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EOS
Earth & Space Science News

100 YEARS

What Are the Earth Blobs?

The DDT Legacy

Forams Forever

VENUS IS ALIVE

Let's go back to this "criminally underexplored" world

AGU 100
ADVANCING EARTH AND SPACE SCIENCE

A New Approach to New Worlds

In September 1960, we planted our flag. I don't mean Neil Armstrong doing his thing 9 years later on the Moon, of course (see our July issue for that celebration). This was when AGU's then president Lloyd V. Berkner invited member H. E. Newell to stake a claim here in the pages of *Eos* on the field of planetary science, as the organization with "the strongest interest in this matter."

Planetary science, then defined as the burgeoning study of the solar system, was the ultimate in convergence science, incorporating so much more than existing astronomy and rocket associations were able to represent. "Once the property of the astronomer, and not too highly valued a property at that, the planets now are brought within the purview of the geophysicist," Newell wrote. "It is hoped that the geophysicists and astronomers will unite now to give them the attention that they deserve scientifically."

Newell was announcing in *Eos* the launch of the Planning Committee on Planetary Science, which Berkner had appointed him to lead. Two years later—only 2 months after John F. Kennedy declared that we choose to go to the Moon—and with overwhelming support from its membership, AGU announced its new Planetary Sciences section.

This month, as we continue our yearlong celebration of AGU's Centennial, we look to our neighbors in this small patch of our universe. Indeed, these days we look even farther beyond—the study of exoplanets was still only theory to our pioneering section leaders.

Let's begin by urging new exploration of a world once thought dead. In our cover story on Venus (p. 20), scientists have taken a contemporary look at the data sent back from the Magellan spacecraft in the 1990s and are revising their theories on the state of the planet's geology. New maps reveal that Venus, previously thought to have succumbed to catastrophic resurfacing, is resurfacing in a steady state, in pieces at a time. Enough questions have been raised by looking at old data with new technology that scientists are extremely eager to find out what they may discover by sending a new mission to collect data with today's capabilities. And Venusphiles aren't the only ones: Now that thousands of exoplanets have been discovered, some of them look suspiciously like our inner neighbor. Understanding Venus can help us understand so many parts of the universe.

While volcanologists have their eyes on Venus, oceanographers have their sights on Europa. A new study reveals that the ocean under the surface of Europa's moon very likely contains sodium chloride—good ol' Terran table salt and the same type of salt found in our own oceans (p. 9). It's an exciting finding, especially for anyone hoping to find life on a world other than our own.

This issue is packed with several more recent studies about metals on the Moon (p. 10), the first detected marsquake (p. 14), and the fine line between giant planets and brown dwarfs (p. 11). We're also taking some liberties in the definition of planetary sciences by reporting on some exceptional research on the makeup of our own, sometimes very strange, planet.

My favorite fact in this issue is from the story on page 32: There are continent-sized "blobs" in Earth's mantle that if they were sitting on the planet's surface, would reach so high that the International Space Station would have to navigate around them. The study of the Earth blobs began in the 1970s, but with multiple published papers concluding contradictory findings, the research has only raised more questions and deepened a fascinating geoscience mystery.

No one at AGU was sleeping on the opportunity for Earth and space scientists to participate in the discoveries offered by our first forays off world, H. E. Newell the least of all: "The new frontier of science in our time is space research. All scientific disciplines will be called upon in its exploration," he wrote in *Eos*. We call you all once more, as we enter the next century of collaboration together through AGU.

Heather Goss, Editor in Chief

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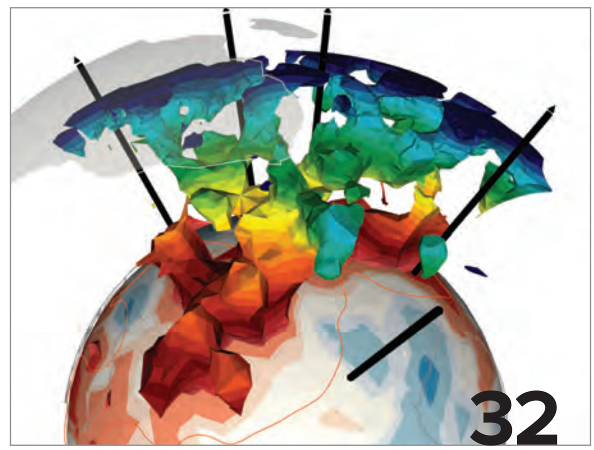

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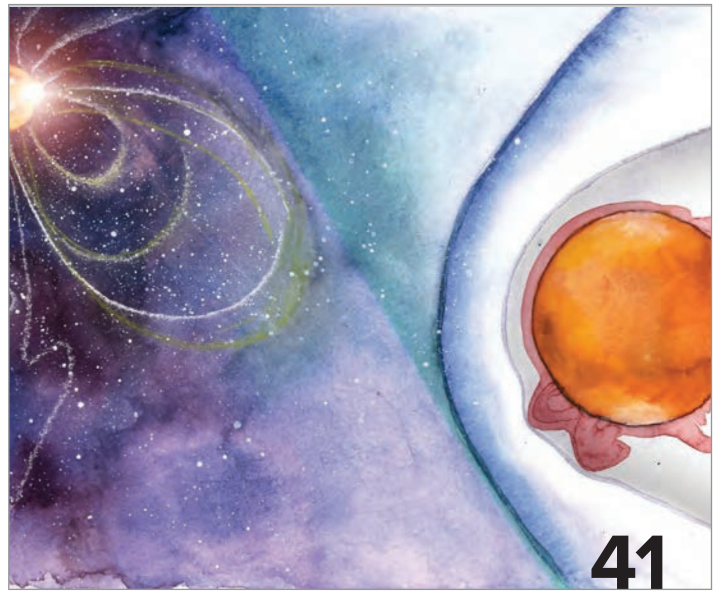
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The Little Ice Age Wasn’t Global, but Current Climate Change Is

The Little Ice Age was a period of bitter winters and mild summers that affected Europe and North America between the 14th and 19th centuries. The cold weather is well documented in written records and supported by such paleoclimatic records as tree rings, glacial growth, and lake sediments. These paleoclimatic records serve as proxies that register past temperatures, confirming that it was colder than usual.

Thanks to paleoclimatic records, climate scientists have identified four cold and warm “climate epochs” during the past 2,000 years: the Roman Warm Period, which covered the first centuries of the Common Era; the Dark Ages Cold Period, from 400 to 800; the Medieval Warm Period, between 800 and 1200; and, most recently, the Little Ice Age.

The temperature proxies that allowed scientists to define these epochs were mostly from the extratropical Northern Hemisphere, particularly Europe and North America. Lacking information from other regions, researchers had long assumed that these climatic epochs must have happened simultaneously around the entire planet, but that might not be true.

To find out, a team of researchers led by Raphael Neukom, a climate scientist at the University of Bern in Switzerland, has used a database of globally distributed paleoclimatic records recently developed by the PAGES (Past Global Changes) international consortium. PAGES helps climate scientists to share climate proxy measurements accompanied by detailed information about the geographical location, methods used, and other data necessary so other researchers can make use of them. This documentation makes it easier to combine different types of proxies, such as tree ring measurements from the Northern Hemisphere and coral growth from the tropics, to extract information about the past evolution of Earth’s climate.

Feeding this information into computer climate simulations, Neukom and colleagues determined that none of these past climate epochs affected the entire planet at the same time, not even the Little Ice Age.

“We know that it was indeed cold during the 15th to 19th century, so we don’t deny this,” Neukom says. “But what we find is that the actual minimum occurred at different times at different places.”

For instance, during the Little Ice Age, minimum temperatures hit the eastern Pacific during the 15th century, northwestern Europe and southeastern North America during the 17th century, and most remaining regions during the mid-19th century. For the previous climate epochs, the spatial coherence is even less significant.

> “Statistically, the spatial coherence of the warming in the last century is totally different from the spatial coherence of any other period in the past.”

This wintry slice of Dutch life in the 1600s was likely made possible by the cold temperatures of the Little Ice Age. Credit: Hendrick Avercamp, Rijksmuseum

“If you have a cooling driver, like a volcanic eruption, from our understanding of the climate system it’s unlikely that this causes the whole globe to cool at the same time and for the same time period,” Neukom says.

Even if the study doesn’t test for the influence of specific culprits for each epoch, it points to natural climatic variability as the most likely explanation. These findings are described in an article published in *Nature* in July (bit.ly/common-era).

Anthropogenic Climate Change Is DiĀerent

The study also reveals that the current period of climate change is different from previous climatic epochs.

This is the first study that assesses the spatial evolution of human-caused global warming, showing that global temperatures haven’t been as high in the past 2,000 years and also that the increase has occurred simultaneously on 98% of Earth’s surface.

“Statistically, the spatial coherence of the warming in the last century is totally different from the spatial coherence of any other period in the past,” says study coauthor Juan José Gómez-Navarro, an environmental physicist at the University of Murcia in Spain.

The study concludes that the current warming pattern cannot be explained by random fluctuations of Earth’s climate.

“The idea that the current warming is not spatially heterogeneous but is spatially uniform I think is an important point to make and puts some context on the current warming in a way that’s new and different,” says Michael Evans, a climate scientist at the University of Maryland who wasn’t involved in the study.

Evans, who has coauthored other studies along with Neukom using PAGES data, notes that although this study sheds light on an important question for the paleoclimate community, its findings also become more uncertain as the researchers delve back into the past. Most trees don’t live for millennia, or they are damaged by natural causes or human activity. The same happens with corals, ice cores, and so on. As a result, for certain areas and time periods studied, the closest temperature proxies are many thousands of kilometers away.

Aware of the problem, the authors used a variety of statistical tests to assess the validity of their claims and gauge the uncertainty in the simulations. “Our final results are solid, as set in stone,” says Gómez-Navarro.

By **Javier Barbuzano** (@javibarbuzano), Freelance Science Journalist

House Committee Calls for Zero Greenhouse Gas Pollution by 2050

Democratic members of the House Committee on Energy and Commerce announced on 23 July that the committee would pursue a goal of a 100% clean economy for the United States by 2050. Pictured with the slogan "100 BY 50" are (left to right) Reps. Bobby Rush (D.-Ill.), Donald McEachin (D-Va.), Paul Tonko (D-N.Y.), committee chair Frank Pallone (D-N.J.), Darren Soto (D-Fla.), and Mike Doyle (D-Pa.). Credit: Randy Showstack

The House Committee on Energy and Commerce announced on 23 July that it has adopted an ambitious goal for the United States to achieve a 100% clean economy with zero greenhouse gas pollution by 2050.

"Communities across the country are suffering from historic flooding, raging wildfires, increasingly severe storms, extreme heat, and persistent droughts," said committee chair Rep. Frank Pallone, Jr. (D-N.J.), who appeared at a briefing on Capitol Hill to announce the goal. "The climate crisis is here, and it requires serious federal leadership that's up for the challenge."

The committee began holding a new series of hearings about climate change, with the initial hearing on 24 July focusing on pathways to decarbonize the U.S. economy. Topics for following briefings include reducing industrial and transportation emissions and modernizing the electrical grid.

"If we don't get to net-zero greenhouse gas emissions by 2050," Pallone said, the consequences are "going to be catastrophic." A 2018 report by the Intergovernmental Panel on Climate Change stated that limiting global warming this century to 1.5°C would require net human-caused emissions of carbon dioxide to be reduced to zero by about 2050.

Pallone compared the committee's plan to the Green New Deal resolution that was introduced earlier this year by Rep. Alexandria Ocasio-Cortez (D-N.Y.) and Sen. Ed Markey (D-Mass.). He said that the Green New Deal resolution contains many good ideas but added that the committee is trying to develop legislation. "What we are really trying to do here is come up with a united front that is driven by the scientific community," he said. The ideas that come from the Green New Deal "are things that we certainly want to hear. But the idea is that there would be specific legislation, a comprehensive package."

The Green New Deal states that reaching net-zero carbon dioxide emissions "should be accomplished through a 10-year national mobilization." Other countries, including France, Germany, and Japan, use 2050 as the target date. "We just think that [the 2050] target is more realistic," Pallone said. "We could develop certain [goals] that have to be met by 2030 or 2040 as well, as part of this 2050 goal."

> "The climate crisis is here, and it requires serious federal leadership that's up for the challenge."

An Ambitious Goal

"Is 2050 ambitious? Absolutely," said Rep. Paul Tonko (D-N.Y.), chair of the Energy Subcommittee on Environment and Climate Change. He said that moving forward with the committee's initiative is not only about resolving issues related to the environment and environmental injustice. It's also a chance "to embrace opportunity" with innovative solutions, he said. "Whoever does that first will be the nation that will be the kingpin in the international economy."

Tonko said that the country "cannot afford another delay" and that dealing with climate change "demands urgency." For many years, "the House ignored climate change, the climate crisis," he said. "Because of that, we now have to catch up."

He added that Congress needs to be working to address climate change now "so that when there is a force within the White House that accepts the concept of climate change, we can move forward aggressively and resolve the people's concerns."

Business Council for Sustainable Energy president Lisa Jacobson said that her group "supports a policy approach to reduce greenhouse gas emissions that is economy-wide, incorporates market-based mechanisms, and embraces the full suite of clean energy technologies." Options for such an approach "include carbon pricing measures as well as complementary energy, infrastructure, and transportation policies that both reduce emissions and improve our nation's resilience to climate change."

"I would like to get some of the Republicans on board here, and I'd like to get the president to sign all or some of this legislation that we're developing" in the committee, Pallone told *Eos* in an interview. However, he said of the president, "you're talking about someone who denies that climate change is even human induced and who wants to withdraw from the Paris Agreement."

"We've got to do something by 2050 that gets us to zero carbon emissions," Pallone added. "If the president wants to go along with it, fine. If not, we'll see what happens after the next election."

By **Randy Showstack** (@RandyShowstack), Staff riter

The Toxic Legacy of DDT Lives On in Remote Canadian Lakes

Sediment cores (left) can be used to study the changing biogeochemistry of lakes and other bodies of water over time. Lake Sinclair in north central New Brunswick in Canada (right) was one of five la es in the region surveyed for DDT contamination. Credit: Josh Kurek

After Rachel Carson's groundbreaking book *Silent Spring* exposed the dangers of widespread pesticide use in 1962, many chemicals, including dichlorodiphenyltrichloroethane (DDT), were restricted or banned starting in the early 1970s. But their chemical legacy lives on: A new study has found alarmingly high levels of DDT in remote wilderness lakes in northern New Brunswick, Canada, as well as evidence that the pesticide continues to impact aquatic species and alter the lakes' food webs more than 50 years after being banned.

From the 1950s into the 1970s, DDT was widely applied from airplanes to North American forests. DDT and other chemicals were deployed to manage insect outbreaks such as spruce budworm, the population of which naturally booms every 30–40 years.

Much of northern New Brunswick is managed as a commercial forest operation, and during the 1950s and 1960s, over 6 million kilograms of DDT were applied to these forests, said Josh Kurek, an environmental scientist at Mount Allison University in Sackville, N. B., and lead author of the study published in June in *Environmental Science and Technology* (bit.ly/DDT-lake-sediments). "The spray program run by the forest stakeholders in New Brunswick was arguably the largest in the world," he said.

To see whether the ecosystem retained relics of its pesticide-soaked past, Kurek and colleagues analyzed sediment cores collected from five remote lakes in different watersheds in north central New Brunswick. They found that all five lakes had "surprisingly high" levels of DDT and its toxic breakdown products (DDTs), Kurek says. DDT's breakdown products, including dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyldichloroethane (DDE), are also toxic to aquatic organisms and wildlife.

"The concentrations of DDTs in the region's lake sediments are some of the highest values reported in North America," Kurek said.

"All five lakes showed similar patterns, with DDT levels well above the probable effect level (PEL) where scientific studies show it can cause harm to life-forms," he said. Modern sediments are, on average, 16 times above PEL for DDE, typically the most abundant breakdown product of DDT.

The team also dated the sediment cores to determine a timeline for when the DDT entered the lakes. Peak DDT concentrations occurred in the mid-1970s, about 10–15 years after the most intense spraying took place. "The lag effect is due to the time it took for the contaminant to move from the trees to the soils and into the lakes," Kurek said.

"The amount of DDTs in these lakes is staggering. It's amazing how much there is, even for those of us old enough to remember the planes flying over and dusting everything in sight," said John Smol, a paleolimnologist at Queen's University in Ontario, Canada, who was not involved in the new study. "We thought we were done with DDT when we banned it. But, of course, it's still around, quietly wreaking havoc."

"We thought we were done with DDT when we banned it. But, of course, it's still around, quietly wreaking havoc."

DDT and Food Webs

The half-life of DDT varies because of environmental conditions but is estimated to be between decades and 100 years. DDT doesn't dissolve in water; it tends to bind to organic materials like algae or soil particles. When the contaminated algae are eaten, the DDT bioaccumulates in the animal's tissues. If the algae eater is then eaten by a fish or other predator, the DDT gets passed up the food web in higher and higher concentrations.

To study the impact of DDT and DDTs on lake food webs, Kurek and colleagues used their sediment cores to reconstruct the population over time of a common species of water flea called *Daphnia*. They found that as DDT levels increased in the lake, the population of *Daphnia* decreased.

When a lake is contaminated by an insecticide, it experiences "death by a thousand cuts," Kurek said. "The effects are not acute but, rather, chronic, playing out over many years."

Next, the team plans to study DDT contamination higher in the food web. "One of the key unanswered questions is whether the higher trophic levels, such as wild brook trout that people eat, are elevated in DDTs," said Kurek.

For anglers, it's possible that nowhere is safe. "I think it would be a real challenge to find a remote lake, wetland, or shallow pond that doesn't record the past use of DDT," Kurek said. "When we ban a chemical, we wash our hands of it and move on. But these legacy contaminants have a nasty habit of sticking around for a very long time."

By **Mary Caperton Morton** (@theblondecoyote), Science Writer

EOS CENTENNIAL COLLECTION
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Gaps, Waves, and Propellers in Saturn's Rings

After more than a decade observing Saturn, Cassini completed its mission in style: A grand finale sent the spacecraft on almost 2 dozen dives between the planet and the rings before it took its final descent into Saturn's atmosphere.

During these trips in 2017, Cassini collected high spatial resolution images and spectral and temperature scans of the rings. In a paper published in June in *Science,* researchers dove into these high-resolution data, and their synthesis revealed new features inside the rings that hadn't been seen before (bit.ly/saturns-rings). They found sculpted areas within the rings—including banded textures and disturbances from embedded bodies—that can be used to help theorists narrow in on how Saturn and its rings may have formed.

Ring Disruptions

During the grand finale, Cassini took the highest-fidelity images ever taken of the rings. "We found a number of things that are new—a number of structures that we'd never been close enough to see before," said Matthew Tiscareno, a senior research scientist at the SETI Institute in Mountain View, Calif., and lead author of the paper.

The team explored disturbances related to moons or smaller moonlike debris embedded in the rings. The moon Daphnis, for example, leaves a wide trail of disruption in its wake, including a wide gap in the ring and trailing waves of debris.

These waves, Tiscareno explained, are created by the rings moving at different speeds: The rings orbiting closer to Saturn move at speeds faster than those farther from the planet. This process creates a shear flow, and "on the outward edge, the ring part, the ring material is falling behind Daphnis and its orbit," he said.

The embedded moon Daphnis creates three waves in Saturn's rings in this image taken by the spacecraft Cassini during its grand final . Credit: NASA/JPL-Caltech/Space Science Institute

> "We found a number of things that are new—a number of structures that we'd never been close enough to see before."

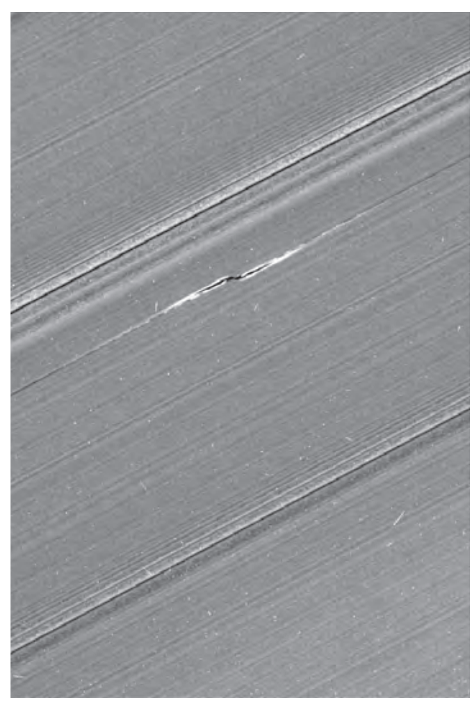
But it's not just big moons like Daphnis that cause disruptions. Smaller objects are trying their best to create ring gaps as well, but with less success. "These are objects that are 10 times smaller, which means they're a thousand times less massive," said Tiscareno. Instead of forming a gap, he said, these objects form a propeller-shaped disturbance.

The researchers knew the propellers existed, so they directed Cassini to perform some targeted flybys to get a closer look. "The details of that [propeller] structure [are] telling us exactly how big the moons are at the center of the propeller…about a kilometer across," said Tiscareno, adding that at that size, it's not possible to see the actual moon with these image resolutions.

Ring Textures

Cassini's instruments also revealed new details on textures within the rings. "We knew that there were textures before, but we had not seen them as comprehensively," said Tiscareno. The team noted that the ring textures ranged from strawlike clumps to feathery regions, with sharp edges on their borders.

One idea for the different textures within the rings is a changing particle composition, said Douglas Hamilton, an astronomer at the



This propeller, informally called Bleriot, formed within Saturn's rings. Propellers are caused by a central moonlet that alters the ring as it orbits around the planet. Credit: NASA/JPL-Caltech/Space Science Institute

University of Maryland who was not involved with the paper. For example, one part of the ring could be more silicate rich, whereas another area has more ice. But Hamilton said that the researchers "make a good case" for these textures being caused by something other than composition.

The team inferred that the sharp borders along the ring textures were not due to a composition change, said Tiscareno, but instead result from the physical properties of the ring particles.

One physical property might be the roughness of ring particles. Tiscareno explained: Is a ring particle more like a billiard ball or more like a snowball? Roughness can affect not only the reflection of light but also how particles interact with each other. "Do they bounce off of each other, like billiard balls do?" he asks. "Or are they kind of sticky, like a snowball would be?"

"Rings are our only natural laboratory to understand disk processes more generally—and that goes to understanding baby solar systems."

Forming a Ring

Getting close-up data from Cassini gives researchers information that reaches beyond our nearby ringed planet. "Rings are our only natural laboratory to understand disk processes more generally. And that goes to understanding baby solar systems, which are disk systems where you have massive objects that are embedded in the disk," said Tiscareno. "We're seeing massive objects embedded in the rings, and we're seeing the disk itself doing things that we didn't expect."

Hamilton said that papers like this help uncover how features like propellers might form. "The theory is our imagination," Hamilton said. Work like this paper, he added, allows theoretical researchers to test their models on Saturn's rings against observed data.

"[These data are going] to be the basis for 10 years of effort by the entire field in trying to figure out how to make all this [propellers, textures] happen," said Hamilton.

By **Sarah Derouin** (@Sarah_Derouin), Freelance Journalist

Poaching Elephants Reduces Carbon Storage in Forests

Forest elephants splash and play at a forest's edge in the Dzanga-Sangha Special Reserve in the Republic of the Congo. Credit: iStock.com/ANDREYGUDKOV

A tropical rain forest drapes over central Africa in the Congo Basin, covering an area 3 times the size of Texas. The forest is the second-largest tropical forest in the world, behind only the Amazon in South America.

African forests have taller trees and fewer tree species than other tropical forests, and researchers have long postulated that Africa's forest elephants are responsible. Forest elephants are "ecosystem engineers" that change the type of plants that survive in the forest.

But a study in *Nature Geoscience* in July found that African elephants do more than garden the Congo: They help the forests store more carbon in their trees (bit.ly/carbon-stocks-enhanced). The latest findings indicate that 7% of carbon stores in central African rain forests will be lost if elephant populations continue to plummet because of poaching for ivory and shrinking habitats.

Trees suck up carbon dioxide when they photosynthesize, and they repurpose the carbon into their trunks, branches, and roots. Certain trees have higher carbon densities, especially trees that are hardwood and slow growing. Elephants encourage the growth of slow growing trees by clomping through the forest and eating, squishing, and knocking over fast growing softwood trees, which they find more palatable.

Researchers in the latest study created a computer model to assess the influence of elephants on vegetation in an undisturbed forest. The model mimicked elephants' impact by giving smaller trees in the model a lower survival rate. After 250 years of elephant intervention, the forest trees were taller and wider and held more carbon above ground than before. The results agreed with field data from forest study sites.

According to the model, elephants boost the forest's carbon-carrying capacity by 3 billion tons of carbon. France emits a similar amount of carbon through fossil fuel emissions over the course of 27 years, lead author Fabio Berzaghi told *Eos*.

As countries release more carbon dioxide into the atmosphere, governments are looking for cost-effective ways to sequester carbon. Yet as poaching reduces elephant populations, which have fallen by 90% over the past century, the study's findings indicate that the amount of carbon stored in the African forest will drop as well. Berzaghi said that there's no way to know how much has already been lost.

Berzaghi noted that countries are missing out on a natural way to store carbon. "Carbon technologies, at the moment, are really expensive," Berzaghi said. "Nature offers a lot of these services for free."

By **Jenessa Duncombe** (@jrdscience), News Writing and Production Fellow

EOS CENTENNIAL COLLECTION
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Mmm, Salt—Europa's Hidden Ocean May Contain the Table Variety

If you're wagering on where life might exist beyond Earth, Europa is always a safe bet. That's because this moon of Jupiter has a liquid-water ocean beneath its icy surface, making it a likely incubator for marine life. Researchers now have shown that Europa's ocean probably contains sodium chloride (NaCl), the same stuff we sprinkle on our french fries and also the dominant form of salt in our own planet's ocean.

A Weird, Watery World

Europa, Jupiter's fourth-largest moon, is an enigmatic world: Ultraviolet aurorae dance over its poles, its surface has hot and cool spots, and enormous blades of ice may be clustered around its equator. Since the 1970s, researchers have hypothesized that Europa might harbor a liquid ocean under its icy surface. Spacecraft-based observations have since confirmed the existence of Europa's hidden ocean and shown that it's salty, and water vapor plumes spotted emanating from the moon have provided additional evidence of its watery interior.

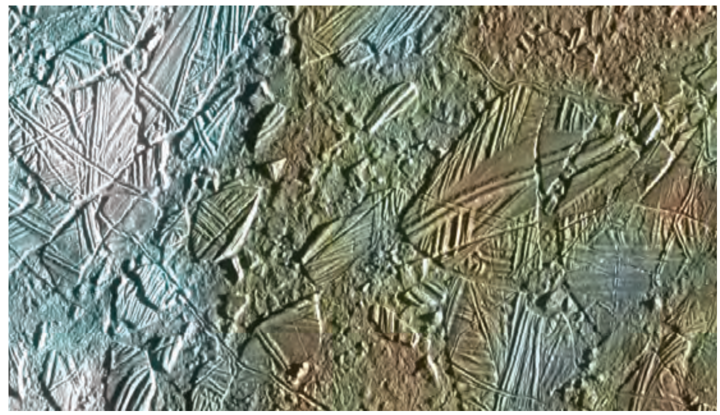
> Finding evidence of sodium chloride was a bit of a surprise.

Samantha Trumbo, a planetary scientist at the California Institute of Technology in Pasadena, and her colleagues now have studied the chemistry of Europa's ocean. They did so by investigating the moon's surface, specifically geologically young regions called chaos terrain, where ocean water likely upwells. In these areas, the icy surface looks to have been wrenched apart, said Trumbo. "These regions are probably the most representative of the internal composition [of Europa]."

Hubble Space Telescope Looks for Salt

In 2017, Trumbo and her collaborators collected spectroscopic observations of Europa's surface using the Hubble Space Telescope. The data, with a spatial resolution of roughly 150 kilometers, spanned from ultraviolet to infrared wavelengths.

The researchers were looking for two absorption features characteristic of sodium chloride that's been bombarded by high-energy electrons. (These electrons, which originate mostly from volcanic eruptions on Jupiter's moon Io, alter NaCl's crystalline structure.) The two absorption features fall within the blue and red parts, respectively, of the visible spectrum.



Europa's chaos terrain, above, is likely the site of upwelling from an enormous ocean beneath the ice. Credit: NASA/JPL/University of Arizona

Trumbo and her team found just the absorption feature in the blue part of the visible spectrum, which actually makes sense, said Trumbo. Laboratory experiments that re-create the absorption in the red part of the visible spectrum bombard sodium chloride with 10,000–100,000 times the true radiation flux at Europa's surface, she said. "At the real flux levels of Europa, this feature would never form."

Finding evidence of sodium chloride was a bit of a surprise, said Trumbo. "Sulfates on the surface of Europa have been the prevailing view since the Galileo mission in the 1990s."

To confirm that sodium chloride was really the cause of the absorption they observed, the researchers took spectra of other irradiated salts like magnesium sulfate ($MgSO_4$), calcium carbonate ($CaCO_3$), and magnesium chloride ($MgCl_2$) in the laboratory. None of the compounds they tested exhibited absorption in the blue part of the visible spectrum, and several had strong absorption features at other wavelengths that the researchers didn't see in their Hubble data.

Concentrated in Chaos

Trumbo and her colleagues found that sodium chloride on Europa was mainly concentrated in the chaos terrain. Because that's where subsurface water likely upwells, this finding is consistent with the salt deriving from the moon's ocean, the researchers suggest.

"This marked correlation with geologically young chaos regions suggests an interior source," they write in their paper, which was published in June in *Science Advances* (bit.ly/europa-nacl).

"This new study took a novel approach that combines telescopic observations, laboratory experiments, and geochemical analysis," Xianzhe Jia, a planetary scientist at the University of Michigan who was not involved in the research, told *Eos.* If NaCl exists in the moon's subsurface ocean, it "suggests that Europa's ocean might be more Earth-like compositionwise than previously thought."

Scientists are looking forward to getting a closer look at Europa and its ocean with NASA's Europa Clipper mission, which will put a spacecraft in orbit around Jupiter. The spacecraft, slated to launch in the 2020s, will fly as close as 25 kilometers to Europa's surface—the closest flyby ever of this moon—and will analyze the celestial body using a suite of cameras, thermal imagers, spectrographs, and ice-penetrating radar.

By **Katherine Kornei** (@katherinekornei), Freelance Science Journalist

EOS CENTENNIAL COLLECTION

The Mystery of the Moon's Missing Metals

The Moon's missing precious metals may never have arrived in the first place.

Colliding asteroids delivered metals such as gold and iridium to both Earth and the Moon early in the solar system's history, with Earth collecting more than its smaller satellite. But samples of Moon rocks collected by Apollo missions revealed that the Moon had significantly less material than could be accounted for by its size. New research now suggests that the dearth may be caused in part by the Moon's inability to hold on to some of these metals, with the late crystallization of the lunar mantle also playing a role.

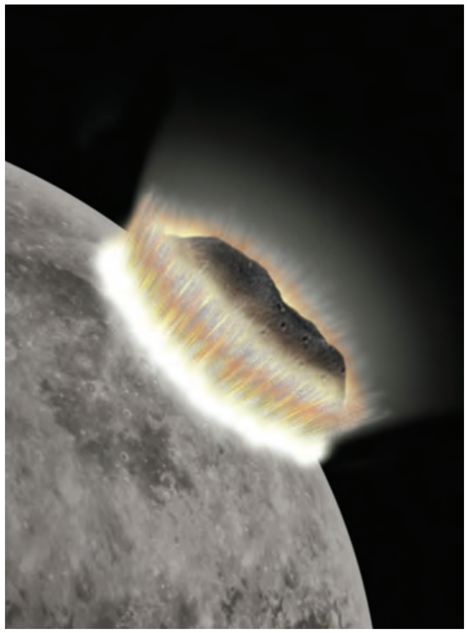
The early solar system was a violent place, with material left over from planet formation crashing into newborn worlds. One collision carved the Moon out of Earth, leaving both worlds briefly molten as their layers settled out. Precious metals, which have an affinity for iron, sank to the cores of newborn worlds, removing them from the crust and mantle. Any of these highly siderophile elements (HSEs) found in the crust today were delivered by collisions with smaller debris.

Because Earth presents a larger target than the Moon, scientists anticipated that the Moon should have roughly 20 times less HSEs at its surface. Instead, Apollo samples revealed that the satellite contains roughly 1,000 times less precious metals than Earth, suggesting that perhaps it was hit by significantly fewer objects. The discrepancy has had scientists scratching their head for the past few decades.

"We identify that a key factor for the interpretation of the HSE record is the impactor retention rate—the fraction of mass retained by the target," Meng-Hua Zhu, a scientist at China's Macau University of Science and Technology, said by email.

Zhu's team modeled how much material the Moon collected from impacts on the basis of their size and the angle at which they hit. The researchers assumed that the more massive Earth retained the bulk of the precious metals delivered to it, an assumption that Simone Marchi calls "reasonable." Marchi is a researcher at the Southwest Research Institute in Colorado who models the formation and bombardment of terrestrial planets and the Moon.

Previous simulations had suggested that the Moon held on to roughly 60% of the material that collided with it, but that still was not enough to explain the HSE difference. Zhu's team made more detailed simulations of lunar collisions that included a wider variety of impactor sizes, velocities, and angles than ever before. The researchers found that the Moon's smaller size and lower gravity mean that most of the impacting material didn't stick around and either escaped the Moon's gravitational grasp or was blown completely from the surface. Although rocks that slammed head-on into the Moon became a permanent part of the lunar composition, other objects only skimmed the surface.



Objects over 100 kilometers across slammed into the Moon to produce impact basins from several hundred to over 2,000 kilometers in diameter. This artist's rendering captures the moment of first contact between one o those asteroids and the surface of the Moon. Credit: Leanne Woolley and David A. Kring, LPI

The new research reveals that the Moon holds on to only about 20% of the material that it collides with, 3 times less than previously assumed.

"This strikingly low value changes previous considerations on the Moon's late accretionary history and suggests that significantly more material must have hit the Moon for a given HSE budget than previously envisioned," Zhu said.

The new research was published in July in the journal *Nature* (bit.ly/moon-accretion).

A Magma Ocean

The amount of debris lost from lunar collisions filled in only part of the discrepancy, bringing the Earth-Moon difference down to only about 100. So Zhu's team turned to the lunar magma ocean.

After the collision that birthed the Moon, the surface of both worlds remained molten. Previous studies have suggested that Earth's magma surface took somewhere between 5 million and 10 million years to solidify into a rocky crust. Apollo samples suggest that the smaller Moon took longer to solidify, between 150 million and 200 million years, although not all scientists agree with this analysis. "It's a problem that's been debated for years," said James Day, a geologist at the University of California, San Diego.

Assuming a long-lived molten mantle, material that slammed into Earth roughly 15 million years after the Moon formed would have polluted the terrestrial crust. But materials colliding with the Moon at the same time would have been absorbed by its mantle and worked their way down to the core. The difference gives Earth a head start in collecting HSEs on its surface and could explain the rest of the discrepancy.

Although Day appreciates the implications of the new collisional model, he's less certain about the molten magma explanation. "Purely from a geochemical point of view, that is still a problem," he said. "I don't think it's a fatal flaw in their model by any stretch of the imagination, but it's something that needs to be considered."

Marchi also has concerns about the Moon's magma ocean. According to the new research, the Moon should have 3–8 times more basins than those that visibly scar its surface today. Zhu argues that the magma ocean would quickly obliterate both crater rims and gravitational signatures, but Marchi isn't certain. Although objects slamming into the Moon immediately after its formation should have been absorbed, it's possible that cooling over the intervening tens of millions of years would have prevented a complete erasure of crater signatures.

"It may be possible, but I think it requires further investigation," Marchi said.

By **Nola Taylor Redd** (@NolaTRedd), Freelance Journalist

EOS CENTENNIAL COLLECTION

Giant Planets and Brown Dwarfs Form in Different Ways

Finding extrasolar planets is hard: They're much fainter and smaller than the stars they orbit, and from our vantage point, they appear crammed next to an enormously bright spotlight.

But thanks to the Gemini Planet Imager Exoplanet Survey (GPIES), which recently wrapped up a direct imaging campaign of hundreds of stars, scientists are getting a more complete picture of these worlds and how they form.

Giant planets and their larger brethren—brown dwarfs, also known as failed stars—form according to different mechanisms, a result that sheds light on the evolutionary linkages among planets, brown dwarfs, and stars, the new data reveal.

Most extrasolar planets found to date have been spotted by looking for tiny blips in a star's light as a planet passes in front of it or by measuring a star's "wobble" due to a planet's gravitational tug. The Gemini Planet Imager, an instrument mounted on the 8-meter Gemini South telescope in Chile, takes a different tack.

Since late 2014, GPIES has been observing young, nearby stars in near-infrared light. A tool called a coronagraph masks out each star's light to reveal the presence of any dim companion objects, which may be up to a million times fainter. (Because the planets and brown dwarfs that Gemini Planet Imager looks for are young, roughly 10 million to 100 million years old, they're still releasing heat from their formation and glow in the near infrared.)

Combing through data from the first half of the survey, which included observations of 300 stars, scientists found six giant planets (defined as being between 2 and 13 times the mass of Jupiter) and three brown dwarfs (more than 13 times the mass of Jupiter). Armed with information about the planets' and brown dwarfs' masses, temperatures, sizes, and orbits, the researchers looked for trends.

"We wanted to answer some really basic questions," said Eric Nielsen, an astronomer at Stanford University in California, and a GPIES team member.

Nielsen and his colleagues found that all six of the giant planets orbited stars at least 50% more massive than the Sun, a surprise because these stars were relatively rare in the survey. "That's pretty remarkable," said Nielsen.

The brown dwarfs, on the other hand, all orbited lower-mass stars. The researchers also found that giant planets orbited their host stars at comparatively smaller distances than the brown dwarfs.

Stars shine down on the Gemini South telescope in the Chilean Andes. Credit: Marshall Perrin

Diverse Formation in the "Middle Ground"

Together, these observations imply that giant planets and brown dwarfs form in different ways. That's an important discovery because these objects represent a sort of astronomical "middle ground": They're more massive than rocky planets like Earth but less massive than hydrogen-burning stars like our Sun. Given these objects' intermediate status between planets and stars, astronomers want to understand how they form.

> "This is kind of the definitive survey of all the nearby stars."

The GPIES observations revealed that giant planets likely form via the accretion of smaller objects, a mechanism called core accretion. That's also how Earth-sized planets form, astronomers believe. But brown dwarfs likely form more like stars, not planets, in a process called disk instability, in which a disk of gas and dust fragments into large clumps, which then attract one another via gravity. These findings were published in June in the *Astronomical Journal* (bit.ly/GPIES).

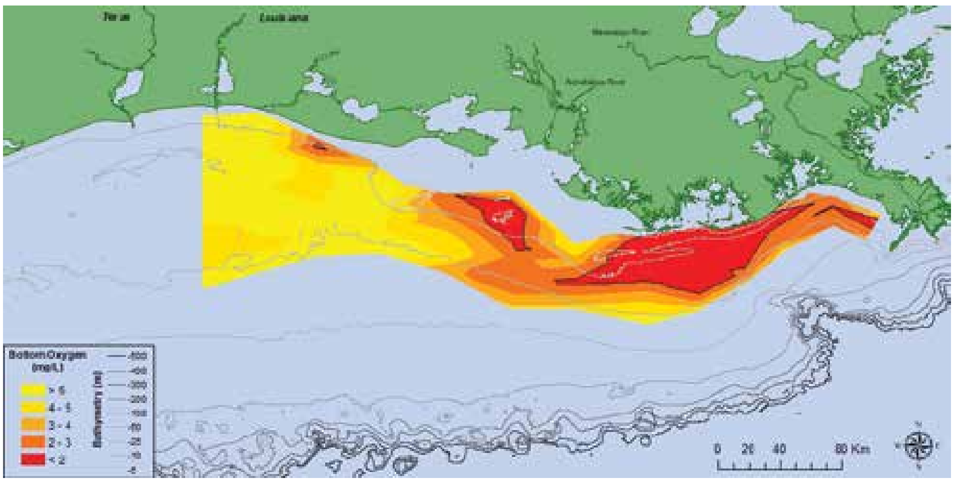
"The exoplanet community is very interested in these results," said Trent Dupuy, an astronomer at Gemini Observatory in Hilo, Hawaii, not involved in the research. "This is kind of the definitive survey of all the nearby stars."

Nielsen and his colleagues look forward to repeating their analysis with the entire GPIES data set, which will include measurements from 531 stars and their companions.

A whole new set of observations may soon be possible as well, said Nielsen. Early next year, Gemini Planet Imager may receive an upgrade and be moved to the 8-meter Gemini North telescope in Hawaii. There will be a "whole new sky of stars" to analyze, said Nielsen.

By **Katherine Kornei** (@katherinekornei), Freelance Science Journalist

Gulf Dead Zone Looms Large in 2019



This summer, the Gulf of Mexico dead zone was predicted to be much larger than it was in 2018 (as seen here), expanding west across the coast of Texas because of flooding in the Midwest this spring. Credit: Eugene urner/LSU

Predictions this year indicate that the Gulf of Mexico will retain the dubious distinction of having the second-largest low-oxygen dead zone on Earth (the Baltic Sea remains firmly in first place). By the end of the summer, the hypoxic region on the seafloor at the mouth of the Mississippi River was expected to occupy over 22,000 square kilometers, an area the size of the state of Massachusetts.

The hypoxic zone, with oxygen levels less than 2 parts per million, forms every summer on the seafloor just off the coasts of Texas and Louisiana, where the Mississippi and Atchafalaya watersheds drain into the Gulf of Mexico.

The dead zone probably started forming in the 1970s when farmers started applying more nitrogen-based fertilizers to crops across the Midwest, said Eugene Turner, an oceanographer at Louisiana State University in Baton Rouge and coauthor of the new forecast, released by the National Oceanic and Atmospheric Administration (NOAA) as part of a larger series of studies on the health of the Gulf (bit.ly/gulf-dead-zone).

"The dead zone is driven by nitrogen and phosphorus runoff from agricultural operations that finds its way into the watershed and then into the Gulf," Turner said. The excess nutrients stimulate algae growth, and the decomposition of this algae on the seafloor leads to widespread hypoxic conditions.

Runo and Rainfall

The new forecast models by Turner and his wife and coauthor, Nancy Rabalais, take into account the discharge rates of the Mississippi and Atchafalaya Rivers as well as U.S. Geological Survey estimates of the amounts of nitrate and phosphate being carried by the rivers. In the month of May alone, 156,000 metric tons of nitrate and 25,300 metric tons of phosphorus were deposited into the Gulf of Mexico.

This year's record-setting size is also due to the unusually high amounts of rainfall that flooded many parts of the Midwest this spring. The more rainfall there is, the higher the river flow is, which carries more nutrient runoff into the Gulf.

Turner and Rabalais have been conducting systematic survey cruises to map the Gulf dead zone since 1985. This year the cruise sailed the last week in July, when the dead zone usually begins peaking in size. The forecasts help guide the systematic survey cruises.

If a hurricane or large storm hits the Gulf before or during a cruise, the temporary mixing of the water column can make the dead zone appear smaller, said Katja Fennel, a biogeochemical oceanographer at Dalhousie University in Halifax, N. S., Canada, who is also a contributor to the larger NOAA-funded Gulf project.

"If you have a year with several big storms or hurricanes, they can disrupt the stratification of the water column and reoxygenate the bottom water," Fennel said. "But the mixing is only temporary: A few weeks later, hypoxia will be reestablished."

Mobile organisms like shrimp and fish tend to migrate out of the hypoxic zone, and the forecasts can also be used to plan shrimping and fishing expeditions in the Gulf, said Robert Hetland, a physical oceanographer at Texas A&M University in College Station who is not involved in the NOAA studies. "We don't have a clear understanding yet of how hypoxia affects mortality rates, but there is some indication that it may affect the growth rates of some Gulf organisms," resulting in smaller shrimp, he said.

Land Use

In 1997, the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force (also known as the Hypoxia Task Force) was established with the mission of reducing the size of the Gulf dead zone to less than 5,000 square kilometers, but so far, little progress has been made, Turner said.

"The only way to accomplish that goal is to reduce the nitrogen loading into the Mississippi," he said. "In agriculture, there's a lot of resistance toward changing land use practices. Farmers are embedded in an economic and political structure that makes it very difficult to change practices without serious economic consequences."

So far, fertilizer load reductions in the United States have been voluntary with no mandated regulations. In Europe, mandatory limits were enacted about 15 years ago on rivers such as the Rhine.

> "Land use practices can evolve…but it will take time and persistence and good will."

"European rivers have been cleaned up quite dramatically, and coastal eutrophication is less of an issue in European waters," Fennel said. "So it is possible to reverse these trends, but relying on volunteer efforts is not the most effective way to do it."

"It is going to take a lot to change what has developed over 2 centuries," Turner said. "Land use practices can evolve with benefit to the nation, farmers, farmland, and the Gulf, but it will take time and persistence and good will."

By **Mary Caperton Morton** (@theblondecoyote), Science Writer

Nineteen Eighty-Forams

Foraminifera are tiny planktonic and benthic organisms that leave shell-like tests. Credit: iStock.com/Mushika

In the future, it will not be a human with years of scientific training who identifies the remains of fossils.

It will be a machine.

At least, that is the vision of the new Endless Forams online image database, endlessforams.org, which uses a type of facial recognition software to identify different species of foraminifera—microscopic marine organisms that come in a multitude of shapes—in a sample based on the creatures' skeletal remains.

"A lot of [experts' accuracies] are lower than the machine accuracies," said computational paleobiologist Allison Hsiang, the database's architect. "On average, the human accuracies are something like 70%–75%, and these are experts in the field. Our model in this case was 87%."

Eos asked Hsiang if the new software will one day replace humans who are experts at identifying foram species.

"I don't think so," she said, laughing.

Eos then asked foram expert and micropaleontologist Michal Kucera of the University of Bremen the same question.

"Yes," he said.

Kucera, who was not involved in the creation of Endless Forams, explained that the software is not quite to the point where it can replace the work of experts, because the diversity of forams that Endless Forams accounts for is not a complete snapshot of the diversity of forams that exists in the place where the database's species come from: the Atlantic Ocean. "The bulk of the images are not taken in a way that represents the full diversity of specimens in a sample," he said.

But it is only a matter of time, he added, until software like Endless Forams overcomes that hurdle and becomes as skilled as the telescreens in George Orwell's dystopian novel *Nineteen Eighty-Four*, which kept a close watch on everyone in society, or today's social media platforms, which do the same thing.

Rise of the Machine

Instead of putting experts like himself out of a job, Kucera thinks that Endless Forams will only be a boon for his and others' research projects. That's because the software can be better than experts at identifying forams, so researchers like him will be able to work with more accurate data sets than ever before.

To make this possible, Hsiang, who is currently at the Ludwig Maximilian University of Munich, trained the software to scan samples and to identify forams it thinks it recognizes by showing her program about 24,000 photographs of forams that four independent experts identified beforehand. Hsiang and her team reported on their work in June in *Paleoceanography and Paleoclimatology* (bit.ly/endless-forams).

The forams they cataloged can be treasure troves of information on modern and ancient oceans because they record information about, among other things, the chemical composition of the oceans in their shells. Forams thus serve as one of the main lines of evidence that allow researchers to infer what Earth's climate was like in the deep past.

There are about 4,000 modern species alone, and Endless Forams accounts for about 50 of those. It can be hard and time-consuming for a scientist to spot and identify the individuals that they need for their work, but Hsiang explained that with the database, researchers can not only train themselves to identify species but also use the software to quickly identify which forams they want to analyze.

And Endless Forams, more than any other foram database, also contains a huge variety of photographs of individual species, like *Globigerina bulloides,* which has over 2,000 photographs on the website. Such a resource will let scientists survey the full range of shapes that a single species can have—and because shape often defines what a species is, having access to all the shapes that a single species can take on will help researchers tackle one of the most fundamental questions in biology: What is a species, exactly?

It pays to keep a close watch on every foram, it seems.

"You can congratulate the authors," Kucera said. "They put a lot of work into this."

By **Lucas Joel,** Freelance Journalist

EOS CENTENNIAL COLLECTION

First Marsquake Detected

Planetary scientists quivered with delight at the first detection of seismic activity beneath Mars's surface. This marsquake was recorded by NASA's Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) lander 128 Martian days (sols) after landing.

"We've been waiting months for our first marsquake," Philippe Lognonné, a geophysicist at Paris Diderot University in France and the principal investigator for InSight's seismometer, said in a statement about the discovery. "It's so exciting to finally have proof that Mars is still seismically active. We're looking forward to sharing detailed results once we've studied it more and modelled our data."

The news of the first recorded marsquake was revealed on 23 April at the Seismological Society of America's conference in Seattle, Wash. This is the first seismic event recorded on another planet. You can listen to a recording of the marsquake signal at bit.ly/Eos_marsquake.

Just a Little Shake

InSight landed on Mars in Elysium Planitia on 26 November 2018. One of the mission's main science goals is to measure how seismically active Mars is today. This information will provide clues about how Mars's interior is cooling and contracting, giving a glimpse of the internal structure of the planet.

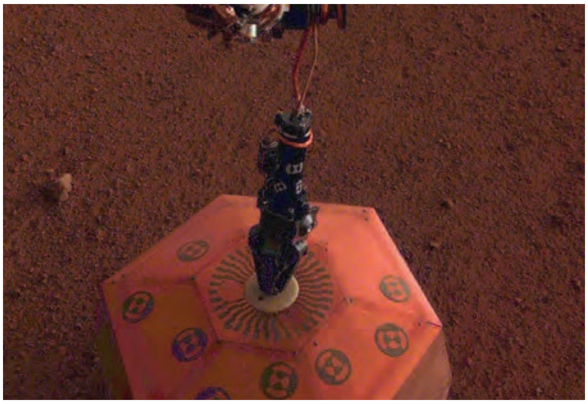
On its 128th sol (6 April on Earth) on the surface, InSight detected shaking from a small underground tremor. The signal was so small that had it occurred on Earth, it would have been lost among the background seismic noise from Earth's weather and oceans.

On seismically quiet Mars, however, the shaking stood out amid the faint ambient noise that the instrument has detected from Martian winds.

Unfortunately for the team, the Martian Sol 128 event was too small to be scientifically useful. Still, the discovery makes Mars the third rocky solar system body, after Earth and the Moon, shown to have seismic activity.

"The Martian Sol 128 event is exciting because its size and longer duration fit the profile of moonquakes detected on the lunar surface during the Apollo missions," Lori Glaze, director of NASA's Planetary Science Division, said in a statement.

"InSight's first readings carry on the science that began with NASA's Apollo missions," said InSight principal investigator Bruce Banerdt of NASA's Jet Propulsion Laboratory in Pasadena, Calif. "We've been collecting background noise up until now," Banerdt said, "but this first event officially kicks off a new field: Martian seismology!"



NASA's Mars InSight deployed its seismometer, seen here, onto the Martian surface on 19 December 2018. This is the first seismomete ever placed on the surface of another planet. Credit: NASA/JPL-Caltech

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

Transcending Science: Can Artists Help Scientists Save the World?

Climate Deniers on Vacation exemplifies an art-inspired approach to climate science communication. Credit: Katie Wittenberg, School of the Art Institute of Chicago

Our climate crisis is more desperate than ever: Ice caps are melting, disease is spreading, heat waves are multiplying, droughts are laying waste to crops and ecosystems, tropical storms are strengthening—and politicians continue to ignore the warning signs. It is no secret that the current administration in the United States is doing nothing to slow the amount of carbon dioxide pumped into the atmosphere every year, a decision that promises to have dire consequences.

Our collective understanding of human-caused climate change dates back over a century, beginning in 1896 when the Swedish scientist Svante Arrhenius first wrote of the link between carbon dioxide (which he called carbonic acid) in the atmosphere and global temperatures via the greenhouse effect.

In the past half century, sophisticated computer models have consistently demonstrated that the increasing concentration of carbon dioxide in the lower atmosphere—carbon dioxide that got there because of burning fossil fuels—has raised the globally averaged surface temperature by over a degree Celsius. This temperature rise, attributed almost entirely to human activity, has precipitated massive and rapid changes across the globe, and these changes are forecast to worsen in the future.

In 2018, the United Nations Intergovernmental Panel on Climate Change warned that we had about 12 years (11 now) to make massive, large-scale, revolutionary changes to our global economy to avoid the worst impacts of climate change.

Proximity to Revolutionary History

As a transgender woman living in America, I am no stranger to revolutionary movements. Fifty years ago, a group of queers, led in part by a few brave trans women of color, started a riot at a bar in New York City. That uprising ultimately initiated the LGBT rights movement, a movement that has seen many monumental successes punctuated by several devastating losses and setbacks.

After considering my proximity to this revolutionary history, in 2017 I left a position as a research climate scientist at the NASA Jet Propulsion Laboratory (JPL) to teach climate change at an art institution, the School of the Art Institute of Chicago.

I made the switch for several reasons, but first and foremost, I wanted to dedicate the remainder of my career to exploring nontraditional ways of bridging divides between scientists, artists, and the public. I took this opportunity as a conscious effort to contribute to a solution to the climate crisis.

Now my career is dedicated to exploring ways in which artists and designers can help scientists both communicate climate science to the public more effectively and *be better scientists.*

Collaboration and Engagement

This excerpt from David George Haskell's "Notes on Ecological Aesthetics and Ethics" (bit.ly/ecological-aesthetics-ethics) inspires me in this effort, daily:

> *Once we—collectively—have an integrated sense of aesthetics, we can begin to discern what is beautiful and what is broken about a place, and, from there, I believe we can begin to form an objective—or near-objective—foundation for ethical discernment. Answers emerge from the community of life itself, filtered through human exp-rience and consciousness.*

In recent decades, though the knowledge of climate change has continued to expand, much of this knowledge remains abstruse, cumbersomely documented, and nonintuitively presented, making engagement with it by "nonscientists" difficult. Perhaps this is the reason a large segment of the general population remains convinced that human beings have not caused the observed 20th- and 21st-century climate change.

There exists, therefore, an exciting and necessary opportunity for scientists to collaborate with artists. Many scholars learn that the scientific method begins with a hypothesis, progresses through research and analysis, and concludes with a result. The design process, in contrast, begins with human engagement and inquiry, progresses through ideation and prototyping, and concludes with a refined artifact.

It is precisely through the initial step of human engagement where artists and designers distinguish themselves from (most) scientists. And, as Haskell writes above, "once we… have an integrated sense of aesthetics, we can begin to discern what is beautiful and what is broken about a place." Perhaps artists can, in fact, help scientists be better scientists.

I maintain that the unique insights of artists, designers, and makers present an opportunity for scientists to collaborate in the creation of evocative visual and auditory artifacts that invite the public to share in both the research process and the scientific conclusions of a study. These collaborations ultimately engender a more thorough and straightforward understanding of scientific knowledge.

In this moment, especially in the field of climate science, we need, more than ever, for the public to engage with science. Through inviting and evocative designs that tell the story of the data in a more intuitive way, we can better foment the magnitude of the climate crisis in the public psyche and, ultimately, encourage people to invest in the necessary solutions. This public buy-in would go a long way toward productively addressing the climate dilemma.

Data Visualization and Better Science

It is perhaps intuitive that art and design can help scientists better communicate their results to the public.

However, I maintain that improvements in data visualization (through collaboration with artists and designers) can also facilitate exploratory research and help researchers ask qualitatively "better" scientific questions. Exploratory analysis, or a precursory evaluation of data with the intent of generating a research inquiry or hypothesis, is often hampered in efficacy by an arduous data-parsing process or incomplete and confusing data visualization.

As a case study, I worked with Adrian Galvin, a designer at JPL, to develop a data interface and visualization tool for the Multi-angle Imaging Spectroradiometer (MISR) smoke plume project (adriangalvin.space/merlin), a unique and valuable data set often overlooked because of its inaccessible interface. Together we conducted a thorough workflow inquiry and iterative prototyping sessions to refine interactions and visual representations. The interface redesign that resulted from this process streamlined exploratory investigation and reduced the time taken to generate visualizations and correlations on the order of days. The result of these efforts facilitated better science.

Through this project, Adrian and I hypothesize that similar human-centered art and design processes can critically enhance the practical value of many Earth and climate science data sets. As we update our understanding of the environment, we must also update the tools we use to study it and the methods we use to present it to the public. There is real potential for art and design to dramatically improve the way climate research is conducted and communicated.

A New Chance to Be Truly Revolutionary

Fifty years ago, queer folks began a revolution that demanded that we be respected as equals—both in life and in law—and that revolution has resulted in enormous progress for LGBT+ people everywhere.

On the last day of class, I tell all my students that the climate dilemma offers another opportunity for us to be truly revolutionary. Through collaboration with artists and designers, we can work toward the demystification of climate science, because when science becomes understandable to the public, people become interested in not only the results but also the scientific process, discussions, and, most important, solutions.

It is my hope that we will follow in the footsteps of our revolutionary ancestors and solve the climate crisis, together.

By **Mika Tosca** (@climategal84), School of the Art Institute of Chicago, Chicago, Ill.

▶**Read the full story at bit.ly/Eos_transcending-science**

Scientists Who Selfie from the Field

When the semester ends, many geoscientists abandon the cold air and fluorescent lights of laboratory research for more natural climes. They wade into swampy waters, scale steep mountainsides, climb into caves, sail the open seas, and traverse frozen tundra. They install seismic networks, drill ice cores, collect sediments, and measure streamflow. They teach the next generation of geoscientists to do the same.

This summer, AGU asked geoscientists to share via social media selfies from the field that showcase exciting research done outside the lab.

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

▶Read the full story at bit.ly/Eos_selfie-from-fie

Sondes Like Important Work

Jose Martinez-Claros (he/him)
@xatruchNMT
Follow

About a month ago doing a test radiosonde launch, preparing for #NCAR #OTREC2019, a research field mission in Costa Rica that starts in August to study tropical convection at the E Pacific near the ITCZ #AGU100 #FieldWorkSelfie

10:57 AM - 14 Jun 2019

A Magnetic Moment in the Field

Lior Kamhaji
@LKamhaji
Follow

Hot summer fieldwork - Paleomagnetic drilling at Troodos mountains, Cyprus for de-magnetization processes and AMS measurements at Dr. Ron Shaar Lab (HUJI) #AGU100 #FieldWorkSelfie

12:37 AM - 14 Jun 2019

A Glacier from a Di. erent Age: 2007

Dan Shugar
@WaterSHEDLab
Follow

Here's my #AGU100 #fieldworkselfie from Black Rapids Glacier about 12 years ago. @theAGU

1:27 PM - 17 Jun 2019

Well, That's Not a Basic Selfie

Rachel Gabor
@RiverChem

@theAGU, here are photos of my amazing undergrads sampling an acid mine drainage stream for the #AGU100 #FieldworkSelfie twitter.com/RiverChem/stat…

Rachel Gabor @RiverChem
Replying to @RiverChem
Wundergrads Chris and Holly did a fantastic job adjusting to the terrain, collecting samples, and pulling each other out of knee-deep mud. This is Chris's 2nd summer with me and this was Holly's first day in the field - these samples are part of her undergraduate honors project.

♡ 4 2:44 PM - Jun 24, 2019

Rockin' Outcrops

Haiyina H. A
@hayinoabio
Follow

Visiting the rocks 'cus we rock 😎 Got the chance to witness the northeastern Taiwan coastal outcrops despite the pouring rain 🌧 #AGU100 #FieldWorkSelfie

11:01 AM - 14 Jun 2019

Hazardous Selfies, for Professionals Only

Sir MarcNeil Amandy
@MarcusNeil
Follow

Hello, @theAGU here are my entries for #FieldWorkSelfie for #AGU100. My photos are from our Geohazard Mapping in Abra Province, Luzon, Philippines. twitter.com/theAGU/status/ …

3:33 AM - 17 Jun 2019

Selfie Near Everest? Check

MB CHAND
@MohanBChand
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Selfie was taken during field trip in Ngozompa Glacier, Everest region, Nepal #AGU100 #FieldWorkSelfie while taking ground control points (GCPs) for the UAV survey.

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RESURRECTING INTEREST IN A "DEAD" PLANET

New research suggests that the surface of Venus is busy, but it may take new missions to the planet to confirm this.

BY DAMOND BENNINGFIELD

It's been a quarter of a century since the Magellan spacecraft burned up as it plunged into the atmosphere of Venus.

The probe's radar mapper, which peered through the planet's clouds, had revealed a rugged surface of high "continents," volcanic mountains, spidery domes, and deep canyons. Scientists interpreted the chaotic landscape as evidence of massive outpourings of molten rock that repaved the planet's surface hundreds of millions of years ago. Modern-day Venus was considered dead, or almost so—a world whose craggy face had been frozen in time.

"These ideas developed that Venus is geologically dead—it had this catastrophic resurfacing and now is completely devoid of geologic activity," said Suzanne Smrekar, a senior researcher at NASA's Jet Propulsion Laboratory in Pasadena, Calif.

In the past few years, though, planetary scientists have looked at Magellan's observations in new ways, leading them to develop a more nuanced picture of the planet's history. The Magellan images, combined with observations by more recent orbiters, have provided hints that Venus could be quite active today.

The new findings have whetted the appetites of many researchers for new Venus missions—perhaps

Ash and gas erupt from a Venusian volcano in this artist's rendering. Although no active eruption has been seen directly, bumps in atmospheric sulfur dioxide suggest that similar eruptions have taken place. Credit: ESA/AOES

The Magellan spacecraft departing space shuttle Atlantis *in 1989. It arrived at Venus on 10 August 1990 and ended its mission 4 years later. Credit: NASA*

a "Magellan 2.0" orbiter to snap higher-resolution pictures of the surface and make better maps of the planet's topography or a long-duration balloon that would measure volcanic eruptions through ripples in the planet's atmosphere.

Such missions would teach us more not just about Venus, the scientists say, but also about Earth and a whole class of exoplanets. "Venus is an Earth-sized planet, and now—who knew?!—there are Earth-sized planets all over the galaxy," said Martha Gilmore, a professor of geology at Wesleyan University in Middletown, Conn. "So now, Venus is even more relevant for that reason."

Catastrophe Strikes Venus

Venus is described as Earth's sibling world. The two planets are about the same size and mass and probably were made from the same mixture of raw ingredients. The surface of Venus, though, is quite different from that of its planetary sibling.

"You're not in Kansas anymore—it's the Oz of the two planets," said James Head, a professor of geological sciences at Brown University in Providence, R.I., and a member of the Magellan radar team.

Instead of yellow brick roads and poppy fields, however, Magellan revealed that this planetary Oz is paved with volcanic rock. Although other craft had used radar to peek through the obscuring clouds, none did so in such high resolution or for so long. Magellan orbited Venus for more than 4 years; during the first 2, its synthetic aperture radar mapped almost all of the planet's surface, most of it at resolutions of 100–250 meters per pixel.

Radar images revealed that more than 80% of the surface is volcanic, more than two thirds is covered by volcanic plains, and much of the rest is dominated by tesserae (regions of rugged, deformed terrain that are higher than the average elevation). The images also showed shield volcanoes up to 9 kilometers tall, pancake-shaped domes, arachnoids—concentric rings surrounded by fractures that look like spider webs—and other intriguing features.

The images contained a surprising dearth of impact craters, though. Scientists counted fewer than 1,000 of them, relatively evenly distributed across the planet and all looking fairly fresh.

"So people hypothesized, 'Gee, most of the craters aren't modified; they're evenly distributed. That would argue that there was some catastrophic resurfacing,'" said Head, who also served as a guest investigator on two earlier Soviet radar missions, Venera 15 and 16. "The idea was that all of this volcanic activity came out at the same time, then it stopped."

Catastrophic resurfacing about 500 million years ago (give or take 250 million years) reigned as the leading description of Venus's geologic history—or at least the idea that got the most attention—for years. And Head said that although the repaving might not have happened in as short a time as originally supposed, it still didn't take long in geological terms.

"The hypothesis was modified to say that the crust itself was highly deformed, then the volcanic activity came out," he said. "It's got to be within tens to a hundred million years between each other. We need to go with a new radar mission to see the rate of volcanism and where the volcanism is to test that hypothesis."

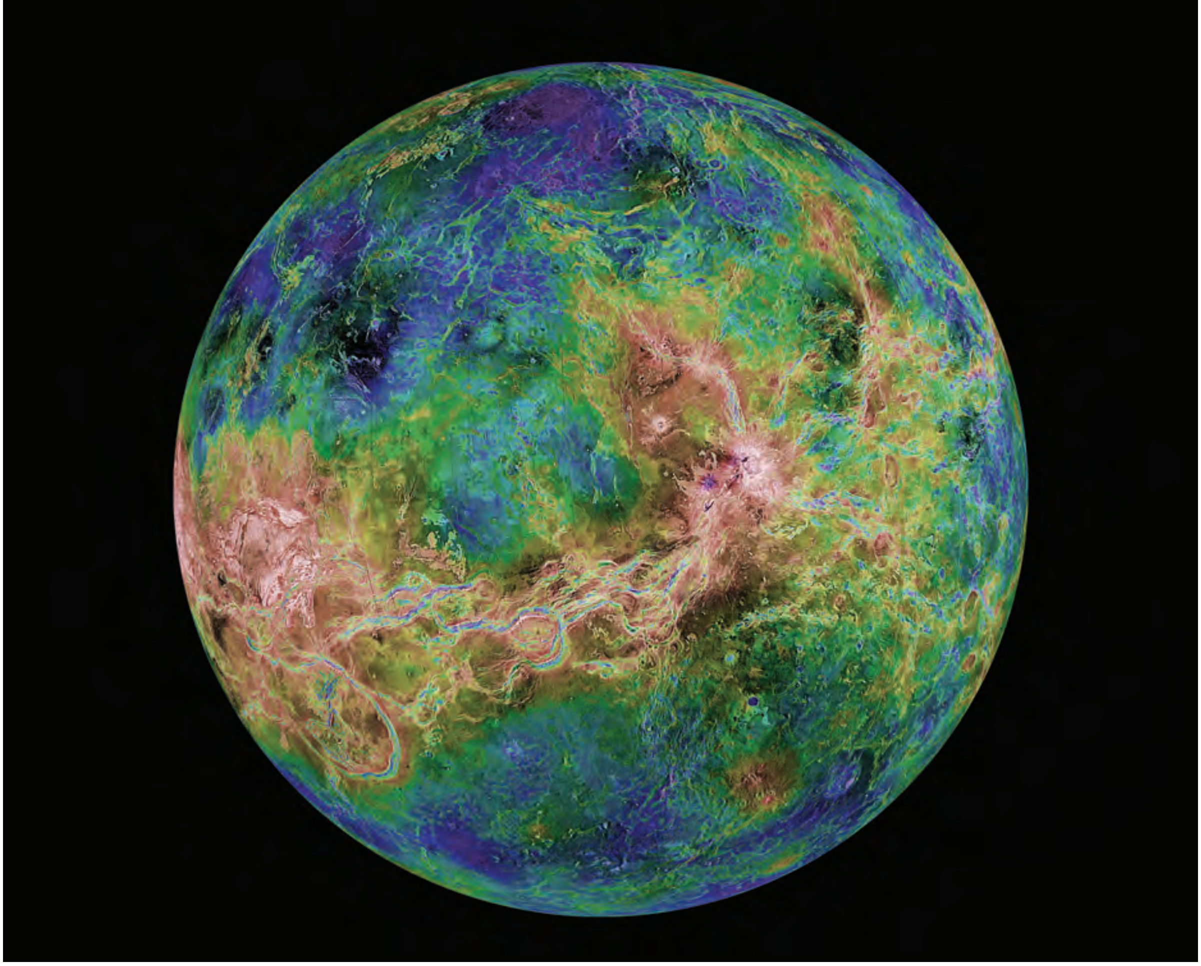
Or Does It?

Many scientists, though, have reinterpreted the surface in a less dramatic way. New maps of Venus have allowed scientists to study the landforms and their relationships to each other in more detail. These new views favor a more "steady state" interpretation, in which different areas of the planet were resurfaced at different times, over a much longer period.

> "YOU'RE NOT IN KANSAS ANYMORE—IT'S THE OZ OF THE TWO PLANETS."

"I think the general view is that rather than this catastrophic resurfacing event, which sounds amazingly dramatic and kind of science fictiony, it's much more piecemeal or episodic," said Paul Byrne, an assistant professor of planetary geology at North Carolina State University in Raleigh. "You have this process where a bit gets resurfaced, then another bit gets resurfaced, then another bit gets resurfaced. At a given time, the resurfacing is still formidable, but it's not necessarily that the whole planet is overturning and vomiting out its guts at one time."

"We can show beyond a shadow of a doubt that there was no catastrophic resurfacing," added Vicki Hansen, a professor of geology at the University of Minnesota Duluth. "You can absolutely re-create the crater database without catastrophic resurfacing." Her detailed mapping of roughly a quarter of the surface, Hansen said, demonstrates that it



A color-coded radar map, compiled primarily from Magellan observations, shows elevation differences on enus. Higher areas, known as tesserae, are in white and tan. Lower regions, primarily volcanic plains, are in blue and green. This view is centered on 180° longitude. Credit: NASA/JPL/USGS

could have been sculpted over a period of up to a few billion years [*Hansen,* 2018].

> “VENUS HAS TECTONISM ALL OVER [ITS] SURFACE FOLDS, FAULTS, FRACTURES, AND OTHER FEATURES.”

Most of the steady state models posit an era in which the tesserae formed, followed by creation of the vast volcanic plains, followed by an era of activity that built the volcanoes and related structures. And the same models agree that Venus is likely to be active today, which would support the idea of a resurfacing process that has played out gradually instead of catastrophically.

There’s little or no evidence, though, of Earth-like plate tectonics on present-day Venus. “We certainly don’t see an interconnected system of plate boundaries like on Earth,” said Smrekar.

That apparent lack of plate boundaries provides insights into Venus’s interior, said Robert Herrick, a research professor at the University of Alaska Fairbanks. It suggests that there’s little water in the lithosphere to help lubricate the motion of tectonic plates, for example. (On the other hand, recent studies have suggested that Venus’s interior may retain 75% of the water it was born with, compared with just 50% for Earth.)

In addition, the planet’s high surface temperature (about 740 kelvins) may prevent surface layers from cooling enough to become dense enough to sink into the mantle, which is a key tectonic process on Earth. “That makes plate tectonics very difficult on Venus,” Herrick said.

“Pack Ice” on a Hot World

Even without crustal plates, “Venus has tectonism all over [its] surface: folds, faults, fractures, and other features,” said Hansen. But its tectonic activity appears to be more small scale and regional. Work published last year by Byrne and his colleagues, for example, found evidence of “blocky” structures across much of the planet’s lowlands [*Byrne et al.,* 2018].

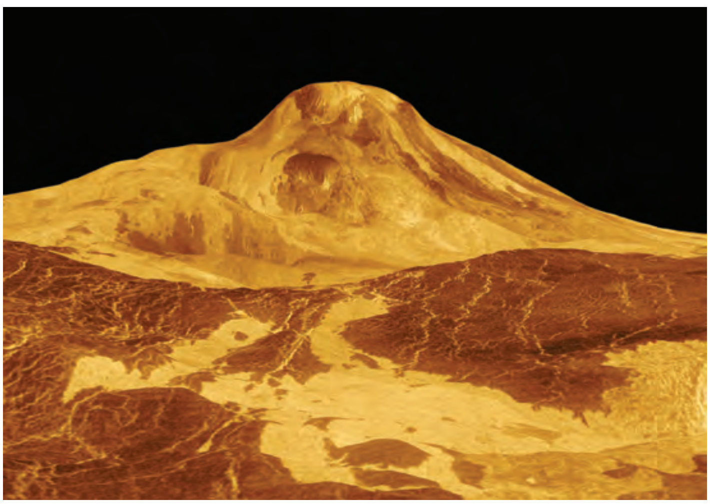
“A lot of those regions have a distinctive pattern of intersecting little mountain belts and rift zones—smaller than the ones on Earth,” Byrne said. “If you start mapping these things, you can convince yourself that there are low-lying discrete portions of the Venus crust that are physically independent of the areas around them.”

Byrne compares the behavior of these areas to pack ice. “Most of the tectonic activity—most of the deformation that affects the ice—goes into the edges of these rafts, these blocks,” he said. “So some parts pull apart, some parts push together, and some parts go side by side. And we think we’re seeing the comparable mechanism of behavior from much of the Venus lowlands.”

The studies have identified dozens of blocks, which range from a few hundred to about 1,500 kilometers wide, distributed across much of the planet. The blocks show relative horizontal motions of up to tens of kilometers. They are found in plains that are thought to be some of the youngest regions on Venus, so it's possible that they are continuing to move today.

Byrne said that the motions could be driven by plumes in the mantle below relatively thin portions of the lithosphere. Roiling convection in the mantle could crack weak layers of crust at depths of 10–15 kilometers, with that deformation propagating to the surface.

"We don't see anything like this on any of the other solar system worlds," Byrne said. "Understanding this isn't just about understanding Venus. It's also [about] looking to understand the rules that govern how rocky planets such as Venus and Earth behave in general."



Maat Mons, the tallest volcano on Venus, stands roughly 9 kilometers above the planet's average elevation. Research suggests that its summit is covered with recently emitted ash. The vertical scale is exaggerated in this image, which was compiled from Magellan radar and altimetry data. Credit: NASA/JPL

Hot Spots for a Hot Planet

Although there's no eyewitness view of an erupting volcano, the circumstantial evidence of an active Venus is piling up, from possible activity around coronae to what appear to be recent deposits of volcanic ash atop Maat Mons, the planet's tallest volcano.

"How recent is recent?" asked Smrekar. "Some new lab work suggests that it's quite recent—years, not millions of years."

A study published in 2012 found that the floors of many of Venus's craters are "radar dark," suggesting that they've been partially filled with volcanic rock [*Herrick et al.,* 2012].

"That could be telling you that craters are continuously being filled and covered over everywhere," said Herrick, who led the study based on 3-D views of Venus he compiled from overlapping tracks of Magellan observations.

Another 2012 study reported spikes in the amount of sulfur dioxide (SO_2), a volcanic gas, in Venus's upper atmosphere [*Marcq,* 2012]. Venus Express, a European Space Agency (ESA) satellite, detected a significant jump in the level of the compound above the clouds not long after it entered orbit in 2006. Since SO_2 is quickly destroyed by sunlight, any found at those altitudes must have just arrived. The SO_2 spike mimicked one detected by NASA's Pioneer Venus orbiter in the early 1980s.

The researchers concluded that the most likely source of both spikes was the recent eruption of one or more volcanoes. Because of the vigorous rotation of the atmosphere, however, it was impossible to pinpoint the culprits.

Venus Express was more successful at isolating possible volcanic activity by discovering hot spots on the surface, reported in 2015. An infrared instrument detected the spots in Ganis Chasma, a rift valley that's one of the youngest known regions on Venus. The four hot spots were consistent with the glow of lava hundreds of degrees warmer than the surrounding terrain, distributed in areas ranging from 1 to about 200 square kilometers.

"Everyone agrees, there is some volcanism on Venus," said Herrick. "It could range from reasonably Earth-like to maybe a magnitude lower than Earth rates. I would tend to guess it's toward the high end. I want it to be more active."

Kick-Starting a New Era

Everyone agrees on one other point as well: We won't know the full answers to Venus's geologic past and present without more data.

"There's still a lot of life left in the Magellan data for us to explore," said Byrne. "But [Venus is] an almost criminally underexplored world.... Why are we not sending legions of spacecraft to this thing to characterize its atmosphere, its surface, its interior?"

A new radar orbiter could provide higher resolution than Magellan and produce much better topographic maps. (The horizontal scale of maps produced with Magellan's altimeter is in the tens of kilometers.) It would allow scientists to look for changes on the surface during the 25 years since Magellan's demise, such as lava flows or ash deposits. And it could obtain more detailed observations of possible volcanic gases.

Yet only two Venus orbiters—the only dedicated missions since the end of Magellan—have arrived at the planet since then: ESA's Venus Express and Japan's Akatsuki. Venus Express was a major success, and Akatsuki continues to operate today.

For the future, ESA is considering a Venus orbiter, EnVision, that would detect minute changes in the planet's surface and probe to 100 meters below the surface. A decision is expected in 2021. India also has announced plans to launch an orbiter in 2023.

NASA has shown little interest in Venus, concentrating instead on Mars and many of our solar system's smaller bodies. It has pondered several proposed Venus missions over the past decade but has rejected them all.

Smrekar has served as principal investigator for several of the proposals to NASA and reprises the role this year. Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS), an orbiter with a radar system and an infrared instrument to look for volcanic activity and measure surface composition, was submitted to the Discovery program on 1 July. It (and a similar mission proposed to the New Frontiers program) was selected as a finalist in earlier reviews but failed to make the cut.

“I HAVE ASTRONOMER COLLEAGUES WHO COME TO ME AND SAY, ‘I’M STUDYING THESE EXOPLANETS AND I’VE GOT 50 VENUSES. WHAT DO WE KNOW?’”

Scientists have proposed Venus landers as well, although the challenges of surviving the high temperature and intense surface pressure make them more daunting.

Other scientists have proposed balloons that would float through and below the clouds. Among other instruments, they could carry seismometers that would detect the vibrations of venusquakes or volcanic eruptions transmitted through the dense atmosphere. In the more benign conditions well above the surface, they might operate for weeks or longer, providing a broader look at geologic activity than any lander.

Any proposal still faces stiff competition from other priorities. But Venus scientists say that the discovery of possible Venus-like worlds in other star systems may stimulate new interest in the original.

“I have astronomer colleagues who come to me and say, ‘I’m studying these exoplanets and I’ve got 50 Venuses. What do we know?’” said Head. “This is great!...You’re not looking at the surface, but there’s a new perspective on things, and that’s really critical. That’s another dimension. The more we understand about Venus, the more we’re able to place these Venus-like exoplanets into context, and that will be really incredible.”

“We only need one mission to spark that interest in other researchers, in policy makers, and [in] the public,” said Byrne. “That might be all we need to kick-start a new golden age in Venus exploration.”

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Marco Bottigelli/Moment/Getty Images

An unprecedented project in Iceland will drill into a magma reservoir that has never erupted to the surface.

AGMA

A JOURNEY TO INNER SPACE

By John Eichelberger

MAGMA IS THE FINAL frontier of Earth's crust. It is unexplored for good reasons: Extreme temperatures and pressures impede access by scientists and their instruments. Further, no geophysical technique has been shown to satisfactorily locate magma reservoirs. Thus, drilling down to magma might seem impossible. At several sites, however, geothermal energy drilling operations have discovered magma accidentally and safely. One of these sites is Krafla caldera in Iceland.

Beginning in 2014, an international group of scientists and engineers developed a plan, the Krafla Magma Testbed (KMT), to conduct long-term exploration of Krafla's rhyolite magma reservoir and its surrounding hydrothermal envelope. Our intent is to build surface facilities and subsurface magma portals where independent research teams can conduct experiments. The levels of funding required and the "user facility" organizational structure make such infrastructure analogous to that for telescope arrays and particle accelerators.

We have established a project office in Reykjavík at the Geothermal Research Group Cluster. Research institutes and companies from countries around the world, along with the government of Iceland, have endorsed KMT. We are optimistic that funding for the KMT project will begin within a year and that the facility, once built, can be maintained in an open state for decades.

Drilling Magma

Intentionally drilling into a magma reservoir is unprecedented, but projects to drill molten rock are not new. Beginning in the 1960s, the U.S. Geological Survey (USGS) began coring into lava lakes on Kīlauea volcano in Hawaii. Foremost among these projects was Kīlauea Iki, a pit crater that had erupted and filled with lava to a depth of 130 meters in 1959. Using small coring rigs, scientists drilled through the crust to the molten zone, retrieving almost perfect core samples. Cold water flowing through the core bit solidified the melt portion into beautiful glass but preserved it unchanged chemically.

Coring of Kīlauea Iki began soon after the eruption ended and continued to 1988, when the last of the melt lens was crystallizing. By the late 1970s, USGS was joined by Sandia National Laboratories in an effort to test the feasibility of extracting energy from magma. In essence, Kīlauea Iki became a test bed of the sort that we envision for unerupted rhyolite magma at Krafla.

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The results of the Kīlauea Iki project were transformational in magma science. Scientists obtained repeated petrologic profiles that traced the melt in time, composition, and space [*Helz and Thornber,* 1987]. Repeated temperature profiles showed that thermal fracturing at the base of the growing crust allowed water and steam circulation to rapidly transfer heat out of the melt lens [*Hardee,* 1980].

The location of Kīlauea Iki's still-molten lava was obvious because it had pooled at the surface, but all discoveries of unerupted magma have been unexpected and serendipitous. The first such discovery began with geothermal drilling into the Kīlauea East Rift in 2005 [*Teplow et al.,* 2009]. After passing through a zone of solid diorite, the drilling encountered crystal-poor dacite magma at a depth of 2,488 meters. The magma flowed 8 meters up the well.

> **All discoveries of unerupted magma have been unexpected and serendipitous.**

At Menengai caldera in Kenya, geothermal drilling began in 2011, and multiple wells have since penetrated syenitic magma 2 kilometers beneath the caldera floor [*Mbia et al.,* 2015]. Not only were these magma bodies or body surprisingly shallow, but also none of this magma had erupted in recent times.

At the Kīlauea East Rift and Menengai sites, as well as at the Krafla site, there is a heat-conductive "magma lid": an abrupt transition zone from solid rock to molten rock and a correspondingly extreme temperature gradient as predicted by *Carrigan* [1984]. An upper "mush zone" of partially crystallized magma, typically seen in lava lakes, is missing.

All of these accidental encounters also share another common feature. Because hydrostatic pressure exerted by the drilling fluid in the

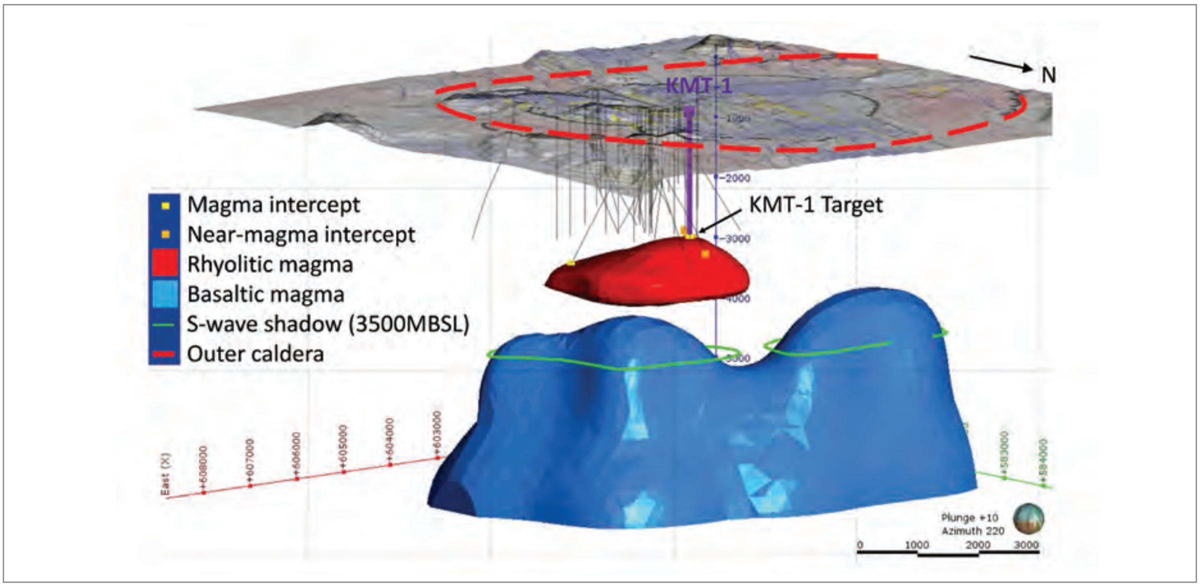


Fig. 1. Simplified schematic of the magma system beneath Krafla caldera (dashed r line), showing boreholes drilled for geothermal development (gray). The location of one large, near-liquid rhyolite magma body (red) is based on data from the intersection and near-intersection points with the boreholes, as shown. The rhyolite body sits above a region of basaltic magma (blue). The rhyolite and basalt regions may be more complex, with multiple smaller bodies of magma. The planned KMT-1 borehole (purple) closely follows the path of the earlier IDDP-1 project. Credit: J. W. Catley

borehole is much less than lithostatic pressure on the magma exerted by the overlying rock layers, magma begins to ascend up the borehole. The cold drilling fluid quickly quenches the viscous magma, forming a rock plug. These magma encounters were unexpected, and thus no measurements or core samples were taken.

To use magma (or to avoid accidental encounters), geophysical techniques must be developed into accurate prospecting tools by testing them against known magma targets with known properties [e.g., *Kim et al.,* 2019]. The results of unexpected magma encounters also warn against assuming that ash and lava from eruptions fully represent the range of magmas beneath a volcano. These are two of the research challenges that our magma observatory project aims to address.

We chose Krafla caldera for our observatory project (Figure 1) because Iceland Deep Drilling Project's IDDP-1 drill hole and some 40 geothermal wells drilled before it have already provided a wealth of descriptive information about this site [e.g., *Mortensen et al.,* 2014]. The Krafla caldera

A 3-D perspective by X-ray tomography of a magma chip (2 millimeters long), from Iceland Deep Drilling Project's IDDP-1. False-color gray crystals, mostly plagioclase, float in orange melt. A clot of crystals in the cu -away section is partially melted felsite from the roof of the magma chamber. The chip was quenched at about 2,100 meters depth and 900°C. Credit: Sample provided by Landsvirkjun; image by F. Wadsworth, Munich University, Germany; E. Saubin, University of Canterbury and C. I. Schipper, Victoria University, New Zealand

geothermal development project of Landsvirkjun, the National Power Company of Iceland, encountered its first unequivocal penetration of magma in 2007. In 2009, IDDP-1 encountered near-liquidus rhyolite at 2,102 meters, and magma flowed 9 meters up the well.

Other wells at Krafla have reached magma or near magma over an area of 3.5 square kilometers. The roof rock (the rock layer just above the magma) at IDDP-1 is partially melted felsite (see sidebar on p. 29). IDDP-1 recorded exceptionally high permeability above the magma, contradicting researchers' expectation that roof rock would be ductile and therefore impermeable. The resultant long-term flow rates of superheated steam, if channeled to a power station, could produce more than 30 megawatts of electricity from this single well.

Plans for the KMT Observatory

Krafla is the site of the most drilling, geoscience, and monitoring of any magma-hydrothermal system worldwide because of its volcanism, rifting at a major tectonic plate boundary, and robust production of geothermal energy. The public-spirited nature of the field operator, Landsvirkjun, and a supportive local population present an exceptional opportunity for broad science, engineering, and community collaboration.

KMT will be built in phases of increasing complexity, with the first estimated to cost $25 million and the total development to cost some $100 million. For phase I, we plan to do the following:

- choose a well site close to IDDP-1 so that we drill through the same rock layers
- drill the well and case it to about 2,050 meters using novel flexible couplings to accommodate thermal expansion and contraction
- core ahead until we penetrate magma
- emplace a thermocouple string to the bottom of the hole
- install a wellhead with a port for insertion of further experiments and pressurize the well with nitrogen to maintain an open hole

Subsequent drilling will provide a time series of observations for the magma-hydrothermal boundary, that is, whether the boundary is getting deeper as the system cools or is rising as the system heats up. We also plan to test extreme sensors (which are also relevant to such applications as aircraft engines and missions to Venus and Io) as well as the casing alloys and cements needed to ensure the long-term operational life spans of superhot boreholes. We will explore spatial variations in the magma body and its envelope and methods of extracting energy from this heat source.

Putting the Knowledge to Use

The KMT observatory will be a rich source of scientific knowledge, but the knowledge we gain will find many practical applications as well.

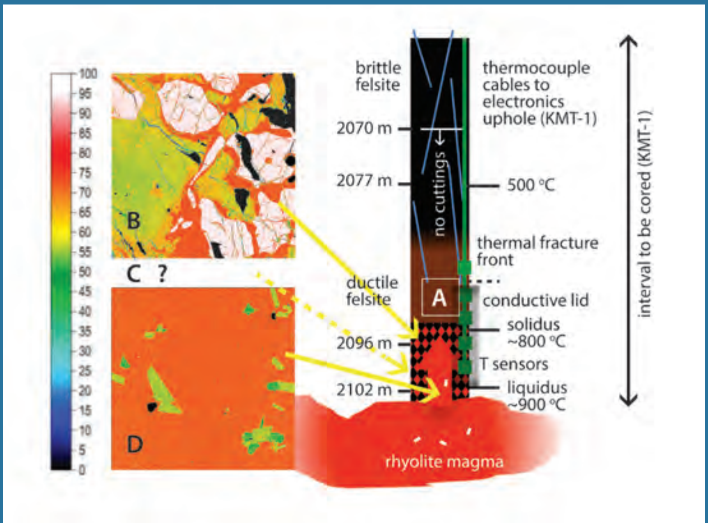
Assessing volcano hazards is one obvious example of such an application. The first questions people ask about a dangerous volcano are whether there is magma and, if so, where it is. KMT provides a test of geophysics against (under)ground truth. At present, we rely on proxy signals such as microearthquakes and surface deformation that provide untested and nonunique interpretations of what the magma is doing. We will be able to manipulate the fluid pressure in the borehole to generate seismic signals to test our inferences of volcano "unrest." Ultimately, development of in situ sensors that can detect pressure and temperature changes within a magma reservoir preceding an eruption will yield a vast improvement in the reliability of eruption forecasting.

> **KMT provides a test of geophysics against (under)ground truth.**

The geothermal energy industry can also benefit from the KMT observatory. Iceland, one of the hottest regions of Earth's crust, is an ideal location for an international test bed to accelerate advances in geothermal energy production. Geothermal energy has the least surface footprint of any energy source, usually produces little or no carbon dioxide (CO_2), and is continuous ("baseload").

Ten percent of the human population lives less than 100 kilometers from active volcanoes [*Newhall et al.*, 2017]. Areas near magma are the best places to find high-energy aqueous fluids: superheated or supercritical hydrothermal fluids that transport heat rapidly to the surface [*Scott et al.*, 2017]. At these fluid conditions, the efficiency of converting heat to electric power approaches the level of hydrocarbon-fired power plants [*Tester et al.*, 2007] but without the problem of carbon-based fuels.

KMT can also help to address some fundamental science questions about how the magma-hydrothermal regime works. Both the absence of magma mush at the chamber roof and the high permeability of what should be ductile, impermeable rock near the magma [*Mortensen et al.*, 2014] pose enigmas. The simplest explanation for the absence of crystal-rich magma mush is convec-



THE MYSTERY OF THE **MISSING MUSH**

The planned KMT-1 borehole will provide the rst cored transect of the margin of a magma chamber and the rst measurement of heat ow from magma to a hydrothermal system. Here we see observed and inferred results from the Iceland Deep Drilling Project's well IDDP-1, along with plans for KMT-1 assuming a similar section. Regions within the cored transect will include felsite (A), partially melted felsite (B), crystal-rich rhyolite magma "mush" that should be present but was missing in IDDP-1 (C), and near-liquidus rhyolite (D).

Images B and D at left are element maps of rock chips recovered after the drill bit stuck at 2096 meters' depth, color-coded according to weight percent of silica (SiO_2), from N. Graham and P. Izbekov at University of Alaska Fairbanks's Advanced Instrumentation Laboratory. Orange is rhyolite melt (now glass) with 75 weight percent SiO_2. Each eld of view is 1 × 1 millimeter.

In image B, the melt has formed along grain boundaries between plagioclase feldspar (lime green) and quartz (white, 100% SiO_2). Black is void space. In image D, melt makes up most of the sample, within which euhedral plagioclase, pyroxene (dark green), and ilmenite (black) oat.

Data from KMT-1 will reveal the depth and temperature relationships of these materials, helping to solve the enigma of why extensively crystallized magma (at C) is not present, even though melting in the rock roof (image B) above the magma should approximately balance magma crystallization. One explanation might be that convection in the magma allows heat given off y crystallization to be extracted from a much larger volume of the magma relative to the volume of the melted static roof.

View of the Krafla power plant in Iceland s Krafla caldera. The plant generates 60 megawatts of electricity and is operated by   andsvirkjun, the National Power Company of Iceland. Credit: jonanderswiken/shutterstock

tion [*Carrigan,* 1984]. The simplest explanation for high permeability is thermal fracturing [*Lamur et al.,* 2018]. These conclusions suggest a tightly coupled system in which magma rapidly advects (transports) heat to the solidified lid over the magma chamber. Cooling causes contraction, which fractures the lid, keeping it thin and heat conducting. High-energy fluids generated in the fractures can then transport this heat to a power plant. Such a system is efficient and sustainable.

Students play Magma Drillers, an online game that teaches them basic principles of drilling, geothermal energy, and volcano monitoring, as well as the career paths required. Credit: Ben Kennedy and Jonathan Davidson (design), Elizabeth Moredensky (art)

The KMT project will also contribute to planetary science by serving as an analogue to similar sites on other planets. Rocky planets differentiate (separate into layers of different composition) when melts separate from crystals and these components float or sink. By tracking melting and crystallization in situ, KMT will provide the first view of the final stages of planetary differentiation.

We are developing multiple levels of educational experiences for this unprecedented journey to inner space. For example, through work at the University of Canterbury, more than 4,000 students have already taken a virtual field trip to Krafla or played Magma Drillers Save Planet Earth, an online game that lets students plan a geothermal energy drilling site (see bit.ly/magma-drillers).

The KMT project will also contribute to planetary science by serving as an analogue to similar sites on other planets.

Past experience, albeit accidental, shows that we can reach and sample magma. Undertaking a planned rather than an accidental journey to magma is imperative for discovering new fundamental insights, mitigating the perils of eruption disasters, and developing energy alternatives to the hydrocarbon fuels currently poisoning the atmosphere with CO_2.

Acknowledgments
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sities of Alaska, Canterbury, Cornell, Lancaster, Liverpool, Munich, and others.

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The Unsolved Mystery

RESEARCHERS PEERING INTO EARTH'S INTERIOR FOUND TWO CONTINENT-SIZED STRUCTURES THAT UPEND OUR PICTURE OF THE MANTLE. WHAT COULD THEIR EXISTENCE MEAN FOR US ON EARTH'S SURFACE?

BY JENESSA DUNCOMBE

Some 2,000 kilometers beneath our feet are enormous masses of hot mantle material that have baffled scientists for the past 4 decades.

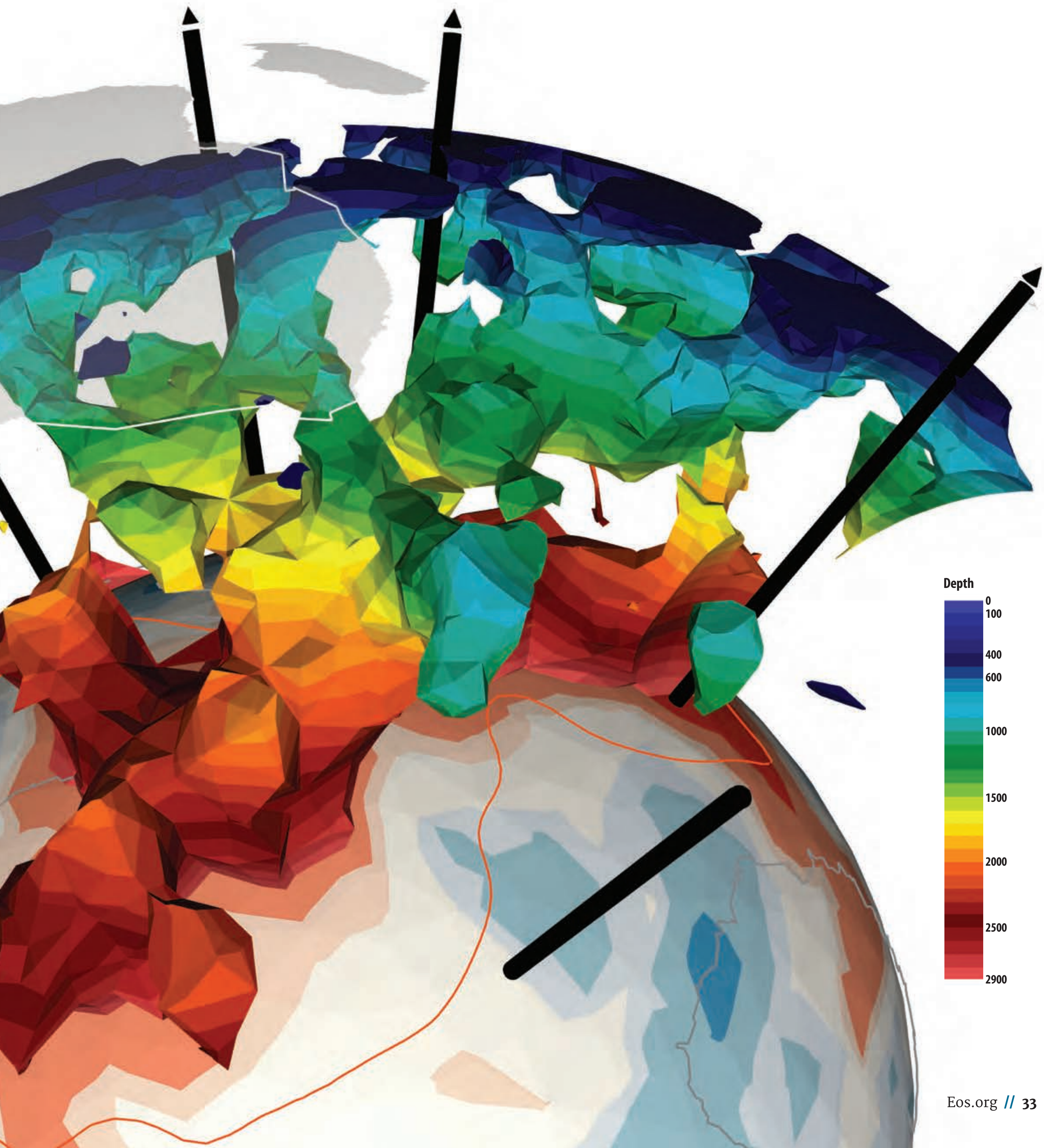
The blobs, as some scientists have taken to calling them, are the length of continents and stretch 100 times higher than Mount Everest. They sit at the bottom of Earth's rocky mantle above the molten outer core, a place so deep that Earth's elements are squeezed beyond recognition. The blobs are made of rock, just like the rest of the mantle, but they may be hotter and heavier and hold a key to unlocking the story of Earth's past.

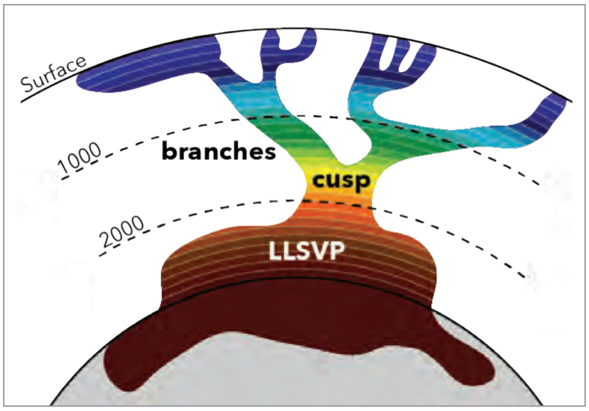
Scientists first spotted the blobs in the late 1970s. Researchers had just invented a new way to peer inside Earth: seismic tomography. When an earthquake shakes the planet, it releases waves of energy in all directions. Scientists track those waves when they reach the surface and calculate where they came from. By looking at the travel times of waves from many earthquakes, taken from thousands of instruments around the globe, scientists can reverse engineer a picture of Earth's interior. The process is similar to a doctor using an ultrasound device to image a fetus in the womb.

"Ultimately, a lot of people believe plate tectonics are one of the reasons why we have life on Earth," said geophysicist Harriet Lau at University of California, Berkeley. Scientists believe these blobs play a role in many of the processes of the deep Earth, including plate tectonics and volcanism.

Once researchers began to form a picture of inner Earth, they started to see things they never imagined. "It was very clear in those models from the get-go that at the bottom of Earth's man-

of the Earth Blobs





On the previous page: Seismic tomography imaging shows a portion of the "blob" that sits at the base of the mantle below Africa. Slow-wave velocity regions above the blob, including the cusp and branches, could indicate plumes or upwelling. Above, a simplified image of the stru - tures. Credit: Maria Tsekhmistrenko

tle, nearly halfway to the center, there were these huge zones where the waves traveled more slowly," said Ed Garnero, professor of Earth and space exploration at Arizona State University in Tempe.

The slow-wave velocity zones are concentrated in two locations: One lies under the Pacific Ocean, and the other sits under Africa and part of the Atlantic Ocean. They appeared like "massive mountains on the core-mantle boundary," said seismologist Sanne Cottaar from the University of Cambridge in the United Kingdom. Other researchers describe them as conical pits of gravel sitting "all on top of each other" or like giant sand piles. The blobs are so large that if they sat on Earth's surface, the International Space Station would need to navigate around them.

> THE BLOBS APPEARED LIKE "MASSIVE MOUNTAINS ON THE CORE-MANTLE BOUNDARY."

"They're basically unmissable," said seismologist Karin Sigloch at the University of Oxford, also in the United Kingdom. "They just show up on everybody's pictures."

There is little doubt that the blobs exist, yet scientists have no idea what they are. A recent paper said that the blobs "remain enigmatic" [*Garnero et al.*, 2016]. Scientists can't even decide on what to call them. They go by many names, most commonly LLSVP, which stands for large low-shear-velocity province.

Part of the reason for this mystery is what Earth scientists have always struggled with: They will never be able to visit the inside of Earth. "We know less about what's deep below our feet than the surface of the Sun or the Moon or Mars," said University College London researcher Paula Koelemeijer. Scientists are constantly trying to come up with new ways to peek inside Earth indirectly.

Fortunately, technological advancements in sensing minuscule wobbles within Earth, as well as efforts to outfit more locations with instruments, have been propelling the field forward. Several recent studies in cutting-edge techniques are bringing new insights to the table.

ARE YOU DENSE, OR WHAT?

Much of the blobs' mystery hinges on pinpointing what they are made of. Most seismic readings cannot determine the density of the material because changes in wave velocity depend on multiple factors, such as rock composition. Not knowing the density leaves many "doors open," said mineral physicist Dan Shim from Arizona State University.

Shim has seen the debate about the blobs' material raging since he was a graduate student in the 1990s. "I've watched this whole controversy throughout my career," he said. Researchers have argued back and forth about whether the masses are made of dense piles of chemically unique rock or bouncy lava lamp plumes that are headed for the crust above.

Researchers speculate that the blobs may feed hot spot volcanoes, which form ocean island chains like Hawaii. And other scientists wonder whether the blobs could have fueled supervolcanoes in the past, potentially contributing to Earth's biggest extinction events. But Shim said that until the density of the blobs is understood, "we cannot go to the next level of questions." Two recent studies, which found a way to measure density using unconventional data, suggest a more complex view than before.

EARTH DOING THE WAVE

Twice a day, Earth's crust rises and falls with the tides. Although we're more familiar with ocean tides, the solid Earth experiences the same forces as our oceans. As the Sun and the Moon pull on Earth, the entire planet flexes and stretches. In some places, the surface of Earth rises and falls by as much as 40 centimeters.

Scientists can track this movement using highly sensitive GPS measurements. A group of researchers led by Linguo Yuan at Academia Sinica in Taiwan analyzed measurements from GPS stations across the globe over 16 years and found that the Earth tide wasn't what they expected: It seemed to be off-kilter just above where the blobs were located. The tides, they wrote in their 2013 paper, "provide significant information on the solid Earth's deeper interior" [*Yuan et al.* (2013)].

Harriet Lau, then a geophysicist at Harvard University, heard about Yuan's work and saw an opportunity with the global data set. "It just so happens that body tides, or solid Earth tides, are very sensitive to density structure," she said. These tides could fill in the knowledge gap that traveling waves used in seismic tomography could not.

Lau created dozens of models to explain the skewed Earth tides and compared them with Yuan's data. She found that the models that fit the real-world data the best were those with blobs denser than the surrounding mantle. These findings, published in *Nature* in 2017, argued that the blobs have some sort of "compositional differences" than the rest of the mantle [*Lau et al.*, 2017].

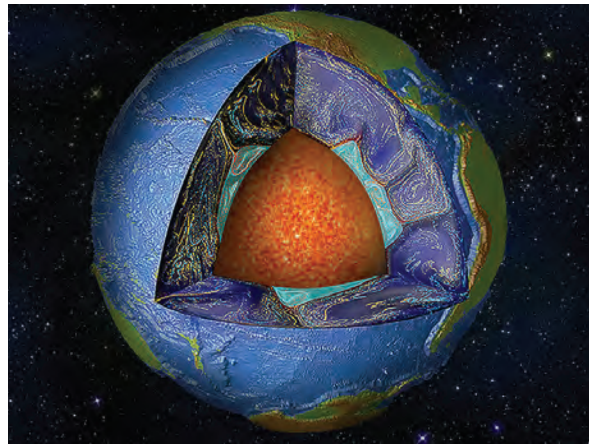
Meanwhile, another study suggested the opposite of what Lau's study found [*Koelemeijer et al.,* 2017]. Koelemeijer began studying normal mode oscillations as a graduate student in 2009. "At the time, not many people were using them," she said. Normal modes provide a powerful way to study the Earth, she said, but they're "more difficult to develop an intuition for." When it comes to the blobs, normal modes reveal features that more conventional seismic methods miss.

Many seismologists analyze waves inside Earth, but not all waves are alike. Most images that map Earth's interior rely heavily on a certain kind of wave, called a body wave. Similar to sound waves that travel through the atmosphere from one person's mouth to another's ear, these waves travel through Earth from one place to the next.

But after large earthquakes, a different kind of wave appears, and it doesn't travel as much as it vibrates. This type of wave is called a standing wave, and it's the type that shudders a violin string. "When you're thinking of a standing wave, you're looking at the whole planet vibrating at the same time," said Koelemeijer. "The Earth is like a bell that's been hit and it's resonating as a whole." Researchers can record these waves with seismometers on the surface.

In Koelemeijer's recent study, she picked a type of standing wave called Stoneley modes that vibrate depending on the density of the blobs. She and her team analyzed records of ground movement in the days following large-magnitude earthquakes, looking for the low-frequency vibrations of standing waves. Comparing their results with models, they found that the blobs must be less dense than the surrounding mantle to explain several constraints, like the slight wobbles on the core's surface.

When asked how to make the two studies congruent, the researchers suggested that both papers could be correct. "One way to perhaps reconcile Harriet Lau's and my work is that this dense material is not distributed over a very large depth range," Koelemeijer explained. Perhaps the blobs are densest in a sliver right next to the core, a detail that Koelemeijer could not rule out in her analysis. Lau echoed this suggestion. "I'm not actually worried at all



What lies below? A cutaway view of Earth down to the liquid core shows the swirling mantle rock (dark blue). Made from a numerical convection model, the image shows mysterious structures underneath the Pacific Ocean that some researchers believe hold the clue to unlocking mysteries of Earth's past (light blue). Credit: Mingming Li/ Arizona State University

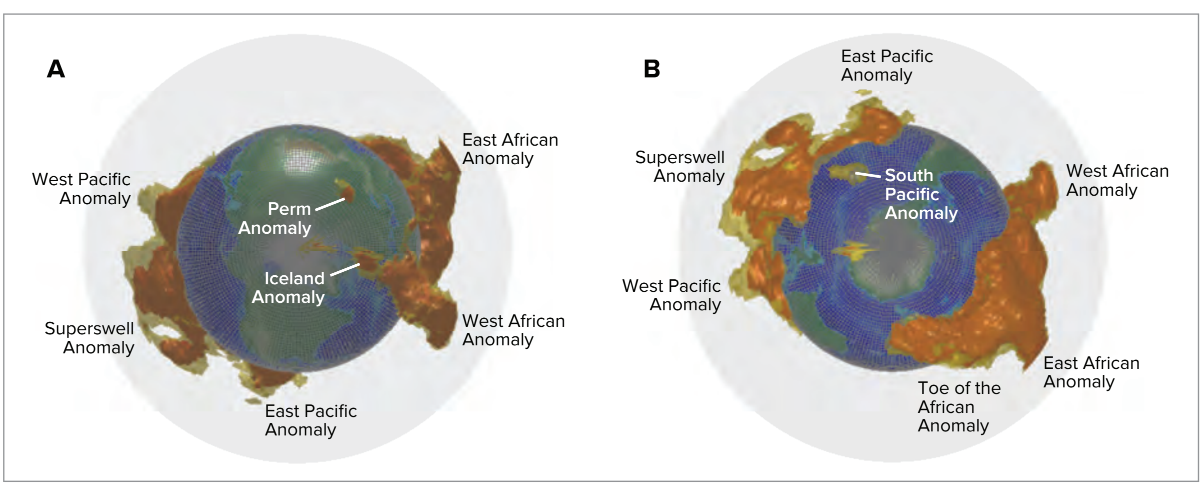
about this seeming contradiction," she said. The results simply help them "fine-tune" their conclusions, she said.

VERY 3-D

When seismologist Ed Garnero's wife was pregnant with twins in 2002, he remembers accompanying her to the doctor for an ultrasound. Despite the new 3-D imaging technology, he said the low-resolution images on the screen were off-putting. "It looked like the brains were floating off to the side. It was really weird," he said.

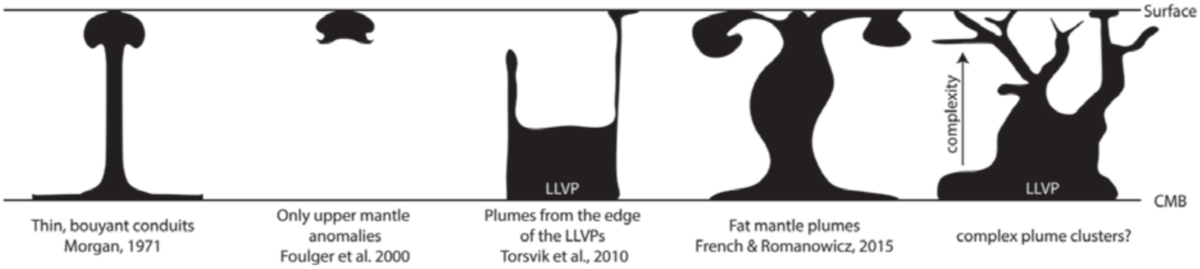
In seismic tomography, researchers deal with similar problems. The blobs received their nickname partly because of their soft, lumplike shape in seismic tomography maps. But what if their structure were actually more delicate? And could knowing the shape of the blobs better help researchers constrain their density?

Last December, doctoral student Maria Tsekhmistrenko from the University of Oxford presented some of the most revealing images of the structures to date. At a session at AGU's Fall Meeting 2018, Tsekhmistrenko showed her seismic tomography maps of the blob under Africa [*Tsekhmistrenko et al.,* [2018]. The images come from an extensive seismometer project that deployed sensors on



The blobs, seen from (a) the North Pole and (b) the South Pole. The two-toned structures show the shapes of the blob based on the agreement of fiv different models (brown) and three different models (tan). Credit Cottaar and Lekic, *2016*

The Kīlauea volcano on the Big Island of Hawaii comes from hot spot volcanism, which scientists believe could be linked to the blobs. Credit: iStock.com/Frizi



*Scientists' shifting ideas of what mantle plumes may look like, through several examples in the literature [*Morgan, *1971;* Foulger et al., *2000;* Torsvik et al., *2010; and* French and Romanowicz, *2015]. LLSVPs are a type of large low-velocity province (LLVP). Credit: Maria Tsekhmistrenko*

the ocean floor around Madagascar, a region that had been, until that point, sparsely studied.

Using a collection of different types of waves, Tsekhmistrenko revealed the jagged and angled sides of the blob and its plumes above it, showing very little of the softness suggested by earlier tomography maps. Taken together, the whole structure looks like a tree that branches up to hot spot volcanoes at the surface, said Tsekhmistrenko's adviser, Karin Sigloch.

At first, Tsekhmistrenko said that they didn't believe what they saw. "We worried that something was wrong with my data," she said. Then she realized they were correct, even though "it looks different than expected."

"Very 3-D," she added.

"WE LITERALLY DON'T KNOW WHAT THEY ARE, WHERE THEY CAME FROM, HOW LONG THEY'VE BEEN AROUND, OR WHAT THEY DO."

Garnero, who saw the presentation, said that it was "the best Earth interior imaging presentation I've seen at AGU." He added that scientists who study the movement of the inner Earth, called geodynamicists, may be excited to get their hands on Tsekhmistrenko's images.

"The slope of that structure turns out to be hugely important in constraining its density," he said. "That's really important for dynamicists." Tsekhmistrenko has already heard from one geodynamicist planning to simulate the structures in a future model.

LOOKING INWARD

Despite critical advances in seismology, the quest to understand the blobs is "an inherently interdisciplinary problem," said geologist Ved Lekic of the University of Maryland in College Park.

Mineral physicists, for example, measure how waves travel through rocks under extraordinary pressures to improve seismology models. Geochemists scour Earth to collect rocks from volcanoes, looking for clues to unique chemical reservoirs that could be linked to the blobs. And modelers construct intricate webs of code to evolve the mantle over billions of years, simulating how the blobs came to form.

Whatever the answer may be, peering under Earth's crust may give researchers a way to contemplate our earliest beginnings. "These questions are very romantic in some ways," said Harriet Lau. "I'm so inspired by questions that go to the root of existence and the universe."

Earth is the only planet known to contain plate tectonics, and recent research has suggested that tectonics may help sustain life by delivering a steady stream of nutrients, like nitrogen and phosphorus, to the surface. And yet researchers aren't sure what causes plate tectonic movement, let alone the blobs.

"I think that their real fundamental and philosophical appeal is their mystery," said Lekic. "They're among the largest things inside the Earth, and yet we literally don't know what they are, where they came from, how long they've been around, or what they do."

Ultimately, the road to uncovering the mysteries may be long, said Garnero. "This is a slow-motion discovery; it's a community thing," said Garnero, who has worked on the blobs for the past 15 years.

Lau, who plans to study the blobs in her new position at the University of California, Berkeley this year, said she isn't fazed by the mystery. "I think science is incremental, and that's why, for example, Paula Koelemeijer's results didn't particularly faze me," she said. "I was actually more excited rather than anything else."

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▶Read the full story at bit.ly/Eos_Earth-blobs

AGU NEWS

AGU's Virtual Poster Showcase Gives Students a Leg Up

In December 2018, AGU welcomed Earth and space scientists from across the globe to Washington, D.C., for its annual Fall Meeting. The hustle and bustle of more than 28,000 attendees filled the conference center with an atmosphere that was electric. The weeklong event is a wonderful opportunity for students to network, learn in an interactive environment, and gain valuable experience in presenting research to their peers. But what if you aren't able to attend because of financial or scheduling reasons?

AGU's twice-annual Virtual Poster Showcase (VPS), launched in 2015, enables students to participate in an online poster competition in which they present their research to peers and judges. VPS entrants build critical, career-boosting oral and written presentation skills and receive expert feedback on the clarity, thoroughness, and competence of their research. Prizes include complimentary AGU membership and Fall Meeting registration. All entrants receive a certificate of participation, earn citations for their abstract, and, most important, are added to the American Geosciences Institute's GeoRef database.

Prudence Crawmer, a past VPS winner studying environmental studies and geography at Pikes Peak Community College in Colorado Springs, Colo., "encourages students to apply, because if you don't have money for travel fees, this is a great way to present your project." During the fall 2018 session, Crawmer presented her research on collecting local magnetic anomalies using a crowdsourcing app called CrowdMag and credits VPS for making her less nervous about future presentations as she progresses in her academic and professional endeavors.

Amanda Gerotto is a Ph.D. student researching paleoceanography at the Oceanographic Institute at the University of São Paulo in Brazil and a winner at the spring 2016 VPS.

VPS entrants build critical, career-boosting oral and written presentation skills and receive expert feedback.

Student Prudence Crawmer and Rick Saltus of the National Oceanic and Atmospheric Administration collect magnetic anomalies in Boulder, Colo., using the CrowdMag app and a magnetometer. Crawmer won when she presented her work at AGU's fall 2018 Virtual Poster Showcase. Credit: Prudence Crawmer

She most enjoyed the feedback that she received. "I learned a lot about myself," said Gerotto. "Having recommendations [to incorporate into my research] from that is amazing." Similarly, Rushana Karimova, a graduate student at York University in Toronto, Ont., Canada, studying carbon dioxide ice properties on Mars, presented her undergraduate thesis research during the fall 2016 VPS. Her favorite part was getting to speak to so many peers and experts: "People asked me questions about my poster and my presentation, and it was really interesting to see what parts of my work they were more interested in."

In a competitive field like the geosciences, presenting research in a succinct, online presentation is a unique experience that students can use to differentiate themselves. The VPS program shows that developing alternative means of inclusivity can offer crucial opportunities to geoscience students facing different situations. The future of VPS is bright, and AGU is eager to see the research that young Earth and space scientists will be bringing forth in upcoming showcases.

Learn more about AGU's Virtual Poster Showcase at bit.ly/VPS-AGU.

By **Julia Jeanty** (jjeanty@agu.org), Talent Pool Intern, AGU; and **Sharon Rauch,** Career Services Coordinator, AGU

EOS CENTENNIAL COLLECTION
AGU100 ADVANCING EARTH AND SPACE SCIENCE

How the Moon Got Its Concentric Rings

The Moon is pockmarked with impact craters from collisions with meteorites and asteroids, some as big as 1,000 kilometers in diameter. These massive impact craters contain three or more concentric rings, a mysterious feature that has long intrigued scientists interested in how Earth's early surface and those of other planets evolved. A new study, in which scientists simulated an asteroid bigger than New York City slamming into a Moon-like object, explores how such rings form.

Billions of years ago, Earth looked a lot like the Moon: riddled with craters from impacts with asteroids and other space debris. Many of these craters have been erased or eroded by the atmosphere and the water owing over Earth's surface, so scientists must look to the atmosphereless Moon to reconstruct how different crater feat res are created.

Researchers already know a lot about how relatively small, simple impact craters form. When a projectile hits its target, it transfers its kinetic energy to the planet or moon, creating powerful shock waves that ripple through the rock. The projectile simultaneously melts and vaporizes, launching molten and solid rock called ejecta hundreds of kilometers away. Then the remaining ejecta rings the crater site and slumps inward, forming a smooth bowl.

On the Moon, this process seems to hold for craters smaller than 20 kilometers in diameter. As impact craters get bigger, however, they grow more complex, eventually forming multiple concentric rings. For example, one of the Moon's most famous impact craters—the nearly 1,000-kilometer-wide Orientale basin—has three distinctive, bull's-eye-like rings that have long confounded scientists.

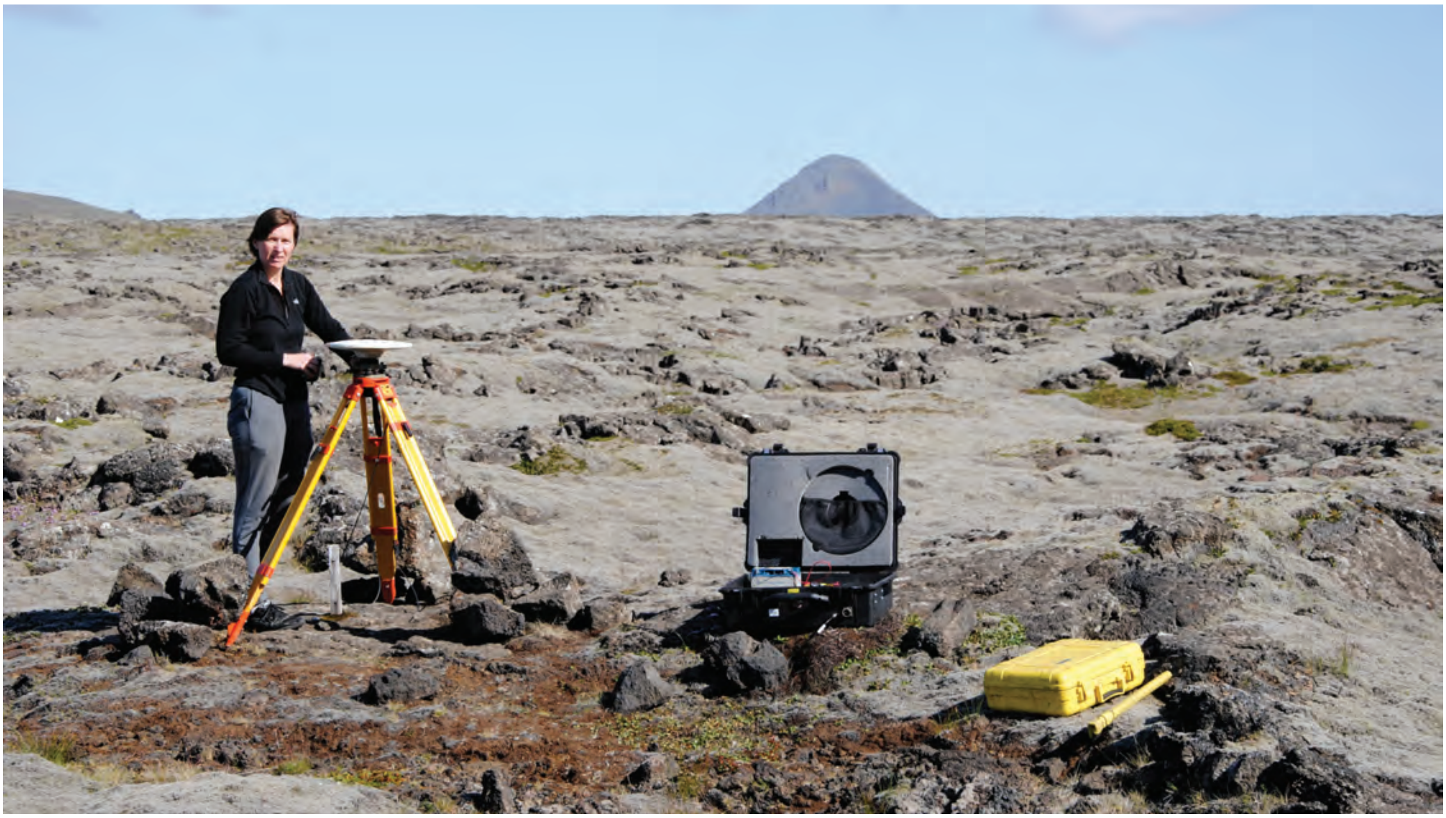
To get a fresh perspective on this complex crater structure, *Johnson et al.* took advantage of data from NASA's Gravity Recovery and Interior Laboratory (GRAIL) mission: two washing machine–sized spacecraft that orbit the Moon and produce a high-resolution map of its gravitational field. Using this new, 10-kilometer-scale data, the authors were able to build a high-resolution computer model of a 64-kilometer-diameter asteroid hurtling into a Moon-like object at 15 kilometers per second.

The team found that the dominant hypothesis for how concentric rings form in impact craters, known as ring tectonic theory, appears to be correct. In this hypothesis, rings are formed as rock flows inward d ring crater collapse, dragging the base of the lithosphere—a planet's or moon's rigid, outermost rock shell—and creating a distinctive pattern of faults in the rock, forming rings.

A view from Lunar Orbiter 4 of the Orientale basin on the Moon. Credit: NASA

By tweaking different variables within the simulation, the researchers discovered that factors such as the interior temperature of the Moon, the strength of the lithosphere, and the thickness of its crust affect ring loc tions and spacing. They were able to reproduce the approximate spacing and offset of Orientale's rings, bolstering both the model's credibility and ring tectonic theory itself, the authors report. (*Journal of Geophysical Research: Planets,* https://doi.org/10.1029/2018JE005765, 2018) **—Emily Underwood, Freelance Writer**

A New Way of Visualizing Iceland's Crustal Deformation



Thóra Árnadóttir sets up a GPS instrument for campaign measurements on Reykjanes Peninsula. Mount Keilir is in the background. Credit: Larus Thorlacius

Iceland is located along the northern Mid-Atlantic Ridge, the volcanically active zone in the center of the Atlantic Ocean where the North American and Eurasian plates are pulling apart from each other at a rate of 18–19 millimeters per year. Most of the plate spreading in southern Iceland is accommodated by east-west transform motion in the South Iceland Seismic Zone (SISZ), which lies between two volcanically active centers: Hekla to the east and Hengill to the west.

The resulting strain is released in earthquake sequences that strike at intervals averaging 80–100 years. Geodetic research indicates that a series of moderate earthquakes that occurred in this zone in 2000 and 2008 released only half of the strain stored in the crust since the previous 1896–1912 sequence.

To better understand how the crust is deforming in southern Iceland, *Árnadóttir et al.* report local strain rates from 2001 to 2015 that they estimated from GPS velocities using a novel method developed in a 2015 study. This technique, which uses the vertical derivatives of horizontal stress, minimizes background noise and enables finer re - olution than the standard processing method.

The results indicate that crustal deformation in the SISZ includes signals stemming from postseismic activity and plate spreading as well as from subsidence in the Hengill area, which the authors attribute to fluid extraction by two local geothermal power plants. Around the Hekla volcano, the researchers also detected a broad area of extension indicative of magma accumulating beneath the edifice. They estimate that its volume has increased an average of 0.02 cubic kilometer per year over the 14-year study period.

The authors also discovered a significant increase in the rate of strain in the area where the 2008 earthquakes originated. Because this increase occurred both prior to and following those tremors, the authors hypothesize that this signal is caused by a combination of plate motion and subsidence in the Hengill area.

This study clearly demonstrates that the previously published method reveals crustal deformation in southern Iceland not previously observed by standard GPS processing techniques. The resulting maps are allowing geoscientists to visualize crustal deformation in entirely new and potentially important ways. (*Journal of Geophysical Research: Solid Earth,* https://doi.org/10.1029/2018JB016068, 2018)

—Terri Cook, Freelance Writer

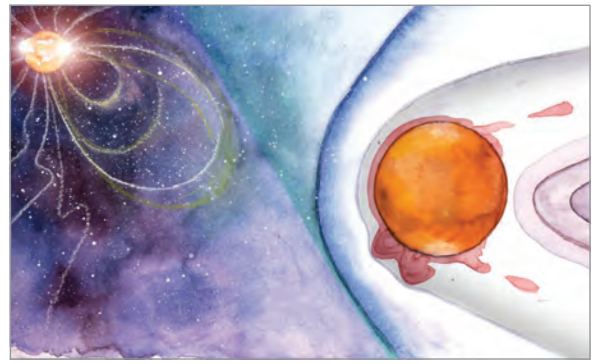
EOS CENTENNIAL COLLECTION

How Mars Lost Steam

About 4 billion years ago, Mars was a sultry planet, a warm, wet world of lakes and rivers blanketed in a thick, steamy atmosphere. At some point in the distant past, this atmosphere disappeared, and Mars became the freezing, inhospitable desert it is today.

The most widely accepted explanation for how Mars lost its atmosphere is that solar winds swept it away. In this scenario, the magnetized plasma hurtling away from the Sun—also called solar wind—induced electromagnetic forces in the ionized upper atmosphere that easily whisked the particles into space. But a new study based on data from the Mars Express spacecraft contradicts this hypothesis, suggesting that solar winds played only a minor role in the loss of Mars's early atmosphere.

Using a decade of ion loss measurements from Mars Express, *Ramstad et al.* calculated an estimated rate of ion escape from Mars's atmosphere over the past 4 billion years. Solar wind–driven ion escape accounted for only about 9 millibars of lost atmospheric surface pressure, the researchers found. That's less than 1% of the total 1 bar of surface pressure that would have been necessary to sustain Mars's lakes and rivers, a loss too minor to explain how Mars arrived at its current, desiccated state.



The solar wind shapes the Martian magnetosphere and erodes the atmosphere. Credit: © Anastasia Grigoryeva

There are some elements of uncertainty in the study, including doubts about the strength of solar winds and ionizing radiation that flowed from the younger Sun. But the work does suggest that solar wind was an accomplice, not the primary thief, in the disappearance of Mars's atmosphere, the team argues. (*Journal of Geophysical Research: Planets,* https://doi.org/10.1029/2018JE005727, 2018)

—Emily Underwood, Freelance Writer

EOS CENTENNIAL COLLECTION

No Underground Magma Ocean on Jupiter's Fiery Moon?

Jupiter's closest Galilean moon, Io, is the most volcanically active object in the solar system. Kneaded and heated by Jupiter's rhythmically reversing tidal stresses, the moon hosts hundreds of active volcanoes, some of which spew lava and sulfur dioxide more than 400 kilometers high.

Scientists have long argued over whether Io's intense volcanic activity is fueled by an underground ocean of magma. A new analysis of data from the Galileo spacecraft provides fresh fodder for that debate, suggesting that such an ocean could be absent.

Galileo flew past Io several times in the late 1990s and early 2000s, including a risky pass between Io and Jupiter that exposed the spacecraft to intense radiation and temporarily damaged its computers. Despite the technical glitch, Galileo collected valuable measurements from the hot, ionized gas, or plasma, that escapes from Io into Jupiter's magnetosphere, feeding a doughnut-shaped ring of dense plasma around Jupiter called a torus. It also captured interactions between Jupiter's powerful magnetospheric plasma and Io's thin atmosphere, which produce brilliant auroras.

On the basis of Galileo's data, some scientists have concluded that Io's own magnetic field is driven by a subterranean magma ocean. As Jupiter's magnetic field sweeps back and forth across the moon, the theory goes, it generates electrical currents within a global conductive ocean of molten rock. This process produces its own magnetic field, which contributes to massive perturbations in the surrounding magnetic field of Io

But in the new study, *Blöcker et al.* argue that the measured magnetic perturbations in Io's environment come instead from asymmetries in Io's thin atmosphere. Io's entire atmosphere collapses into frost on a daily basis, whenever it falls into Jupiter's shadow. The atmosphere is also larger and denser on the side of the moon that faces away from Jupiter. On a local level, massive volcanoes also make Io's atmosphere irregular. Computer models used in past studies haven't focused much on these asymmetries, leaving room for error, the researchers argue.

To remedy that omission, the scientists used the same type of computer model that past groups have used, called a 3-D magnetohydrodynamic model. Instead of focusing on Io's interior, they focused solely on the moon's atmosphere. Their goal was to see whether an asymmetrical distribution of gas in Io's atmosphere alone, independent of any contribution from a global conductive magma ocean in Io's interior, could produce magnetic perturbations similar to those observed by Galileo.

The model produced the same magnetic field pert rbations in Io's simulated atmosphere as those observed by Galileo. The study doesn't entirely rule out the possibility that an underground magma ocean could exist on Io, but it suggests that there's no need for one. Instead, the moon's unusual atmosphere accounts for Galileo's observations all on its own. (*Journal of Geophysical Research: Space Physics,* https://doi.org/10.1029/2018JA025747, 2018)

—Emily Underwood, Freelance Writer

Seasonal and Annual Changes in Pitch of Blue Whale Calls

The call pitch of blue whales, like the one seen here, can vary both seasonally and year by year, according to an analysis of more than 1 million whale vocalizations recorded across the southern Indian Ocean. Credit: NOAA

Whales make a wide variety of sounds, including clicks and vocalizations, to interpret their surroundings and communicate with other members of their pods. Since the emergence of acoustic monitoring technology several decades ago, researchers have noted that blue whale songs have steadily decreased in pitch, but the cause of this phenomenon, including whether humans may shoulder some of the blame, remains uncertain.

To extend the geographic range of whale call observations, *Leroy et al.* studied acoustic recordings collected at six sites across the southern Indian Ocean. Using Deformation of the Ocean Lithosphere using Hydrophones (DEFLO-HYDRO) and Observatory of Hydroacousticity from Sismicity and Biodiversity in the Indian Ocean (OHA-SIS-BIO) hydrophone array data sets, which collectively represent a nearly continuous record from 2010 to 2015, the authors captured more than 1 million Antarctic blue whale calls, as well as vocalizations from fin whales and three acoustically distinct pygmy blue whale populations: Australian, Sri Lankan, and Madagascan.

The results indicate that the vocalization pitch has steadily decreased in all five whale populations by a few tenths of hertz per year. This finding is consistent with previous studies of Antarctic blue whales but is the first documented occ rrence of this phenomenon in both fin and Madagascan pygmy blue whales. The authors argue that the trend could reflect increasing whale populations, differences i the ocean's acoustic properties due to changing environmental factors like ocean acidification, or a combination of both

Because of the study's long duration and broad spatial distribution, the team was also able to detect seasonal, up-and-down shifts in the pitch of Antarctic blue whale calls superimposed upon this interannual trend. These intra-annual fluctuations peak d ring the austral summer and correlate with seasonal fluctuations in ocean noise, pa ticularly the low-frequency sounds emitted by drifting icebergs, a primary source of ambient noise in the southern Indian Ocean. The change in call pitch is believed to be linked to a change in call intensity in response to the seasonal variation of noise level.

The authors' evidence for both seasonal and interannual changes in the pitch of whale vocalizations and their suggestion that these phenomena may result from different drivers are likely to be of broad interest to the scientific community. This study clearly demonstrates the value of obtaining widespread and long-term acoustic recordings of cetacean calls to determine why they are changing and the importance of interdisciplinary collaboration to effectively collect and pr cess massive data sets and interpret the results. (*Journal of Geophysical Research: Oceans,* https://doi.org/10.1029/2018JC014352, 2018)

—Terri Cook, Freelance Writer

Atmospheric Sciences

Postdoctoral Positions in Improving Land-Atmosphere Interactions in the GFDL climate and Earth System models

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks postdoctoral or more senior researchers for new projects exploring the implications of sub-grid land heterogeneity for land-climate interactions, particularly for (1) atmospheric boundary layer and convection and (2) land surface radiation exchanges.

The first position sought is in association with the Center for Ocean-Land-Atmosphere Studies at George Mason University in Fairfax, Virginia. The candidate will work collaboratively with investigators at both institutions and other national climate modeling labs to assess improvements to the models through existing diagnostic tools and the development of methods for characterizing land-atmosphere coupling and interaction. Additional work will include focused assessments of diurnal-scale land-atmosphere behavior at data-rich locations in conjunction with coordinated large-eddy simulations performed at Duke University.

The second position will focus on advancing the representation of atmosphere-to-land radiation exchange processes in the NOAA/GFDL ESM4, including the effects of mountain shading and reflections between mountains and snow, canopy air and snow impurities, and interactions of radiation with vegetation in complex terrain. The candidate(s) will collaborate with the atmospheric radiation experts at the University of California, Los Angeles as well as other national climate modeling centers.

Positions will support newly funded, interdisciplinary, multi-agency Land-Atmosphere interactions 'Climate Process Team (CPT)' projects. The ideal candidates have to demonstrate a strong background in Earth system modeling and climate science, as well as experience using and analyzing numerical models and/or large observational datasets.

Candidates must have a Ph.D. in atmospheric physics, hydrology, meteorology, Earth system science, climate studies, or related fields. The initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding.

Complete applications, including a CV, a statement of research interests, and contact information of 3 references should be submitted by August 15, 2019 for full consideration. Applicants should apply online to http://jobs.princeton.edu/acad-positions/position/12202. For more information about the research project and application process, please contact Elena Shevliakova (elena.shevliakova@noaa.gov) or Kirsten Findell (kirsten.findell@noaa.gov).

This position is subject to the University's background check policy.

Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Section Head, Atmosphere Section, GEO

Become a part of our mission to maintain and strengthen the vitality of the US science and engineering enterprise. For over 70 years, the National Science Foundation (NSF) has remained the premier Federal agency supporting basic research at the frontiers of discovery across all fields, as well as science and engineering education at all levels.

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Responsibilities

Serves as a member of the Division leadership team and as the Directorate's principal spokesperson in the area of lower atmosphere research. Responsible to the Division Director, Division of Atmospheric and Geospace Sciences, for the overall planning, management and commitment of budgeted funds for the Atmosphere Section, which includes programs in Atmospheric Chemistry, Climate and Large-scale Dynamics, Physical and Dynamic Meteorology, and Paleoclimate. The incumbent also serves as the Division's primary source of guidance concerning research priorities and program development in atmospheric sciences.

The incumbent is responsible for the day-to-day operations of the Section, including developing and executing management plans for assigned projects and evaluating and ensuring the effective use of Section staff and resources in achieving organizational goals. (S)he also develops and maintains effective liaison with officials in the scientific community; other federal, state, and local governments, and the private sector to represent Foundation and Division activities and interests and represents the Division on committees, boards, and panels in his/her areas of expertise.

Apply by emailing execsrch@nsf.gov

Geochemistry

Geochemistry Lab Manager

The Department of Geology and Environmental Earth Science at Miami University invites applications for a Geochemistry Lab Manager position. The Lab Manager will be expected to manage trace metal geochemistry, ICP-OES/MS and powder XRD labs. Duties will include training and supervision of lab users, laboratory maintenance, data quality assurance, assistance in teaching laboratory-based courses, oversight of radiation and environmental health and safety compliance, and laboratory financial management. Laboratory technique development and adaptation for analysis of diverse geologic and environmental materials expected, with opportunities to pursue research and external funding. Required: M.S. or Ph.D. in geology or related field, at least 4 years of experience in major and trace element analysis of geologic materials by plasma techniques at the time of the appointment, and proven experience in successful training and supervision of geochemistry lab users. Desired: experience in LA-ICP-MS, powder XRD and HPLC analysis; expertise in laboratory technique development, and electrical and mechanical abilities. Submit letter of application, curriculum vitae and unofficial copy of transcripts to http://jobs.miamioh.edu/cw/en-us/job/495595. Letters of reference will be requested upon receipt of application. Inquiries can be directed to Cathy Edwards at edwardca@miamioh.edu. Position not eligible for H-1B sponsorship. Review of applications will begin on September 2, 2019 and continue until position is filled.

Miami University, an Equal Opportunity/Affirmative Action employer, encourages applications from minorities, women, protected veterans and individuals with disabilities. Miami University prohibits harassment, discrimination and retaliation on the basis of sex/gender (including sexual harassment, sexual violence, sexual misconduct, domestic violence, dating violence, or stalking), race, color, religion, national origin (ancestry), disability, age (40 years or older), sexual orientation, gender identity, pregnancy, status as a parent or foster parent, military status, or veteran status in its recruitment, selection, and employment practices. Requests for all reasonable accommodations for disabilities related to employment should be directed to ADAFacultyStaff@miamioh.edu or 513-529-3560.

As part of the University's commitment to maintaining a healthy and safe living, learning, and working environment, we encourage you to read Miami University's Annual Security & Fire Safety Report at http://www.miamioh.edu/campus-safety/annual-report/index.html, which contains information about campus safety, crime statistics, and our drug and alcohol abuse and prevention program designed to prevent the unlawful possession, use, and distribution of drugs and alcohol on campus and at university events and activities. This report also contains information on programs and policies designed to prevent and address sexual violence, domestic violence, dating violence, and stalking. Each year, email notification of this website is made to all faculty, staff, and enrolled students. Written notification is also provided to prospective students and employees. Hard copies of the Annual Security & Fire Safety Report may be obtained from the Miami University Police Department at (513) 529-2225. Criminal background check required. All campuses are smoke- and tobacco-free.

Interdisciplinary

Assistant Professor (tenure track) of interactions between atmospheric and Earth surface processes

The Faculty of Geosciences and the Environment of the University of Lausanne invites applications for a

professorship on the interactions between atmospheric and Earth surface processes, to be based in the Institute of Earth Surface Dynamics.

We are looking for an atmospheric scientist in the broad fields of anthropogenic climate change, decadal and centennial-scale variability. We are particularly interested in candidates who can bring an understanding of local and regional climate impacts on Earth and Environmental processes, and the proxies used to study them. We seek someone who has a deep understanding of physical climate processes through modeling, observations and/or theory. This position is envisioned to bridge across emerging topics and expertise within the climate change dimension. Engagement in interdisciplinary projects with the social sciences and humanities is encouraged.

The successful candidate will actively participate in the research activities of the Institute of Earth Surface Dynamics, will teach in the Bachelor of Geosciences and Environment and Masters programs taught by the FGSE, and will supervise masters and doctoral students.

Appointment will be at the Assistant Professor level. However, exceptionally, we will consider outstanding candidates for direct appointment to the Associate or Ordinary Professor level, notably if this corresponds with our equal opportunity objectives. Application deadline: September 30th 2019

The application will be considered only if sent through this website where you find a full description of the position: https://bit.ly/32fBMXW or www.unil.ch/central/en/home.html -> Jobs -> search -> Atmospheric

Earth system modeling and carbon-climate-human system feedbacks researcher

Purpose

The Environmental Sciences Division at Oak Ridge National Laboratory in Oak Ridge, Tennessee seeks an established scientist to develop and lead Earth system modeling research efforts, with particular focus on improved understanding and prediction of carbon-climate feedbacks, human-climate interactions, and coupled Earth system-human system implications of climate policy decision scenarios.

You will leverage ORNL's world-class capabilities in Earth system model development, climate system feedback analysis, ecosystem-scale observation and experimentation, high performance computing, and data science to help answer pressing questions at the frontiers of climate change science, analysis of climate policy implications for coupled Earth system dynamics, and prediction of future ecosystem states in a changing climate system.

Qualifications

PhD in a relevant scientific discipline, and at least 8 years of employment post-PhD in a research-oriented position is required. Additional qualifications include a strong publication record showing significant impact in one or more relevant fields of research, and excellent communication skills. Experience with project management is desirable.

For questions please contact Dr. Peter Thornton (thorntonpe@ornl.gov).

To apply: https://jobs.ornl.gov/s/RApYsy

Benefits at ORNL: Benefits include a matching 401(k), contributory pension plan, paid vacation, and medical/dental plan options. Onsite amenities include a credit union, medical clinic, cafeteria, coffee stands, and fitness facilities.

For more information about our benefits, and working at ORNL, visit the "About" tab at jobs.ornl.gov.

ORNL is an equal opportunity employer. All qualified applicants, including individuals with disabilities and protected veterans, are encouraged to apply. UT-Battelle is an E-Verify employer.

Assistant Lecturer/Assistant Teaching Professor

The Department of Geology and Environmental Earth Science at Miami University invites applications for a full-time Assistant Lecturer or Assistant Teaching Professor position on the Oxford campus, beginning August 2020. The Assistant Lecturer/Assistant Teaching Professor will teach undergraduate courses, including foundation courses in physical and environmental geology, as well as intermediate level courses; advise undergraduate students; and provide professional service to the department and university. Required: M.S. in geoscience (for appointment as Assistant Lecturer) or Ph.D. in geoscience (for appointment as Assistant Teaching Professor) by time of appointment, and documented teaching experience; applicant must be a U.S. citizen, a lawful permanent resident, admitted for residence as an applicant under the 1986 immigration amnesty law, refugee or asylee. Desired: interest in contributing to supervision of undergraduate student research and field-based experiences. Submit letter of application, curriculum vitae, and evidence of teaching effectiveness to http://jobs.miamioh.edu/cw/en-us/job/495551. Letters of reference will be requested upon receipt of application. Inquiries can be directed to Cathy Edwards at edwardca@miamioh.edu. Review of applications will begin on October 2, 2019 and continue until position is filled.

Miami University, an Equal Opportunity/Affirmative Action employer, encourages applications from minorities, women, protected veterans and individuals with disabilities. Miami University prohibits harassment, discrimination and retaliation on the basis of sex/gender (including sexual harassment, sexual violence, sexual misconduct, domestic violence, dating violence, or stalking), race, color, religion, national origin (ancestry), disability, age (40 years or older), sexual orientation, gender identity, pregnancy, status as a parent or foster parent, military status, or veteran status in its recruitment, selection, and employment practices. Requests for all reasonable accommodations for disabilities related to employment should be directed to ADAFacultyStaff@miamioh.edu or 513-529-3560.

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Faculty Position in Paleontology

The Museum of Paleontology and the Department of Earth and Environmental Sciences at the University of Michigan are searching for a full-time tenure-track faculty candidate in the field of Paleontology at the assistant professor/assistant curator level. This is a university year appointment with an expected start date of September 1, 2020. The Museum of Paleontology has recently relocated its internationally significant collections of plant, invertebrate and vertebrate fossils to the

Swiss Federal Institute for Forest, Snow and Landscape Research WSL

The Swiss Federal Institute for Forest, Snow and Landscape Research WSL is part of the ETH Domain. It employs approximately 500 people working on the sustainable use and protection of the landscapes and habitats and a responsible approach to handling natural hazards. Please find further information on our homepage **www.wsl.ch.**

To facilitate international collaboration we invite up to 6 scientists a year to join the thriving community of research scientists in Birmensdorf, Davos, Lausanne or Cadenazzo as a

Visiting Fellow in Switzerland

Photo: Markus Bolliger

You will work in innovative interdisciplinary science projects with collaborators of WSL and make significant contributions to the advancement of environment research. Furthermore, you will connect with, work with, or learn from world-class researchers across many scientific disciplines and contribute to critical environmental research that can improve lives and decisions.

You are faculty on leave or sabbatical, or research scientists on leave. You will get financial support to help cover additional costs while staying at WSL. Your application needs to be accompanied by a letter of support of one of our research units. For detailed information please consult your colleagues at WSL as well as the respective fact sheet you can get from them.

Please send your complete application online to Human Resources WSL on www.wsl.ch/fellowship. Deadline for applications is 31 October 2019. Fellowships can start as early as summer 2020.

new Research Museums Center. Paleontology faculty labs and offices are in the newly completed Biological Sciences Building, which houses other academic units and the Museum of Natural History which attracts over 165,000 visitors a year.

We seek applicants who have broad research and teaching interests within developing areas of evolutionary or environmental paleontology. We are especially interested in applicants investigating the invertebrate fossil record, although exceptional candidates with other areas of taxonomic expertise will be considered. The Museum and Department invite applicants in fields including, but not restricted to: macroevolution, interactions of developmental biology and evolution, extinction dynamics, paleoecology, organismal paleobiology, and biotic responses to global change.

The successful candidate is expected to establish an externally funded research program and contribute to excellence in undergraduate and graduate teaching. Applicants must have a Ph.D. at the time of appointment and should submit the following: 1) cover letter; 2) CV; 3) statement of current and future research plans; 4) statement of teaching philosophy and experience; 5) evidence of teaching excellence, if available; 6) statement of activities contributing to diversity, equity, and inclusion in academia; 7) up to four publications; and 8) the names and contact information for at least four references.

Information about the Museum and Department can be found at www.lsa.umich.edu/paleontology and www.lsa.umich.edu/earth. To apply please go to https://ummp-earth.lsa.umich.edu/search19/, complete the online form, and upload the required application documents as a single PDF file. If you have any questions or comments, please send an email message to ummp-earth-search@umich.edu.

The application deadline is August 31, 2019 for full consideration with on-campus interviews beginning January 2020, but applications will continue to be reviewed until the position is filled.

The University of Michigan is supportive of the needs of dual career couples and is an Affirmative Action/Equal Opportunity Employer. Women and members of minority groups are encouraged to apply.

Postdoctoral Position: Seasonal to decadal climate variability, predictability and change

The Atmospheric and Oceanic Sciences Program at Princeton University, in association with NOAA's Geophysical Fluid Dynamics Laboratory (GFDL), seeks a postdoctoral or more senior scientist for research related to seasonal to decadal climate variability, predictability and change. The research will make extensive use of both observations and a variety of modeling tools, including the latest generation of GFDL climate models. The selected candidate will engage in research in one or more of the following areas: (1) research to explore predictability of the climate system on seasonal to decadal time scales, including climate extremes with an emphasis on hydroclimate;
(2) research to better understand the mechanisms of climate variability and predictability, including interactions among the ocean, land, and atmosphere, the role of the stratosphere, and the impact of radiatively forced climate change on variability and predictability; (3) research to improve initialization systems for climate prediction and to assess the connection between initialization systems and skill on seasonal to decadal time scales. Candidates wishing to focus on a specific timescale (seasonal, multiannual, decadal) will also be considered.

The selected candidate will have one or more of the following attributes: (a) a strong background in climate dynamics or a closely related field, (b) experience using and analyzing climate models, and (c) strong diagnostic skills in analyzing large data sets.

Candidates must have a Ph.D. in Atmospheric Science, Oceanography, or a closely related field. The initial appointment is for one year with the possibility of renewal subject to satisfactory performance and available funding.

Complete applications, including a CV, publication list, and 3 letters of recommendation should be submitted by September 30, 2019 for full consideration. Applicants should apply online to http://jobs.princeton.edu/acad-positions/position/12364. For additional information, contact Tom Delworth (tom.delworth@noaa.gov) or Sarah Kapnick (sarah.kapnick@noaa.gov).

This position is subject to the University's background check policy.

Princeton University is an equal opportunity employer and all qualified applicants will receive consideration for employment without regard to race, color, religion, sex, national origin, disability status, protected veteran status, or any other characteristic protected by law.

Director, Electron Microbeam Laboratory, University of Wisconsin-Madison

The Department of Geoscience at the University of Wisconsin-Madison invites applications at the Assistant, Associate, or Senior Scientist level to fill the Director's position in the Eugene Cameron Electron Microprobe Laboratory (http://www.geology.wisc.edu/~johnf/sx51.html). This is a full-time, institutionally-supported position with competitive salary. The lab houses SX51 and SX5FE electron microprobes, a Hitachi S3400 VP scanning electron microscope, and a lab manager to assist with SEM maintenance and operations. The lab serves as a hub for interdisciplinary scientific inquiry, providing hands-on training of students from disciplines across campus. Additional departmental resources include two electronics engineers and a staffed thin-section lab. Applicants should hold a Ph.D. in Earth Sciences, Chemistry, Physics, Material Science, or related fields at time of appointment. Demonstrated ability and experience in the use of electron beam instruments for high-quality, quantitative analyses is required. Two or more years of daily hands-on management of an electron microprobe lab is preferred, as is demonstrated ability to pursue fundable research using electron microbeam instrumentation. Applicants should submit the following: (1) cover letter that includes your research statement, (2) curriculum vitae, and (3) the names and contact information for three referees. Please apply by October 15, 2019 to guarantee full consideration, although applications will continue to be accepted until the position is filled. For more information and to apply, go to: https://jobs.hr.wisc.edu/en-us/job/502003/epma-lab-director.

Ocean Sciences

Oceanography Tenure-Track Faculty

Data Science in Oceanography spans disciplines from climate science to molecular biology. Its integration into Oceanography has the potential to change conventional research approaches by combining emerging data analytics technology with high-resolution and multidisciplinary ocean-related datasets. We seek an interdisciplinary early career scholar with a record of active research and publication in the area of Ocean Data Science to join the Department of Oceanography at Texas A&M University at the rank of tenure-track Assistant Professor. We expect this individual to play an active role in strengthening our existing interdisciplinary research programs by nucleating new research initiatives that utilize data analytics, information processing, and/or high performance computing to address problems in Oceanographic research. In addition to collaborations within the Department of Oceanography, the newly established Texas A&M Institute of Data Science (TAMIDS) (https://tamids.tamu.edu) provides an excellent platform to launch new Data Science related research collaborations. We welcome applicants with any disciplinary specialty in Ocean Data Science application and technology, including biological oceanography, ocean remote sensing, ocean and climate modeling, and others.

Applicants should have a Ph.D. (or equivalent) and at least 5 years of research experience in Ocean Data Science application and technology. Candidates for this position should submit a letter of application, curriculum vitae, and the names of three confidential references to http://apply.interfolio.com/62774. Review of applications will begin on September 1, 2019 and continue until the position is filled.

The Department of Oceanography at Texas A&M University, located in College Station, Texas is part of an alliance of Ocean Sciences that includes the Marine Biology and Marine Sciences Departments at TAMU Galveston, the Geochemical and Environmental Research Group, the International Ocean Discovery Program, and Texas Sea Grant. This alliance of Ocean Sciences represents a unique concentration of educational and research resources. The capacity is greatly enhanced by close ties to the College of Geosciences Departments of Atmospheric Sciences, Geography, and Geology & Geophysics, as well as the Berg Hughes Center, the Texas Center for Climate Studies and the International Laboratory for High-Resolution Earth System Prediction. The Department web site http://ocean.tamu.edu contains a full description of our program.

Texas A&M University is committed to enriching the learning and working environment for all visitors, students, faculty, and staff by promoting a culture that embraces inclusion, diversity, equity, and accountability. Diverse perspectives, talents, and identities are vital to accomplishing our mission and living our core values.

The Texas A&M System is an Equal Opportunity/Affirmative Action/Veterans/Disability Employer committed to diversity.

Questions regarding this position should be directed to the committee chair: Dr. Ping Chang at: ping@geos.tamu.edu.

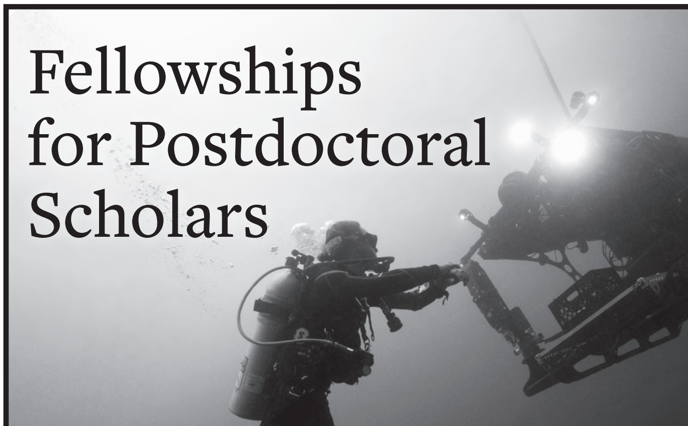
Planetary Sciences

Assistant Professor–Earth & Planetary Science–College of Letters & Science

The Department of Earth and Planetary Science at the University of California, Berkeley invites applications for an Assistant Professor faculty position with an expected start date of July 1, 2020. We seek outstanding candidates from any area of Earth and planetary science. Candidates whose research falls into this broad range of disciplines are invited to apply. For more information about the position, including required qualifications and application materials go to: https://apptrkr.com/1553365

The application deadline in October 30, 2019. For questions, please contact Erin Blazick, AP HR analyst at academicpersonnel4eps@berkeley.edu. UC Berkeley is an AA/EEO employer.

Fellowships for Postdoctoral Scholars



Woods Hole Oceanographic Institution

New or recent doctoral recipients with research interests associated with the following are encouraged to submit scholarship applications prior to October 15, 2019.

DEPARTMENTS - Awards related to the following areas are anticipated: Applied Ocean Physics & Engineering; Biology; Geology & Geophysics; Marine Chemistry & Geochemistry; Physical Oceanography. Interdepartmental research, including with the Marine Policy Center, is also encouraged.

A JOINT USGS/WHOI award will be given to a postdoc whose research is in an area of common interest between WHOI Scientific Staff and the USGS laboratory located on the WHOI campus. The individual will interact with both USGS and WHOI based advisors on their research.

THE OCEAN BOTTOM SEISMOGRAPH INSTRUMENT CENTER (OBSIC) will award a fellowship for research on the earth's internal structure and its dynamic processes using seafloor seismic measurements. Research areas include: seafloor seismic instrumentation; earth structure emphasizing the use of ocean-bottom seismograph data; earthquake-related processes using seafloor seismology and/or geodesy; interplay between seafloor seismic measurements and oceanographic processes; and other projects within this scope.

Awards are competitive, with primary emphasis placed on research promise. Scholarships are 18-months with an annual stipend of $61,200, a health and welfare allowance and a research budget. Recipients are encouraged to pursue their own research interest in association with resident staff. Communication with potential WHOI advisors prior to submitting an application is encouraged. Awards will be announced by December. Recipients of awards can initiate their study and research period at the Institution any time after January 1 and before December 1, 2020.

Further information may be obtained at:

www.whoi.edu/postdoctoral

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WOODS HOLE OCEANOGRAPHIC INSTITUTION 1930

Dear AGU:

The Luquillo Experimental Forest in Puerto Rico is rapidly recovering from the devastation of Hurricane Maria. Although the upper canopy remains broken, the greater openness has led to a very lush understory. But the interest of our group from the Oak Ridge National Laboratory is in what's happening below the surface.

Armed with soil-coring equipment, (from left to right) Daniela Yaffar, Nate Stenson, Joanne Childs, and Kristine Cabugao (with Rich Norby behind the camera) collected soil and roots down to 1 meter at four sites that vary in their phosphorus fertility. Our goal is to collect data on the root–soil–phosphorus interface as a function of depth to inform an Earth system model. We all got plenty dirty, but the reward was being able to cool off in the ocean nearby.

—**Rich Norby,** Oak Ridge National Laboratory, Oak Ridge, Tenn.

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