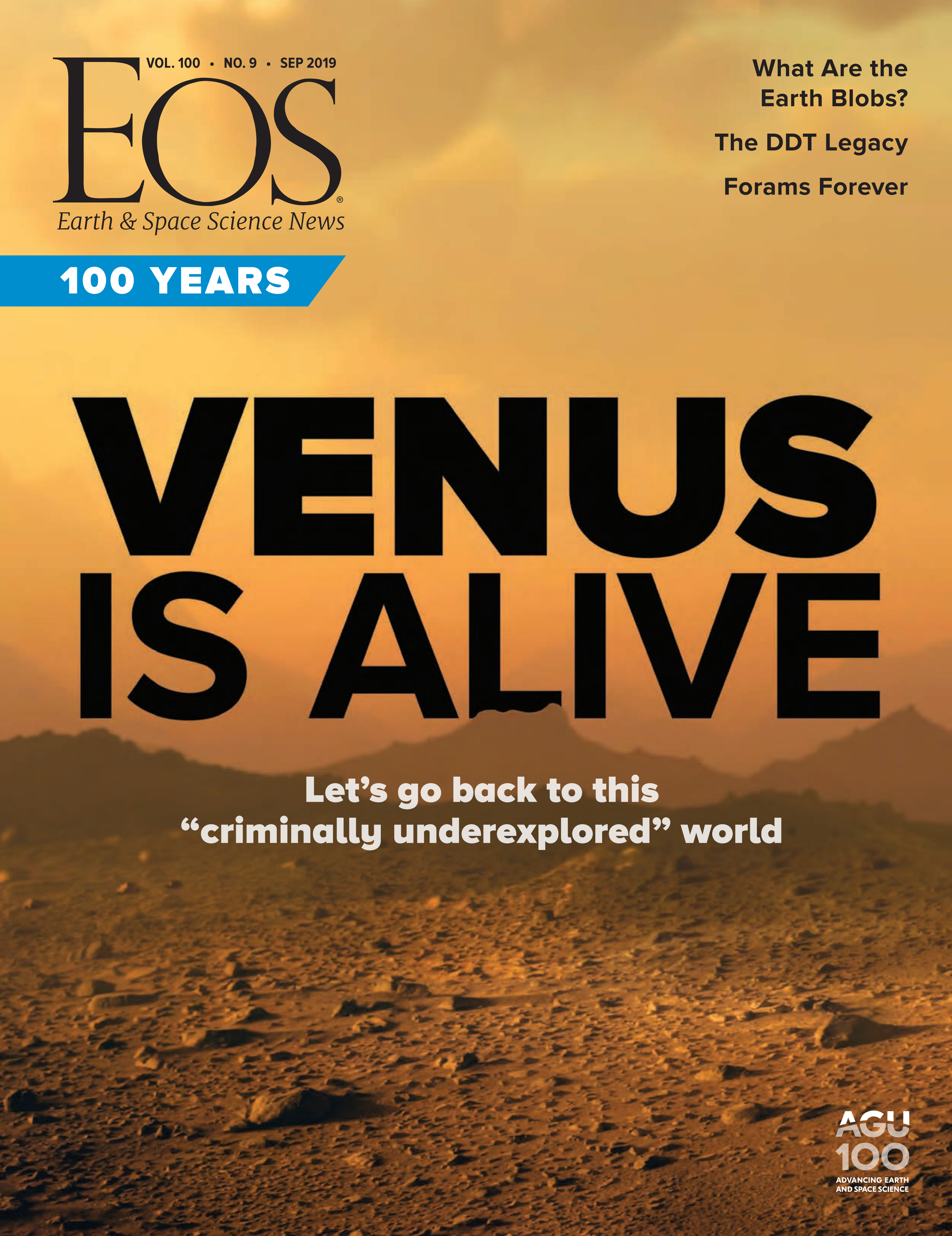


VOL. 100 • NO. 9 • SEP 2019

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

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.

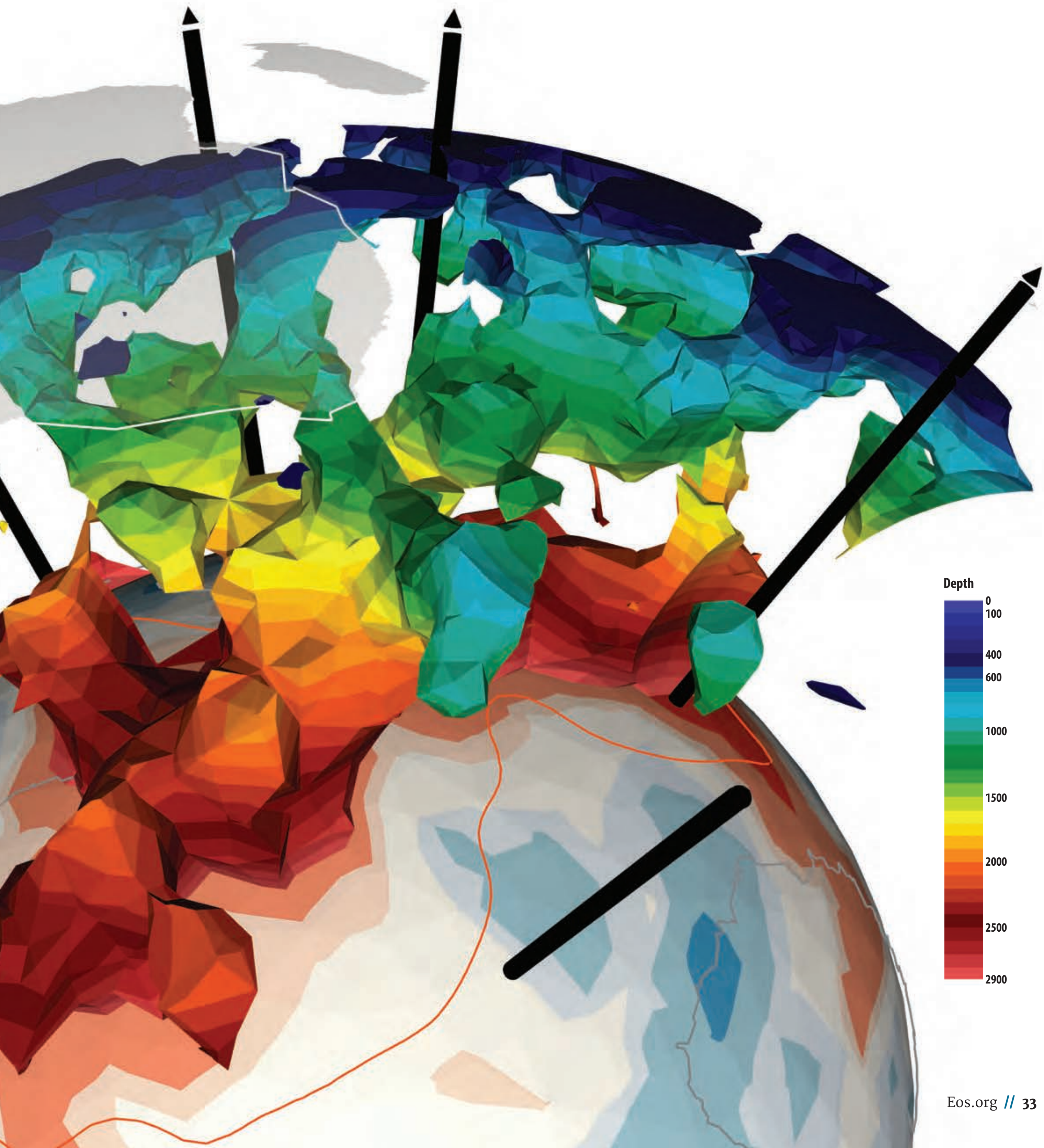
Scientists first spotted the blobs in the late 1970s. Researchers had just invented a new way to peer inside Earth: seismic tomography. When an earthquake shakes the planet, it releases waves of energy in all directions. Scientists track those waves when they reach the surface and calculate where they 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.

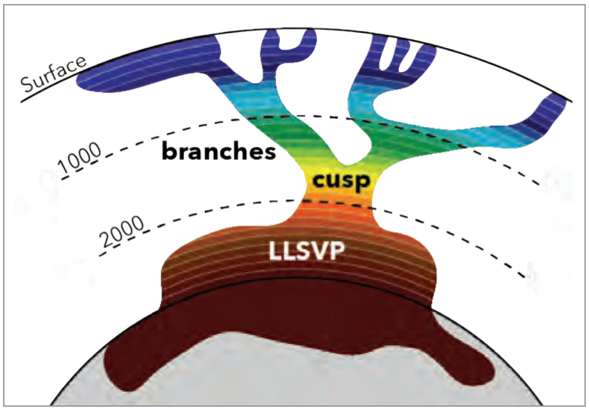
"Ultimately, a lot of people believe plate tectonics are one of the reasons why we have life on Earth," said geophysicist Harriet Lau at University of California, Berkeley. Scientists believe these blobs play a role in many of the processes of the deep Earth, including plate tectonics and volcanism.

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-

EOS CENTENNIAL COLLECTION

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].

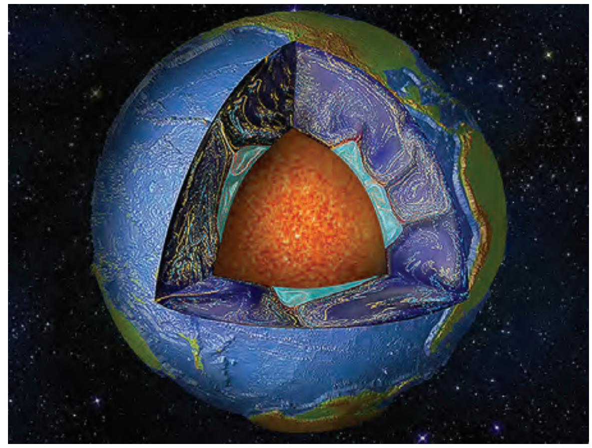
Meanwhile, another study suggested the opposite of what Lau's study found [*Koelemeijer et al.,* 2017]. Koelemeijer began studying normal mode oscillations as a graduate student in 2009. "At the time, not many people were using them," she said. Normal modes provide a powerful way to study the Earth, 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 about this seeming contradiction," she said. The results simply help them "fine-tune" their conclusions, she said.



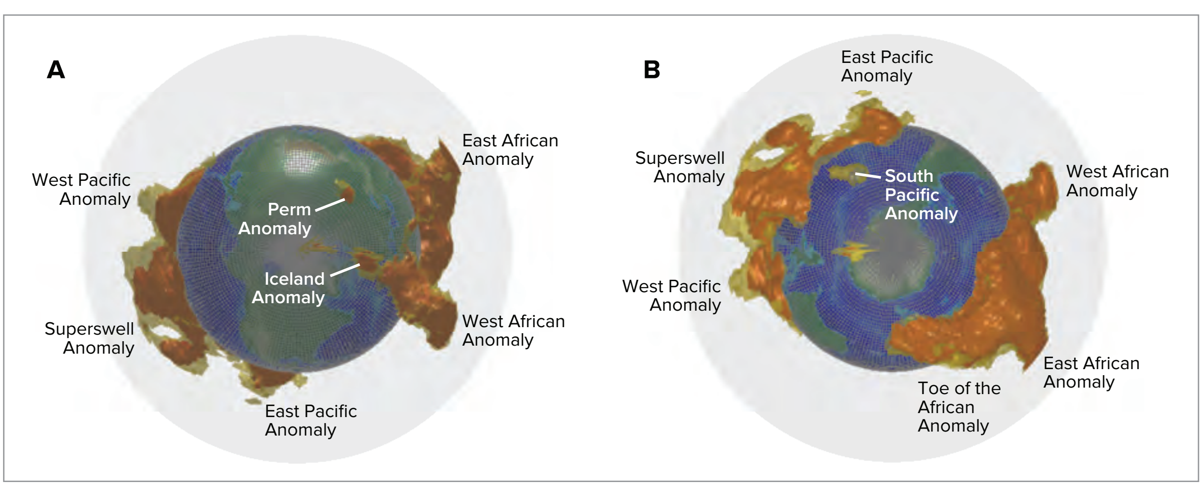
What lies below? A cutaway view of Earth down to the liquid core shows the swirling mantle rock (dark blue). Made from a numerical convection model, the image shows mysterious structures underneath the Pacific Ocean that some researchers believe hold the clue to unlocking mysteries of Earth's past (light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

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.

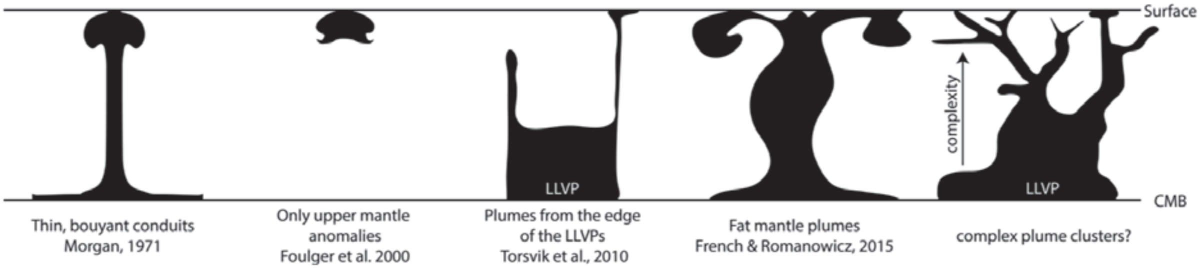
In seismic tomography, researchers deal with similar problems. The blobs received their nickname partly because of their soft, lumplike shape in seismic tomography maps. But what if their structure were actually more delicate? And could knowing the shape of the blobs better help researchers constrain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