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SCIENCE NEWS BY AGU

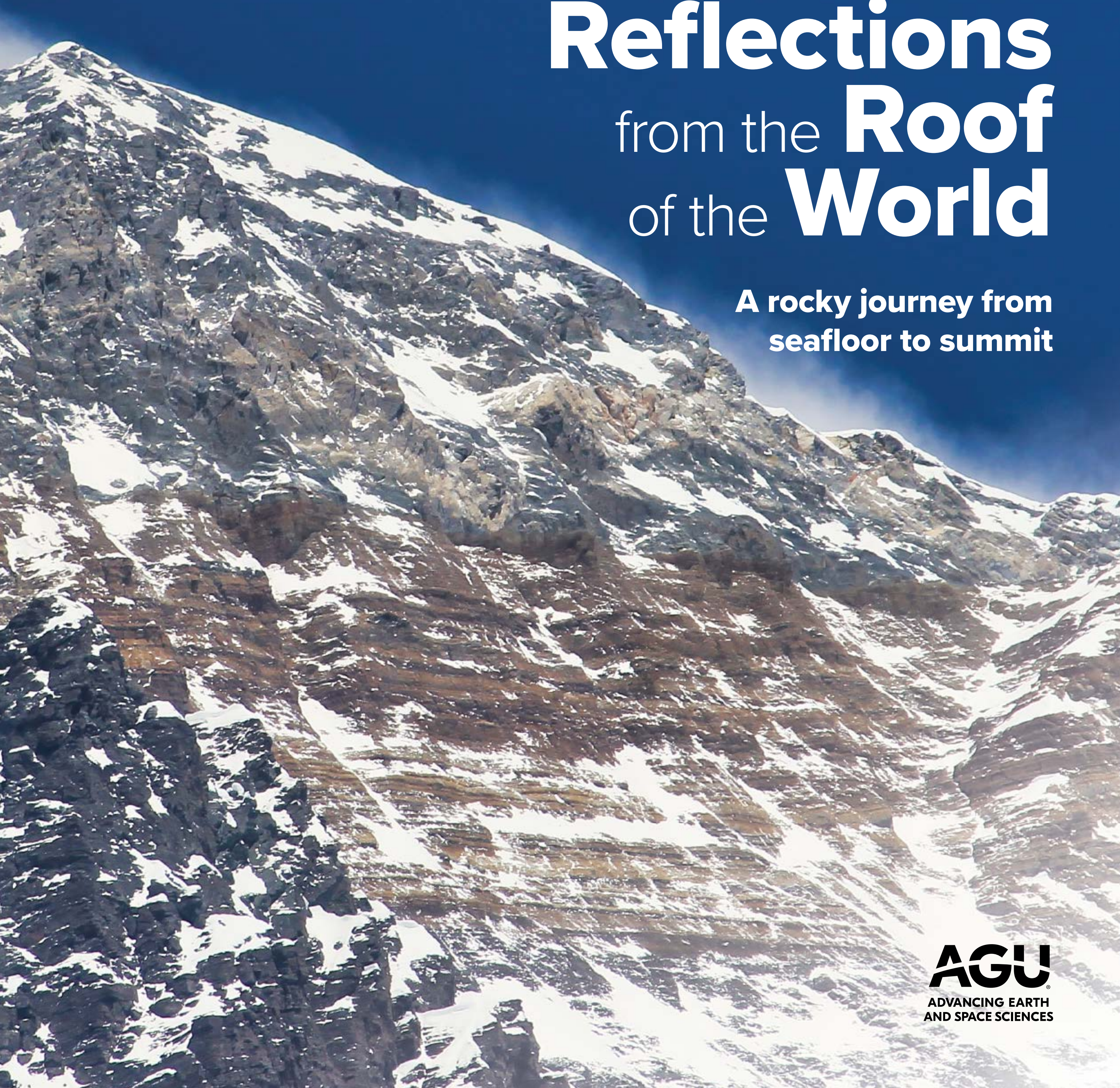
A New Tornado Database

Three Ways to Track Venusquakes

Using Satellite Measurements for Seafloor Maps

Reflections from the Roof of the World

A rocky journey from seafloor to summit



AGU
ADVANCING EARTH AND SPACE SCIENCES

From the Editor

The summit of Mount Everest is the highest elevation on our planet, hardly obscure but still a mystery: Geoscientists continue to puzzle over the mechanisms that moved (and continue to move) the mountain. Join them on page 20 as they dig deep into jet stream highs while investigating “How to Build the World’s Highest Mountain.”

Other stories in this issue explore how Everest and the rest of the Himalayas are casting long shadows both north and south. To the north, climate change and global energy demands are redefining China’s approach to managing mineral resources in the northern Tibetan Plateau (“Concerns over Lithium, Water, and Climate in Earth’s Two Highest Deserts,” p. 15). To the south, melting ice packs are making “Millions in India Vulnerable to Glacial Lake Floods” (p. 13).

From summit fossils hinting at an ancient ocean to satellite data modeling future floods, geoscientists are using innovative tools and intellectual acumen to better understand Everest and the roof of the world.

On the Cover

The stratigraphy of Mount Everest is evident in this view of the southwest face of the mountain’s summit pyramid. Credit: iStock.com/InnerPeaceSeeker

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Views expressed in this publication do not necessarily reflect official positions of AGU unless expressly stated.

Janice Lachance, Interim Executive Director/CEO

Watching a Solar Event from All Angles

An aurora appeared in the skies over British Columbia on 10 May 2024. Credit: NASA/Mara Johnson-Groh

In spring 2024, the night sky burst into a churning sea of colorful aurorae. As night crept across the globe, people from the Florida peninsula to the South Island of New Zealand marveled at the unusually widespread atmospheric light show, which lasted about 48 hours.

These serene aurorae arose from chaotic explosions on the Sun days earlier. From early May until late June, an area of the Sun with a temporarily elevated magnetic field, known as an active region, spewed a stream of charged particles and radiation into the solar system. Some large solar events can disable electrical components on spacecraft and rain charged particles onto planetary bodies—which sometimes affects power grids and satellite communications on Earth.

In this case, the storms were mostly harmless, but something besides their intensity set them apart: The largest fleet of solar probes yet was watching. Until recently, the only spacecraft closely observing the Sun were located on Earth's side of the solar system, leaving scientists in the dark about active regions once they rotated out of sight.

That changed when the European Space Agency launched its Solar Orbiter in 2020. In tandem with instruments aboard a constellation of other spacecraft, it has provided scientists with a way to view regions of the Sun throughout its 27-day rotation for the first time.

"It's enabling us to do this type of research that was not available 5 or 6 years ago," said George Ho, a space physicist at the Southwest Research Institute.

"It's enabling us to do this type of research that was not available 5 or 6 years ago."

Stitching together observations from both sides of the Sun, scientists vigilantly tracked the active region, gaining new insights into how powerful particles fire off the Sun's surface and wreak havoc within Earth's magnetic field.

"Solar Orbiter is providing us with this new information, especially for these intense and very energetic events," said David Lario, a research astrophysicist in the Heliophysics Science Division at NASA's Goddard Space Flight Center. Lario and his colleagues presented their research at AGU's Annual Meeting 2024 in Washington, D.C. (bit.ly/solar-observations).

Seeing the Sun in a New Light

Active regions can produce geysers of plasma known as coronal mass ejections (CMEs), explosions of radiation called solar flares, and shotgun blasts of high-speed particles, or radiation storms.

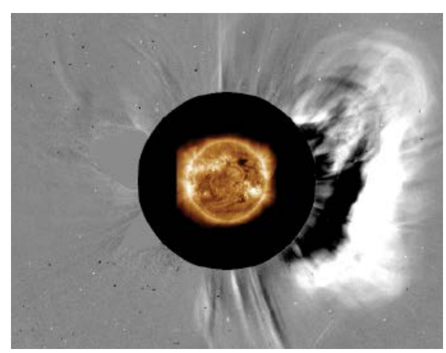
A single active region can spit out any number of these hazards, which is what happened last May and June, when one hyperactive zone repeatedly fired off CMEs and flares.

"It was quite an intense and prolific active region," Lario said.

CMEs and solar flares and storms can affect our planet more strongly when they occur on Earth's side of the Sun, but their effects are not completely absent when they occur on the Sun's farside. Hanging off the Sun are tentacles of magnetism called magnetic field lines. When these latch on to Earth's magnetic field, particles can spiral energetically along the field lines toward our planet's poles.

Solar particles can also reach our planet through other paths that are less understood.

Lario and his team combined observations of last spring's active region from Solar Orbiter; Solar Terrestrial Relations Observatory (STEREO) A, which observes Earth's side of the Sun; and three near-Earth satellites or



This composite image depicts the solar eruption that occurred on 11 May 2024. The inner (color) image was captured by the Solar Dynamics Observatory (SDO). The outer (black-and-white) image is a running difference image captured by the Solar and Heliospheric Observatory (SOHO). Credit: Inner image courtesy of NASA/SDO and the AIA science team; outer image courtesy of SOHO and the LASCO instrument; composite image courtesy of David Lario, created with JHelioviewer software satellite networks: Geostationary Operational Environmental Satellites (GOES), the Solar and Heliospheric Observatory (SOHO), and the Solar Dynamics Observatory (SDO).

This suite of spacecraft exposed the active region's churnings for two full rotations that included the eruption of a powerful solar flare on 20 May.

Solar Orbiter allowed scientists to link the particles flooding out of the Sun's farside with those being observed by spacecraft closer to our planet, similar to observing both the source of a flood and its downstream effects.

When this flare occurred, its source region was positioned so far from Earth that the Sun's magnetic field lines likely wouldn't have strongly bridged the distance to our planet. Even so, the instruments detected charged particles near Earth.

The researchers proposed that instead of traveling along field lines, the energetic particles slowly pushed their way *across* them, heading toward Earth.

Solar Orbiter allowed scientists to link the particles flooding out of the Sun's farside with those being observed by spacecraft closer to our planet, similar to observing both the source of a flood and its downstream effects. This particle path gives scientists more to consider when imagining all the ways our star can affect—and even harm—Earth.

To date, Solar Orbiter has documented even stronger events than those observed last spring, but they occurred at times when Earth was not in the Sun's crosshairs.

"I guess we can say we dodged the biggest bullet," said Ho, who was not involved in the research.

By **Collin Blinder** (@collinblinder), Science Writer

A New Tornado Database Helps Researchers Worldwide

Over the past 70 years, more than 75,000 tornadoes have been recorded in the United States. Recordkeeping of these phenomena outside the United States has been largely fragmented, isolated in books, government databases, and research archives. But a new effort to scour as many publicly accessible records as possible is highlighting the scale of this hazard around the world.

In a new study, Malcolm Maas, an undergraduate student at the University of Maryland, College Park, and a team of tornado researchers compiled a tornado database that they hope will boost tornado research globally (bit.ly/tornado-database).

"The most developed countries have permanent, usually governmental, organizations tasked with compiling records of tornado occurrence, and thus have the most thorough datasets," Maas said. "Datasets for other countries mostly come from independent researchers who are limited to putting together reports from newspapers and websites."

The first challenge the group faced was that vast amounts of data about tornadoes that occurred in the United States prior to the creation of the National Weather Service in 1870 weren't available in a digital format. The researchers found records in a 1993 book by meteorologist Thomas P. Grazulis, *Significant Tornadoes, 1680–1991.* "There was a big effort involving a lot of people to go through the book and put it into a format that's accessible by geographic information systems," Maas said.

Some of the tornado locations were recorded as descriptions such as "five miles north of this town," he said. "But the town didn't exist anymore, so we had to pull out old maps to find it." More than a dozen people worked on the project at any one time, describing about 7,000 tornadoes in total.

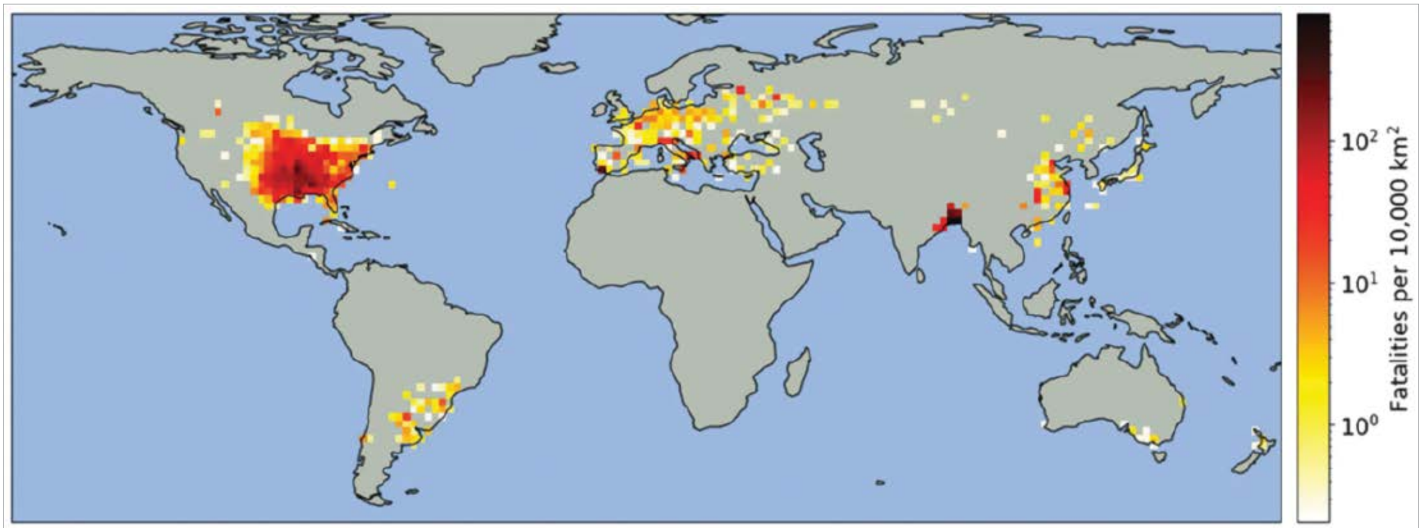
For records of tornadoes occuring outside the United States, the team downloaded existing databases from the Internet. Sometimes tracking down a database instead involved sending someone an email to get their spreadsheet or accessing a Ph.D. thesis, Maas said.

"The tricky part is that every single dataset keeps track of this information in a slightly different way," Maas said. "This is the most challenging part, because you have to massage everything to get it to come together."

Nascent Research

Outside the United States, tornado research has only recently picked up speed. Records in these regions are harder to come by, and populations generally have less knowledge of the phenomenon.

A tornado touches down in Manitoba, Canada. Credit: Justin Hobson/Wikimedia, CC BY-SA 3.0 (bit.ly/ccbysa3-0)



The global distribution of total recorded tornado fatalities per 10,000 square kilometers is shown here. Data are not available for South African and most Chinese tornadoes. Credit: Maas et al., 2024, https://doi.org/10.1175/BAMS-D-23-0123.1

In May 2019, seven tornadoes hit near cities in southern Chile, spurring several research groups to begin studying what atmospheric ingredients give rise to tornadoes there, explained meteorological researcher Julio César Marín Aguado of the Universidad de Valparaíso in Chile. "We now know more about the synoptic conditions and some mesoscale characteristics associated with these events, but there are still many aspects to be investigated," he said. A global, unified database could help fill in vital gaps.

A similar genesis of tornado research happened in East Africa. Sosten Chiotha, regional director for the nongovernmental organization Leadership for Environment and Development (LEAD) and an environmental scientist based in Zomba, Malawi, published the country's first paper about local tornadoes after an automated weather station installed at his office picked up strange readings in 2017. South Africa has a long track record of publishing tornado research, but Malawi has limited knowledge and capacity to systematically track and document tornadoes, he said.

"The first picture of the tornado that we published was captured by someone who thought it was smoke from burning tires and took the picture out of curiosity," Chiotha said.

The hope is that observations from more regions, included in a global database, would help provide a more complete picture of tornado occurrence across the world.

Fatal Tornadoes

More than 60% of the 35,170 fatalities recorded in the new database occurred in the United States. But tornadoes wreak havoc in other countries as well: Bangladesh accounts for 8,325 fatalities in the database, India has seen 1,473, and the rest of the world combined accounts for 3,824.

> **"Other countries may turn into hot spots due to increasing global temperature, so credible data is critical to reduce vulnerability of people to tornadoes."**

"The frequency, intensity, and lifespan of tornadoes in South Asia are generally less severe than those in the United States. However, due to the dense population in these countries, even low-intensity, short-lived tornadoes can result in significant deaths and damages," said meteorologist Nasreen Akter at Bangladesh University of Engineering and Technology.

That impact could shift in the future. Ashraf Dewan, an environmental geographer from Bangladesh now at Curtin University in Australia, said that although the United States is currently a hot spot, the climate is changing. "Other countries may turn into hot spots due to increasing global temperature, so credible data is critical to reduce vulnerability of people to tornadoes," he said. The researchers hope the new database can be used to collate more data from the Global South, especially where government agencies don't have the capacity to collect such data.

Subhash Chander Bhan, a recently retired agrometeorologist and forecaster with the India Meteorological Department, agreed with the new study's methodology but said the next big challenge is to incorporate information not available in official records or existing research.

"I know about quite a few reports of tornadoes in northwest India in various electronic platforms which have not been systematically documented," Bhan said. "Collating all available information and its digitization, in terms of exact time, coordinates, path, and damage, would certainly help researchers work further on climatological, synoptic, dynamic, and thermodynamic aspects; and for incorporating the knowledge in early warning systems."

Maas acknowledged that in a relatively small dataset, any trends might turn out to be statistical artifacts; he added that his dream would be a central international organization that keeps track of tornadoes.

By **Andrew J. Wight,** Science Writer

Greenland Ice Sheet Stores Hidden Water Throughout the Melt Season

Greenland is largely covered with an ice sheet that contains enough water to raise global sea levels by several meters were it all to melt. Even losing a fraction of that ice that would flood island nations and coastal cities around the planet.

How quickly this would happen depends on the path of the meltwater from ice sheet to sea and how long it would take, though spotting that complicated journey under the ice has been difficult.

A recent study published in *Nature* tracked this water into and out of hidden pools beneath the surface by analyzing subtle changes in the vertical motion of the bedrock in Greenland, using Global Navigation Satellite System (GNSS) stations (bit.ly/Greenland-pools).

"You can imagine that the solid Earth behaves like a very stiff spring," said geoscientist Pavel Ditmar of Delft University of Technology. "When the surface load is removed, then the solid Earth returns to its original position. The deformations are relatively minor, but if we remove all the signals of no interest, we come up with a signal amplitude of about 5 millimeters. Nevertheless, the accuracy of GNSS receivers is sufficient to detect these deformations."

Using these data, Ditmar and his collaborators showed that meltwater collects within and beneath the Greenland ice sheet during warm summer months. The water can linger in these hidden reservoirs for 1–2 months before draining to the ocean, a previously unknown lag that has important implications for climate change simulations.

"What we consider as warm summers nowadays may became ordinary in the future."

"Being able to directly measure these quantities is super informative for how we model subglacial hydrology and how these glaciers are going to respond to changing conditions in the future," said Michalea King, a University of Washington ice sheet researcher who was not involved in the study. (King is one of *Eos*'s science advisers.)

"What we consider as warm summers nowadays may became ordinary in the future," Ditmar warned, pointing out that models currently underestimate by 20% or more how much hidden meltwater there is. "If we are concerned about future sea level rise, it's critical to make a proper adjustment of existing models."

Secret Lakes and Hidden Flows

Climate change's amplified effect in the Arctic makes Greenland one of the most vulnerable places on Earth. However, direct measurement of melting and its contribution to sea level rise is difficult, and fieldwork is often impossible.

"It's really challenging to observe how water moves through the subglacial hydrology system in Greenland," King said, adding that many glaciers end in the ocean rather than on dry land. "They're inaccessible and can be dangerous environments. We think we understand the basics of subglacial drainage, but we're just sort of inferring what's going on at the bed. This paper is really, really important because it provides

"This paper is really, really important because it provides direct observations of how much water is not immediately making its way out to the ocean."

Global Navigation Satellite System stations throughout Greenland, including the TREO station in Umivik Bay on the country's southeastern coast, are used to measure subtle uplift and subsidence of the ground. Credit: Thomas Nylen/Technical University of Denmark direct observations of how much water is not immediately making its way out to the ocean."

The new study used 22 GNSS stations built on solid rock around the ice sheet's periphery. The stations can monitor tiny vertical shifts in the rock in real time, spanning 200 kilometers around each station.

Ditmar and his collaborators used these data to reconstruct what happens inside and beneath the ice sheet through the spring and summer melt seasons.

Starting in February of each year, each GNSS station recorded a slow then accelerating downward displacement as meltwater from the entire surface of the ice sheet drained through channels in the ice and accumulated in hidden lakes between the ice and the bedrock. That subsidence reached its maximum in July and was followed by a slow rebound as the water drained to the ocean.

Differences in the amount of subsidence between stations showed regional differences likely due to ice sheet structures: In the southeast, where glaciers flow directly into the ocean, the rebound was much faster than elsewhere in the ice sheet where there is more exposed rock between the ice sheet and open sea.

Current ice sheet models do not include the possibility of meltwater storage over months-long periods, so by comparing the subsidence and rebound of rock to what these theories predict, the researchers isolated just how much water is present, how long it is stored, and how quickly it drains to the ocean. They also double-checked their conclusions using data from the GRACE-FO (Gravity Recovery and Climate Experiment Follow-On) satellites, which use gravity measurements to track movement of mass. Though these satellites can't provide the same resolution in space and time that GNSS does, they provided independent confirmation of the total compression and rebound.

The result showed that researchers have been greatly underestimating hidden water flows within ice sheets and how they contribute to sea level rise, highlighting a necessary correction to current climate models. Though the GNSS method likely won't work for the lower ice mass in alpine glaciers or where little bare rock is exposed, as in Antarctica, improvements to theory from this work could guide researchers in their understanding of how vulnerable ice melts—before it is all gone.

By **Matthew R. Francis**, Science Writer

Improving Earthquake Early Warning Access for the Deaf Community

When a strong earthquake occurs, the ShakeAlert earthquake early warning system triggers organizations to send alerts through phones in affected areas of California, Oregon, and Washington. The warning may give people valuable seconds to drop, cover, and hold on. In the moments after an earthquake, other audible clues such as the sounds of things falling or the crackle of fire can alert people to lingering danger.

But those in the deaf and hard of hearing (DHH+) community may not notice these signals, putting them at greater risk of harm. Statistics from past earthquakes reflect the disparity: The fatality rate for the 1995 Kobe earthquake in Japan, for example, was more than 4 times higher among Deaf people than among hearing people, according to the Kobe Deaf Association.

Research regarding the effectiveness of earthquake early warning systems such as ShakeAlert within the DHH+ community is virtually nonexistent. But a group of Deaf scientists is studying the issue, interviewing DHH+ community members about their experiences with earthquake early warning. They presented their results at AGU's Annual Meeting 2024 in Washington, D.C. (bit.ly/DHH-EEW).

"Technology takes off without our input, our feedback, or our opinions."

"Technology takes off without our input, our feedback, or our opinions," signed Kota Takayama, a social worker at Gallaudet University and a coauthor on the new research who is deaf. "The technology becomes pointless because it's not helping us; they didn't ask us what we needed."

Accessible Alerts

For an earthquake early warning system to be effective, a person must receive the alert, understand the message of the alert, and know what to do.

These apps alerted people to potential shaking when an earthquake hit Los Angeles last August. But the alerts aren't accessible to many deaf and hard of hearing people, according to new research. Credit: Robert de Groot

The research team held dialogue sessions with eight students in the DHH+ community who had each experienced an earthquake to learn about their experiences with earthquake early warning systems—both the alerts themselves and the extent to which training and prior education influenced their ability to respond to the alerts.

All participants reported that they preferred receiving alert messages in English, though one deafblind participant noted that text-based alerts can be inaccessible to screen readers and incompatible with braille pads that translate text into an accessible format.

In 2023, the Federal Communications Commission adopted rules requiring wireless providers to make Wireless Emergency Alerts, one of the systems that disseminates ShakeAlert messages, available in American Sign Language (ASL). The agency is currently seeking community input about the effectiveness and format of ASL videos that could be included in alerts.

"The incidental information is very limited for [those in the DHH+ community] who are widely marginalized from emergency information and training," signed Audrey Cooper, a late hard of hearing linguistic and public anthropologist at Gallaudet University and a coauthor on the new study. "When a disaster does happen, it exacerbates the situation for the community because they have little information to rely on."

According to the research team, an accessible earthquake early warning system would include more visual and haptic cues, as well as additional options for different languages within text alerts. Earthquake early warning alerts should come from places other than one's mobile phone, too, such as alerts on public transportation, on television, or from a wearable smart watch, signed Takayama. But more research is needed to determine exactly what would make an earthquake early warning system most accessible for the DHH+ community, the team said.

ShakeAlert has partnerships with some organizations already implementing non–cell phone alert delivery. Some commuter rail systems in Southern California use ShakeAlert to automatically slow trains, and one school district in Washington sends earthquake alerts through its public address system. Other partnerships include a hospital, college campus, fire station, and water utility systems.

"Oftentimes, these systems and software weren't built considering accessibility," said Carson MacPherson-Krutsky, a natural hazards researcher at the Natural Hazards Center at the University of Colorado Boulder who was not involved in the new research. The new research is "really important and really exciting," especially because most of the authors have lived experience in the DHH+ community, something unusual in hazard research, she said.

Robert de Groot, a ShakeAlert operations team lead, said the ShakeAlert project has been communicating with the research team and other linguistically diverse communities to advance the goal of "earthquake early warning for all."

"USGS ShakeAlert and its state partners are intent on making sure that what they learn from their research actually gets put to use immediately," he said.

Before Disaster Strikes

Though changes to actual alert systems are important, Takayama emphasized that the bulk of the accessibility improvements needed are to community-based earthquake preparedness and training. "We need to include DHH+ people earlier," he signed.

Participants in the study reported that they were relying primarily on informal networks, such as their families or other members of the DHH+ community, for information on how to respond to the alerts. Seven of the eight participants reported that either before or after receiving the initial alerts, they would have liked access to expanded contextual information in ASL and Pro-Tactile American Sign Language that described how to respond to alerts.

The 2011 Tōhoku earthquake in Japan caused widespread destruction and a devastating tsunami. The mortality rate of those with disabilities during and after the earthquake was more than twice as high as that of people without disabilities. Credit: Douglas Sprott, CC BY-NC 2.0 (bit.ly/ccbync2-0)

Many DHH+ people experience "dinner table syndrome," a term that describes the isolation and exclusion that occur when DHH+ people surrounded by hearing people are excluded from conversations. This routine exclusion leads to gaps in knowledge about all kinds of important information, including earthquake preparedness information. Earthquake trainings that occur in schools are not always accessible to DHH+ students, either, said Michele Cooke, a structural geologist at the University of Massachusetts Amherst and a coauthor on the new study who is deaf.

"The potential for partnering with the disability community is huge here."

There is "no public information in advance to share with the whole DHH+ community as to what they can expect when these kinds of emergencies happen," Cooper signed.

In their 2024 paper revealing the dearth of research on earthquake early warning and the DHH+ community, Takayama, Cooper, Cooke, and their coauthors stressed that DHH+ people must be included in conversations about how to improve disaster alert systems and trainings for these systems to be actually accessible to the community (bit.ly/EEW-accessibility).

"The potential for partnering with the disability community is huge here," Cooper signed."If scientists, public engagement people, and trainers just reach out to [DHH+] community members, that's where they're going to get all these cool ideas about how to make the whole system better."

Removing barriers for DHH+ scientists is key to making disaster response systems accessible, too, Takayama signed. "We need more of them."

By **Grace van Deelen** (@GVD__), Staff Writer

Editor's note: Unless otherwise requested by a source, this article uses lowercase "deaf" to refer to a person's audiological status and uppercase "Deaf" to refer to members of the community, some of whom are hearing friends, family, and allies.

Water Testing Builds Trust in Science as Maui Communities Recover

In August 2023, communities in western Maui, Hawaii, were devastated by the deadliest U.S. wildfires in more than 100 years. The fires burned more than 6,700 acres; destroyed thousands of homes, community buildings, and historic cultural sites; and killed at least 102 people.

In the days after the fires, Maui County declared a precautionary unsafe water alert, and officials began testing municipal and residential water supplies for contamination. In partnership with community members, researchers conducted supplementary water tests to understand how contamination varied throughout the burned area and over time and to share those findings with Maui's residents.

The project detected some volatile organic compounds (VOCs) and disinfection by-products in a few mains, service lines, and home water samples, though the contamination was not widespread. The project demonstrated how partnerships between scientists and affected populations can reveal lingering wildfire impacts and empower communities as they rebuild.

After a disaster, "there's sometimes a hard line between 'us and them,' or 'government agencies and people needing help,'" said Liza McLatchy, a geospatial research engineer at the University of Hawaiʻi at Mānoa's Water Resources Research Center. "What we're focusing on is where universities can fill that gap and provide that support."

Building Trust

Wildfires can damage water infrastructure by melting plastic pipes and components, depressurizing the water distribution system, and contaminating source waters with ash, soot, or surface runoff from firefighting, explained Erica Fischer, a civil engineer at Oregon State University in Corvallis who was not involved with the Maui project.

Damaged water infrastructure can worsen water quality, introducing contaminants like volatile and semivolatile organic compounds (SVOCs), heavy metals, fire-suppressing compounds, and disinfection by-products. If a system doesn't use plastic pipes, depressurization is usually the primary source of water contamination.

"When the fire service is putting high demands on the water distribution system at the same time that homes have burned down, communities have observed depressurization of the water distribution system," Fischer explained. "Ash and soot that is sucked into the system contains VOCs, among other harmful contaminants. This ash and soot sticks to the interior of the pipes, gaskets, and valves and takes multiple flushing attempts to remove."

Regulatory agencies tested water quality throughout burned areas, looking for VOCs and SVOCs like benzene, toluene, styrene, methylene chloride, and other contaminants regulated under the Clean Water Act. These chemicals can affect liver, kidney, and circulatory function and increase the risk of cancer.

The team of hydrologists and engineers, some of whom live on Maui and are members of the affected communities, tried to find the right way to contribute their expertise in the wake of the disaster. They began gathering water samples with the supplies they had on hand in their labs, hoping to enhance the water testing already being done by government agencies, said Christopher Shuler, a hydrologist also at the University of Hawaiʻi at Mānoa's Water Resources Research Center.

"It just sprung up from the community, spending time with people, seeing what was going on on Instagram," said Shuler. "We just one day decided to go out and start taking some samples, and then we built that into a testing pipeline."

Some homeowners distrusted government disaster response teams from U.S. EPA and the Federal Emergency Management Agency (FEMA) because of misinformation or past government mistreatment. That distrust hindered some of the agencies' in-home sampling efforts, communication, and outreach.

The researchers felt that they themselves could respond to those needs. They hired new staff from the affected communities to conduct widespread sampling.

"There's a lot of trust [needed in] letting someone into your home."

"Maui is a small community," Shuler said. "We knew the importance of interacting with homeowners under stress, of having somebody that people knew and trusted going into people's homes, a very sensitive space, especially after this trauma."

Community members began recognizing the sampling team, inviting them into their homes or recommending them to their neighbors. Knowledge of the project spread by word of mouth and text groups.

"There's a lot of trust [needed in] letting someone into your home," McLatchy said. That community buy-in was invaluable in earning the trust needed to gather in-home samples.

Informing Communities

When invited by residents, the team tested for 78 VOCs from indoor faucets and outdoor spigots. Most of their sampling requests came from people who were about to or had already moved back home, so the houses' water supplies had already been tested and cleared by regulatory agencies.

"These water samples are in no way meant to replace what needs to be collected by government agencies and are not able to tell residents if their water is safe through a qualified test," Fischer pointed out.

The researchers found few cases in which residents' water supply contained VOCs that agency testing had missed. Most VOCs they detected came from burned-down or unoccupied structures adjacent to livable houses, Shuler said.

"What surprised community members through our data and especially in tap water samples was the concentration of disinfectant by-products," McLatchy said. Disinfectants are commonly used to treat drinking water, and the researchers expected to find their by-products.

"But we saw shock from homeowners because that kind of information was not easily shared," McLatchy said. "We were able to step in and explain where that was coming from, explain that this was not fire-related…and provide some guidance of maybe investing in a home filtration system."

As they analyzed samples from across Maui, the team put together a community information portal with an interactive map to share their results with people affected by the wildfires. The results of the project were presented at AGU's Annual Meeting 2024 in Washington, D.C. (bit.ly/Maui-Project).

Empowering Recovery

Johanna Blake, a hydrologist and geochemist at the U.S. Geological Survey's New Mexico Water Science Center, said, "The work being done by this group is very important. The urban-wildland interface during wildfires is becoming increasingly important to study and understand."

"Projects like these complement government water quality testing, as the government may not be testing for VOCs or other potentially harmful analytes," added Blake, who was not involved with this research. "Providing water quality information to communities helps them be better prepared for postfire recovery by identifying water quality issues in as many ways as possible."

The team is continuing to analyze the results of their water quality sampling to better understand how VOCs are distributed through a burned area and how that distribution changes over time.

"The type of work that the research team has performed is critical to better understanding the mechanistic behavior of VOC and SVOC contamination within communities due to fires," Fischer said.

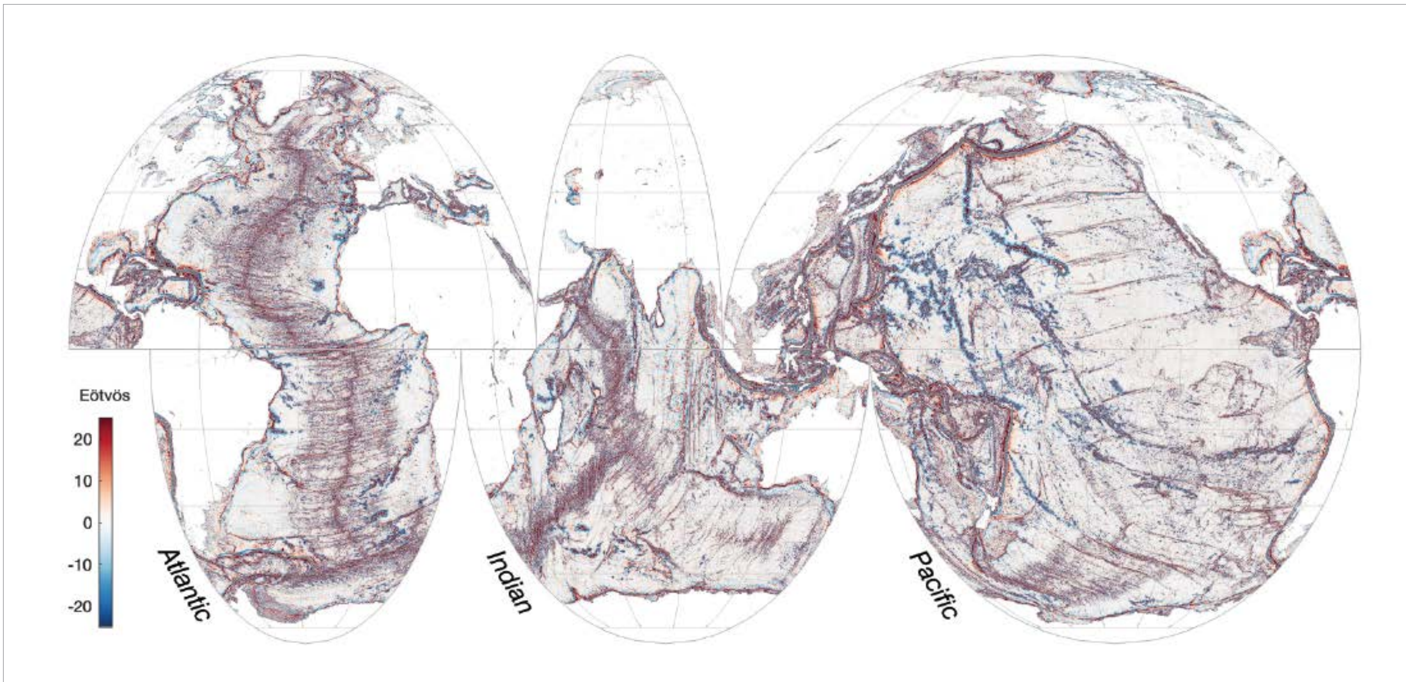
The U.S. EPA tested drinking water quality in Lahaina, Hawaii, after the 2023 wildfires. Credit: EPA

"Once we can fundamentally understand that," Fischer continued, "we will be able to determine where vulnerabilities are within communities and how they can mitigate against this occurring, or prepare for it for when it happens. That is ultimately how we can empower communities to mitigate against this secondary hazard."

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

Opposite: Fostic – stock.adobe.com

Satellite Measurements Make Major Seafloor Map Improvements



Using satellite altimetry data from Surface Water and Ocean Topography (SWOT) instruments, scientists created a global map of marine gravity, uncovering thousands of new seamounts. The scale is measured in Eötvös, a unit that gauges the ocean's vertical gravity gradient. Credit: Yao Yu, Yu et al., 2024, https://doi.org/10.1126/science.ads4472

The Surface Water and Ocean Topography (SWOT) mission instruments have allowed for the clearest satellite-produced map of the seafloor to date, according to a new study in *Science* (bit.ly/SWOT-seafloor-map). The work could help researchers better understand everything from biodiversity hot spots to plate tectonics to tsunami propagation.

Ship-based sonar has a resolution of about 200–400 meters (650–1,300 feet). The Seabed 2030 project aims to map the entire ocean floor by the end of the decade using this method. However, the relatively time-consuming and expensive technique has imaged only about 25% of the seafloor so far.

Most seafloor map images are derived from satellite altimetry, which measures height variations of the ocean's surface. Scientists use this information to make inferences about seafloor features that influence sea surface level by affecting marine gravity (e.g., sea level is higher over a seamount). Over the past 30 years, data gathered by satellite instruments have allowed scientists to map marine gravity at a resolution of about 12–16 kilometers (7.5–9.9 miles).

Jointly developed by NASA and the Centre National d'Etudes Spatiales (CNES, the French national space agency) and launched in 2022, SWOT measures sea surface height in two dimensions rather than one. In the new study, researchers used SWOT data from April 2023 to July 2024 to map marine gravity at a resolution of 8 kilometers (5 miles).

"So, 1 year of SWOT data beat the past 30 years of traditional nadir altimeter [data] in constructing marine gravity," said Yao Yu, lead author of the study and a postdoctoral researcher studying marine geophysics and physical oceanography at the Scripps Institution of Oceanography at the University of California, San Diego.

The improved resolution has uncovered thousands of small seamounts and is allowing researchers to better characterize abyssal hills and map submarine canyons. Detecting these features could help improve studies of ocean circulation and deep-ocean mixing, which can affect ocean temperatures and carbon dioxide absorption.

"I am mostly impressed with the ability to [map] abyssal hills and seamounts so much [more clearly] than ever before," Ole Baltazar Andersen, a geophysicist at the Danmarks Tekniske Universitet in Lyngby, Denmark, wrote in an email. Andersen was not involved with this research but has collaborated with David Sandwell, Yu's adviser and a paper coauthor. "This paper represents a huge leap forward in our ability to map our planet," Andersen said.

Nadya Vinogradova Shiffer, an ocean physicist and SWOT program scientist at NASA, wrote in an email that the work was "impressive" and brought a new level of detail to satellite altimetry capabilities.

"Improved seafloor mapping at such level of detail opens new frontiers" in areas including geodesy, ocean modeling, hydrology, navigation, and benthic ecology, she said.

By **Emily Dieckman** (@emfurd), Staff Writer

Nebraska High Schoolers Test Well Water Quality

Dan Snow grew up on a farm in Iowa, where one of his jobs was to remove the dead mice sometimes found floating in his family's well. After enough times looking at the water and thinking "We're drinking that stuff?" he convinced his mom they should have their well water tested.

"I have to imagine that that influenced my career trajectory," said Snow, now a hydrochemist at the University of Nebraska–Lincoln (UNL). A few decades after getting his own well tested, he helped to launch the Know Your Well program, which provides high school students in Nebraska with the tools and training needed to test water quality in local wells.

Federal guidelines recommend testing wells once per year, and testing is particularly important in domestic (private) wells, which can be more vulnerable to contamination because they don't have the same treatment and monitoring protocols as public water systems. However, fewer than 30% of domestic well owners in Nebraska have done such testing.

Know Your Well's mission is twofold: to engage teenagers in hands-on science, technology, engineering, and mathematics (STEM) work and to gather more information about water quality across the state as part of an effort to keep Nebraskans healthy and informed. The program has partners at local and regional agencies, such as natural resource districts, who visit classrooms and provide their expertise on local water issues.

Students in the program are "collecting real data and interacting with real chemistry and making this capital-C Chemistry—a kind of scary thing—a lot more manageable," said Sara Brock-Contreras, a Ph.D. student in the UNL School of Natural Resources studying social science, with a focus on hydrology. "What influence can that have on community decisionmaking and individual decisionmaking?"

Brock-Contreras, whose graduate studies since 2022 have centered around Know Your Well, presented research exploring these questions at AGU's Annual Meeting 2024 in Washington, D.C. (bit.ly/KYW-AGU24).

Students in the Know Your Well program test private wells for contaminants, including nitrate, nitrite, pesticides, metals, and coliform bacteria. Credit: Sara Brock-Contreras

Out of the Classroom and into the World

Know Your Well launched in 2017 and has worked with more than 30 schools and hundreds of students. Using test kits and guidelines provided by the program, these students have tested more than 300 private wells for contaminants, including nitrate, nitrite, pesticides, metals, and coliform bacteria. Students test for some contaminants in the classroom, send samples off to UNL's Water Sciences Laboratory to run more tests, and then share the results with well owners.

Mackenzie Vanness, now a senior, participated in Know Your Well during the 2023–2024 academic year as part of her chemistry class at Wausa High School in northeastern Nebraska. She and her classmates tested several wells in the community, including the one on her family's property.

"You're testing the water, you're coming back to the classroom and testing it here too, and just kind of doing all these things to potentially help somebody down the road," she said. "Seeing [contaminants] in somebody's water is really interesting, and just knowing that they are out there and they're not just on some chart or table."

Mary Boden, manager of the Nebraska Department of Health and Human Services' Public Health Environmental Lab, said she thinks Know Your Well is a good program to get teens interested in science, but she doesn't think well owners should necessarily rely on the data coming from the project.

"I would take all [the data] with a grain of salt," she said. "There's lots that goes into quality data, especially when it comes to things like nitrates and bacteria."

Brock-Contreras said the Know Your Well team recognizes that student-gathered data aren't the same as those gathered by formally trained scientists. But because of the thorough training and the quality chemistry kits the students use, as well as research by the program's former manager showing that the student test results tend to align relatively well with UNL lab results, Brock-Contreras said Know Your Well researchers still feel comfortable reporting results back to well owners and using the data for research purposes (bit.ly/youth-well-testing).

"Seeing [contaminants] in somebody's water is really interesting, and just knowing that they are out there and they're not just on some chart or table."

For Locals, by Locals

As a social scientist, Brock-Contreras is focused on studying the outcomes of students who participate in Know Your Well. Many community science projects are voluntary or extracurricular, which means only some people have the time or the resources to participate.

"That tends to play out in very specific demographic biases for race and socioeconomic status and gender," she said.

In contrast, because Know Your Well is part of the curriculum, students are required to participate, making these groups of young

Read the article at Eos.org

Sara Brock-Contreras of the Know Your Well program speaks to students at Mullen High School in Nebraska. Credit: Tawnee Jewell

scientists more representative of their communities. This inclusion means more equitable opportunities for students as well as an increased likelihood that community members will listen to what they have to say.

"People just listen to these kids."

A few years ago, Brock-Contreras presented some of her research to state decisionmakers at a water conference. During her talk, people listened politely, but when a group of high school students presented their work from Know Your Well, the audience was rapt.

"People just listen to these kids," Brock-Contreras said. "It definitely influences their excitement and enthusiasm for the program, because who doesn't love kids? Who doesn't love water?"

By **Emily Dieckman** (@emfurd), Staff Writer

Millions in India Vulnerable to Glacial Lake Floods

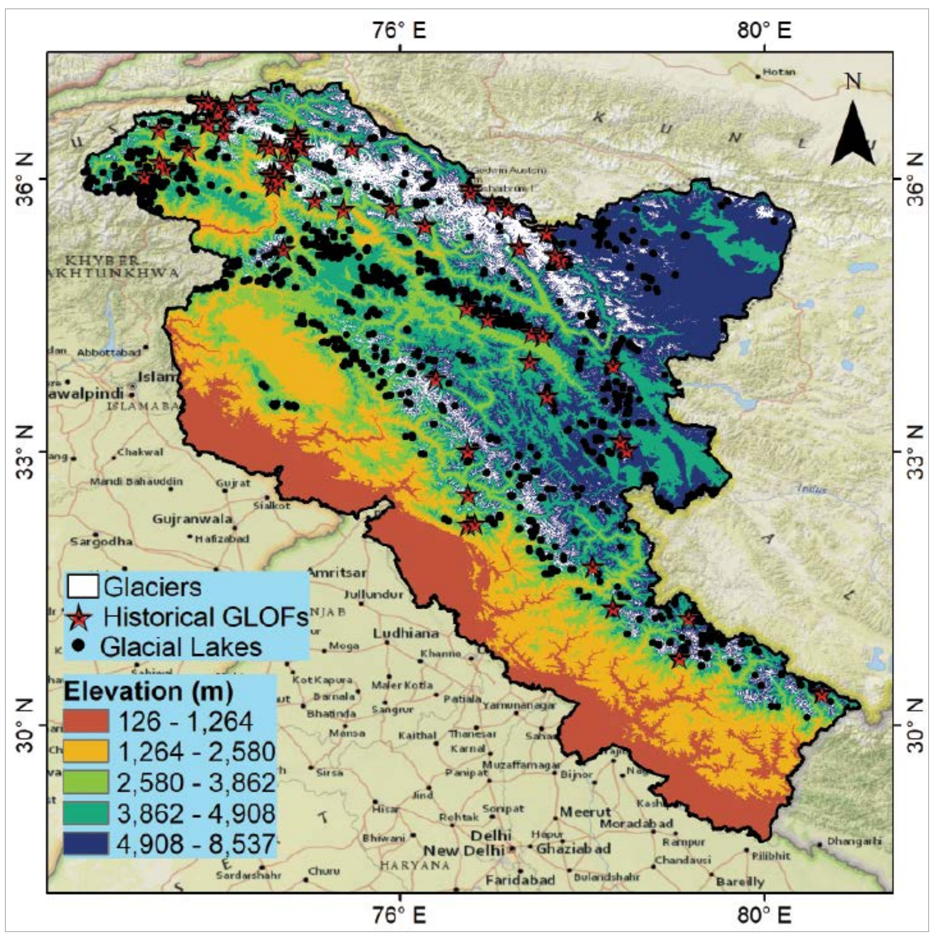
In June 2013, Uttarakhand in northern India received 375% of the rainfall it normally experiences at that stage of monsoon season.

Intense rainfall melted portions of Chorabari Glacier, raising the level of its basal lake by 7 meters (23 feet). The lake then burst through the dam, releasing 262 million liters (69 million gallons) of water in under 10 minutes. The resulting floods and landslides killed more than 6,000 people, destroyed or damaged thousands of villages, and trapped 300,000 pilgrims and tourists seeking Kedarnath Temple and other religious sites.

Chorabari Lake remains mostly dry today, but it's one of thousands of glacial lakes in the Himalayas. More than 10% of Himalayan glacial lakes have grown over the past decade because of anthropogenic climate change, increasing the risk of similar glacial lake outburst floods (GLOFs).

A new analysis explored the GLOF risk of nearly 1,600 glacial lakes in the northwestern Indian Himalayas. Factoring in regional weather, topography, and geology, researchers found that 10% of the land downstream of these lakes is vulnerable to GLOFs and that more than 2 million people could be at risk.

"With the rise in global warming and climatic events, there could be potentially more GLOF events in the near future," said Anup Upadhyaya, a climate scientist at the Indian Institute of Technology Kharagpur in West Bengal.



Researchers examined the glacial lake outburst flood (GLOF) vulnerability in Himachal Pradesh, Jammu and Kashmir, Ladakh, and Uttarakhand (colored area within black boundary). Credit: Anup Upadhyaya

Regions at Risk

The Himalayan Mountains hold the third-largest ice deposit in the world. As anthropogenic climate change warms the planet and shifts precipitation patterns, Himalayan glaciers have been melting and draining into glacial lakes. Glacial lakes are bulwarks against downstream disasters, but they have limited storage capacity.

"Glaciers melting will increase the size of these glacier lakes in this region, and that can be potentially devastating," said Abhishek Rai, a climate scientist also at the Indian Institute of Technology Kharagpur.

Motivated by the 2013 GLOF event and more recent disasters, Rai and Upadhyaya wanted to identify areas in the northwestern Indian Himalayas that are particularly vulnerable to future GLOFs.

They gathered archival satellite data on 1,569 glacial lakes at elevations of 2,200–6,000 meters (7,200–20,000 feet) in Himachal Pradesh, Jammu and Kashmir, Ladakh, and Uttarakhand. Their statistical models incorporated climatic factors such as temperature and precipitation anomalies, topographic factors such as elevation and slope, and geographic factors such as distance to rivers and glaciers to calculate a region's GLOF vulnerability.

Glacial meltwater flows through snow in the Himalayas in Uttarakhand, India. Credit: Sharada Prasad CS from Berkeley, India/Wikimedia Commons, CC BY 2.0 (bit.ly/ccby2-0)

"The most triggering factor for a GLOF to occur is an avalanche or an extreme precipitation event high up in the Himalayas."

"Rather than identifying [the vulnerability of] each and every lake in the northwest Himalayas, we decided to look at the regions that can be vulnerable," Upadhyaya said. "So even if new lakes form in the future, those lakes would still be considered vulnerable if they fall into those regions."

Their models suggested that nearly 10% of the land area downstream of those glacial lakes could be considered vulnerable and 3%–5% very vulnerable. The researchers found that heat waves, anomalous precipitation, and distance to the lake were the most important factors that made a region vulnerable.

Elevation was also key. Most glacial lakes in this region sit at elevations of 4,000–6,000 meters (13,000–20,000 feet), and those lakes grew in area by 9% over a 5-year period.

"With the rise in temperature and heat waves, particularly in the higher-elevation areas, we can have more glaciers rapidly melting, and the most triggering factor for a GLOF to occur is an avalanche or an extreme precipitation event high up in the Himalayas," Upadhyaya said.

This research was presented at AGU's Annual Meeting 2024 in Washington, D.C. (bit.ly/Himalayan-GLOFs).

Increasing Vulnerability

Most of India's vulnerable lakes lie in remote areas, so the populations likely to be affected are far downstream of the lakes themselves. The 2013 outburst of Chorabari Lake, Rai pointed out, was more than 6 kilometers (3.7 miles) from Kedarnath Temple but had devastating impacts.

To assess a GLOF's potential danger, "we have to see where the water will go," Rai said. "If [the lakes] can impact the population downstream, then we consider them potentially dangerous lakes."

But as India has not conducted a complete census since 2011, it's hard to calculate how many people currently live in at-risk areas, Upadhyaya said. On the basis of the most recent population density maps, the researchers estimated that 6%–9% of the population in the regions studied (at least 1.8–2.7 million people) live on highly GLOF-vulnerable land.

Rachel Carr, a glaciologist at Newcastle University in the United Kingdom who was not involved with the research, said that these results align with previous investigations into how glacial lakes are growing in response to climate change (bit.ly/global-GLOF-risk). Research into GLOF risk in the Himalayas also can help scientists understand other GLOF-vulnerable regions, such as the Andes, which have not been as well studied.

"Lessons learned in India can be applied in the Himalayan regions and vice versa, but noting the need to understand the specific physical, social, economic, and cultural context of each country and region," Carr added.

Worsening anthropogenic climate change not only will increase GLOF risk by accelerating glacial melting, Carr said, but also might alter the human element of GLOF risk.

"GLOF risk must also consider the exposure of downstream populations…and the vulnerability of those populations," Carr said. "These factors may also change with climate change, for example, if people migrate due to changing water supplies or agricultural patterns."

The researchers are refining their GLOF hazard zone maps and aim to share this information with local and government stakeholders to help inform disaster management and resilience efforts.

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

Concerns over Lithium, Water, and Climate in Earth's Two Highest Deserts

Integrating renewable energy into power grids at scales needed to mitigate rising atmospheric greenhouse gas concentrations and global warming requires reliable storage—and lots of it. This requirement results from variabilities in wind and incoming solar radiation that supply most of this energy. Increasingly advanced batteries are the favored means for supplying this storage.

Enter lithium, whose light weight, high electrochemical potential, and high charge-to-weight ratio make it desirable for use in batteries for everything from electronic gadgets to vehicles to power grids. Demand for such batteries has driven rapid growth in the global production of lithium: An estimated 180,000 tons was produced in 2023, compared with about 35,000 a decade earlier.

Lithium is primarily mined from the hard rock mineral spodumene—in Australia, for example—and brine from dried salt lakes in regions such as South America's "Lithium Crescent" (LC) and China's Qaidam Basin (QB). In those two areas, local residents as well as the press, governmental agencies, and nongovernmental organizations are devoting growing attention to water and environmental problems related to brine mining, and tensions with mining companies are becoming more public.

However, the hydrological community is paying limited attention to many water-related scientific questions in the LC and the QB. These questions involve the natural connectivity and transport of regional water resources and how climate and mining operations are affecting their quantity and quality. Hydrologists, hydrometeorologists, and hydrogeologists, using established technologies and surveying methods and consulting with residents, governments, and mineral extraction industries, should work to answer these questions and provide a more holistic picture of how brine mining can be made more sustainable.

Lithium from a Crescent and a Bowl

The LC and the QB—located amid the world's second-largest and largest plateaus, respectively—are arid endorheic basins, meaning they are hydrologically disconnected from the ocean. Numerous salt lakes exist in both regions, with surface areas ranging from 1 to 10,000 square kilometers in the LC and from less than 1 to more than 600 square kilometers in the QB. The lakes get freshwater from streamflow originating from glaciers, snow, and rainfall in adjacent mountains and from groundwater fed by streamflow and precipitation. The main way for water to leave these basins is by evapotranspiration, which over time concentrates mineral salts in deposits in the basin floor, making brine mining possible.

The hydrological community is paying limited attention to many water-related scientific questions in the Lithium Crescent and the Qaidam Basin.

Brine-based lithium sources in the border region of Bolivia, Argentina, and Chile in the Andes Plateau (Figure 1, left)—the so-called Lithium Crescent (a smaller area within the LC is commonly known as the Lithium Tri-

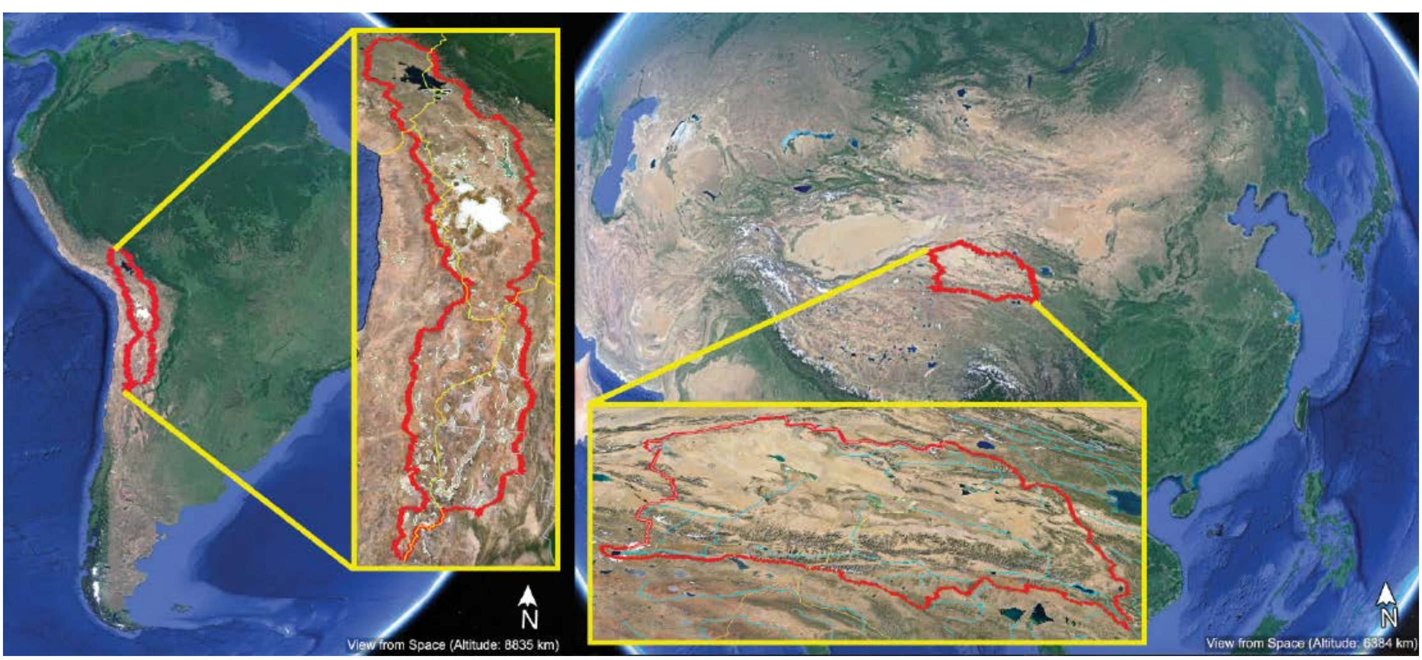


Fig. 1. Red outlines denote the geographic locations of the Lithium Crescent (LC, left) amid South America's Andean Plateau and China's Qaidam Basin (QB, right) in the northern Tibetan Plateau. The outlines of both basins are from HydroBASINS. Credit: map data from Google Earth, SIO, NOAA, U.S. Navy, NGA, GEBCO, Landsat, Copernicus, IBCAO

angle)—account for about 53% of the world's known lithium reserves [*Steinmetz and Salvi*, 2021]. This region also produces about a third of the world's lithium compounds.

China, meanwhile, holds about 6.5% of known lithium reserves and contributed about 18% of the global production of lithium compounds in 2023. Several brine-mining operations in China are performed in the country's "Treasure Bowl"—the Qaidam Basin of Qinghai Province in the northern Tibetan Plateau (Figure 1, right). In 2023, 21.2% of China's total lithium carbonate production was from the QB [*Qinghai Bureau of Statistics*, 2023].

The QB produces not only lithium compounds but also potash, petroleum and natural gas, sodium chloride, and other resources that contribute greatly to China's industry and agriculture. Potash produced in the QB in 2023, for example, accounted for 69.4% of China's total production of the resource and 6.5% of the world's potash production (figures calculated on the basis of data from the *Qinghai Bureau of Statistics* [2023] and from the U.S. Geological Survey).

Water storage is predicted to diminish because warming may reduce glaciers and snow in both regions, and these changes could enhance streamflow variability.

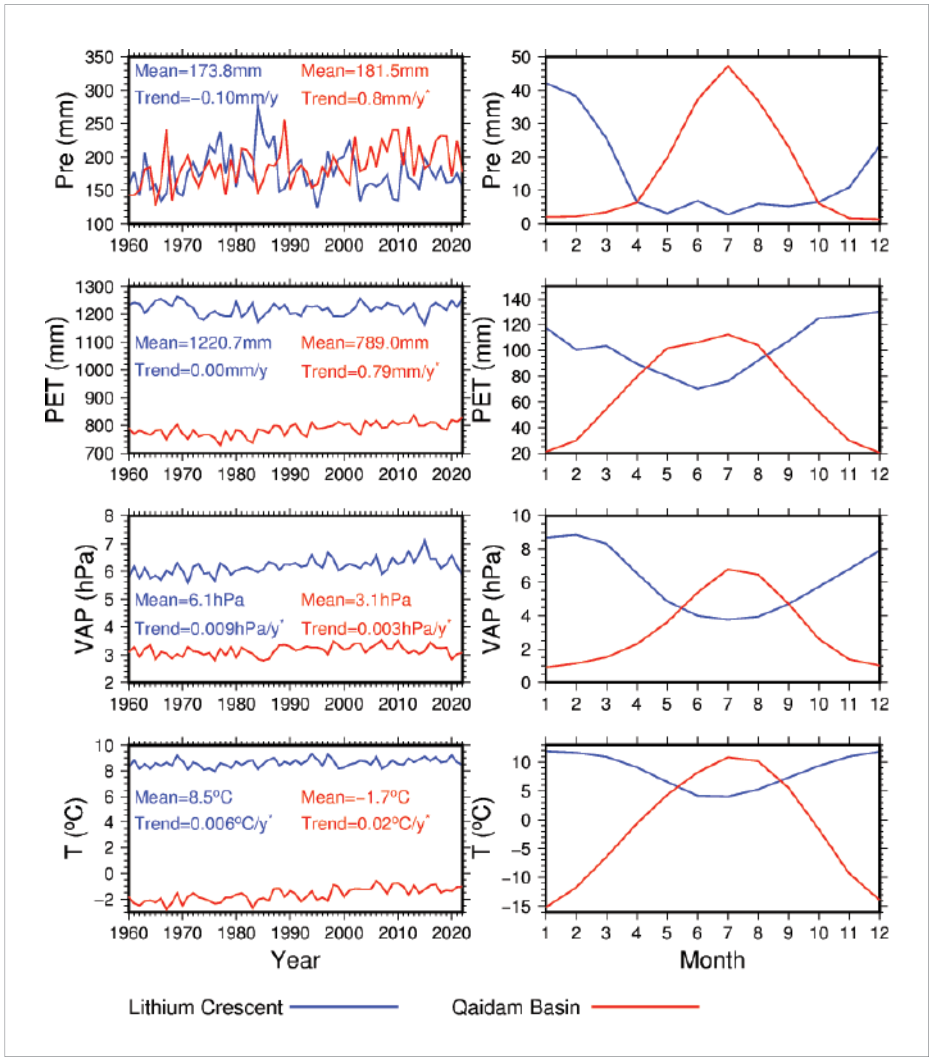


Fig. 2. The plots here show annual and mean monthly precipitation (Pre), potential evapotranspiration (PET), vapor pressure (VAP), and air temperature (T) in the LC and QB from 1960 to 2022. Stars indicate the significance of trends at p *< 0.05. Data are from Climatic Research Unit TS version 4.07.*

More Demand amid Changing Conditions

The LC and QB receive similar amounts of precipitation—with average annual totals of about 170–180 millimeters—which falls primarily in their respective summers, but whereas precipitation is decreasing slightly in the LC, it is gradually increasing in the QB (Figure 2). The LC is also warmer and more humid on average and exhibits much higher potential evapotranspiration than the QB, yet temperatures in both are increasing.

These climate trends are projected to continue in the coming decades, and the climate changes will have consequences for water resources. Water storage is predicted to diminish because warming may reduce glaciers and snow in both regions, and these changes could enhance streamflow variability and alter streamflow regimes. Together with the warming, decreasing precipitation will exacerbate drought conditions in the LC. In the QB, increasing precipitation and melting of glaciers and snow will likely cause more compound extreme events similar to the catastrophic floods that occurred in the region in 2010 [*Ma and Xu*, 2011] and 2022. These floods damaged brine fields, dams, and infrastructure and caused more than $10 million in economic losses.

Meanwhile, the brine-mining industry has been booming in recent decades in both regions. And exploitation of resources, especially lithium, is expected to intensify in the near future, following the recent trend.

To extract the desired materials, miners drill holes in salt flats and pump mineral-rich brine to the surface. The brine is left exposed for about 12–18 months, during which about 90% of the original water evaporates. Remaining material is then collected and processed into sellable mineral products. This process of pumping brine and enhancing evaporation at the surface disrupts natural local hydrological cycles. Furthermore, freshwater is needed throughout the processing stage to help purify chemical compounds.

Evaporation ponds used for lithium mining in part of Bolivia's Salar de Uyuni—the largest salt flat in the world and part of the "Lithium Crescent" of South America—are seen in this image taken by the Copernicus Sentinel-2B satellite in May 2017. Credit: contains modified Copernicus Sentinel data (2017), processed by ESA, CC BY-SA 3.0 IGO (bit.ly/ccbysa3-0igo)

In recent years, reports have connected brine mining to waste generation, water and soil contamination, landscape change, and flora and fauna degradations, as well as to major problems related to water quantity and quality. Conflicts and tensions between local people and mining companies in the Tibetan Plateau and the LC related to reduced water resources and contaminated groundwater and streamflow have also been reported [*Marconi et al.*, 2022; *Giglio*, 2021].

Studies are documenting effects on ecosystems as well. For example, reductions in some Andean flamingo populations correlate with a lowered groundwater table [*Gutiérrez et al.*, 2022], and cyanobacteria populations that feed Andean flamingos are decreasing in lagoons near Salar de Atacama in Chile because of water consumption and pollution caused by lithium extraction [*Gutiérrez et al.*, 2018].

The amount of water used in brine-mining operations can vary depending on weather, mineral concentrations, and the technology used, but for the LC, researchers have estimated that about 100,000–800,000 liters of water are needed per metric ton of lithium extracted [*Vera et al.*, 2023]. No such estimate exists for the QB, but the thriving mining industry there is also increasing water demand.

We have limited knowledge of brine lakes' role in regional hydrological cycles or about how the expansion of brine-mining operations to feed demand for lithium may alter this role.

In the southern QB, industrial water usage increased from 90 million cubic meters in 2000 to 383 million cubic meters in 2019, respectively accounting for 10.2% and 40.8% of total water consumption in the region in those years [*Han et al.*, 2023]. In 2016, water diversion facilities and channels were constructed to transport water from nearby sub-basins to brine fields and cities to meet increasing demand. In December 2023, three major brine-mining factories in the QB breached their water use quotas by illegally pumping groundwater and extracting water from protected wetlands and lakes to meet their production demands. These actions were publicly criticized by China's Ministry of Ecology and Environment, which ordered the factories to stop pumping water illegally.

Illuminating the Hydrology Around Brine Mining

Like the ocean and other pools of water below, on, and above Earth's surface, the world's brine lakes are players in their regional hydrological cycles. However, we have limited knowledge of brine lakes' role in these cycles or how the expansion of brine-mining operations to feed demand for lithium may alter this role.

Several overarching questions confront hydrologists: How and to what extent does brine mining affect the various pools and fluxes (e.g., groundwater recharge, diverted streamflow, evaporation) of the regional

Evaporation ponds amid the West Taijinai'er Lake in the Qaidam Basin are seen here in September 2023. Credit: Lan Cuo

hydrological cycle? How does surface runoff from surrounding mountains reach groundwater reservoirs, and how are these reservoirs connected beneath the desert basins where brine lakes occur? What are the ages and chemical compositions of this groundwater?

Addressing these questions will inform knowledge of both the quantity and quality of available water resources, which in turn will help decisionmakers allocate water fairly to different sectors and track and protect water quality during brine mining.

Further, because the LC and the QB are experiencing similar warming but different precipitation trends—and their respective regional water cycles may thus be affected differently by the changing climate—hydrologists should explore questions related to these differences. How are glaciers and snow in these regions responding to warming paired with more (or less) precipitation, and how do streamflow regimes (comprising the magnitudes, timings, frequencies, and durations of both high and low flows) respond to changes in glaciers, snow, and precipitation? What mechanisms drive extreme events such as drought and flooding in these regions? Answering these questions will shed light on how climate change is affecting scarce water resources in the LC and QB and can inform mitigation efforts to conserve these resources.

Investigating all these questions requires a variety of approaches. In situ measurements of precipitation, evaporation, glaciers, and snow, as well as of groundwater, lakes, rivers, and soils, are needed to determine the availability and quality of water resources in specific locations in the LC and QB. Analyses using stable isotopes and tracers can help determine the sources and ages of water on and below the ground surface. Satellite observations of how landscape variables, such as desertification, lake area, glaciers and snow, soil moisture, and vegetation, are changing will help track effects of climate change and brine mining on water resources and ecosystems.

We will also need hydrogeological modeling studies to understand surface hydrology and groundwater storage and movement, and how they are affected by surface runoff in the LC and QB. (In situ measurements are further required to validate satellite and modeling studies.)

Furthermore, collaborations among researchers from both regions should be pursued to enable detailed comparisons and illuminate differences and commonalities in the water issues of each. Such collaborations would also facilitate sharing of research best practices and potential policy solutions with respect to brine mining and water resources.

Involving All Stakeholders for a Better Outcome

Water resources in the LC and QB are already stressed by virtue of their locations amid the world's highest deserts and because of changing climatic conditions. Brine mining to help supply lithium and other raw materials for renewable energy transitions may exacerbate this stress. This mining will be sustainable only when operations, from cradle to grave, use water efficiently; minimize harm to the environment, ecosystems, and communities; and compensate for damage when it does occur.

Combining multiple scientific approaches to study regional hydrology will produce holistic and comprehensive knowledge of water quantity and quality in these areas. But to support the sustainability of brine mining and water resources management in the LC and QB, scientists must share the information and answers gleaned from these approaches with relevant government agencies, mining companies, and local communities through research reports and through conferences and town hall meetings that bring these groups together.

Involving community members will especially help reveal not only the effects on hydrology and ecosystems but also the human toll of mining activities and climate change. And improved communication among these groups will help lawmakers and regulators make and enforce rules to govern responsible mining operations while mitigating negative impacts and meeting community needs.

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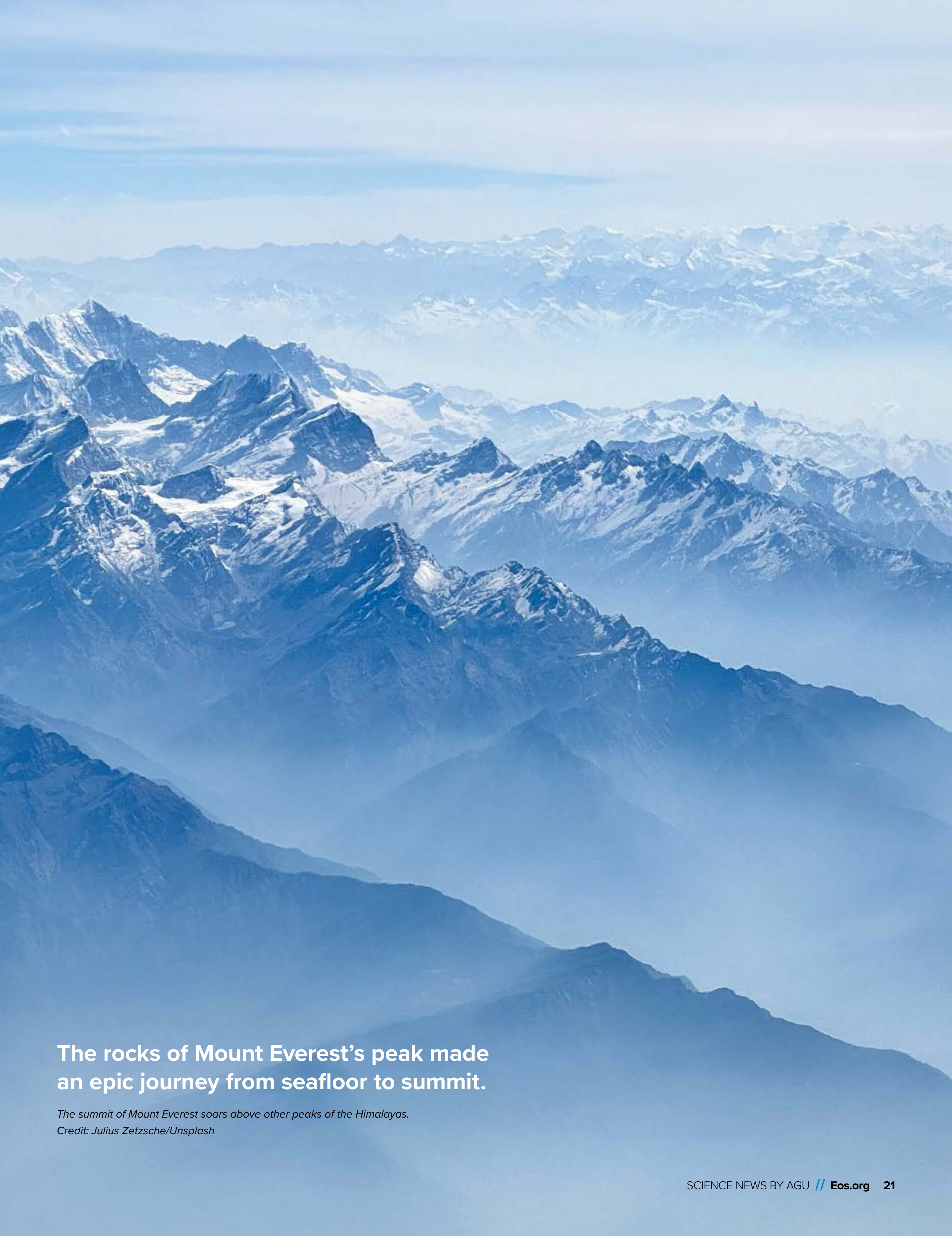
HOW TO BUILD THE WORLD'S HIGHEST MOUNTAIN

By Nathaniel Scharping



The rocks of Mount Everest's peak made an epic journey from seafloor to summit.

The summit of Mount Everest soars above other peaks of the Himalayas. Credit: Julius Zetzsche/Unsplash

At the top of the world, there is a sea—the remains of one, at least. The summit rocks of Mount Everest, the highest elevation on Earth, contain fossils of trilobites, arthropods, and other denizens of the ancient Tethys Ocean, which once separated the landmasses that are now Asia and the Indian subcontinent.

Today these sea creatures are entombed 8,849 meters (29,032 feet) above sea level. At that elevation, Mount Everest scrapes the jet stream; winds of well over 160 kilometers (100 miles) per hour are common, and temperatures can regularly dip below -30°C (−22°F). Oxygen levels are just one third of what they are at sea level, putting Everest's summit in the "death zone" where most organisms (including humans) cannot survive for more than a short time.

The fossilized marine organisms that crown Everest have been along for one of the most visibly dramatic geologic rides of the past 60 million years: a reshaping of Earth's crust that produced the highest mountain range on the planet. The Himalayas include 10 of the world's 14 "eight thousanders," the peaks higher than 8,000 meters (26,247 feet), including Kangchenjunga, K2, and, rising above all of them, Everest (also known as Chomolungma or Sagarmatha).

How sediments that once sat under an ocean came to form the roof of the world is a question that has puzzled geologists for more than a century. Expeditions to the high Himalayas to retrieve rock samples and map visible faults, paired with analytical techniques such as seismic profiling and low-temperature thermochronology, have revealed Everest's internal structure and hinted at how millions of years of tectonic movement have caused it to grow.

Today, scientists have a good picture of the forces that have worked both to push up and bring down Everest. But many questions remain, including when the mountain reached such great heights, whether the rocks that built it were warm and flowy rather than brittle, and how long the world's highest peak will hold its crown.

"The structures in the Himalayas were the first time people realized that you could get low-angle normal faults in a compressional tectonic environment."

Making a Mass of Mountains

Scientists trace the beginnings of Everest and the modern Himalayas to a fated collision that began between 50 million and 60 million years ago. For about 80 million years after breaking from the ancient supercontinent Pangaea, the Indian tectonic plate raced northward before ploughing into the southern edge of Central Asia.

Exactly when the collision started is still debated, but the earliest stratigraphic evidence for it is provided by 59-million-year-old nanofossils and reworked zircons from the Eurasian plate that show up in Indian plate sediments. Evidence from marine sediments puts the final closure of the Tethys Ocean much later, around 34 million years ago.

At that time, the Tibetan Plateau was already a land of mountains. Earlier convergence between the Eurasian plate and oceanic crust underlying the Tethys would have built mountains with a chain of volcanoes, though it's not clear exactly how high and how far north that mountainous region extended. Today the 4,000- to 5,000-meter-high (13,100- to 16,400-foot-high) Tibetan Plateau covers 2.5 million square kilometers (965,000 square miles) north of the Himalayas.

Some studies using oxygen isotopes, which glean paleoaltimetry data from the composition of rainwater that once fell on the surface, indicate the region may have been 3.5 kilometers (2.2 miles) above sea level as far back as 60 million years ago.

Other oxygen isotopic evidence shows that the plateau likely rose later and that the Himalayas could have looked something like they do today 40 million years ago, said John Cottle, a geologist at the University of California, Santa Barbara. Some researchers go even fur-

Everest's rock layers can be seen on its north face. Credit: Mark Horrell/Flickr, CC BY-NC-SA 2.0 (bit.ly/ccbyncsa2-0)

ther and argue that the plateau reached its modern elevation only within the past 15 million years.

Regardless of the exact timing, the elevated plateau set the stage for creating the roof of the world, but another colossal geological event was needed for the modern Himalayas to rise.

A continent-on-continent collision is akin to an unstoppable force meeting an immovable object—in this case, the force being the Indian plate and the object being Asia. The base of the Indian plate rammed underneath Asia while its upper sedimentary layers wrinkled and folded on top of themselves like snow piling against a moving shovel. The force of the collision compressed and shortened the Indian plate by as much as 900 kilometers (560 miles), pushing the landscape to towering heights.

The Himalayas today sit just south of the suture, the surface boundary between the still-colliding tectonic plates. Everest itself is near the middle of the range, straddling the border between Nepal and China's Tibet Autonomous Region.

"We don't really have a very clear idea of what are the fault orientations when they go in the subsurface."

We still don't know when Everest took shape as a mountain peak. The rocks from which it is assembled range from tens of millions to hundreds of millions of years old, and many have been metamorphosed by the high temperatures and pressures involved in the collision between the Indian and Asian plates. Some evidence as to when the mountain emerged comes from its tip: The limestone at its summit records evidence of light deformation around 40–45 million years ago, followed by a period of rapid cooling around 35 million years ago, an indication that it was shallowly buried and then pushed to the surface, said Kyle Larson, a structural geologist at the University of British Columbia. That pattern could place an upper limit on the peak's age.

One study using oxygen isotope paleoaltimetry measurements indicates that Everest was already 5,000 meters (16,400 feet) high by the early Miocene, between 23 million and 16 million years ago. However, this estimate is speculative, as the technique may not be very accurate, said Matt Kohn, a metamorphic petrologist at Boise State University.

How Everest, and not another nearby Himalayan peak, got to be the highest mountain in the world is probably "just luck," Larson said. "There's nothing specifically special about Everest."

"With things like the Indian monsoon, Earth is trying to tear [the Himalayas] down as fast as they're being built."

Inside Everest

If we could peer inside the Himalayas, we would find a sequence of squished and buried rocks scraped off the Indian plate, separated by faults that slice through much of the crust. These faults all stem from the Main Himalayan Thrust (MHT), along which the Indian plate is still sliding beneath Asia. Each split off the MHT over millions of years as successive layers of material stacked up. The faults all generally dip just slightly to the north and intersect the surface south of Everest, giving geologists a tilted view of the layers that make up the mountain.

At the bottom, deep beneath Everest, are the highly metamorphosed gneisses and granitic rocks of the Indian shield, part of an Archean craton that underlies the subcontinent.

The MHT, which is nearly horizontal, separates these basement rocks from a stack of deformed layers above, each of which contains a different chapter in the tale of collision and mountain building. Older, structurally higher segments of the MHT are now inactive; the Main Frontal Thrust (MFT) is the currently active arm of the MHT. It emerges at the surface far south of Everest, where it thrusts sedimentary rocks of the Siwalik Group, which eroded from the Himalayas to the south into a basin beginning 15 million years ago, over young sediments forming today.

The Siwalik sediments are capped by the Main Boundary Thrust (MBT), which was active around 5 million years ago (though some estimates put this as early as 14 million years ago). Above the MBT are the lightly metamorphosed sediments of the Lesser Himalayan Sequence (LHS) exposed in the lowlands of India, Nepal, and Bhutan. These metamorphosed marine sediments were deposited on the edge of the Indian plate beginning almost 2 billion years ago and have been scraped off and folded by a series of stacked faults that lifted the layers above them.

The Main Central Thrust (MCT), which was active from around 25 million to 13 million years ago, separates the LHS from the Greater Himalayan Sequence (GHS) above. This tens-of-kilometers-thick sequence of highly metamorphosed rocks contains gneisses, as well as pockets of leucogranites formed by partial melting.

The GHS makes up the bulk of Everest and most major Himalayan peaks. Its features are indicative of the titanic forces that have uplifted the range.

Many of the GHS rocks began as sediments deposited in the Precambrian era, more than 540 million years ago, but most of the metamorphism began around 40 million years ago and continued to 15 million years ago. That intense period of metamorphism shows when compressive forces, and perhaps crustal thickening and uplift, were strongest, said Mike Searle, a structural geologist at the University of Oxford.

Above the GHS are more metamorphic rocks topped by the roughly 160-meter-thick (525-foot-thick) Yellow Band, a well-known layer of marble that signals to climbers the summit is near.

At the very top of Everest, beginning at around 8,600 meters, are limestones and other sedimentary and metasedimentary rocks of the Tethys Ocean. The Tethyan rocks are generally younger than rocks of the GHS, though younger leucogranites in the GHS are evidence that that layer was pushed in millions of years after the Tethyan rocks were emplaced. Debate about how and when this happened has yet to be resolved.

Strikingly visible on the mountain's sheer southwest face, the South Tibetan Detachment System (STDS) separates the GHS from the Tethyan sediments that cap the mountain. Elsewhere in the Himalayas, the STDS is one main fault. However, in Everest it consists of two strands: the lower Lhotse Detachment and the upper Qomolangma Detachment. These faults were likely active at the same time as the MCT, indicating that all three faults are linked.

The STDS is a normal-sense fault that is oriented nearly horizontally, a distinct oddity in a landscape dominated by thrust faults. Along the STDS (and its strands), the rocks of the GHS moved to the south and upward. So-called detachment faults like this are typically found in places where the crust is being stretched and thinned, such as in the U.S. Basin and Range Province, Searle said.

"The structures in the Himalayas were the first time people realized that you could get low-angle normal faults in a compressional tectonic environment," he said.

Did It Flow, or Did It Wedge?

How a type of fault known to facilitate crustal thinning came to be found at the top of the world's highest mountain is a long-standing, unsolved problem. In the late 1990s and early 2000s, researchers began describing two distinct hypotheses to decipher it.

One model, known as channel flow, is based on evidence of deformation and metamorphism from the rocks of the GHS in Everest's deep innards and the MCT and STDS faults that bound them. Leucogranites formed when parts of the Indian plate were partially melted after being pushed deep under Asia and heated, suggesting that the GHS was warm and capable of flowing. Pressed between hard Tethyan rocks above and hard LHS rocks below, the viscous rocks of the GHS flowed outward along the Himalayan range front beginning around 25 million years ago, helped along by strong erosional processes removing material as it was pushed to the surface.

"It's like squeezing a tube of toothpaste and then taking a cap off the toothpaste," Larson explained.

Another model, known as critical wedge, presents a different story. Its proponents suggest that within the LHS and GHS, thrust faults repeatedly pushed rocks on top of one another. The duplexing, or stacking of layers, seen in the LHS is consistent with this model, Kohn said, as is evidence that metamorphic rocks in the GHS get progressively younger and less metamorphosed deeper down.

"What you end up with is [the idea that] these rocks under[neath] were transported the least distance into the orogen and the rocks up on top came from the deepest parts of the orogen," he said.

Both the channel flow and critical wedge models involve the rocks of the GHS being pushed up and to the south beneath the Tethyan sediments, which would necessitate the normal-sense STDS on top and a thrust fault (the MCT) on the bottom, as seen within Everest. Unlike along other normal faults, the rocks above the STDS did not slide down so much as the GHS moved up while Tethyan rocks sat passively above them.

Decisive evidence favoring one theory over the other has yet to emerge, in part because obtaining high-quality data from underneath the Himalayas is challenging. "We don't really have a very clear idea of what are the fault orientations when they go in the subsurface," said Malay Mukul, a geologist at the Indian Institute of Technology Bombay. "That's a big knowledge gap."

Many agree that each model likely explains different aspects of the Himalayas, though to what degree isn't settled. More recent work has suggested a kind of synthesis of the channel flow and critical wedge models, implying they may have worked in concert to build the Himalayas.

Most scientists, regardless of which theory they support, agree that the STDS and MCT became inactive by about 13 million years ago, though a few estimates using different dating methods give younger ages. Meanwhile, the MFT is still pushing the mountain upward.

Everest, Present and Future

While the collision between the Indian plate and Asia was working to push the Himalayas skyward, Everest and other peaks were being carved by rivers and glaciers into the silhouettes we see today.

"With things like the Indian monsoon, Earth is trying to tear [the Himalayas] down as fast as they're being built," Larson said. "Because of the large-scale deformation that's still ongoing, these [peaks] are able to still poke up and be anomalously high."

Summer monsoons bring at least 300 centimeters (118 inches) of precipitation to parts of the south side of the Himalayan range crest each year. The northern Himalayas and the Tibetan Plateau are relatively dry.

This contrast means Everest is two-faced, experiencing a rain shadow effect with far more erosion happening on the south side and much less on the north.

Everest today stands atop the current high point of the Himalayan crest, which divides the southern lowlands from the Tibetan Plateau and bears the brunt of the erosion. What that means for the mountain's future is uncertain, with opposing forces of tectonic uplift and surface erosion vying to determine the mountain's height.

GPS measurements show the Himalayas are currently rising by roughly 2 millimeters (0.08 inch) per year, which fits with other evidence showing that the subduction and thickening of the Indian plate are still occurring.

"I wouldn't be surprised if Everest continues growing up and up and up."

Even more recent events may have given the mountain a boost. A 2024 study claimed the nearby Arun River swelled in size around 90,000 years ago, increasing erosion and leading to isostatic uplift, a process in which the crust rebounds as weight is removed. That process could have added a millimeter (0.04 inch) per year to Everest's growth, the study's authors said, though some scientists disagree with their conclusions, which are based on modeling.

Still, scientists widely agree that Everest continues to rise, though how long that might continue and how tall the mountain will get aren't clear. The mountain may already have reached its limit, Cottle said. "The thickness of the crust that you need to support that elevation is probably already somewhat at a maximum," he said. Any taller and the crust underneath may move or change, causing the mountain to sink down once again.

Searle, on the other hand, thinks the mountain may have room to grow. As long as the continental collision continues, he said, the Himalayas will rise. "I wouldn't be surprised if Everest continues growing up and up and up."

Further in the future, on the order of millions of years, movement on the MFT could stop, because thrust motion could shift to another part of the Indian plate to the south. That new thrust could form nearby, meaning the Himalayas may simply move a few tens of kilometers south, or it could happen much farther away.

Should that happen, the upward motion of the Himalayas would cease, leaving the mountains to be slowly ground down by erosion. Everest is a monument to the gravity-defying power of tectonics. But it is no match for wind, water, and, most of all, time.

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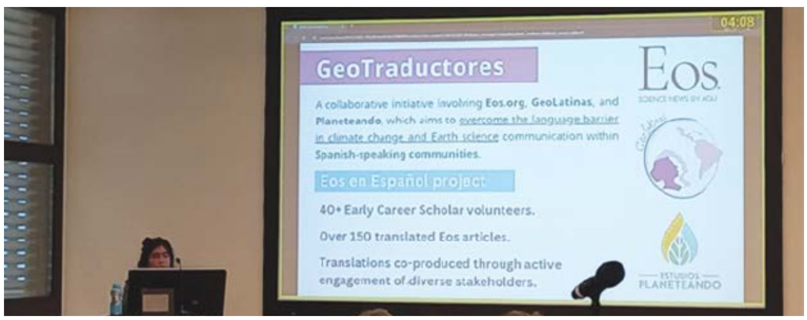
Nathaniel Scharping, Science Writer

Read the article at Eos.org

GeoTraductores Democratizes Science, One Translation at a Time

English is the dominant language for communicating research and discoveries in scientific journals. The same is true for science communication outlets such as news articles, multimedia, and press releases. However, sharing this information only in English excludes large audiences, which can be particularly detrimental when it comes to Earth and space science topics. Without access to the latest science information in their native language, community members may be less equipped to manage hazards such as climate change, volcanic eruptions, and earthquakes.

In an effort to enhance diversity, equity, and inclusion in the Earth and space sciences, *Eos*, the nonprofit organization GeoLatinas, and the science communication collective Planeteando joined forces to communicate science news to Spanish-speaking communities. Their collaboration, GeoTraductores, began in 2020 and focused initially on translating science articles from *Eos* into Spanish. Over a 4-year period, approximately 40 GeoTraductores participants and several *Eos* staff members worked together to translate, edit, and publish more than 150 Spanish articles for *Eos* en Español.



GeoTraductores volunteer Sofía Barragán-Montilla presented information about the science democratization initiative at the European Geosciences Union General Assembly 2024 (EGU24). Credit: Malena Orduña Alegría

Navarro-Perez et al. examined the impact of GeoTraductores on visitor traffic to Eos.org and found a surge in traffic from Latin American countries. Readership in Colombia, Mexico, and Panama each increased by more than 85%, and traffic from Brazil, Chile, Costa Rica, Ecuador, and Peru each grew by 20%. In Spain, readership increased by 40%.

The authors point out that most GeoTraductores participants were women (85%), and almost all were early-career scientists. They add that this collaboration is an example of how bilingual science communication can help democratize scientific literature for Latin American audiences—including Spanish-speaking populations within the United States. (*Community Science*, https://doi.org/10.1029/2023CSJ000070, 2024) **—Sarah Derouin**, *Science Writer*

Editor's note: Caryl-Sue Micalizio, editor in chief of Eos, *is a coauthor of the paper covered in this research spotlight.*

GeoTraductores Democratizan la Ciencia, Una Traducción a la Vez

El inglés es el idioma predominante para la comunicación sobre investigaciones y descubrimientos en publicaciones científicas. Lo mismo ocurre en los medios de comunicación científica, como artículos de noticias, multimedia y comunicados de prensa. Sin embargo, compartir esta información únicamente en inglés excluye a grandes sectores de audiencias, lo cual puede ser particularmente perjudicial en temas de ciencias de la Tierra y del espacio. Sin acceso a la información científica más reciente en su idioma nativo, los miembros de la comunidad pueden estar menos equipados para manejar peligros como el cambio climático, las erupciones volcánicas y los terremotos.

En un esfuerzo por mejorar la diversidad, equidad e inclusión en las ciencias de la Tierra y del espacio, *Eos*, la organización sin fines de lucro GeoLatinas, y el colectivo de comunicación científica Planeteando unieron fuerzas para comunicar noticias científicas a la comunidad hispanohablante. Su colaboración, llamada GeoTraductores, comenzó en 2020 y se centró inicialmente en traducir artículos científicos de *Eos* al español. Durante un período de 4 años, aproximadamente 40 voluntarios de GeoTraductores y varios miembros del personal de *Eos*, trabajaron juntos para traducir, editar, y publicar más de 150 artículos en español para *Eos* en Español.

Voluntaria de GeoTraductores Sofía Barragán-Montilla presentó información de la iniciativa de democratización de las ciencias en la Asamblea General 2024 de la Unión Europea de Geociencias (EGU24). Crédito: Malena Orduña Alegría

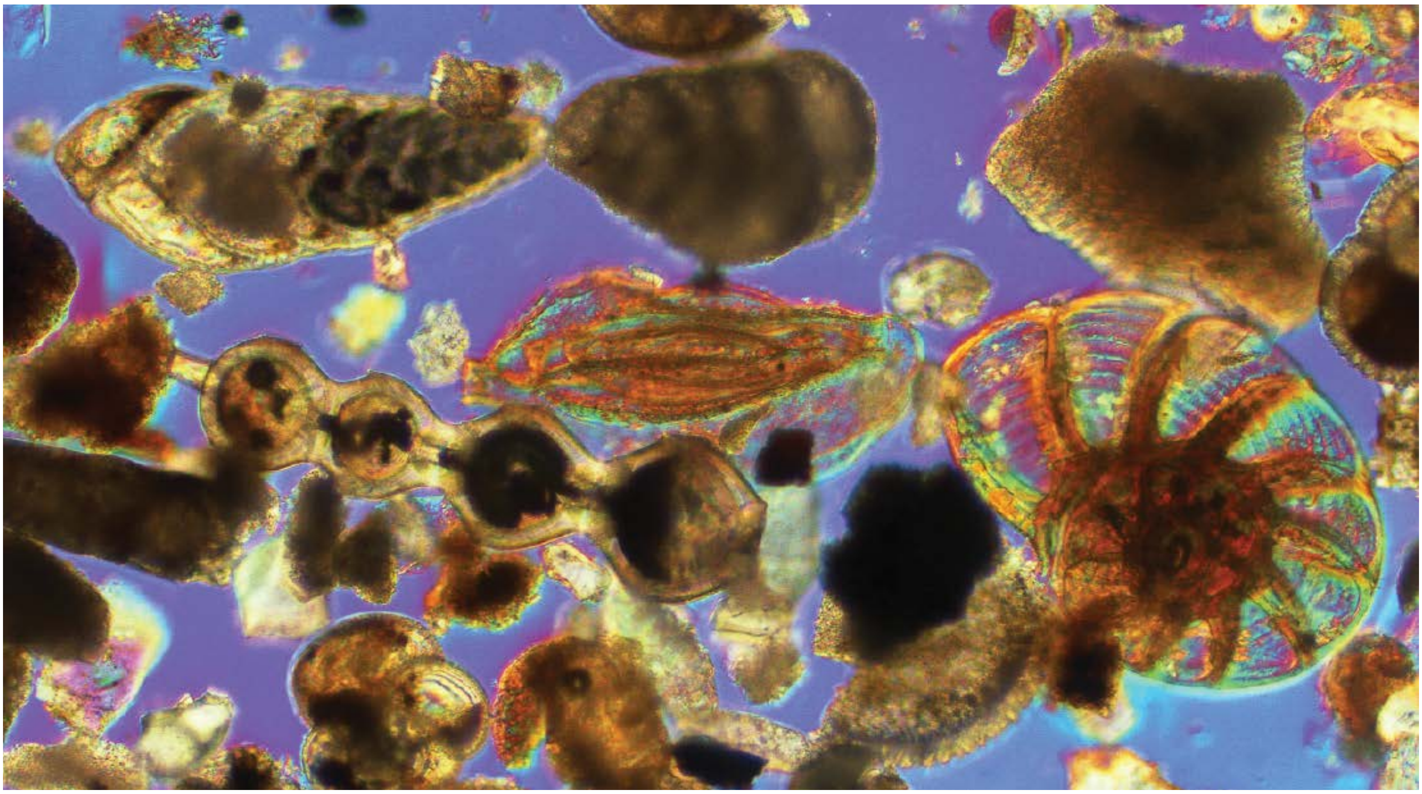
Navarro-Perez, et al. examinaron el impacto de GeoTraductores en el tráfico de visitantes al Eos.org y encontraron un aumento en el tráfico desde países latinoamericanos. La cantidad de lectores de Colombia, México y Panamá aumentaron en más del 85% cada uno, y el tráfico desde Brasil, Chile, Costa Rica, Ecuador y Perú creció un 20%. Los lectores de España aumentaron 40%.

Los autores señalan que la mayoría de los voluntarios de GeoTraductores eran mujeres (85%) y casi todas eran científicas en etapas tempranas de su carrera. Ellos añaden que esta colaboración es un ejemplo de cómo la comunicación científica bilingüe puede fomentar la democratización de las ciencias para las audiencias latinoamericanas—incluyendo a las poblaciones hispanohablantes en los Estados Unidos. (*Community Science Journal*, https://doi.org/10.1029/2023CSJ000070, 2024) **—Sarah Derouin,** *Escritora de ciencia*

This translation was made possible by the GeoTraductores partnership. Esta traducción fue posible gracias a la asociación GeoTraductores.

Nota del editor: Caryl-Sue Micalizio, editora en jefe de Eos, *es co-autora del artículo cubierto esta pieza de research spotlight.*

Getting to the Bottom of Cenozoic Deep-Ocean Temperatures



Foraminifera are single-celled organisms that often have external shells, or tests. Scientists use carbonate contained in these tests to learn more about how ocean temperatures have changed over time. Credit: Doc. RNDr. Josef Reischig, CSc./Wikimedia Commons, CC BY-SA 3.0 (bit.ly/ccbysa3-0)

Understanding ancient ocean temperatures—particularly from the Cenozoic era (the past 66 million years), during which Earth experienced dramatic climate shifts—helps scientists reveal more about the planet's past climates.

To reconstruct ocean temperatures, researchers look at ratios of stable oxygen isotopes in deep-sea waters by measuring oxygen held in seafloor carbonate. The ratio of the "heavy" oxygen-18 isotope, which has eight protons and 10 neutrons in its nucleus, is measured relative to more common "light" oxygen-16, which contains the same number of protons but only eight neutrons. Waters enriched in heavy oxygen reflect colder climates and ice ages, whereas enrichment in light oxygen indicates higher temperatures and reduced global ice volumes.

Isotope ratios are measured using mass spectrometry, which separates different isotopes and finds their relative abundance.

Clumped isotope thermometry is a newer method that focuses on the rate at which rare heavier isotopes bond to one another rather than to lighter isotopes.

Both methods can produce Cenozoic ocean temperature reconstructions. However, the two techniques indicate different water temperature progressions through time, and the discrepancy is clouding our understanding of past ocean conditions.

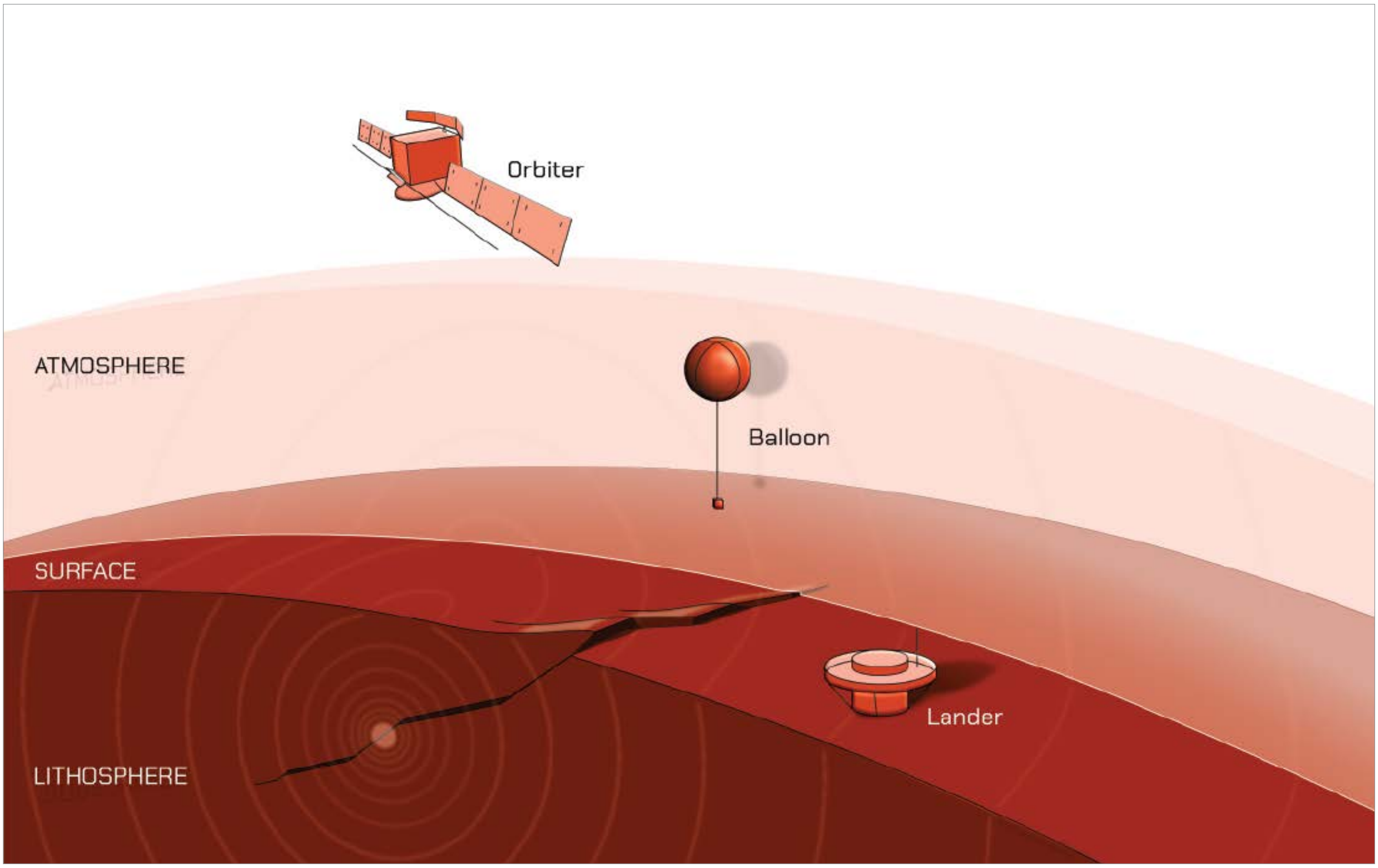
Rohling et al. compared reconstructions from published studies using the two approaches to better understand why their results vary so drastically. The authors evaluated a range of potential reasons, such as whether changes in ice sheet morphology and salinity levels affect the results of each method to different degrees.

None of the individual mechanisms the researchers explored explained the discrepancies between the results.

But they did find that they could significantly reduce the discrepancies when both methods accounted for the effects of pH and warm saline deep water on isotope variance. The reconciliation between the methods was further improved by revising the temperature calibration for the clumped isotope thermometry method, resulting in reconstructed temperatures about 2.2°C lower.

The authors note that their results require further refinement but suggest that they lay a foundation for advancing ocean temperature reconstructions. In particular, given that most sediment samples analyzed with the two isotopic methods to date have come from the Atlantic Ocean, the authors' new model also best represents past Atlantic temperatures. Considering samples from other regions is needed to improve the representation of global average conditions, the authors write. (*Paleoceanography and Paleoclimatology*, https://doi.org/10.1029/2024PA004872, 2024) **—Aaron Sidder,** *Science Writer*

Three Ways to Track Venusquakes, from Balloons to Satellites



An artist's depiction of different methods for measuring seismic and acoustic waves on Venus shows a seismometer on the ground, pressure sensors on balloons, and infrared imagers on orbiters. Credit: Fabio Crameri

Instruments aboard robotic landers have measured seismicity on the Moon and Mars, helping researchers learn about the inner workings of those celestial bodies. But the internal makeup of Venus is still not known, in part because high winds and blistering temperatures make it significantly more difficult to detect quakes on the second planet from the Sun.

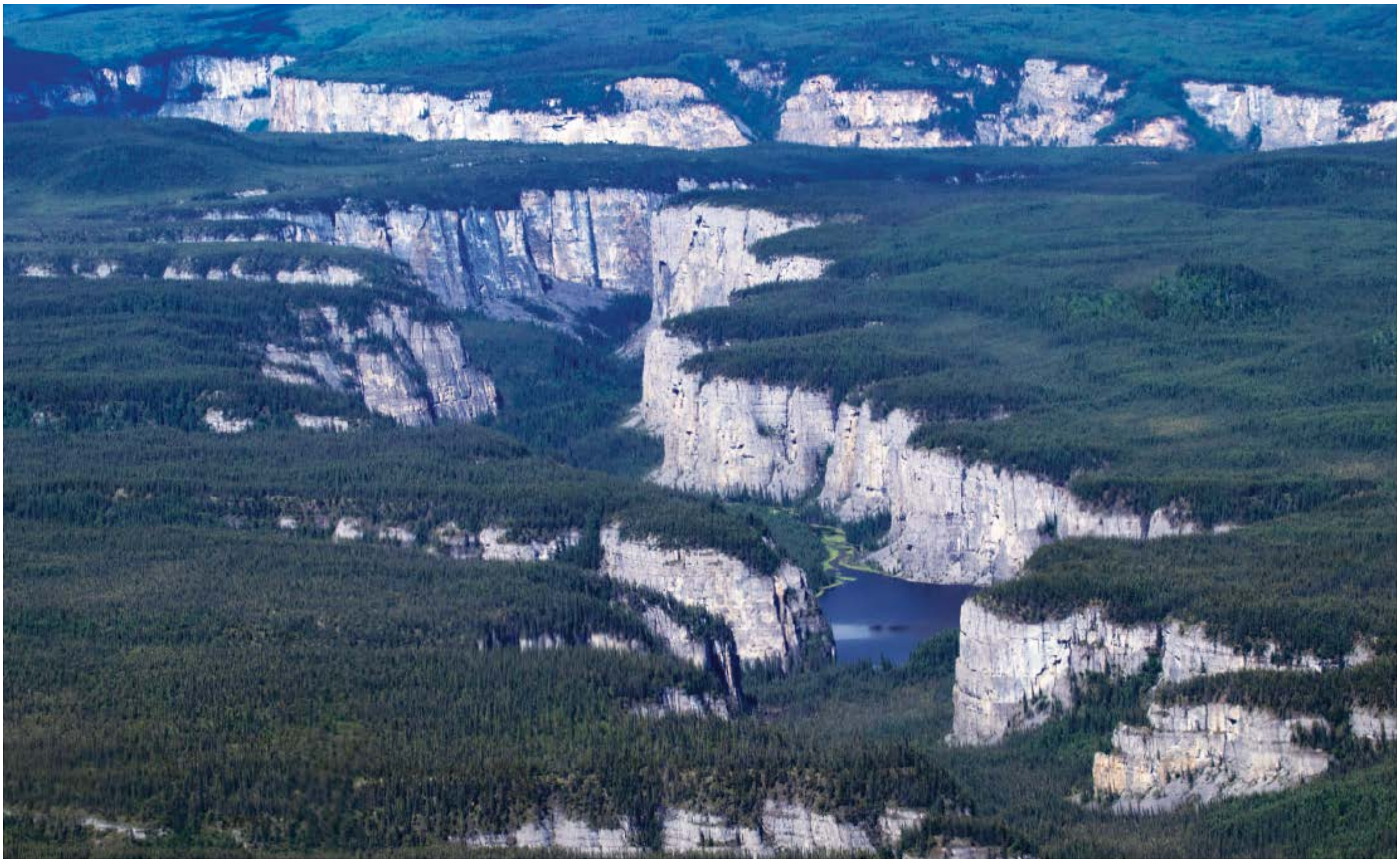
Three approaches to studying quakes on Venus are currently plausible, write *Garcia et al.* Ground sensors like those used on the Moon and Mars can measure seismic waves. Balloon-based pressure sensors can measure infrasound waves, a form of low-frequency waves in the atmosphere created by quakes. And satellite-based instruments can measure airglow, or light emissions from molecules in the upper atmosphere that show subtle variations when perturbed by infrasound waves. In this study, the authors considered current estimates of seismicity on the planet to weigh the pros and cons of each method.

Sensors on Venus's surface could detect quakes smaller than magnitude 4.0, but current ground-based technologies would likely survive less than a day on Venus, where surface temperatures exceed 450°C. Balloons similar to those used in the Soviet Vega program might survive for months, and their ability to detect and characterize seismic waves on Earth was recently documented for the first time. However, they can detect quakes of only magnitude 4.0–4.5 and larger. Satellite-based imagers taking airglow measurements could detect venusquakes of about the same magnitude, and they may be able to gather data for years.

Airglow measurements currently offer the best option for detecting seismic activity on Venus, the authors conclude. If possible, combining airglow measurements with longer-duration balloon-based sensors would offer an even more robust approach and reduce the possibility of misinterpreted readings, they say.

The study helps constrain requirements for future Venusian missions aimed at studying seismicity while pointing to areas for improvement. These areas include better understanding the geographical distribution of quakes and creating more detailed noise models for each technology. (*Earth and Space Science*, https://doi.org/10.1029/2024EA003670, 2024) **—Nathaniel Scharping,** *Science Writer*

High-Pressure Reactions Can Turn Nonporous Rocks into Sponges



The effects of water moving through rock in deep Earth can resonate in features on the surface, as they do at Scimitar Canyon in Nahanni Park Reserve in Canada's Northwest Territories. Credit: Gharvart/Wikimedia Commons, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

In deep Earth, rocks take up and release water all the time, and the effects can be wide reaching. Dehydration can cause rocks to crack and trigger tiny earthquakes, and over geologic timescales, this water cycling can influence plate tectonics and move continents.

Schmalholz et al. asked how water can move through impermeable rocks, such as those found in mantle wedges, the deep lithosphere, and the lower crust. They hypothesize that certain reactions can cause temporary porosity in these rocks. By mathematically modeling the hydration and dehydration of rock at high pressure, they derived equations to estimate how the porosity of rock changes as water cycles through it.

Previous work suggested that at very high temperatures, minerals can react with each other to form denser minerals, squeezing water out of the minerals and generating less dense, more porous rocks in the process. As the reaction progresses, a "dehydration front" moves through the rock. On the other hand, some reactions cause rocks to act like dry sponges, soaking up surrounding water and becoming denser. The progression of this reaction is known as a hydration front.

In the study, the researchers present 1D simulations for three scenarios (one for a hydration front and two for dehydration fronts) in which a rock with no porosity becomes temporarily porous.

In a hydration reaction, water flows into the rock from an external source, so the hydration front always moves in the direction in which the fluid is flowing. Dehydration reactions have two possible scenarios. In simple dehydration, water flows out of the rock and into the surrounding environment, moving in the opposite direction of the dehydration front. In the second scenario, called dehydration inflow, water is squeezed out of minerals, and additional water flows in to fill up the created porosity, so the fluid moves in the same direction as the dehydration front.

In whichever direction water is pushed, it has the potential to enter impermeable surrounding rocks if the reactions generate a porosity that allows for it. Describing how water moves through deep Earth is challenging, the researchers note, but their newly derived equations provide a framework for others researching how water drives geological processes beneath Earth's surface. (*Geochemistry, Geophysics, Geosystems*, https://doi.org/10.1029/2023GC011422, 2024) **—Saima May Sidik,** *Science Writer*

How Did Magma Oceans Evolve on Early Earth and Mars?

Before Earth became the Blue Planet, it was engulfed by a very different kind of ocean: a vast magma ocean reaching hundreds or perhaps even thousands of kilometers deep.

Different types of minerals crystallize at different temperatures, so as early Earth's magma ocean cooled and solidified, the chemical makeup of the molten rock changed over time. And as the magma released gases that made their way to the surface, the chemical makeup of early Earth's atmosphere changed as well.

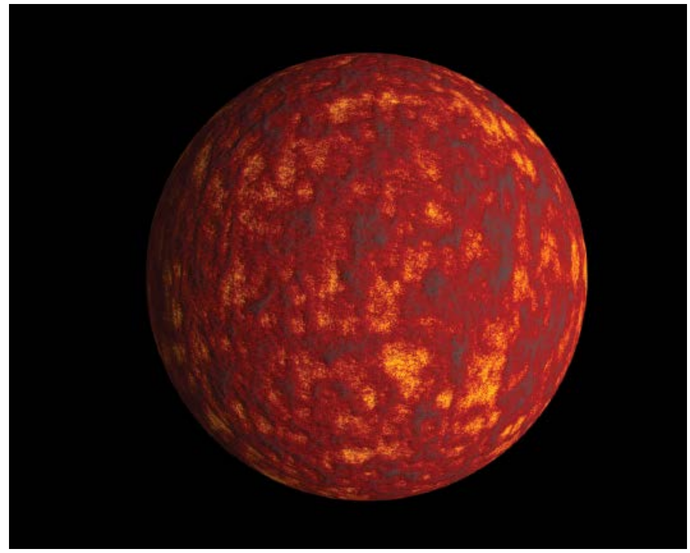
During their formation, Mars and many other rocky planets went through similar magma ocean stages. However, because this all occurred in the distant past for Earth and Mars—and in distant space for younger rocky planets—it is very difficult to know exactly how it all happened. However, information about the chemical makeup of rocky planets' early atmospheres is preserved in unreactive noble gases.

Now, *Schaefer et al.* present novel models simulating how Earth's and Mars's magma oceans might have changed over time as they crystallized, using these atmospheric clues and information about iron chemistry.

The models incorporate new calculations that capture how ferrous (reduced) and ferric (oxidized) iron behave as magma crystallizes in the mantle. The research team tested the model with different initial magma ocean depths and chemical makeups to see which combination would create the atmospheres they know existed around early Earth and Mars.

The researchers found that for Earth, models that start with a shallow magma ocean outperform models that start with a fully molten mantle. A shallow magma ocean could indicate either a mantle that was only partially melted or a fully melted mantle that began solidifying from its middle, with the innermost and outermost layers remaining molten for some time.

For Mars, none of the models successfully aligned with prior research findings about the Red Planet's early atmosphere, unless the magma initially contained less ferric iron than thought.



During their formation, many rocky planets are covered by a vast ocean of magma. A new modeling study reveals novel insights into magma oceans on early Earth and Mars. Credit: Merikanto via Wikimedia Commons, CC BY-SA 4.0 (bit.ly/ccbysa4-0)

These findings contribute to a deeper understanding of how rocky planets such as Earth and Mars form while also highlighting the need for more experimental research on the behavior of iron in molten rock. (*Journal of Geophysical Research: Planets*, https://doi.org/10.1029/2023JE008262, 2024) —**Sarah Stanley,** *Science Writer*

Bat Poop Records Fire History

With wildfires growing more frequent and more intense in many parts of the world, scientists are looking to the past to better understand where and when fires have burned. Lakes and wetlands, which capture charcoal particles when they fall from the atmosphere, have provided most records of ancient fires, or paleofires.

Now, researchers have found a new tool to help reconstruct fire history: bat poop.

Bats can collect charcoal on their fur as they fly and by brushing up against plants on which charcoal has settled. As they roost in caves and groom themselves, they can ingest—and then poop out—charcoal. Other charcoal particles also may fall to the cave floor, where guano accumulates. Though some previous research has used pollen and nitrogen preserved in bat guano to reconstruct vegetation records and learn more about past climates, no one had used guano records to examine fire histories.

To test whether bat guano accurately recorded fires, *Tsalickis et al.* collected a 2-meter core of guano buildup from a limestone cave in central Tennessee. Radiocarbon dating revealed that the guano mound started building up around 1952. They analyzed the core centimeter by centimeter, dated the tiny pieces of charcoal they found, and compared that charcoal record to data from historical wildfires and prescribed burns in the area.

The dates from charcoal in the bat poop core matched up with those from the historical fire data, providing the first evidence that guano can be used for paleofire reconstructions. However, because bats hibernate in winter, the records are reliable only for nonwinter fires.

In addition, bat poop charcoal dates correlated more strongly with dates of prescribed burns than of wildfires. That could be because bats flee wildfires (and thus are not in the area to poop out records of the fires) or intentionally seek out prescribed burn areas for foraging (as has been found in previous studies) or a combination of both.

The study gives scientists a new tool for reconstructing paleofire histories where lakes are absent and for distinguishing between human-caused fires and wildfires. (*Geophysical Research Letters*, https://doi.org/10.1029/2024GL112045, 2024) —**Rebecca Dzombak,** *Science Writer*

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Tenure Track Assistant, Associate, or Full Professor in Physical Oceanography

The Oceanography (OC) Department in the Naval Postgraduate School (NPS) invites applications for the faculty position in the broadly defined area of Physical Oceanography. We anticipate an appointment at the Assistant Professor level, but exceptional candidates at the Associate Professor or Full Professor level will be considered. We are seeking candidates with core strengths in areas that include but are not limited to: global and regional modeling, field observations using moorings or autonomous vehicles, mesoscale and sub-mesoscale dynamics, general circulation, ocean remote sensing, geophysical fluid dynamics, air-sea interaction, and ocean acoustics. The successful candidate is expected to develop an externally funded research program that spans basic to applied research areas and involves graduate students. The candidate must have a strong commitment to graduate teaching. Teaching duties are broad and may include ocean acoustics courses in addition to core physical oceanography courses.

We are seeking a colleague to join our vibrant OC Department, which has a long history of excellence in physical oceanography, ocean acoustics, ocean dynamics, nearshore processes, ocean waves and turbulence, ocean analysis and prediction, and high latitude ocean dynamics. The OC Department has a strong research infrastructure, such as facilities and vessels located in Monterey Bay, CA, an experienced group of technical staff, and access to computational resources provided by the Department of Defense HPC program. NPS is also home to the Consortium for Robotics and Unmanned Systems and Education, which funds internal projects and fosters collaborative research. The OC department promotes interdisciplinary research, and currently collaborates internally with the Physics, Meteorology, Undersea Warfare, and Computer Science departments.
The Monterey Bay area is home to an extensive network of local oceanographic research centers, including Stanford Hopkins Marine Station, Moss Landing Marine Laboratories, Monterey Bay Research Institute, UC Santa Cruz, and the US Geological Survey. Additional information can be found online at https://nps.edu/web/oceanography.

NPS is a federal institution within the U.S. Department of Defense that awards MS and PhD degrees. The student body is composed of U.S. and international military officers rom all services, as well as federal employees. In addition, the OC faculty supports a number of civilian National Research Council post-doctorates.

Requirements for this position include a PhD in physical oceanography or a related area, and U.S. Citizenship. A letter of application including a CV, statement of teaching and research interests and philosophy and the names of three referees should be sent by 28 February, 2025 to:

Dr. Derek Olson, Faculty Search Committee Chair
Department of Oceanography
Naval Postgraduate School
Monterey, CA 93943
831-656-2054
derek.olson@nps.edu

Salary is commensurate with qualifications and experience based on federal government Administrative Determined (AD) pay scale including locality adjustments. NPS is committed to increasing the proportion of women and members of groups that have been historically underrepresented in research and teaching positions and therefore encourages qualified candidates to apply. Applications will be accepted until the position is filled.

Dear *Eos:*

Life in submerged karst sinkholes in the Laurentian Great Lakes is composed almost exclusively of prokaryotic bacteria and archaea that build colorful mats capable of both photosynthesis and chemosynthesis. Because of the prevailing low-oxygen conditions, aerobic organisms such as eukaryotic invertebrates and vertebrates are usually excluded from these isolated benthic habitats, which can be as small as a room or as big as a football field.

Exceptions abound, though. On the fringes of these ecosystems, where groundwater's influence is diluted by mixing with well-oxygenated lake water, diver-collected mats and observations often reveal a host of eukaryotic protists such as diatoms, invertebrates such as nematodes and tardigrades, and even small fish such as gobies.

Finding larger fish in the low-oxygen groundwater at the center of a sinkhole is quite uncommon, however. Like human divers, this burbot (*Lota lota,* an indigenous member of the cod family) can be only a transient visitor to this otherworldly world. Modern-day sinkholes with actively venting high-salt, high-sulfur, low-oxygen groundwater remain microbial refugia that can provide a glimpse into life's early salty, sulfurous, and anoxic origins.

—**Jon Slayer,** Force Blue, Mount Pleasant, S.C.; **Stephanie Gandulla,** Thunder Bay National Marine Sanctuary, NOAA, Alpena, Mich.; **Steve Ruberg,** Great Lakes Environmental Research Lab, NOAA, Ann Arbor, Mich.; and **Bopi Biddanda,** Robert B. Annis Water Resources Institute, Grand Valley State University, Muskegon, Mich.

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