Tatooine is a ubiquitous reference in the science communicator's toolbox.

Macdonald recounted teaching an introductory astronomy class not long after the discovery of the circumbinary world Kepler-16b. Her class, which had been relatively disinterested, perked up at the comparison to Tatooine.

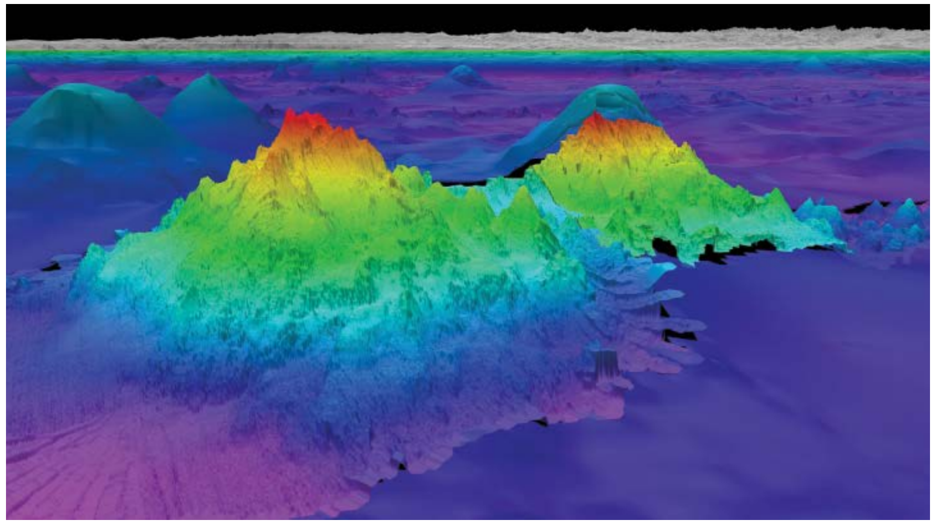
"They began asking questions like, Well, could Luke live there? Would it be a desert planet? Would the sunsets look like the movie?" Macdonald recalled. "The students were now thinking critically and asking the types of questions and thinking in the way we want introductory science classes to learn."

Puranen said that some scientists, teachers, and science communicators still hesitate to use sci-fi to make new discoveries more accessible to nonscientists because not all sci-fi makes clear distinctions between science and fiction.

"My hope is this study can help science communicators craft lesson plans to take advantage of the huge enthusiasm people already have for sci-fi to help people become more scientifically literate and engaged," she said.

By **Kimberly M. S. Cartier** (@AstroKimCartier), Staff Writer

New Seafloor Map Only 25% Done, with 6 Years to Go



The largest of four seamounts recently discovered by researchers aboard Schmidt Ocean Institute's R/V Falkor (too) *is 2,681 meters tall and covers 450 square kilometers. Credit: Schmidt Ocean Institute, CC BY-NC-SA 4.0 (bit.ly/ccbyncsa4-0)*

Ten years have passed since Malaysia Airlines Flight 370 vanished after departing from Kuala Lumpur, Malaysia, with 239 people aboard. Military and scientific personnel spent months combing unexplored reaches of the Indian Ocean, and though they failed to find the Boeing 777, the quest highlighted the fact that beneath the waves, vast areas of Earth's ocean are still a mystery.

Seabed 2030 is a long-term mapping project attempting to fully chart the seafloor and reveal all features 100 meters or larger by 2030. But with just a quarter of the job now done, it still faces tremendous challenges.

The General Bathymetric Chart of the Oceans (GEBCO) and Nippon Foundation, a Japanese nonprofit that funnels profits from motorboat racing to philanthropic causes, established Seabed 2030 in 2017. The aim was to use ocean mapping to support United Nations Sustainable Development Goal 14, namely, to "conserve and sustainably use the oceans, seas and marine resources for sustainable development." At the time, only 6% of the ocean floor had been mapped to modern standards, according to the project.

"We cannot manage what we don't know."

"Maps enable us to manage how we utilize marine space, [guide] ocean commerce and use of resources, mitigate our impacts, and achieve an improved understanding of threats such as tsunami, storm surges, and underwater landslides," said hydrographic surveyor Jamie McMichael-Phillips, Seabed 2030's project director. "Essentially, we cannot manage what we don't know."

New Discoveries

An oft-repeated observation is that we know more about the surface of Mars than about Earth's seafloor.

But that has been changing with recent discoveries. Off the coasts of Central and South America, researchers with the Schmidt Ocean Institute, a Seabed 2030 partner, found four seamounts in January 2024, including a massive one covering 450 square kilometers that is 2,681 meters tall, about 5 times the height of New York City's One World Trade Center.

At a depth of 1,150 meters, the giant seamounts were well hidden beneath the waves. To find these features, researchers aboard the institute's R/V *Falkor (too)* looked for clues on the surface of the ocean. Satellite altimetry data can show variations in the height of the ocean surface caused by gravity anomalies. A slight depression could point to a trench, and a rise could reflect a seamount.

"The most significant aspect of our findings is the validation of the satellite altimetry data that we used to target these seamounts," said John Fulmer, lead technician aboard the *Falkor (too)*. "As all of our findings were in international waters, there is no apparent political significance to speak of, but the ease with which we were able to identify potential seamounts is a testament to the importance of collective and open data resources at our disposal."

Bringing New Tools to Bear

Crowdsourcing and the use of open-source data are crucial to the Seabed 2030 project. It relies on data donations from a range of sources: scientists and philanthropists; offshore survey companies; and fishing, cruise, and cargo vessel operators.

In November 2023, for instance, Seabed 2030 announced the donation of a data set covering 8,000 square kilometers of remote areas. U.K.-based remote sensing company ARGANS (Applied Research in Geomatics, Atmosphere, Nature and Space) provided the high-resolution bathymetric data derived from satellite observations, one of the main data-gathering methods, along with aircraft-based lidar sensing and sonar readings.

In another example, the Japan Coast Guard donated to GEBCO a large bathymetry data set covering areas around Japan and Antarctica, according to Haruka Ogawa, a researcher in the coast guard's Hydrographic and Oceanographic Department.

"The most significant aspect of our findings is the validation of the satellite altimetry data that we used to target these seamounts."

All Seabed 2030 data are uploaded to the free-access GEBCO grid of the seafloor. The grid shows that 24.9% has been mapped at the resolution specified by Seabed 2030, leaving about 75% to be done over the next 6 years if the project's goal is to be met. That's a massive undertaking considering such challenges as permanent ice cover near the poles and the fact that about half of the global ocean is deeper than 3,200 meters.

Because vessels are usually needed for the job, it makes for a slow, costly endeavor with a bias toward areas with expertly equipped ships, said Katleen Robert, a seafloor and habitat mapping researcher at Memorial University of Newfoundland, in Canada. She said she sees autonomous vehicles, both underwater and surface, as having the largest impact on how much of our oceans we will map in the near future.

"These will act as force multipliers and enable us to acquire higher-resolution data and repeat data sets to monitor changes over time," said Robert, who is not directly involved with Seabed 2030, although expedition data she was involved with support it.

In 2023, Seabed 2030 partnered with U.S. company Saildrone to promote the use of uncrewed hydrographic vessels. Powered mainly by wind and solar, Saildrone's 20-meter surveyor drone can gather multibeam sonar data to depths of 7,000 meters for a fraction of the operating cost of crewed ships. One surveyor found a 1,000-meter seamount off California during a months-long surveying mission that saw 35-knot winds and 5-meter swells, according to the company.

> **"We know that we will be much closer to a fully mapped planet than the 6% that had been mapped when the project started."**

Other researchers are hoping that artificial intelligence will accelerate the mapping mission. In addition to surface and underwater exploration vessels, researchers at the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) are deploying deep learning techniques to enhance the resolution of existing topographic data.

An approach using convolutional neural networks is "surprisingly effective" and can be used as a complementary method to direct depth sensing, said Eiichi Kikawa, a data scientist at JAMSTEC. He added that a paper on the research has been submitted for publication.

It's too early to tell whether these tools could help Seabed 2030 meet its goal in 6 years, but the project is relying on more partnerships to increase coverage of the seafloor.

"We are aware of the magnitude of the challenge that still remains and are working with the global community to push to complete the job by 2030," McMichael-Phillips said. "However, with the progress that has already been made, and with the time left until the end of the decade, we know that we will be much closer to a fully mapped planet than the 6% that had been mapped when the project started."

By **Tim Hornyak** (@robotopia), Science Writer

Snapping Science in the Field

Microbes helped to form microbialite mounds (blue outlines) at Antelope Island State Park in Utah's Great Salt Lake. Students, pictured here, study the mounds at their feet during a field excursion in September 2021. The remains of former lake shorelines in the distance (and meters above where the students are standing) are identified with green lines. The photo was annotated with Snapchat, which makes it quick and easy to point out geological features that are harder to see in photos. Credit: Sabrina Kainz

Creating effective, information-laden field sketches is often a key skill for geoscientists to develop as they progress in their career journeys. From our first field trip to our hundredth visit to a research site, we are taught that visuals are vital for documenting important and often subtle place-based information, and for doing good science.

Hand-drawn sketches of outcrops, fault lines, and other scientifically interesting features can record and highlight important details—such as fracture patterns or obscure trace fossils—that may be difficult to spot in photographs. However, not all of us have the gift of artistic finesse. We may find ourselves squatting next to an outcrop for far too long, only to end up with a mess of squiggles somehow meant to resemble a tree (or maybe it's some cross-bedding?).

Practice can make perfect for some, but backing up field notes with digital images often provides greater context. Taking photos on smartphones is already commonplace in field geoscience. However, corroborating these pictures with handwritten notes and later trying to decipher what you were photographing in the first place can be frustrating.

What if you could annotate field photos on site and in real time?

As early-career scientists and avid smartphone users, it seems almost second nature to us to use Snapchat for this purpose. Although the app's primary use is for messaging, its huge range of features has made it extremely popular as a photo and video editing tool.

Here we briefly describe how we have used Snapchat on our smartphones to create and share informative, quick, and eye-catching annotated images of regional geology in the Rocky Mountains. (Today, many social media apps—including Instagram, TikTok, and others—have editing capabilities similar to Snapchat's and can also be useful for annotating images, organizing notes, and communicating science accessibly and engagingly.)

We hope our experiences illuminate applications of an accessible, easy-to-use tool that other scientists may find similarly useful in their work.

Annotations, Mapping, and More

For geoscientists, writing and drawing directly on pictures is perhaps the most useful editing feature of Snapchat. The app's pencil tool, which can be changed to various colors and weights, is a simple but powerful aid that helps organize notes and draw attention to important features in photos of landscapes, outcrops, and collected samples.

During a recent geobiology field course tovisit the rocks of the Green River Formation in Colorado, Utah, and Wyoming, we documented a wide range of geological informa-

Fig. 1. Scenes from a field trip to southwestern Wyoming to view the Green River Formation were annotated using Snapchat: The Mahogany Zone (left) is a prominent and well-studied shale layer; collections of ostracod shells (middle top) occur in the formation and give clues about ancient lake shorelines; fossilized layers of ancient microbes called stromatolites (middle bottom) are also found in the formation, sometimes encircling fossilized tree trunks (right). Credit: Andrea Halling and Sabrina Kainz

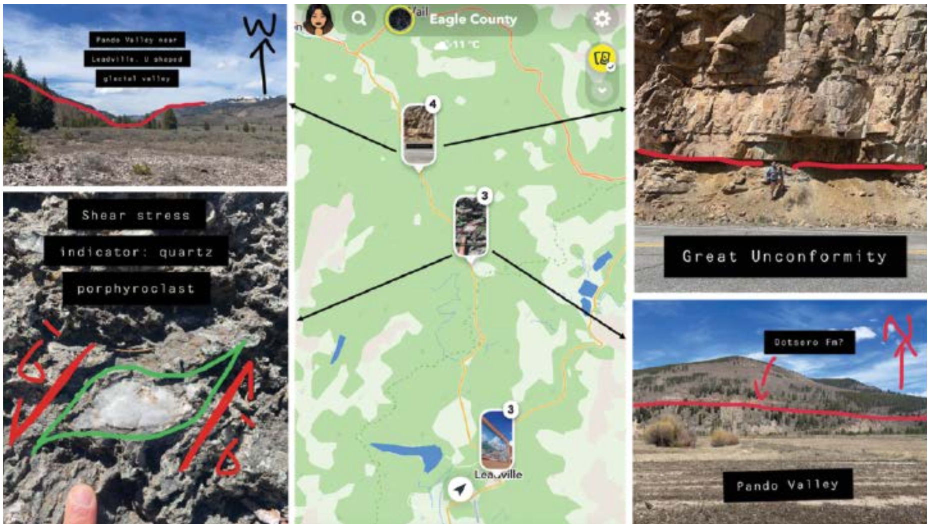


Fig. 2. The authors used Snapchat's Snap Map feature to map a trip through roadside geology along U.S. Route 24 from Vail to Leadville (middle). Annotated photos of different sites and features taken during the trip were geolocated on the map. Credit: Sabrina Kainz

tion, from large landscapes to centimeter-scale rock fabrics. Figure 1 highlights examples of our annotations related to the Mahogany Zone, a layer of shale in the Green River Formation. The well-preserved and well-studied outcrops of the Green River Formation record roughly 6 million years of sedimentation of Eocene (~54–48 million years ago) lake basins along the modern-day Green River.

Much of the geological context can be lost in field photos, but annotating our "snapped" images preserves that extra information.

The regularly repeating thicknesses of the strata in this formation are striking and illustrate cycles in the rising and falling shorelines of these ancient lakes. Small shells of crustaceans called ostracods give clues about the depths and locations of these past shorelines (Figure 1). Ancient fossilized stromatolites, layered sedimentary structures produced by microbes, are also abundant in this landscape. Mysterious stromatolite rings can be seen surrounding what look like fossilized tree trunks from the Eocene.

Much of the geological context can be lost in field photos, but annotating our "snapped" images preserves that extra information.

Another useful feature of Snapchat is its capability to make personalized maps. When you save an image to the app's personal Memories function, it preserves geolocation data and adds them to an internal Snap Map that only you can access. Referenced images let you know exactly where outcrops and formations of interest were located or where samples were collected.

In our research, for example, we have used the maps tool, alongside conventional GPS tools, to track sample transects. And during a recent road trip in Colorado from Vail to Leadville, we used Snap Map to document the locations where we stopped to view metamorphic features, glacial landscapes, and exposures of the Great Unconformity, a globally recognized geological feature characterized by a gap in the rock record of up to 1.3 billion years (Figure 2). We also took many photos from inside a moving vehicle, which Snapchat easily saved and added to our road trip map.

In addition to annotations, we have added "stickers" and geotags displaying information like date, time, temperature, and elevation to Snapchat photos (Figure 3). Although we do not advocate replacing equipment designed to collect location and environmental information rigorously, Snapchat's features offer an easy way to provide quick, first-pass contextual information about a site. The maps and annotated images also offer a rough draft of sample names and noteworthy attributes that can be carried around in your pocket. Further, these capabilities allow researchers to create interactive maps and other visual aids that can be included in poster and oral presentations.

Snapping and Sharing

In addition to their benefits for easy, on-the-go note-taking and organization, using social media apps in field research can be an excellent way to communicate your science to wider audiences. By adding clear, colorful text, labels, and annotations to photos and videos, geoscientists can easily create informative, engaging, and accessible content to share and promote public engagement and scientific literacy. Our audience could be hundreds of people diligently watching our Snap stories or just a cousin we haven't caught up with since the last family reunion.

With the "story" feature in Snapchat, users can create narratives—about a particular geological site or feature, for example—to

Fig. 3. Snapchat stickers can be used to annotate images with environmental and temporal information, as in this photo taken at Great Sand Dunes National Park and Preserve in Colorado. Credit: Sabrina Kainz

Fig. 4. During a trip to Great Salt Lake, the authors posted live updates of their study of a microbial mound, dubbed Thomas. Stories about Thomas were posted to Snapchat so the public could follow his journey from collection to dismemberment. Credit: Andrea Halling

engage viewers and help convey complex scientific concepts. (Similar features are available in other apps, such as Instagram stories and reels or TikTok videos.) These narratives create a way for peers to look at your science, while keeping a record for you.

During our geobiology field course, we spent 3 days at Great Salt Lake in Utah, in part to study its actively growing microbial mounds. These living stromatolites offer fascinating insights into processes that may have shaped how the features formed in the ancient past.

Participants in the course were tasked with completing a small group field project.

Our group chose to analyze microscopic and macroscopic structures we observed in a single microbial mound (which we lovingly named Thomas). While documenting our fieldwork, we also posted live updates to our Snap stories for our followers, who include both geologists and nongeologists. In these updates, we narrated the process of selecting a microbial mound, described in detail how it felt and smelled (of rotten eggs), and posted updates as Thomas was dissected.

A handful of followers were invested in Thomas's fate and reacted to our stories with comments or science-themed emojis (Figure 4).

Read the article at Eos.org

Caveats and Concerns

Along with the benefits of using social media apps for science and science communication, there are drawbacks and potential pitfalls to consider. One drawback of some Snapchat tools, for example, such as the stickers that provide environmental information about a location (as in Figure 3), is that they require mobile data or Wi-Fi service to work properly. This coverage is often not available at remote field sites, which constrains some of the app's features.

Even far from cell service, however, features like the pencil annotation offer good ways to keep a personal visual diary of observations. And when real-time sharing isn't possible, stories and images can be saved and shared later or through a different platform.

Beyond issues related to service availability, there are, as with all social media, privacy and other concerns to consider when using Snapchat. Scientists sharing novel ideas or data before they are published must be aware of the potential concerns, including those over intellectual property claims, priority and credit issues for new discoveries, ethical considerations, and potential scientific misinterpretations. It is also important to note that social media platforms often share user data with third-party platforms (e.g., for targeted advertising).

Digital pitfalls abound in the Internet age, so we must be smart about what we choose to share online—once it is out there, there is no taking it down. Considering possible repercussions intentionally and getting necessary permissions (e.g., from individuals featured in photos) before posting are imperative for mitigating privacy concerns and protecting our (and others') work.

Embracing New Tools

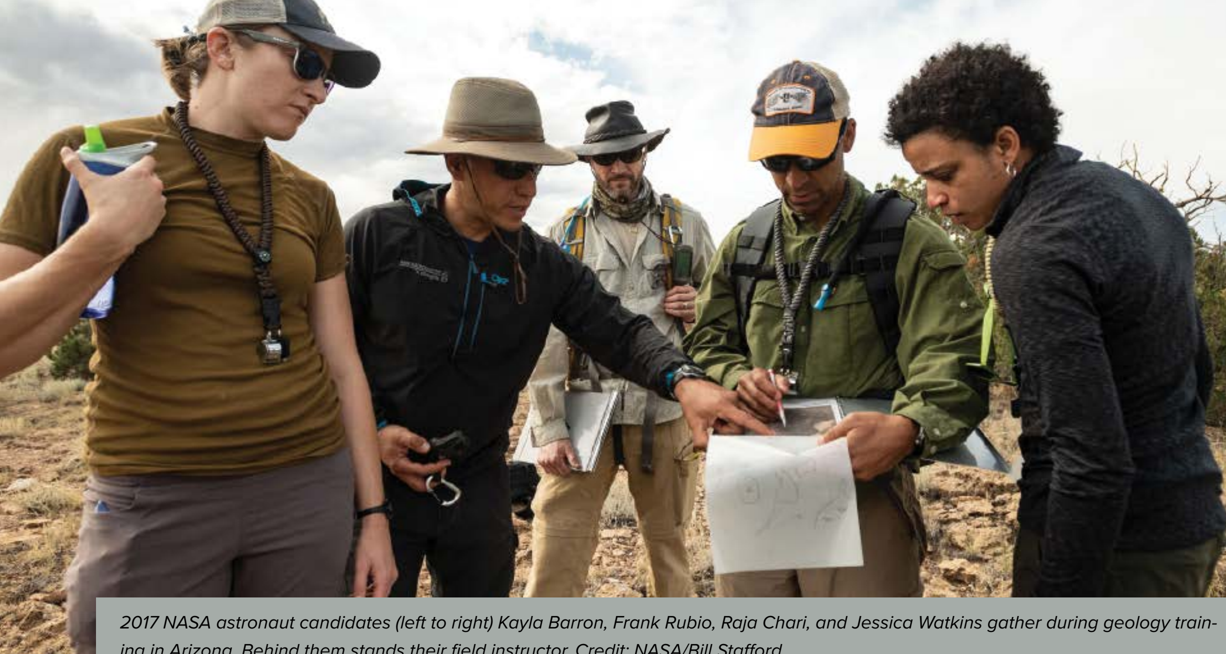
Snapchat popularized instant photo sharing, but other social media apps have followed in its footsteps, and easy photo and video editing and sharing are now the norm. Many of these apps can be useful for supporting scientific observation and advancement; in our experience, Snapchat has proven to be a versatile, easy-to-use, and effective platform.

There are challenges and concerns for scientists to overcome with social media usage, but the potential benefits of using Snapchat and other apps in field science should not be ignored.

Researchers can leverage Snapchat's range of features—from image annotation to mapping to location-based filters, augmented reality, and real-time communication—to capture and share geospatial data with ease, collaborate with peers, and engage wider audiences. Further, the popularity of social media platforms among young people provides opportunities to promote scientific literacy and inspire the next generation of geoscientists.

We feel it is important, as technology continues to evolve, for scientists to embrace new tools and platforms, both to advance their work and to meet audiences where they are, to better communicate the fascination and relevance of scientific research.

By **Sabrina Kainz** (skainz@uw.edu; @brinaluvsrocks), University of Colorado Boulder; now at University of Washington, Seattle; and **Andrea Halling,** University of Colorado Boulder



2017 NASA astronaut candidates (left to right) Kayla Barron, Frank Rubio, Raja Chari, and Jessica Watkins gather during geology training in Arizona. Behind them stands their field instructor. Credit: NASA/Bill Stafford

The Art of Doing Fieldwork on the Moon

By Mark Betancourt

David Kring, call sign EV1, describes a boulder that was ejected from Arizona's Meteor Crater to students listening in from a virtual science operations center. Credit: NASA/SSERVI/Ricky Guest

HOW EARLY-CAREER PLANETARY SCIENTISTS ARE PREPARING TO SUPPORT THE ASTRONAUTS WHO WILL RETURN TO THE LUNAR SURFACE AND BEYOND.

2017 NASA astronaut candidates and their field instructors hike as a team at Meteor Crater in Arizona. Credit: NASA/Bill Stafford

2017 NASA astronaut candidates with their field instructors during geology training in Arizona. Credit: NASA/Bill Stafford

Warren Hoburg conducts fieldwork during Earth and planetary science training in Rio Grande del Norte National Monument's upper Rio Grande Gorge area near Questa, N.M., in 2017. Hoburg was an astronaut candidate in 2017 and has since piloted a SpaceX vehicle as part of a NASA Commercial Crew and is part of the Artemis program. Credit: NASA/Norah Moran

2017 NASA astronaut candidates Kayla Barron (left) and Jessica Watkins (right) examine samples. Credit: NASA/Bill Stafford

Walking to the edge of Meteor Crater, David Kring wore hiking clothes, a day pack, and a wide-brimmed canvas hat. The look fit the traditional image of a field geologist scouring a unique landscape. His earpiece and microphone didn't quite fit the image, but they allowed him to communicate with his support team at Mission Control while keeping his hands free to swing a rock hammer.

Meteor Crater, lying just west of Winslow, Ariz., is possibly the best preserved impact crater on Earth. During a warm week in September, Kring took advantage of its similarity to the craters of the Moon. Over the course of 2 days, he played astronaut to give two groups of graduate students and postdoctoral researchers a sense of what's involved in extraterrestrial fieldwork.

> "If the students in the science operations center work with the astronaut correctly, then some really great science can come out of that."

Kring, a planetary scientist at the Lunar and Planetary Institute in Houston, is a veteran field geologist who specializes in impact craters. Among other discoveries, he helped link the Chicxulub crater in Mexico to the apocalyptic collision that killed off nonavian dinosaurs.

The students, who video conferenced in remotely from their homes and offices all over the world, were tasked with directing Kring's traverse. They were armed with satellite images of the area, along with a list of tools he was carrying, a digital elevation model, and a slope map. A NASA technician followed Kring with a camera, streaming video to the students.

"It was like a third-person video game, watching him walk through this terrain," said Hunter Vannier, a fourth-year planetary science Ph.D. candidate at Purdue University in Indiana who studies volcanism on the Moon. He hopes one day to play a role in lunar exploration, and participating in the first of Kring's two traverses was a step in that direction.

The mock extravehicular activity (EVA) course is just one of several trainings Kring has developed over the past 15 years in anticipation of NASA's return to the Moon. Kring's program supported the short-lived Constellation crew's flight program, as well as its successor, Artemis.

Artemis astronauts will be the first to walk on the Moon since 1972, with a crew expected to touch down as early as 2026. After the half-century hiatus from the lunar surface, researchers, astronauts, and flight engineers are relearning how to explore in the field beyond Earth.

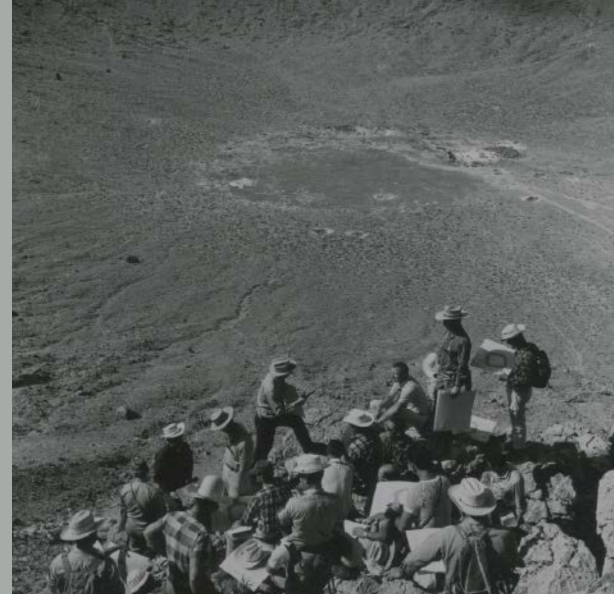
Kring is helping to prepare the next generation of planetary scientists to support crewed missions to the Moon and, one day, to Mars. Handling the Meteor Crater EVA, where the moonwalk is simulated but the geology is real, will get them started. "If the students in the science operations center work with the astronaut correctly, then some really great science can come out of that," Kring said.

ARMCHAIR EXPLORATION

Many of the Meteor Crater EVA students had trained in the field as part of their formal education, but extraterrestrial fieldwork requires a unique skill set not usually taught at university field camps.

Not only must the scientists know how to map and catalog the geology of a landscape by probing, scratching, and occasionally smashing parts of it and making off with the pieces; they also must be able to direct someone else—an astronaut—to do it for them. And they'll have to do it by committee.

David Kring (right) works with graduate students at his Field Training and Research Program at Meteor Crater in 2011. Credit: David Kring



Gene Shoemaker (gesturing with a rock hammer) gives a geology lesson to a group of astronauts-in-training at Meteor Crater in the 1960s. Credit: USGS

Rather than having students all chiming in with instructions, Kring's communication system allowed him to hear only one person: the SciCom, in operational parlance. In this case, the role was played by NASA planetary scientist Debra Needham, patched in from Washington, D.C.

The students decided on a course of action for Kring, then typed it into a Discord chat for Needham, who relayed the request to Kring. (Discord is an instant messaging and VoIP social platform.)

Christina Verhagen, a postdoctoral researcher at Michigan Technological University who studies how impact events can make a planetary surface more habitable, logged on from a beanbag chair in her basement while a sitter watched her toddler upstairs. Verhagen was hoping Kring could sample the smaller craters that dot the plain surrounding Meteor Crater, to see whether the rocks there also showed signs of the heat and shock pressures created when a 30- to 50-meter-wide iron asteroid slammed into Earth around 50,000 years ago.

Once Kring's feed came up, he described the landscape from his landing site, then took a "contingency sample" from the area near his feet—a consolation prize in case the rest of the mission had to be scrapped. Then the clock started on his field trip. He had 4 hours—the remainder of his make-believe oxygen and coolant supplies.

"Houston, EV1," he said into his headset, using his designated call sign. "Standing by for traverse instructions."

IN THE FOOTSTEPS OF APOLLO

More than 50 years ago, Apollo astronauts trained at Meteor Crater, too, learning to sample rocks and trying out their Moon buggies on a nearby lava flow. Those outings taught astronauts, most of whom were trained as test pilots, the basics of making scientific observations in the field.

Their teachers were all "bona fide" field geologists, Kring said; the legendary pioneer of astrogeology Gene Shoemaker, who helmed the astronauts' geological education, had mapped Meteor Crater itself. The instructors all had rigorous careers studying rocks on Earth, and they were learning on the fly how to take the enterprise elsewhere.

"There was no planetary science," Kring said, until humans sallied forth into the cosmos to collect samples and firsthand observations. "Apollo created the need for a field of planetary geology and planetary science."

Later, after the last crewed Moon landing, the field became all about remote observations made by robots and orbiting instruments.

"Rather than, you know, hiking through the dirt and stubbing your toe on rocks," Kring said, "you suddenly had people simply looking at pictures or looking at spectra of a surface, and that drew talent from other fields." Writing code and handling large amounts of data became key skills. Physicists and astronomers came into the fold, as did atmospheric scientists who studied the spectroscopic makeup of distant bodies.

FIELDWORK FOR ACADEMICS AND ASTRONAUTS

Kring's trainings are meant to help recenter geological field expertise within the planetary science community. In addition to the mock moonwalk, the trainings include an intensive course on spaceflight operations at NASA's Johnson Space Center in Houston and an 8-day field camp at Meteor Crater or another lunar-analogue site. Hundreds of students from across disciplines have participated in the trainings since Kring began the program in 2008, and several have gone on to work for NASA.

> "It takes years to learn a language, and we consider geology something of a language here."

Kring offers similar courses to the new generation of astronauts, who must learn not only to conduct fieldwork but also to act as an extension of the collective will of a roomful of researchers back in Houston. Because the science team at Mission Control will be able to see only so much through remote cameras, the astronauts must learn how to describe what they're seeing in a running commentary that's rich with scientific information.

"It takes years to learn a language, and we consider geology something of a language here," said Cynthia Evans, a field scientist at Johnson Space Center.

Evans directs NASA's multiyear Artemis geology training program. It involves a traditional "field camp" where astronauts learn how to make geological observations and collect samples (often intersecting with Kring's trainings, which are conducted through the Lunar and Planetary Institute), as well as mock exercises designed to give astronauts practice doing fieldwork with the equipment they'll use on a real mission.

The program is developing basic geology courses for operational managers and engineers, who may not have a background in geology, so they can develop an appreciation for the scientific goals and challenges of the Artemis program.

Wishing to give astronauts a unique look at the Moon's layered rocks, mission planners might prepare to send astronauts into underground lava tubes, for example. But basic geological training would help them realize that lava coats the inside of those tubes as it flows through them and cools, obscuring the layers from view. An engineer may suggest sending astronauts out with expensive instruments to identify rocks, but a bit of field training would show them that most rocks can be identified by sight or brought back for further study in a lab.

Evans pointed out that it's a two-way street, with scientists also learning about the operational constraints of conducting fieldwork in an airless environment almost 400,000 kilometers from home. "There's just a lot of logistics involved in putting one step ahead of the next," she said.

"It's humbling."

Meteor Crater, in Arizona, played the part of the Moon in a recent exercise simulating moonwalks for students and early-career planetary scientists. Credit: National Map Seamless Server

SEEING THE BIG PICTURE

As Kring set out on his second mock EVA, some of his students got a small taste of that humility right away.

"We actually had a bit of a challenge finding him," Verhagen said. There are no lunar satellites to guide a GPS, and a compass is useless in the Moon's spotty magnetic fields, so Kring carried neither. The team asked him to walk toward a nearby outcrop to give them a known starting place for his traverse, but they got turned around on the way.

At times, Kring stood still while they deliberated, waiting for instructions. In his debriefing afterward, he advised the students to keep the astronaut moving because time is so precious, and it will be a long time, if ever, before anyone can return to a given site. "Traverses are linear," he said. "If you do not capture it then, it is forever lost."

That time constraint was novel to Vannier, who noted that he can take as long as he wants gleaning observations from orbital imagery. With a crew of astronauts putting their lives on the line for science, a support team can't afford to waffle about which samples to take.

"Decisions need to be made much faster than planetary scientists are used to," Vannier said.

That means science support teams need to be well versed both in what astronauts are describing to them and in the challenges the crew is facing.

Before studying as a postdoc with Kring, most of Amy Fagan's field experience was in the verdant mountains of western Virginia, and she hadn't yet considered how challenging fieldwork can be at a site like Meteor Crater. "It's a fairly small impact crater," said Fagan, who is now an associate professor of geology at Western Carolina University, "but you stand on the rim and it's huge, and imagining trying to get down to the bottom is very difficult. And it's certainly not anything you would want your crew to do." (Meteor Crater is a little more than 1 kilometer from rim to rim—some craters on the Moon are hundreds of kilometers wide.)

The experience also placed the Apollo samples she'd been analyzing in the lab into an entirely new context. She could see how the rocks were formed and why they ended up where they did. Being there, she could visualize the complete story of a meteor impact for the first time.

Kring talks about this kind of moment in a crescendo of zealous excitement. "Field geology is when you go into a mountain range and you find a 100-meter-thick sliver of ultramafic rock and you realize, 'Oh, my God, I'm looking at the ocean floor that's been obducted onto the continent,'" he said. "It's a completely different level of vision; three-dimensional vision and fourth dimensional, in terms of time."

The art of field science is often about noticing patterns or things that stand out, even if you don't yet know why they might be important.

To illustrate this, Kring often tells his students the story of Seatbelt Rock. During the 1971 Apollo 15 mission, astronauts David Scott and James Irwin had just wrapped up an EVA and were driving their rover back to the lander. Scott spotted a vesicular, low-titanium and olivine-bearing piece of basalt that looked different from everything else around it. Knowing that Mission Control might not approve a detour, he pretended to have trouble with his seatbelt. While he and Irwin were "sorting it out," Scott dashed over to collect the rock.

And beyond understanding what scientists expect them to find on the Moon, astronauts must also prepare for those expectations to be completely wrong.

Apollo 16, which landed on the Moon in 1972, said Kring, was a perfect example. The geologists back on Earth said, "'You're going to land and there's going to be two volcanic terrains there.' John Young and Charlie Duke landed, and they said—cryptically, because they knew they were on an open mic and the world was listening—'Houston, there's no volcanic rocks here.' It was 100% impact crater terrain."

HUMAN LIMITS

After Kring got sidetracked on his EVA, the student science team pushed him toward the main crater to make up time. He started to sweat. He reminded them that he was using up more of his imaginary space suit's coolant. As he worked his muscles harder, he was also burning through more of his oxygen supply. And the terrain itself was getting dicey. Knowing the slope of a crater wall is one thing, Kring said later; actually climbing down it is another. As he approached the crater rim, he advised the team that it didn't look safe for him to keep going.

> The trick is to "maximize the unexpected."

The exercise was eye-opening for Vannier. Though he's done fieldwork in Iceland and Hawai'i, he hadn't developed an appreciation for the challenges of moving around a landscape like the ones he studies in orbital images of the Moon. "I can't get nearly enough fine-resolution detail from just remote sensing data to allow me to have an appreciation of how difficult this is," he said.

As time ticked by, Kring began to worry about his remaining life support. "I can't see my lander," he told the team. As they discussed their next move, he said it again.

For Verhagen, the concern in Kring's voice, however simulated, invoked memories of narrowly escaping lightning storms or getting lost while conducting her own terrestrial research. The danger on a lunar mission will be incomparably greater, but so will the reward, and the potential thrill of being surprised when an astronaut describes—and brings back—something truly new. Rather than be a setback, Verhagen said, surprises can open up new paths, and new discoveries. That's the nature of fieldwork. The trick, she said, is to "maximize the unexpected."

Though the second team managed to get Kring back to his "lander" before his "oxygen" ran out, he didn't have time to properly sample much of the area. What they needed to do from the outset, Kring said, was to direct him to head straight for the crater in a radial line, along the way collecting from every rock type that was excavated by the meteor's collision with the surface. By eating up time getting oriented, the students lost their chance to capture a complete picture of the impact event.

But the samples themselves weren't the goal of this particular mission. "It also made it evident to most of the students that if they wanted to proceed down this path, if this is an area of science and exploration that they want to participate in, [then] they have some learning to do," Kring said. "In that sense, it was a home run."

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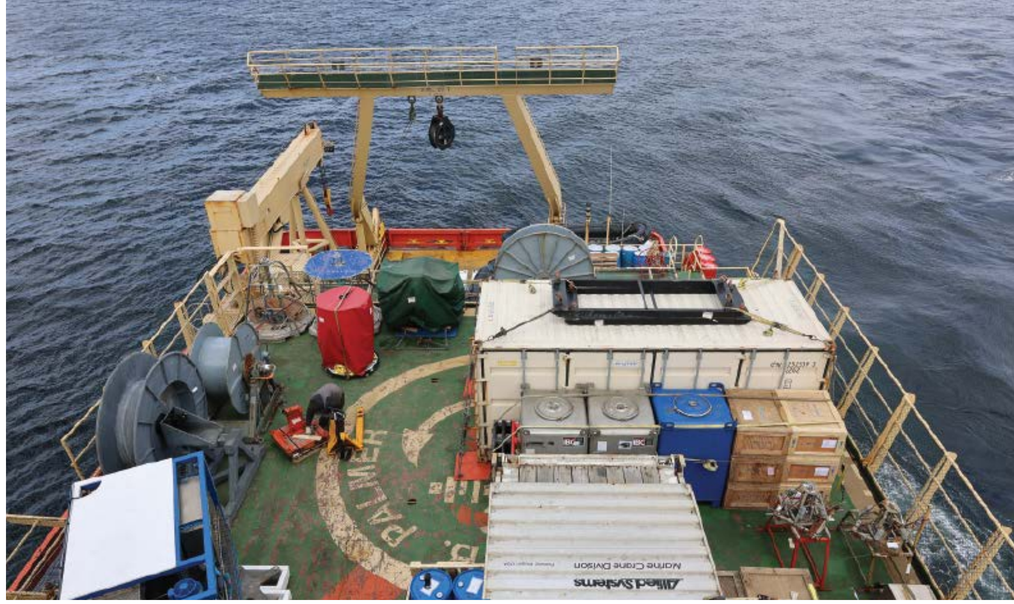
Read the article at Eos.org

Confined at Sea at the End of the World

By Sofia Moutinho

Embedded on a research cruise in the Antarctic, a journalist joins a scientists' "summer camp."

An ice floe floats in the Amundsen Sea close to the shore of West Antarctica. Credit: Sofia Moutinho



Boxes, crates, and barrels of scientific equipment crowd the deck of R/V Nathaniel B. Palmer. *Credit: Sofia Moutinho*

As I stood on the bow of the icebreaker, cold wind gently touched my skin, and the never-setting summer Sun shone over snow-covered mountains emerging from the calm sea. Dozens of penguins accompanied the ship. They swam like torpedoes, cutting through the glassy water below while snow petrels surfed on gusts above. And a lazy seal, lying like a giant slug on an ice floe, lifted its head as the sounds of camera shutters filled the air.

I was on a cruise in Antarctica. Every year, hundreds of tourists pay thousands of dollars to see this landscape.

But this was no vacation. I had joined GEOTRACES 17-ANT (GP17-ANT), a scientific cruise led by an international research team focused on understanding marine biogeochemical cycles. Launched in 2010, the GEOTRACES initiative surveys every major ocean basin in the world, including the Southern Ocean, where we sailed.

"It is not a cruise, really. It is an expedition with a lot of work."

For 65 days, we cruised alongside the icy continent on the 94-meter R/V *Nathaniel B. Palmer*, a U.S. icebreaker. Within the confines of the ship's steel walls, 35 researchers worked in shifts around the clock, with no weekends, holidays, or days off. Hundreds of kilometers from civilization, we remained at sea at all times with little to no Internet connection or phone service. The scientists' job: collect and analyze thousands of liters of water, snow, and sea ice.

"Americans call this a cruise, and of course, everybody immediately thinks of a huge cruise boat with many fun activities," said Carl Lamborg, an oceanographer at the University of California, Santa Cruz, who studies mercury in the ocean. "But it is not a cruise, really. It is an expedition with a lot of work."

GOING SOUTH

Our journey started in the small Chilean port town of Punta Arenas in November 2023. The *Palmer* left port late because of 69-mile-per-hour (111-kilometer-per-hour) wind gusts that forced the port to close for a day and because of problems with some essential cargo:

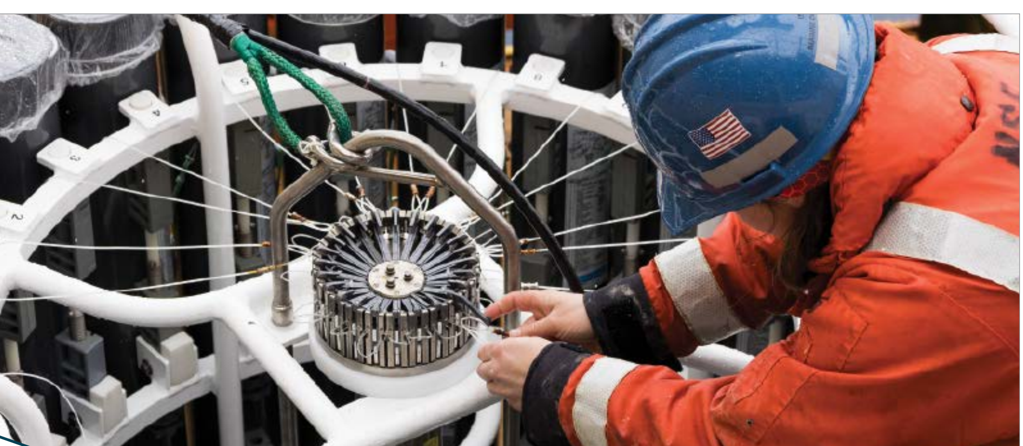
- A $13,000 consignment of acid destroyed in transit from the United States to Chile had to be replaced.
- A crucial piece of equipment, needed and tailored for the ship, didn't fit the space where it should go, so metalworkers had to be called in to adapt it to the *Palmer*'s actual specifications.
- Some lab boxes and personal luggage (including mine) were lost in the airport.

When the weather allowed and the issues were resolved, we left Chile. We navigated 4 days through Drake Passage, which separates South America and Antarctica and is universally recognized as one of the roughest seaways on the planet. Seasoned mariners shared stories about facing 10-meter-tall waves in the passage, but we were lucky: Waves didn't surpass 5 meters high on our worst days.

It took us another week to cross the Antarctic Circle at 66°S and reach one of Earth's most remote places: the Amundsen Sea, in West Antarctica. Only a few research cruises had ventured there, and no GEOTRACES expedition before ours had done so.

As Lamborg talked to me in the ship's main lab, the continuous sound of ice crashing against the ship's hull muffled his voice. Sea ice melts during the Antarctic summer—but it never melts totally. During our journey, the *Palmer* plowed through the Amundsen Sea, ramming through blocks of sea ice up to 2 meters thick.

In addition to sea ice, we also encountered several immense icebergs, like B-22A, the fourth largest in the world and 4 times the size of New York City.



Laura Moore prepares Rosie the rosette on board the Nathaniel B. Palmer. *Credit: Sofia Moutinho*

West Antarctica and the Amundsen Sea are home to the fastest melting glaciers on the continent, including Thwaites, known as the "Doomsday Glacier" because of the catastrophic effect its collapse would have on sea level rise. (B-22A calved from Thwaites in 2001.) Scientists estimate that West Antarctica is currently losing about 80 billion metric tons of ice per year.

All that discharge is not only increasing sea level but also changing the ocean's chemistry. As the glaciers melt, they dump into the sea a variety of materials trapped from the atmosphere or scraped from Antarctic bedrock hundreds or sometimes thousands of years earlier.

The goal of the scientists of GP17-ANT was to map the distribution and concentration of different trace elements in the water to understand how the ecosystem is changing as the planet gets warmer. Trace elements such as iron, thorium, and manganese can reveal details of ocean phenomena such as algal blooms, currents and circulation, and carbon storage.

"Most of the work in this region has been focused on the geophysics of ice melt," said expedition coleader Phoebe Lam, a chemical oceanographer at the University of California, Santa Cruz. "But we are using chemistry to look for clues to understand the geochemical and biological environment of this part of the ocean."

"It feels like you're at a summer camp" with people passionate about the same things you are.

WORK, EAT, SLEEP, REPEAT

The search for these trace elements involved a lot of hard work. It didn't matter whether it was day or night; a weekend; or even Thanksgiving, Christmas, or New Year's Eve (holidays we spent on the *Palmer*).

Despite long hours and hard work, the shared experience bonded the researchers into an onboard fraternity. "It feels like you're at a summer camp" with people passionate about the same things you are, said Marissa Despins, Lamborg's Ph.D. student at the University of California, Santa Cruz. "So it's a lot of fun because you get to go to an interesting place and be surrounded and immersed in science."

The majority of the 67 passengers on the *Palmer* were researchers, mostly graduate students supervised by a few principal investigators and chief scientists. Although affiliated with universities in the United States, researchers came from all over the world, including Australia, France, Germany, and Nepal. They were largely divided into two main groups: analysts processing and analyzing samples in *Palmer*'s onboard labs and the so-called supertechs, science technicians in charge of the sampling.

Apart from the science team, there were also marine technicians, hired by the U.S. Antarctic Program to oversee deck and machine operations; a marine project coordinator; a marine lab technician responsible for lab safety; electronics technicians; and 21 crew members. And there was me, a journalist.

The responsibilities of GP17-ANT kept scientists and crew so busy that most interactions between the teams were confined to the chief scientists and the captain and mates to discuss the *Palmer*'s route.

Wearing safety helmets, steel-toe boots, heavy orange floating coats, and rubber pants, the supertechs had the most physically demanding jobs among the scientists on board.

Supertech responsibilities included helping set up equipment like the rosette, a large barrel-shaped metal frame with more than a dozen sampling bottles clustered around it. (The ship had two of these, nicknamed Gladys and Rosie after the results of an informal whiteboard poll.)

A cable lowered this instrument into the sea with bottles cocked open. As the instrument sank, the bottles closed to collect water at different depths. Once the rosette was back on deck, the supertechs either filled separate containers with the water or carried the rosette's bottles directly to the *Palmer*'s labs, where the samples were analyzed or stored for later studies.

On this cruise, the supertechs also collected samples from pumps attached to a wire and lowered into the ocean to get large volumes of water and from the tow-fish, a small torpedo-shaped sampler towed alongside the ship to collect surface water.

The author poses in her emergency floating suit designed for the icy waters of the Southern Ocean. Credit: Sofia Moutinho

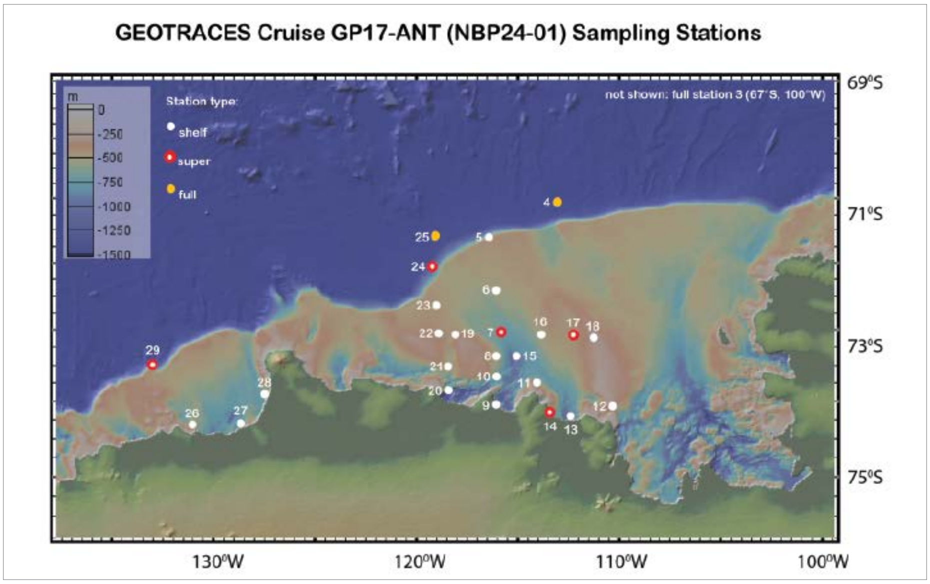
"Typically, on every cast, each technician collects at least 25 kilos of water and moves those samples around, up and down stairs in the ship," said supertech Marty Fleisher, an oceanographer at Columbia University's Lamont-Doherty Earth Observatory. "My back hurts, but that's OK. I've gotten used to it. You know, every cruise is the same. I'm here to eat, sleep, and work," Fleisher added stoically. At 65 years old, he has been to Antarctica on the *Palmer* four times.

SUPERSTATIONS, VANS, AND A BAD CASE OF CRUISE HANDS

Some labs were set up in rooms inside the ship, whereas others, called vans, were truck-sized shipping containers installed on deck. Despins spent most of her time during GP17-ANT inside a van analyzing mercury concentrations in seawater samples. She secured all her equipment to the floor and walls with cables and ropes, which proved necessary when the ship broke through ice.

"There's a general rumbling in the ship, but it is 10 times worse in the van, where the walls are shaking, and everything attached to the van is shaking," said Despins. "It almost feels like you're in an earthquake."

Researchers working on the decks experienced firsthand the harsh and rapidly changing Antarctic weather.



The GP17-ANT cruise was able to reach 27 of its scheduled sampling stations. Credit: Sofia Moutinho

They were outside on sunny days and foggy days, as well as in heavy snows and winds and when temperatures dropped to as low as -21°C (-6°F). Because of the constant exposure to the cold, water, and sea salt, many ended up with what they call "cruise hands."

"I'm getting a very bad case of cruise hands," French oceanographer Margot Debyser told me, showing her dry palms and fingers covered with small cuts. A postdoc researcher at Woods Hole Oceanographic Institution, she spent long hours outside during the cruise setting up pumps and analyzing radium isotopes in the seawater. "My hands feel like sandpaper right now. When I am in bed, they catch on the sheets. It's kind of gross. I've been trying to do [exfoliating] scrubs, but it's not really worked out."

Sampling seawater takes a long time. The pump deployment alone takes up to 9 hours. At the *Palmer*'s so-called superstations (sites where all instruments can be launched to several depths) the process can take more than 40 hours.

Different teams took turns operating each instrument. Half of the scientists worked in shifts of 12–16 hours, whereas the other half were available at any time. With such intense work, keeping a healthy sleep routine could be challenging.

When we spoke, Debyser was on her way to mastering the skill of taking several naps instead of getting a full night of sleep in her bunk bed. "I'm just sleeping when I can once my instruments are running, which ends up being 3 hours in one go, 4 hours in another," she said.

Still, researchers were unanimous in telling me that this cruise was one of the best they had been on regarding time to rest. Many scientists were used to working on cruises during which they'd had to stay awake at times for more than 24 hours straight.

WALLED IN ON THE VAST SEA

The *Palmer* is divided into six decks accessible by heavy steel doors and stairs. Unlike those of the leisure cruise ships we encountered in Punta Arenas, accommodations were humble. Scientists and crew had tiny cabins shared by up to four roommates. We slept in small bunk beds with sliding curtains to maintain a minimum of privacy and had a few cabinets in which to store our clothes and objects—barely enough to fit the voluminous extreme weather gear provided by the U.S. Antarctic Program, which manages all U.S. scientific research on the continent and its surrounding waters.

To blow off steam, we had a small sauna, a gym, and a video room equipped with a foosball table, some board games, a guitar, books, massage chairs, and a TV.

But it was hard to forget that we were confined in a metallic beast. All around us were cues indicating how dangerous life on board a ship can be. From the hallway walls hung emergency kits, fire axes, and signs warning "Danger" and "Caution."

The science party had to take online training on shipboard safety and preventing sexual harassment before departure and attend onboard orientation sessions on what to do in emergencies. As part of the training, we all learned how to muster and wear our floating suits, a rubbery dark orange covering that makes you look like either a Teletubby or a giant lobster.

The loud alarm of weekly emergency drills echoed through the steel rooms, reminding us that threats were always lurking. Immense icebergs floating in the sea like ghosts amplified this eerie feeling, as did the knowledge that melting glaciers could collapse at any moment, producing waves capable of harming the vessel and its equipment and passengers.

Less alarming but definitely distinctive was the ship's water supply, which we all bathed in and drank. Although safe, the water—distilled and desalinated from local seawater—could be very smelly when we were in regions where the ocean had high algae concentrations, because the treatment system could not remove the unicellular microbes. Descriptions of the stink varied from rotten lettuce to farts.

Despite a relatively placid sea, some people fell seasick and required attention from the doctor on shift in the *Palmer*'s small infirmary designed to deal with simple health issues. Serious illnesses were not expected because everyone had to undergo an extensive medical evaluation involving dozens of blood tests, vaccinations, and heart exams to be allowed on board. GP17-ANT was fortunate to have had no major emergencies.

LEARNING FROM THE ENVIRONMENT

The *Palmer* did not dock anywhere in Antarctica, as the point of the expedition was to study the ocean. But Laura Whitmore, a chemical oceanographer at the University of Alaska Fairbanks and one of the principal investigators of GP17-ANT, had the luxury of leaving the ship several times, sometimes on an inflatable boat called a Zodiac and sometimes lowered directly to sea ice by an onboard crane.

Whitmore drilled cores in the sea ice and collected snow samples with a few other scientists. GP17-ANT was her first trip to Antarctica, and she said her time on the ice was the best part of the experience because she fully connected on a

Even in the Antarctic summer, towering icebergs dwarfed Zodiacs in the Amundsen Sea. Credit: Sofia Moutinho

personal level with the place she was studying.

"There's no better way to learn than to be out here learning from the environment itself," Whitmore said. "It's a very different experience to work in a place where a penguin is running up to you and just watching you for a while."

One of the most memorable happened the night before Christmas. The *Palmer* was moored on "fast ice," sea ice that is connected to the continent, and I joined Whitmore and her colleagues as they sampled.

Not long after the work started, I saw black dots on the white horizon. They were moving fast, and right toward us. Eventually, a long black line formed. They were Adélie penguins, perhaps a hundred of them walking or sliding on their bellies like a clumsy army.

Our visitors arrived ruffling their wings. They inspected the science work closely, gracelessly gaiting around the equipment and finding a special interest in the shovels.

The scientists (some in tears of joy) were divided between watching the birds and keeping their site intact. After the rendezvous, the winged visitors got bored and proceeded to take naps close to the ship, to the delight of those on board.

Whitmore emphasized that in addition to allowing her to meet playful penguins, the Antarctic fieldwork improved the quality of her science. "It allows me to go home and do better work with the data I collected because I know exactly where it came from," she said. "I know exactly how it was sampled and maybe even what issues happened when it was sampled."

For Bettina Sohst, a lab supervisor and technician at Old Dominion University in Virgina, the landscape allowed for the introspection necessary to develop and organize ideas. "I've had great ideas just staring at the ocean," she said. "No pressure, just looking out there: no people, just blue and white in my eyes."

Every day, we witnessed breathtaking landscapes and an overwhelming abundance of wildlife. We saw multiple species of penguins: Adélies, chinstraps, gentoos, and emperors. In areas covered by sea ice, it was routine to spot crabeater seals alone or with their cubs. Humpback and fin whales also got close to the ship, showing off their tails and spouting feathery jets of water.

Scientist Alexis Floback gets to be outside as she ferries samples from the deck to the lab. Credit: Sofia Moutinho

The intense science work, however, could easily overtake a researcher's day, making it difficult to enjoy the scenery. University of Minnesota Ph.D. student Nicole Coffey spent several hours a day processing seawater samples in a windowless lab on the ship's lower deck. It was her first time in Antarctica, and she made it a routine to take short breaks whenever she could to breathe fresh air and appreciate the view outside.

"I joked around that I sometimes helped carrying bottles to the rosette just because it got me outside and I could see things," Coffey said. "It was surreal. Half the time, I felt like the landscape was a green screen and this was all a big prank."

LOST IN TIME…AND ROUTINE

Antarctica is the only continent that does not have any official time zones. With the summer Sun shining 24 hours a day, however, the hour on the clock didn't make much difference.

We started our journey following the time at our departure point in Chile. Then, throughout the trip, the captain announced time changes so we would arrive at our final destination, New Zealand, at the local time.

"My perception of time here merged into this massive blur, and I feel like it goes both really fast and really slow at the same time," said Debyser.

The passage of time was marked mainly by the meals served on a military schedule. In the mess, where the noise of ice hitting the hull was loudest, we ate breakfast, lunch, and dinner, plus an extra midnight buffet nicknamed midrats. The menu included a variety of American classics, like burgers and pizza, but also a recurring Taco Tuesday and frequent Asian Mondays with dishes to please the majority Filipino crew.

I have never seen people so happy as the day that the cook decided to serve breakfast food for midrats. Exclamations of "It is the best day ever!" could be heard across the communal tables as hungry scientists devoured waffles and pancakes with syrup and whipped cream.

People working at night and waking up for lunch had been missing breakfast for more than a month, but I suspect that was not the only reason for the enthusiasm. It was the change in routine that tasted so good.

Life on a ship is a weird mixture of excitement and intense work, with moments of boredom and a lot of repetition. "Repetitiveness is almost required because you want to be sure that you're doing things the same way each time so that there's not some issue related to how you collected the samples or something like that," said Fleisher.

Regardless, people found other ways to break the routine and have fun. One of them was a quiz game in which the chief scientists had to answer funny questions about the cruise, in the style of the American TV show *Jeopardy!* (whose reruns played over and over on our cabin TVs). Another was a secret ceremony near the end of the cruise to mark our crossing the Antarctic Circle. Such ceremonies, sometimes called baptisms, are common when crossing geographical markers at sea, like the equator or the tropics.

As a participant in this voluntary ritual, I am allowed to say only that King Neptune and his court paid us a visit and set up a tribunal to judge those crossing for the first time. The accusation: loitering in his most southern domain and stealing his precious water. To find redemption, the newbies (like myself) had to pay our dues by entertaining the royal court. By doing so, we entered the select group of the Order of the Red Nose.

"It allows me to go home and do better work with the data I collected because I know exactly where it came from."

A penguin shows particular interest in a small shovel. Credit: Sofia Moutinho

WEATHER IS KING

Things often don't go according to plan in Antarctica. The science schedule was erratic and unpredictable. Most of the time, the culprit was the weather. Shifting winds and thick sea ice cover often prevented the ship from following its planned course.

For instance, the expedition's lead scientists had planned to sample seawater in Pine Island Bay, a coastal region of West Antarctica highly understudied because of its remote location and because it is frequently filled with heavy packs of sea ice.

GP17-ANT chief scientist Peter Sedwick, an oceanographer at Old Dominion University was excited to get to Pine Island Bay to analyze the water chemistry of this delicate

Scientists and their equipment are lowered to the sea ice by a crane. Credit: Sofia Moutinho

ecosystem. However, after a few attempts, it became clear that we wouldn't make it. The sea ice was just too thick for the 32-year-old icebreaker. (Traveling at 3 knots (5.6 kilometers per hour), the *Palmer* can break through about a meter of level ice.)

"The captain described the ship as a little kid coming up and trying to hit you as hard as they could, and an adult was keeping his hands on the little kid's head," Sedwick said. If we persisted in entering Pine Island Bay, he said, we risked being trapped between the ice pack and the continent.

Because of issues like this, our route and daily work plans had to be constantly updated. Scientists followed updates on a detailed schedule available in many places on board: written on a whiteboard in the main lab, posted on the ship's intranet, and broadcast to televisions in every room. Because the schedule was always changing, scientists jokingly called it "the board of lies."

"My mom asked me for an itinerary before we lost service. And I was like, 'No one has an itinerary,'" said first-time cruiser Annie Stefanides, a research assistant at Woods Hole Oceanographic Institution. "There's a plan, but there's no plan. You know? So it's really how much we can get done in X amount of days."

At the beginning of the cruise, the official itinerary included 30 sampling stations. Despite delays, the researchers managed to sample at 27 of the original planned stations. They made it to that many only because the National Science Foundation had permitted doubling the number of engines running on the ship, making transits faster.

IT TAKES A VILLAGE

On the one hand, there was intense work, harsh weather, isolation, and confinement. On the other, there was the chance to do science in a unique and wild place almost untouched by humans. For people on board the *Palmer*, the trade-off was more than worth it.

"Not every moment on the cruise is some amazing epic moment where you're seeing something that just blows your mind. There are also low moments where you're missing home, bored, and wish you were sleeping in your own bed," said Despins, who spent her last two Christmases and New Years on cruises. "But then you remember that you're in the Southern Ocean and how amazing that is."

For others, the isolation and remoteness are actually sources of inspiration. "Here, we have no cell phone service. We have no Internet. Then you get to focus on what we're doing in a very different way that I find refreshing and energizing," said Coffey.

For Lam, who has been on more than 20 cruises, the union among colleagues is what makes the experience so special. "I like it more and more the older I get," she said.

"On land, everyone's too busy with their own lives. But here," she said, "no one has a life except for the life on the ship. So this becomes your village, and you help your village members."

Carl Lamborg, Kameko Landry, and Nicole Coffey celebrate a job well done. Credit: Sofia Moutinho

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Read the article at Eos.org

Uncovering Earthquake Evidence in Azerbaijan's Greater Caucasus Mountains

On the northern side of the Greater Caucasus range, a fault propagation fold in limestone beds records a long history of deformation. Credit: Ian Pierce

The Greater Caucasus mountain range stretches between the Black and Caspian Seas across parts of Russia, Georgia, and Azerbaijan. These formidable peaks rose when the Arabian plate subducted beneath the Eurasian plate.

The energy imported by the tectonic forces pushing these two plates together and uplifting the mountains is stored along faults and released during earthquakes. These tectonic movements have mostly been accommodated by the Kura fold-thrust belt, which runs for approximately 275 kilometers along the southern front of the mountain range between Tbilisi, Georgia, and Shamakhi, Azerbaijan. Large, destructive earthquakes in central Azerbaijan, including one each in 1668 and 1902, are described in historical records. Aside from these examples, scientists don't know much about earthquakes that may have ruptured along this major plate boundary fault system.

A study by *Pierce et al.* offers new insights into the earthquake record for this region, as well as a warning. Using elevation models produced from satellite and drone images, the researchers identified evidence of not only long-term tectonic deformation but also geologically recent earthquakes in the landscape. By digging two paleoseismic trenches and using radiocarbon dating on the sedimentary layers below the surface, researchers identified several past seismic events and learned more about the fault's potential for future large earthquakes.

In the first paleoseismic trench, radiocarbon dating of sediment revealed evidence of two major earthquakes, one occurring between 1713 and 1895 and the other sometime between 1872 and 2003. Given uncertainty in these dates, the events could correlate to the known quakes in 1668 and 1902. Information gathered at the trench led the scientists to suggest that the 1902 earthquake may have had a magnitude of up to 7.4, rather than 6.9, as previously believed. The second trench, 60 kilometers to the west, held evidence that at least one surface-rupturing earthquake occurred between 334 and 118 BCE and another may have happened sometime in the past 2,000 years.

Farther west along the Kura fold-thrust belt, no historical ruptures are reported in the past 4–8 centuries. The scientists suggest that ruptures in this western portion of the fault belt may be more infrequent but more destructive and that tectonic motion may have built up sufficient strain to produce an earthquake of magnitude roughly 7.7 or above in the future. They note that further field research is needed to confirm their results, to better estimate the magnitude and length of these ruptures, and to learn more about the histories of other faults within the belt. (*Tectonics*, https://doi.org/10.1029/2023TC007758, 2024)
—Rebecca Owen, *Science Writer*

Manila Confronts Its Plastic Problem

Governments and international organizations have long touted the circular economy, in which materials and products stay in circulation for as long as possible, as an antidote to our global plastic problem. (The equivalent of 2,000 garbage trucks full of plastic enters oceans, rivers, and lakes every day.) But as wardens of waste management, cities often shoulder the burden of managing plastic pollution.

As a step toward managing plastic waste, 51 communities around the world have participated in the Circularity Assessment Protocol (CAP).

Developed by *Jambeck et al.*, the protocol provides communities with data on circular materials management and local sources of plastic pollution. Most recently, the Philippines' capital region, Metro Manila, an urban agglomerate home to 12.9 million people—and having a serious plastic problem—participated in the CAP process.

Among the authors of the new paper are representatives from the local organization Save Philippine Seas, which surveyed Quezon City, Manila City, and Mandaluyong City, three localities within the capital region. The organization conducted surveys at retail shops and vendors to document plastic-wrapped items such as snacks, beverages, personal care products, tobacco products, and household supplies.

Collectively, the data buckets portrayed the life cycle of plastics in Manila. The authors identified where plastic originates, how products are designed and used, how waste is collected, and, ultimately, where plastic litter ends up. For instance, they found that 77% of products use multilayer film packaging and that most grocery stores surveyed did not offer alternatives to single-use plastic products.

In addition, the authors recorded each community's feelings about plastic through interviews and social media analyses. A workshop with local stakeholders provided residents with the opportunity to interact with the study's findings and offer suggestions for reducing plastic waste. For example, residents expressed interest in buying products that don't use plastic packaging or that come in refillable containers.

A plastic-covered beach is emblematic of the serious plastic problem in Manila, Philippines. Credit: Adam Cohn/Flickr, CC BY-NC-ND 2.0 (bit.ly/ccbyncnd2-0)

Although Manila's plastic pollution was comparable in many ways to that of other large cities around the world, the CAP provided community-specific insights and solutions. The authors note that community-level efforts such as these can eventually lead to larger change as more cities address plastic pollution. (*Community Science*, https://doi.org/10.1029/2023CSJ000042, 2024) **—Aaron Sidder,** *Science Writer*

High Water Levels Cause Problems for Mississippi Shipping

The effect of drought on the navigability of rivers is well documented: During the summer and fall of 2022, barges in the Mississippi River were left stranded, raising concerns about increased shipping costs for key products. Between 2015 and 2019, barges carried an average of 400 million tons of goods along the Mississippi River system each year, including 92% of the United States' agricultural exports.

However, a new study by *Amorim et al.* found that over the past 60 years, anomalously high water levels have posed a greater threat to navigability than low water levels.

High water levels can cause problems, because as water rises, river currents speed up, making it difficult for boats and barges to maneuver safely. High water levels can also overwhelm locks and dams. If locks aren't fully operational, navigation is limited. And if currents are too strong, locks can be closed completely, leaving barges at a standstill.

The researchers examined daily river gauge data from 1963 to 2020 for 39 sites along the Mississippi River. They grouped sites into regions and ranked regions as having average or anomalously high or low water levels compared with their respective baseline flows.

The team found that since 1963, rankings of "average" flows have become less common than anomalously high and low flows, with the middle stretch of the Mississippi losing about 21 days of average flow over the study period, or 0.37 day per year. Their analyses also suggested that high water levels, rather than low ones, were more strongly associated with decreased navigability over the study period.

By studying the length and timing of consecutive days with anomalous water levels, the researchers also found that stretches of average flow have become more likely to be interrupted by high water levels.

Despite deteriorating conditions, the total amount of cargo shipped on the Mississippi River system has remained stable over the past decade. Although half a century of technological advances has made shipping more efficient, researchers suggest it has also obscured some of the challenge rising waters pose to navigation. (*Geophysical Research Letters*, https://doi.org/10.1029/2023GL104619, 2023) **—Shannon Banks,** *Science Writer*

Out With the Old, in With the Cold

Undergraduate students from the Enhancing and Nurturing Careers in Astronomy with New Training Opportunities (ENCANTO) program are one group that has conducted research using the Arecibo Observatory's 12-meter telescope and its new cooled receiver. Credit: Anish Roshi

Constructed within a natural sinkhole in Puerto Rico, the 305-meter-wide Arecibo Telescope played a part in numerous discoveries, including the first detection of an exoplanet. It was the largest radio telescope in the United States from 1963 until it collapsed in 2020.

However, since 2011, the Arecibo Observatory has also been home to a second, smaller radio telescope. *Roshi et al.* describe how recent updates to this telescope expand possibilities for future discoveries.

The 12-meter telescope originally operated over a relatively narrow bandwidth of radio frequencies, limiting its applications. In addition, its receivers operated at room temperature, which resulted in noisier signals and lower sensitivity compared with telescopes with receivers cooled to cryogenic temperatures.

Now, the researchers have outfitted the telescope with a new receiver system that operates over a significantly wider bandwidth (2.5–14 gigahertz) and is cooled to 15K (–432°F).

In summer 2023, the newly outfitted telescope demonstrated its capabilities by making a number of observations. These included detecting methylidyne emissions from dark molecular clouds toward the center of our galaxy, observing a previously discovered pulsar, and capturing an image of a region of magnetic activity on the Sun that produces intense solar flares.

With additional improvements planned, the 12-meter telescope at Arecibo could soon contribute to a wide range of future research and educational projects. (*Radio Science*, https://doi.org/10.1029/2023RS007839, 2024) **—Sarah Stanley,** *Science Writer*

Fault Maturity or Orientation: Which Matters More for Quakes?

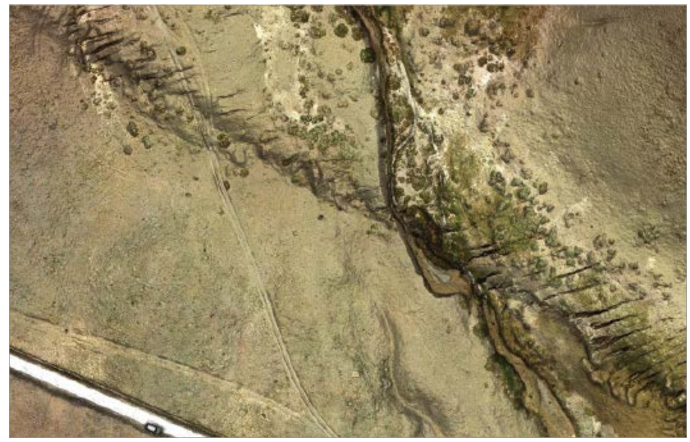
In the early morning of 22 May 2021, a magnitude 7.4 quake rattled China's remote Maduo County on the Tibetan Plateau. It was the most recent in a series of nine earthquakes with a magnitude of 7 or greater since 1997, and its surface rupture was twice as long as the global average for similarly sized quakes. The tremor occurred on the eastern part of the relatively immature left-lateral Jiangcuo fault system, which slips slowly, about 1 millimeter per year, and was unmapped before the quake.

Uncovering the geological dynamics of this disaster could help inform future efforts to assess seismic hazards in the region and around the world. In a new report, *Liu-Zeng et al.* analyze the Maduo quake to probe the relationship between fault structure and earthquake dynamics.

To do so, the researchers combined field observations with satellite images taken prequake and postquake as well as with centimeter-resolution photos of the fault system taken by an unmanned aerial vehicle. These remote sensing techniques enabled them to analyze fractures that would otherwise be inaccessible because of their high altitude and harsh surrounding environment.

The research team assessed changes to Earth's surface both on and near the fault segments involved in the quake. The segments had varying orientations with respect to the overall regional patterns of seismic stress, as well as varying degrees of maturity. Maturity is not necessarily synonymous with age; rather, it indicates the degree of a segment's development, or how much it has changed with time and activity.

Prior research has highlighted the importance of fault maturity in earthquake dynamics. However, in the case of the Maduo quake, the researchers found that the faults' orientations played a larger role in the magnitude and the degree of localization of surface deformation than their maturity levels. These findings suggest that future seismic hazard assessments might be enhanced by more thoroughly accounting for fault segment orientation in the context of regional stress conditions. (*AGU Advances*, https://doi.org/10.1029/2023AV001134, 2024) **—Sarah Stanley,** *Science Writer*



Researchers used unmanned aerial vehicle images superimposed on centimeter-resolution topography to study the surface rupture of the 2021 magnitude 7.4 Maduo earthquake in China. This image shows the fault scarp, tensional cracks on the hanging wall, and the left-laterally offset channel. Credit: Yanxiu Shao

Coming to a Consensus on Carbon

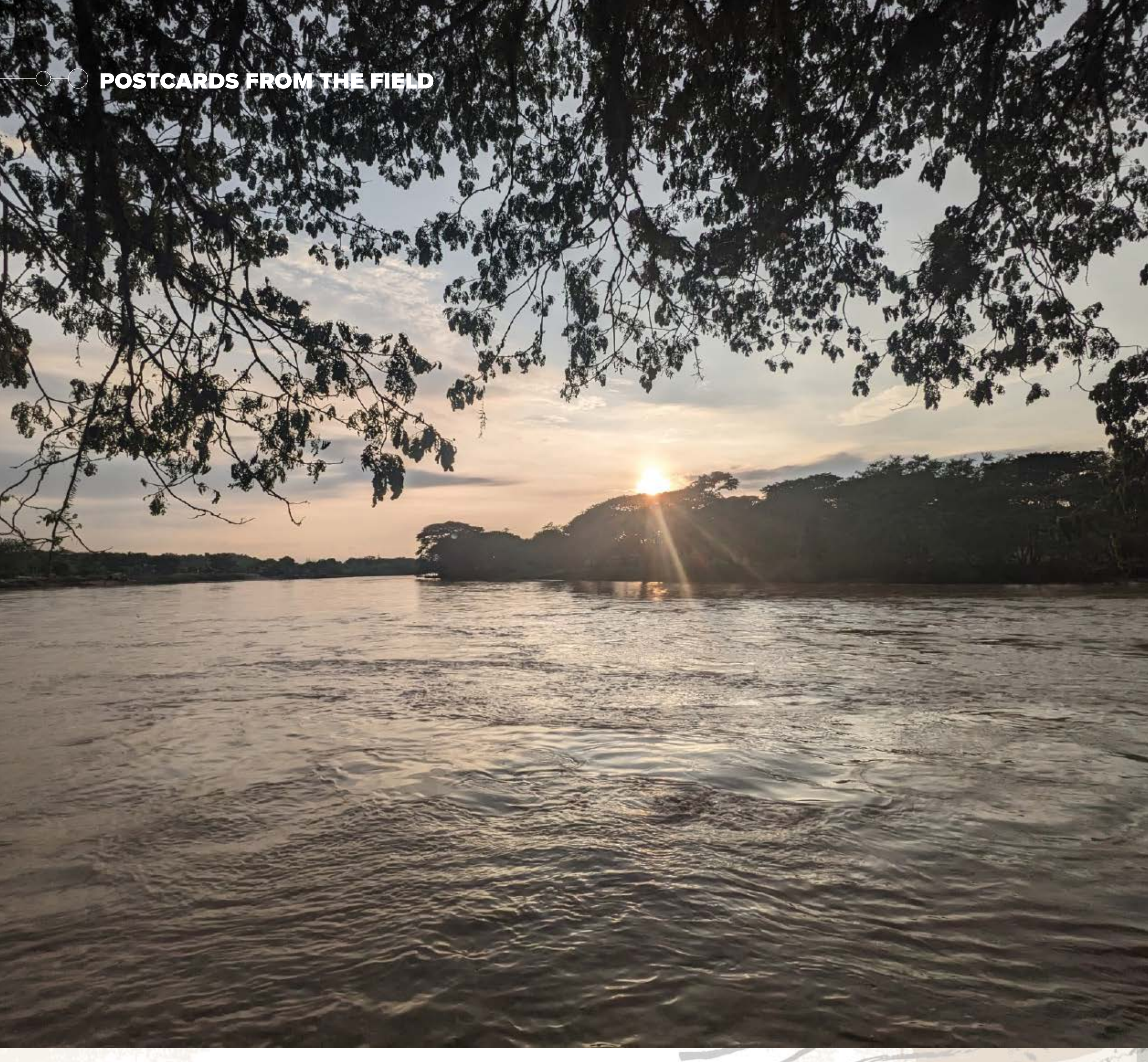
Soil carbon is exactly what it sounds like: carbon collected and stored in soil. Plants pull carbon from the atmosphere during photosynthesis and deposit it into the soil as their leaves, stems, and roots decompose. In fact, soil contains more than 3 times as much carbon as the atmosphere.

Scientists are uncertain, however, about how soil carbon storage responds to climate change. Increased carbon dioxide (CO_2) in the atmosphere could lead to more plant growth and a resulting increase in soil organic carbon. On the other hand, studies have shown that climbing temperatures can cause soil to release its carbon into the atmosphere.

Earth system models help researchers understand how Earth and its inhabitants are contributing to and affected by climate change. But their projections are not necessarily reliable for estimating changes in soil organic carbon. *Shi et al.* examined the reliability of soil carbon predictions in the outputs of 24 Earth system models. The researchers used two generations of models available through the Coupled Model Intercomparison Project: CMIP5 and CMIP6.

Seventeen out of 24 models predicted gains in global soil organic carbon under high emission scenarios by 2100, with a mean rise of 43.9 petagrams—or 43 billion metric tons. Eleven of the 17 predicted a rise in soil organic carbon of more than 50 petagrams. Two models predicted large soil carbon losses of more than 50 petagrams, whereas soil carbon levels remained relatively constant globally in the five remaining models. Particularly among CMIP5 results, large differences in soil carbon predictions across models raised questions about accuracy and reliability. Although global soil carbon changes in CMIP6 were much less variable, the models came up with similar results for very different reasons. This inconsistency suggests that there is not yet a true consensus among models—an issue for scientists and policymakers working to prepare for a warming planet.

The researchers suggest that future models should take updated biological and physical observations into account. Microbial activity, changes in permafrost, and fire patterns in tundra and tropical regions all affect the amount of carbon released into the atmosphere as CO_2 instead of being stored as carbon in soil. Along with rising temperatures, these factors also have serious implications for the future of soil carbon in a changing climate. (*AGU Advances*, https://doi.org/10.1029/2023AV001068, 2024) **—Rebecca Owen,** *Science Writer*



Greetings from the River of Gold!

This photo of the Río Nechí, or Río de Oro (River of Gold), was taken on 6 July 2023, in the municipality of Zaragoza in Antioquia, Colombia. This river is the cradle of vast biodiversity, but it is also one of the most polluted in the country due to mercury emissions associated with mining activities.

My doctoral research, conducted with my adviser, Kathleen Smits, seeks to document and characterize the use of local plants by artisanal gold miners. In Colombia, this ancient practice, which has been ignored for years, could represent a more environmentally responsible alternative to mercury use in artisanal and small-scale gold mining.

By highlighting the importance of local knowledge in formulating engineering projects, we can contribute to more sustainable mining in the country.

—**Linda Jaramillo Urrego,** Southern Methodist University, Dallas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