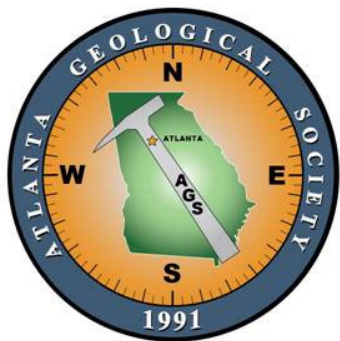




Atlanta Geological Society Newsletter

ODDS AND ENDS

Dear AGS members,

The Truth, as we know it now. I ran across this phrase recently. It went on to expand the idea that what we know is the truth is not permanent, soon to have be upended by new irrefutable developments or better science. Into my news feed comes this animation about tectonic movements going forward 250M years. Guess what? Gondwana is reunited but what caught my eye was that Baja and the Gulf of California didn't move. Wasn't Los Angeles supposed to move across from Oakland eventually? Then in my newsfeed comes this story from the May issue of Wired magazine about the Walker Lane seismic zone. It starts in the south near the Salton Sea but then goes more northerly up towards Reno bringing in hot springs, young volcanoes and various other indications of a seismic zone. This geologic connect the dots game is the favorite theory of James Faulds, the Nevada State Geologist, another boomer geologist crisscrossing his state looking for a theme for the outcrops he sees. Here I thought the San Andreas fault was the truth but here comes this other theory that could also be the truth, revised. Referenced in the article is a book called Timefulness which says: "To think geologically is to hold in the mind's eye not only what is visible at the surface but also present in the subsurface, what has been and will be." Maybe I'll mull that over that next month. Hope to see you on the 30th.

Ben Bentkowski, President

April Meeting

Join us **Tuesday, April 30, 2019** at the Fernbank Museum of Natural History, 760 Clifton Road NE, Atlanta GA. The social starts at 6:30 pm and the meeting starts approximately at 7:00 p.m.

This month out presentation is **"Geology of the Isle of Skye Scotland"** presented by Ben Bentkowski P.G. Please find more information about the presentation and Mr. Bentkowski's bio on the next page.

Please come out, enjoy a bite to eat, the camaraderie, an interesting presentation and perhaps some discussion on the importance of accurate mineral characterization.

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Atlanta Geological Society March Speaker

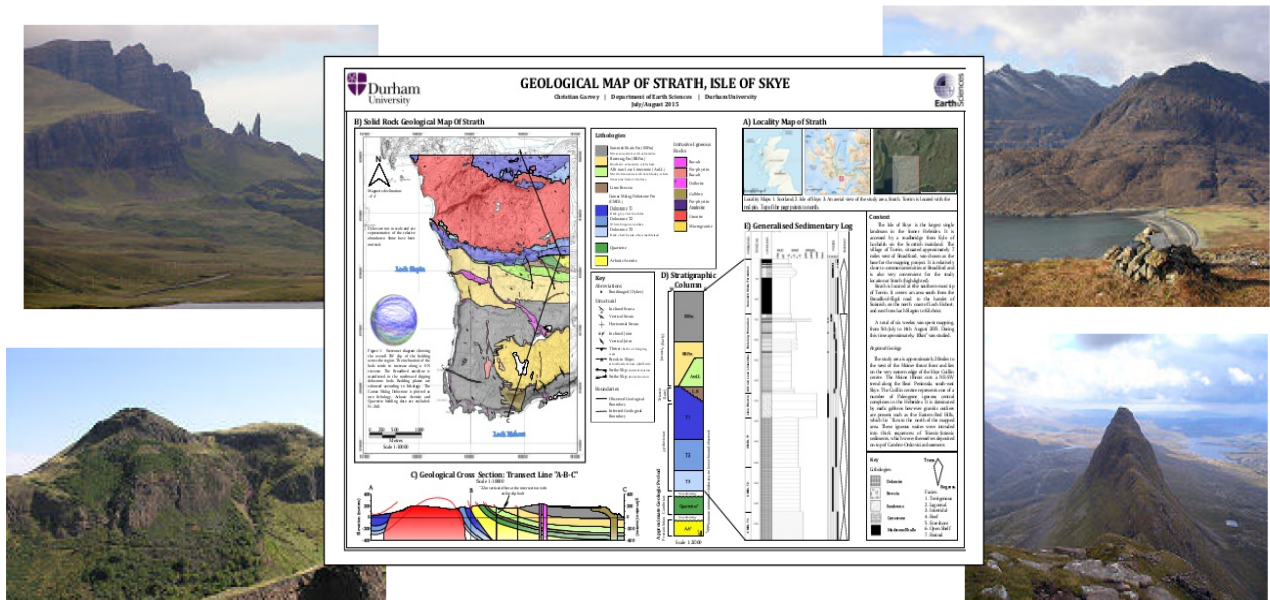
“Geology of the Isle of Skye Scotland”

Speaker Ben Bentkowski's Biography:

Ben Bentkowski is a senior hydrogeologist at the Region 4 office of the Environmental Protection Agency. He is a registered professional geologist in Georgian and a member of the Board of Registration. He is currently serving as the president of the Atlanta Geological Society and enjoys the intertwining of geological exploration and vacations. BS in Geology, Florida Atlantic University and MS in Geology from Oklahoma State University.

Abstract:

The Isle of Skye is part of the Inner Hebrides located along the west coast of Scotland. The oldest rocks exposed are Lewisian gneisses 2,800 million years old. Jurassic limestones are exposed primarily along the coastline and can be quite fossiliferous. The predominate rock type at the surface is the upper part of the igneous rocks associated with the considerable lava flows from the Cullin volcano located on the south end of the island. One reference suggests that there were 24 separate flows of lava, accumulating to between 2-3,000 feet thick. The final main event of the geologic history of Skye is the repeated glaciation during the Ice Ages. These events left the biggest imprint in the scenery visible today, including the largest landslide(landslip) in the British Isles. Structurally, the southern portion of Skye has among the earliest thrust faults identified associated with the Caledonian Orogeny, 435 mya, (a.k.a. Appalachian orogeny) which has a very distant familial connection to the speaker.





Shadowy First Image of Black Hole Revealed

Two decades ago, Eric Agol, an astronomer at the University of Washington in Seattle, first modeled how a black hole's intense gravity would bend light around it to form a perfectly circular shadow. Last week, when the Event Horizon Telescope (EHT) team revealed in simultaneous press conferences across six countries that it had succeeded in its mission to image such a black hole shadow for the first time, Agol happened to be on a plane. "I missed that emotional moment," he says regretfully. But he nevertheless feels pride in helping kick-start the quest. "It's remarkable how similar it looks to simulations," he says.

A lack of surprises didn't stop the image from grabbing headlines and gracing screens around the world. In it, a fuzzy ring of light surrounds the black hole at the heart of Messier 87 (M87), a giant galaxy 53 million light-years from Earth. Now, the EHT team is eager to sharpen its pictures. That could help it test the predictions of Albert Einstein's theory of gravity, general relativity, and understand the physics of how black holes feast on the matter that swirls around them and launch powerful jets that can be seen from across the universe. "EHT has taken a big step but more steps are possible," says astronomer Roger Blandford of Stanford University in Palo Alto, California.

Although few doubt the existence of black holes, seeing one was an immense challenge. Black holes are so massive that even light cannot escape their gravity. They are defined by a black spherical shell called an event horizon. In 2000, Agol and his colleagues predicted that the shadow of an event horizon could be seen against the light from hot gas whipped up by the black hole.

From that prediction grew the EHT team, with 200 astronomers from 13 institutions around the world. They observed the nearby galaxy's black hole, known as M87*, over 5 nights in April 2017, using eight radio telescopes sensitive to millimeter wavelengths that can penetrate the haze of dust and gas around galactic centers. M87* holds the mass of 6.5 billion suns, yet its event horizon is only slightly larger than our solar system—tiny by cosmic standards.

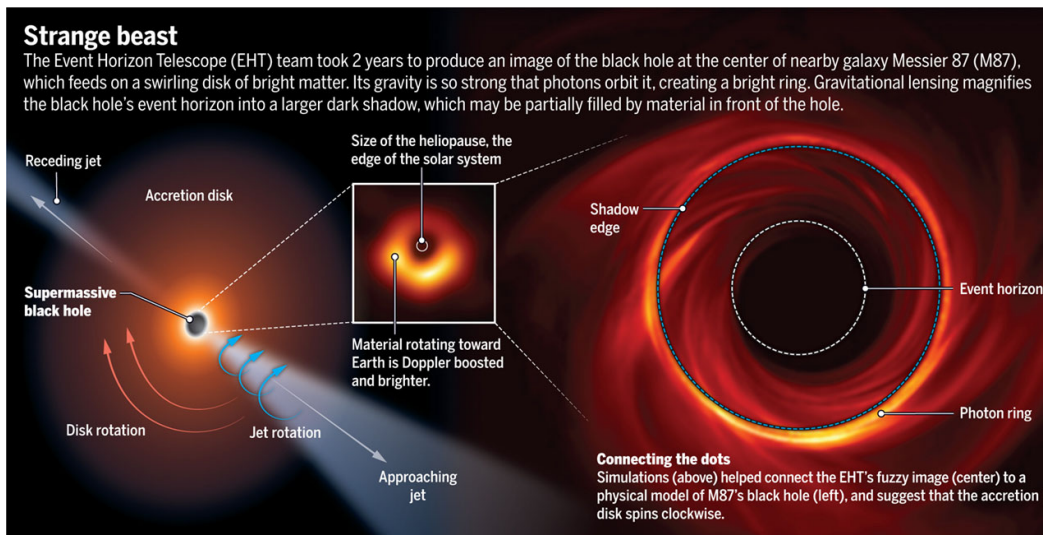
No single telescope could see such a distant object, so the EHT banded globe-spanning radio telescopes into a virtual telescope the size of Earth using a process called very-long-baseline interferometry. In 2017, the team had enough dishes to make a go at imaging M87*. "There were weather and technical concerns," says Feryal Özel of the University of Arizona in Tucson, but her team got lucky and it turned out to be "one of the smoothest parts of the project."

After 2 years of data processing, the EHT revealed the black hole's shadow. If Einstein's theory holds sway, it should be a perfect circle, independent of the surrounding gas disk or how it moves, says EHT project scientist Dimitrios Psaltis at the University of Arizona. "If it is noncircular, it has to be something wrong with general relativity," Psaltis says. With the current data, the shadow is circular to within 10%, the team reported last week in a series of six papers in *Astrophysical Journal Letters*. The EHT team knows it has to do better: It was a deviation of less than 1% in Mercury's orbit, detected in the 19th century, that doomed Newtonian gravity. "It's not a test of general relativity yet," says Michael Kramer of the Max Planck Institute for Radio Astronomy in Bonn, Germany. "We need better image quality."

A priority for the EHT team is imaging the other black hole shadow within range: the one at the center of the Milky Way, known as Sagittarius A* (Sgr A*). At 4 million times the sun's mass, it's much smaller than M87*, but also much closer, so it appears roughly the same size on the sky. The EHT took data on Sgr A* in 2017, but focused on M87* as the easier job. Sgr A* is more challenging because it must be viewed through the gas and dust in the Milky Way's disk. Also, being smaller, the material swirling around the black hole



Shadowy First Image of Black Hole Revealed (Continued)



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Another near-term goal is to measure the polarization of light from electrons twirling around magnetic field lines in material close to the black hole. By observing the polarization, astronomers can map the magnetic fields and try to discern what is powering the jets. If the fields are orderly, the accretion disk could be responsible for funneling material to the jets. If the fields are chaotic, they may only heat up the swirling gases—and the black hole could be the jets' engine. “The jets are coming from very close in, but are they driven by the spin of the black hole or by the swirling gases around it?” Blandford asks. “There could well be surprises in store for us.”

To answer such questions, the EHT team plans to add to its array. The recently installed Greenland Telescope at Thule Air Base will help in observations of M87*, which is in the northern sky. An enlargement of the Plateau de Bure telescope array in the French Alps will soon be up and running, and there are plans to move a dish from Chile to Namibia to create an African millimeter telescope. They also plan to observe at shorter wavelengths to reduce the glare of the surrounding gas and sharpen pictures of the shadow.

Improving pictures much more will require a telescope bigger than Earth. Last week, the day before the M87* image was released, a group of astronomers including EHT members published a proposal for an Event Horizon Imager, a constellation of three orbiting radio telescopes. It could image Sgr A* in exquisite detail in a matter of months. “It's going to be a challenge but is a reasonable thing to take on,” Blandford says.

Read more about this article at: <https://science.sciencemag.org/content/364/6437/217>

Space Ripples May Untangle Black Hole Tango

Physicists working with the Laser Interferometer Gravitational-Wave Observatory (LIGO) have spotted a third merger of black holes, the ultra-intense gravitational fields left behind when massive stars collapse. This time, the subtle tremor of spacetime that signaled the merger also revealed a key feature of the black holes: their spins, which were out of kilter. That could help reveal how the black holes paired up in the first place.

“These black holes are not like two aligned tornadoes orbiting each other, but like two tilted tornadoes,” says



Space Ripples May Untangle Black Hole Tango (Continued)

Laura Cadonati, a physicist at the Georgia Institute of Technology in Atlanta and deputy spokesperson for the 1000 scientists working with LIGO. “That may have implications for formation scenarios.”

In September 2015, the gigantic LIGO detectors in Livingston, Louisiana, and Hanford, Washington, sensed gravitational waves from two black holes weighing 29 and 36 times as much as the sun as they spiraled together and became one (*Science*, 12 February 2016, p. 645). Three months later, the detectors spotted a merger of lighter black holes. How such stellar-mass black holes form is no mystery: Each starts out as a huge star. It eventually runs low on hydrogen fuel and puffs up into a giant. A few hundred million years later, nuclear fusion in its core can no longer fight gravity, and it collapses into a black hole, typically generating a supernova explosion.

But theorists struggle to explain how such black holes could form pairs. “Whatever you cook up, it has to fulfill two things,” says Selma de Mink, an astrophysicist at the University of Amsterdam. “It has to make two massive black holes, and they have to be close enough” to merge within the age of the universe. A pair of black holes could be born from massive stars that collapse while orbiting each other. Or the black holes could form first and pair later. But either scenario is trickier than it sounds.

Giant binary stars, for example, typically produce black holes lighter than the ones LIGO sees and too far apart to merge. So, according to one leading theory, the stars must start out close enough together to swap matter as they evolve. When one star collapses, the resulting black hole and the other star wind up swirling through a “common envelope” of gas—literally the outer layer of the star. Friction then saps their energy and draws them closer together. The collapse of the second star leaves two black holes in a tight orbit. However, some researchers say this common envelope scenario requires more “fine tuning” than they like.

Alternatively, black holes could form first and hook up later. When two wandering black holes cross paths in space, however, they just swing around each other and go their separate ways. To form a pair, a least one other stellar object must join in the process in a so-called dynamical formation channel, says Carl Rodriguez, an astrophysicist at the Massachusetts Institute of Technology (MIT) in Cambridge.

For example, two binaries consisting of a star and a black hole could meet. In a complicated exchange, the black holes could pair, while throwing out the stars. Then encounters with other stars could siphon off more energy and angular momentum and pull the black holes closer. Modeling shows that such encounters could take place in dense star clusters. But some researchers question whether the clusters can produce as many black hole pairs as LIGO seems to see.

How two black holes paired should show through in their spins. If the black holes started out as paired stars, then they should spin in the same direction as their orbital axis. If the black holes formed before they paired, then they could spin in any direction. “If the black holes were not spinning in the same direction as the orbit, that would probably be a pretty good indicator of the dynamical formation channel,” Rodriguez says.

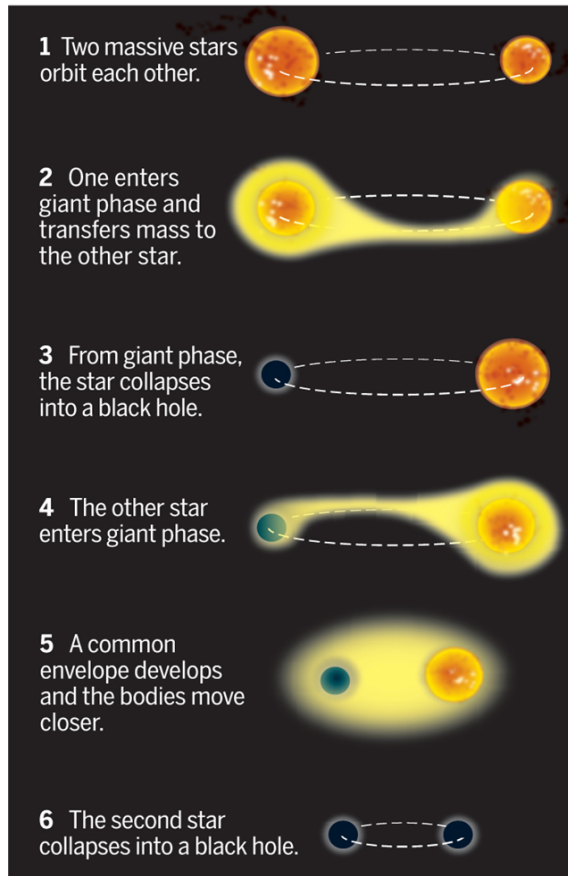
On 4 January, LIGO spotted black holes of 31 and 19 solar masses spiraling together 3 billion light-years from Earth. By comparing the second-long ripple picked up by the detectors with previously calculated “waveforms,” the LIGO team determined how closely the black holes' spins aligned with their orbital axis. Black holes with randomly aligned spins merge relatively quickly, Cadonati explains. But if the spins are aligned with the orbital axis, the extra angular momentum slows the merger, stretching it out a few more orbits. (Similar analyses of the previous events were ambiguous.)



Space Ripples May Untangle Black Hole Tango (Continued)

Dancing in the dark

One leading scenario for forming tightly orbiting black holes starts with a pair of massive stars already orbiting each other. A “common envelope” of material drags the bodies into a closer orbit.



LIGO researchers found that the black hole spins were not aligned, and that there's an 80% probability that at least one of them spun in generally the opposite sense of the orbital motion. In this case, at least, the dynamical pairing scenario seems more likely.

With just one event to go on, it's too early to say which scenario is more common overall, Cadonati says. “We are going to have to see more of these things in order to constrain models,” she says. Seeing enough of them may take time. LIGO will end its current run in August, says David Shoemaker, a physicist at MIT and spokesperson for the LIGO scientific collaboration. Researchers will then spend 12 to 18 months trying to boost the machines' sensitivity, which has improved only slightly since the 2015–16 run.

Read more about this article at:

<https://science.sciencemag.org/content/356/6341/895?intcmp=trendmd-sci>

LIGO Detects Another Black Hole Crash

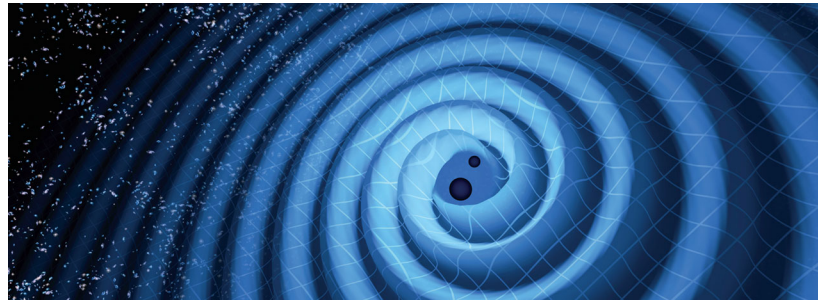
The biggest discovery in science in 2016—the observation of ripples in space-time called gravitational waves—was no fluke. For a second time, physicists working with the two massive detectors in the Laser Interferometer Gravitational-Wave Observatory (LIGO) have detected a pulse of such waves, the LIGO team reported on June 15 at a meeting of the American Astronomical Society in San Diego, California. Once again, the waves emanated from the merger of two black holes, the ultra-intense gravitational fields left behind when massive stars collapse into infinitesimal points. The new observation suggests that after fine-tuning, LIGO will spot dozens or even hundreds of the otherwise undetectable events each year.

“It's very reassuring,” says Gabriela González, a physicist at Louisiana State University, Baton Rouge, and chair of the 1000-member LIGO Scientific Collaboration. “You need another one to be completely convinced and this is it.” Cole Miller, an astrophysicist at the University of Maryland, College Park, who is not a member



LIGO Detects Another Black Hole Crash (Continued)

of the collaboration, says that the new find shows that LIGO “is genuinely a new window on the universe.” Astrophysicists' catalog of stellar-mass black holes, he says, “is going to be overwhelmingly increased by LIGO.”



On 26 December 2015, LIGO detected gravitational waves from two black holes spiraling together.

The new observation came at 3:38.53 Coordinated Universal Time on 26 December 2015—late on Christmas day at LIGO's detectors in Livingston, Louisiana, and Hanford, Washington. As in the first event, the detectors sensed an oscillating stretching of spacetime, the signal, according to Einstein's general theory of relativity, of massive objects in violent motion. Computer modeling indicated that its source was two black holes spiraling together about 1.4 billion light-years away. (LIGO researchers had seen a weaker signal on 12 October 2015 that may be a third black hole merger.)

The first signal LIGO spied, recorded in September 2015 and unveiled to the world in February (*Science*, 12 February, p. 645), emanated from surprisingly heavy black holes, with masses 36 and 29 times that of the sun. It lasted only 0.2 seconds, and physicists glimpsed only the last 10 cycles of the black holes' spiraling motion before their collision. The December 2015 sighting involved smaller black holes, 14 and 7.5 times as heavy as the sun. Physicists witnessed 55 cycles of the death spiral, a full second.

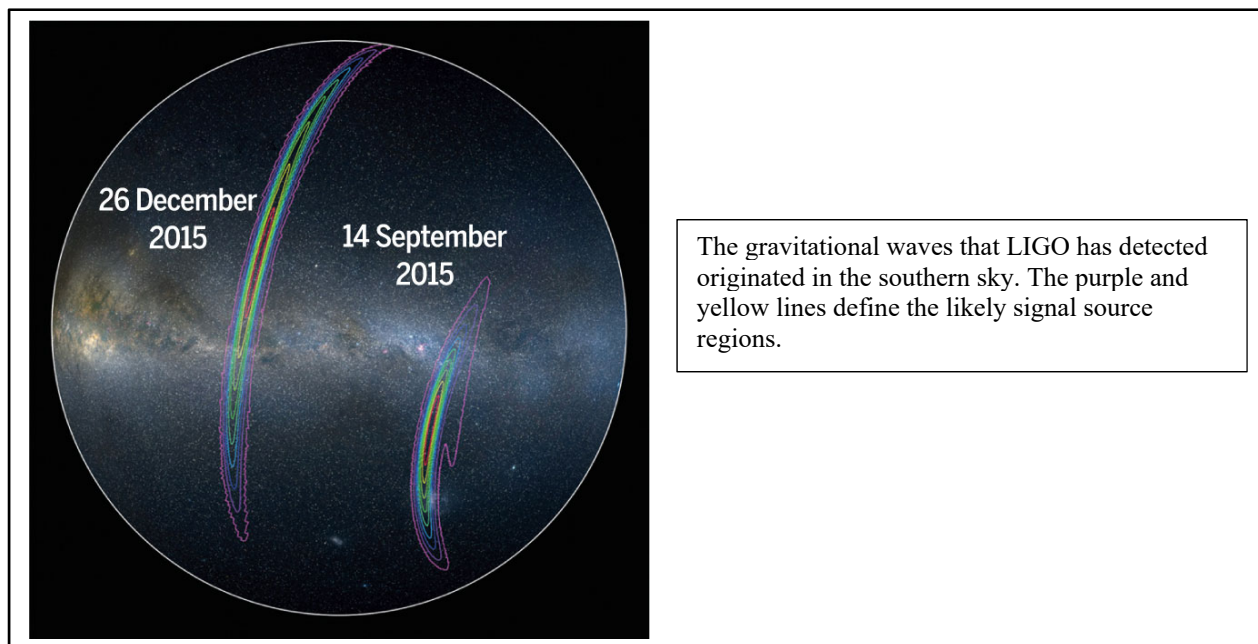
The first observation remains a riddle. Those two black holes were twice as massive as the relatively nearby stellar-mass black holes identified from the x-rays emitted by hot gas swirling into them. Astrophysicists don't know how such jumbo black holes formed. The black holes in the new event “are much more garden variety,” says Sebastian Heinz, an astrophysicist at the University of Wisconsin, Madison.

Nevertheless, the latest event yields new insights. For example, physicists determined that one of the black holes was spinning frenetically, at roughly 20% of the maximum spin rate allowed by general relativity. And because the new event includes many more cycles, it tests predictions of general relativity somewhat more stringently than the first event, González says. (Einstein's theory passes the test.)

Most important, the second observation shows that going forward, LIGO should reap a vast harvest of black hole mergers. Rebuilt from 2010 to 2015, the new LIGO detectors have not yet reached their design sensitivity. If they do, they should see as many as one black hole merger per day, estimates Stephen Fairhurst, a gravitational-wave astrophysicist and LIGO team member at Cardiff University in the United Kingdom. The resulting sample should lay bare the mysterious evolution of black hole binaries, he says, showing whether they start out as pairs of stars that turn into black holes or as black holes that form independently and ultimately find each other.



LIGO Detects Another Black Hole Crash (Continued)



Reaching the design sensitivity—a factor of 2.5 better than today's—is a challenge, as the instruments currently suffer from a “mystery noise” at low frequencies. David Reitze, LIGO's executive director at the California Institute of Technology in Pasadena, says he's cautiously optimistic that physicists can eliminate the noise and reach design sensitivity by 2019. “I won't say with 100% confidence that we will get there, but I won't say that we won't either,” he says.

Physicists hope LIGO will eventually detect waves from other kinds of cosmic collisions. Mergers involving neutron stars, for example, would plumb the mysterious physics of these objects, which are essentially gigantic atomic nuclei with masses between 1.5 and three times that of the sun. LIGO physicists are combing their data for such signals but finding them is a long shot at the present sensitivity, González says.

LIGO's next big splash will likely come in 2017. The detectors, now restarting after tune-ups, are expected to begin a second data run this fall. They should also be joined by the revamped VIRGO detector, an interferometer near Pisa, Italy, that will help pinpoint sources in the sky and measure their distances. LIGO may well have more surprises in store, Heinz says: “There's always that great possibility of finding something unexpected.”

Read more about this article at: <https://www.sciencemag.org/news/2016/06/ligo-detects-another-black-hole-crash>

Drifting Floats Detect Quakes to Plumb Earth's Deep Interior

A versatile, low-cost way to study Earth's interior from sea has yielded its first images and is scaling up. By deploying hydrophones inside neutrally buoyant floats that drift through the deep ocean, seismologists are detecting earthquakes that occur below the sea floor and using the signals to peer inside Earth in places where data have been lacking.

In February, researchers reported that nine of these floats near Ecuador's Galápagos Islands had helped trace a mantle plume—a column of hot rock rising from deep below the islands. Now, 18 floats searching for plumes



Drifting Floats Detect Quakes to Plumb Earth's Deep Interior (Continued)

under Tahiti have also recorded earthquakes, the team reported last week at the European Geosciences Union (EGU) meeting here. “It seems they’ve made a lot of progress,” says Barbara Romanowicz, a geophysicist at the University of California, Berkeley.

The South Pacific fleet will grow this summer, says Frederik Simons, a seismologist at Princeton University who helped develop the floats, called MERMAIDs (mobile earthquake recorders in marine areas by independent divers). He envisions a global flotilla of thousands of these wandering devices, which could also be used to detect the sound of rain or whales or outfitted with other environmental or biological sensors. “The goal is to instrument all the oceans.”

For decades, geologists have placed seismometers on land to study how powerful, faraway earthquakes pass through Earth. Deep structures of different density, such as the cold slabs of ocean crust that sink into the mantle along subduction zones, can speed up or slow down seismic waves. By combining seismic information detected in various locations, researchers can map those structures, much like 3D x-ray scans of the human body. Upwelling plumes and other giant structures under the oceans are more mysterious, however. The reason is simple: There are far fewer seismometers on the ocean floor.

Such instruments are expensive because they must be deployed and retrieved by research vessels. And sometimes they fail to surface after yearlong campaigns. More recently, scientists have begun to use fiber optic communication cables on the sea floor to detect quakes, but the approach is in its infancy (*Science*, 15 June 2018, p. [1160](#)).

MERMAIDs are a cheap alternative. They drift at a depth of about 1500 meters, which minimizes background noise and lessens the energy needed for periodic ascents to transmit fresh data. Whenever a MERMAID's hydrophone picks up a strong sound pulse, its computer evaluates whether that pressure wave likely originated from seafloor shaking. If so, the MERMAID surfaces within a few hours and sends the seismogram via satellite.

The nine floats released near the Galápagos in 2014 gathered 719 seismograms in 2 years before their batteries ran out. Background noise, such as wind and rain at the ocean surface, drowned out some of the seismograms. But 80% were helpful in imaging a mantle plume some 300 kilometers wide and 1900 kilometers deep, the team described in February in *Scientific Reports*. The widely dispersed MERMAIDs sharpened the picture, compared with studies done with seismometers on the islands and in South America. “The paper demonstrates the potential of the methodology, but I think they need to figure out how to beat down the noise a little more,” Romanowicz says.

Since that campaign, the MERMAID design was reworked by research engineer Yann Hello of Geoazur, a geoscience lab in Sophia Antipolis, France. He made them spherical and stronger, and tripled battery life. The floats now cost about \$40,000, plus about \$50 per month to transmit data. “The MERMAIDs are filling a need for a fairly inexpensive, flexible device” to monitor the oceans, says Martin Mai, a geophysicist at King Abdullah University of Science and Technology in Thuwal, Saudi Arabia.

Between June and September of 2018, 18 of these new MERMAIDs were scattered around Tahiti to explore the Pacific Superswell, an expanse of oddly elevated ocean crust, likely inflated by plumes. The plan is to illuminate this plumbing and find out whether multiple plumes stem from a single deep source. “It’s a pretty natural target,” says Catherine Rychert, a seismologist at the University of Southampton in the United Kingdom. “You’d need a lot of ocean bottom seismometers, a lot of ships, so having floats out there makes



Drifting Floats Detect Quakes to Plumb Earth's Deep Interior (Continued)

sense.”

So far, the MERMAIDs have identified 258 earthquakes, Joel Simon, a graduate student at Princeton, told the EGU meeting. About 90% of those have also been detected by other seismometers around the world—an indication that the hydrophones are detecting informative earthquakes. Simon has also identified some shear waves, or S-waves, which arrive after the initial pressure waves of a quake and can provide clues to the mantle's composition and temperature. “We never set out to get S-waves,” he said. “This is incredible.” S-waves can't travel through water, so they are converted to pressure waves at the sea floor, which saps their energy and makes them hard to identify.



A MERMAID undergoes testing off Japan's coast in 2018.

In August, 28 more MERMAIDS will join the South Pacific fleet, two dozen of them bought by the Southern University of Science and Technology in Shenzhen, China. Heiner Igel, a geophysicist at Ludwig Maximilian University in Munich, Germany, cheers the expansion. “I would say drop them all over the oceans,” he says.

Read more about this article at: <https://science.sciencemag.org/content/364/6437/218>

Viscosity Jump in Earth's Mid-mantle

The viscosity of Earth's mantle controls the rate and pattern of mantle convection and, through it, the dynamics of our planet's deep interior, including degassing of and heat transport from the interior, mixing of compositional heterogeneity, plume ascent and passive upwelling, and slab descent. The long-wavelength nonhydrostatic geoid is a key geophysical constraint on Earth's internal viscosity structure. At the largest spatial scales (spherical harmonic degrees 2 to 7), the geoid is most sensitive to density structure and viscosity contrasts in the lower mantle. At smaller scales, the geoid becomes increasingly sensitive to upper mantle structure, which is primarily associated with subducting slabs. Because lateral viscosity variations have minor effects on the geoid at large spatial scales —though they may become more important at shorter length scales —it is possible to infer deep mantle viscous layering from geoid observations. However, most studies of Earth's mantle viscosity structure impose layer interfaces to be coincident with seismic velocity discontinuities. Thus, these studies may not resolve viscous layering whose origin is distinct from that of



Viscosity Jump in Earth's Mid-mantle (Continued)

pressure-induced phase changes (e.g., at 410- and 660-km depth), or may miss phase transitions not clearly associated with seismic discontinuities.

We use the long-wavelength nonhydrostatic geoid to infer the mantle radial viscosity structure in a manner distinct from that of previous attempts in three key ways. First, we employ a transdimensional, hierarchical, Bayesian inversion procedure that does not specify at the outset the number or location of interfaces in our layered viscosity structure. The Bayesian approach is very attractive for this inverse problem because it yields a posterior probability distribution that can be analyzed to quantify uncertainties of and trade-offs between model parameters (e.g., layer depth and viscosity contrast). Second, we explore various choices for the conversion between seismic velocity anomalies and density anomalies, including depth-dependent conversion factors based on thermodynamic principles, calculated using HeFESTo. Finally, we use a recent whole-mantle tomographic model, SEMUCB-WM1, developed with waveform tomography using highly accurate wave propagation computations, to infer mantle density structure and a modern geoid model based on 10 years of GRACE satellite observations, combined with revised estimates of the hydrostatic flattening of Earth.

A posterior probability density function for the radial profile of viscosity is shown in [Figure. 1](#), where the mean (taken in log-space) viscosity at each depth is shown as a purple curve. In this particular inversion, we find evidence for relatively uniform viscosity throughout the upper mantle and transition zone. Below the mantle transition zone, there is a region of lower viscosity and an increase in viscosity between 670- and 1000-km depth. The preferred depth of this viscosity increase can be inferred from [Figure. 1B](#) and is centered about 1000 km.

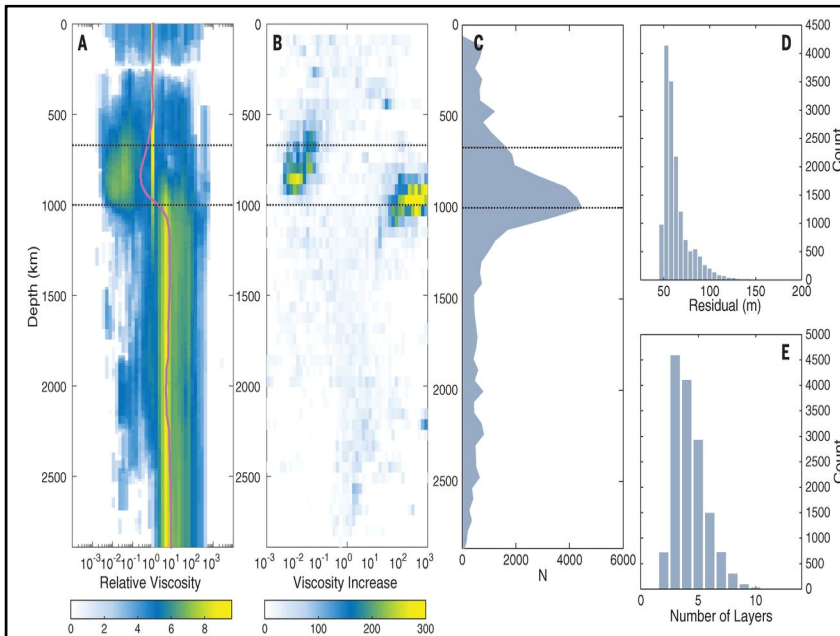


Figure. 1 Properties of ensemble solution.

Viscosity inversion using depth-dependent $R_{p,s}$ from HeFESTo, $l_{\max} = 3$, and assumption of uncorrelated errors yields radial viscosity profiles with a viscosity increase at 1000-km depth and a lower-viscosity channel between 670 and 1000 km. (A) A 2D histogram showing the posterior likelihood of viscosity and depth values. Horizontal dotted lines indicate depths of 670 and 1000 km. (B) A 2D histogram showing the posterior likelihood of layer interface depth and viscosity increase (>1 means viscosity increases with increasing depth). (C) Posterior likelihood of having a layer interface at each depth. (D) Distribution of residuals of solutions in ensemble solution. (E) Distribution of number of layers in models in the ensemble solution.

We carried out multiple inversions to explore the effects of (i) our treatment of data and model uncertainty, (ii) the degree of truncation of the spherical harmonic expansion of the geoid used to constrain our models, and (iii) the density scaling $R_{p,s} = d\ln\rho/d\ln V_s$ ([Figure. 1](#)). We consider features of the viscosity profiles to be robust if they are common among the separate inversions. We find that all solutions place the depth of viscosity increase considerably below 670-km depth, most often near 1000-km depth. This result appears to be independent of assumptions made, including maximum spherical harmonic degree $l_{\max}$, choice of depth-



Viscosity Jump in Earth's Mid-mantle (Continued)

dependent or constant $R_{p,s}$, or treatment of data and model covariance. Other features of the solutions are sensitive to these choices and, therefore, their robustness is proportional to the likelihood of the assumptions from which they result. Inversions with $l_{\max} = 7$ (dashed curves in **Figure. 2**) generally have a more pronounced peak in viscosity in the mid-mantle, underlain by a weaker region between 1500- and 2500-km depth and an increase in viscosity in the lowermost mantle. Several solutions, using depth-dependent $R_{p,s}$ or $R_{p,s} = 0.4$, feature a lower-viscosity layer between 670- and 1000-km depth. Some solutions include a high-viscosity “hill” in the mid-mantle between 1000- and 1500-km depth, separating upper and lower mantles of lower viscosity.

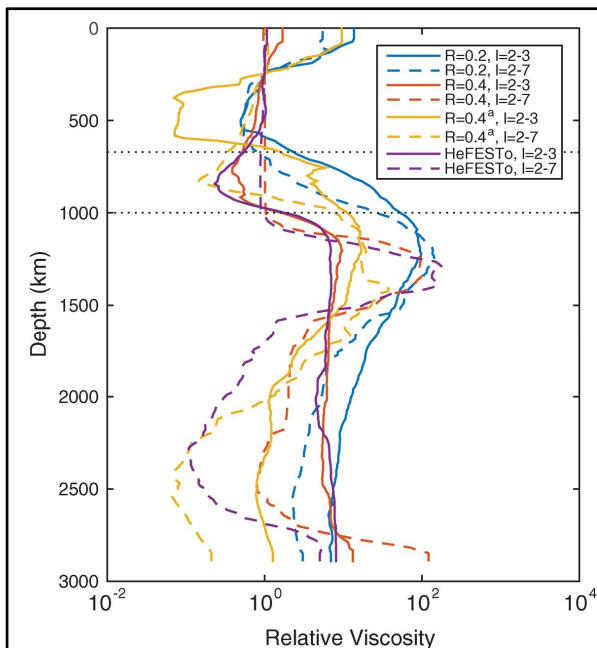


Figure. 2 Results from multiple inversions.

Mean radial profiles of viscosity obtained in eight inversions varying $R_{p,s}$, $l_{\max}$, and eliminating buoyancy contributions from the lowermost 1000 km of the mantle (denoted by a superscript “a”) all exhibit an increase in viscosity between 670- and 1000-km depth. Models with $l_{\max} = 7$ are characterized by low viscosity in the mid-lower mantle.

Many early studies advocated for layered mantle convection with an interface at or somewhat below 670-km depth, and in particular Wen and Anderson noted that the amplitude and pattern of the long-wavelength geoid and surface topography could be well reproduced using mantle flow models with an imposed barrier to flow about 250 km deeper than the 670-km seismic discontinuity. However, tomographic images of relict Farallon and Tethys slabs in the lower mantle suggest that the concept of layered mantle convection is at best incomplete, and we emphasize that our mantle flow calculations do not impose layered convection.

Our results favor viscosity structures in which the overall increase in viscosity is a factor of 10 to 150, in agreement with previous studies. All of our results favor the location (interface depth) of this viscosity increase lying below 670-km depth, and most models place this viscosity increase deeper still, in the vicinity of 1000-km depth. This result is particularly intriguing given the observation that most actively subducting slabs stagnate below the 670-km seismic discontinuity, at depths of 1000 km. For instance, both the GAP-P4 model and SEMUCB-WM1 reveal slabs stagnating above the 670-km discontinuity in the Northern Honshu arc, but passing through the 670-km discontinuity and stagnating above 1000-km depth along the Tonga and Kermadec arcs. In at least one region, Central America, the slab appears to enter the lower mantle without stagnation. The mechanism responsible for this slab stagnation is unclear, as there is no velocity discontinuity at this depth in one-dimensional (1D) seismic models, nor a known phase transition.



Viscosity Jump in Earth's Mid-mantle (Continued)

Two mechanisms have been recently suggested for slab stagnation in the mid-mantle. First, King *et al.* have suggested that the pyroxene to majoritic garnet phase transition in subducted slabs is kinetically hindered, and thus older, colder, slabs are more prone to stagnation. Marquardt and Miyagi, based on high-pressure deformation experiments of (Mg,Fe)O, argued that viscosity in the regions surrounding settling slabs in the shallow-most 900 km of the lower mantle may be about two orders of magnitude higher than previously expected, causing slabs to spread laterally and to settle very slowly through this region. Our results indicate that there may be a viscosity increase in the mid-mantle, and many of our inversions have viscosity contrasts at depths comparable to those suggested. However, we note that the observation of regional differences in slab behavior, and in particular the speculation that old, cold, slabs preferentially stagnate, cannot be explained using our 1D viscosity structure or by a viscosity contrast that would occur in the mantle surrounding all slabs, irrespective of age, without invoking additional mantle dynamic processes or subduction zone histories, such as the prevalence of trench rollback.

Previous inversions for layered viscosity structure with prescribed layer interfaces depths revealed some indication of an increase in viscosity at or around 1000-km depth. In particular, King and Masters inverted for layered viscosity structure constrained by the geoid using a uniform velocity to density conversion factor, with velocity anomalies inferred from *S*-wave tomographic models, and found evidence for a viscosity increase of ~ 20 at 670-km depth and a second increase of ~ 5 at 1022-km depth. Forte and Peltier also found, using a combination of a slab density model and lower-mantle tomographic model, that the agreement between modeled and observed geoid was better for a layered viscosity structure with an interface at 1200-km depth than at 670-km depth. Kido *et al.* performed inversions for layered mantle viscosity structure (with prescribed layer depths) using a genetic algorithm and found evidence for a decrease in viscosity at 670-km depth and subsequent increase in viscosity at 1000-km depth. Our study is different in that we do not prescribe at the outset the number or locations of layer interfaces in our layered viscosity structure and as a result, we place the largest viscosity contrast in the model somewhat deeper than previous studies.

Many studies from the 1980s and 1990s employed layered structures with layering identical to that of the tomographic models then available (~ 11 layers), or layered structures with layers at the major seismic discontinuities. Subsequent models have introduced additional layers [for instance, 25 in]. To justify such parameterizations, either additional observational constraints, such as rates of glacial isostatic adjustment, plate motions, or patterns of seismic anisotropy, or additional assumptions about the smoothness of the mantle viscosity structure, are required. Paulson *et al.* used geoid and relative sea-level data as constraints on a Monte-Carlo inversion for mantle viscosity structure with one, two, and three layers. One of the central conclusions was that the GRACE and relative sea-level data cannot be used to uniquely constrain a layered mantle viscosity structure with more than two layers. Two markedly different two-layer models were permitted by these inversions (with prescribed interface depth at 670 km), one having an upper mantle with viscosity around 5×10^{20} Pa-s and a lower mantle ~ 4.33 more viscous and the other having an upper mantle viscosity about an order of magnitude smaller and a viscosity contrast of ~ 1500 , similar to what was found by Ricard *et al.* Our results generally support the suggestion that the geoid alone cannot uniquely constrain the viscosity of more than a handful of layers. Indeed, many individual models in the posterior population for each of our inversions do have more than five layers (e.g., Figure. 1), but owing to trade-offs, the layer properties of these more complex structures cannot be uniquely constrained. The posterior distribution of solutions inherently captures these trade-offs between model parameters, and the precise viscosity structures of these inversions are largely dependent on assumptions in the inversion.



Viscosity Jump in Earth's Mid-mantle (Continued)

A viscosity contrast at 1000-km depth has important implications for the dynamics of convection in Earth's mantle, including its thermal and chemical evolution. As ascending plumes encounter abrupt changes in viscosity (in numerical models), they can be laterally deflected and thinned. Similarly, downwelling's in numerical simulations become elongated laterally and compressed vertically as they encounter viscosity increases. Deflection of upwellings is observed in some tomographic models. For instance, recent tomographic images obtained by full waveform tomography with sophisticated forward-modeling approaches reveal apparent deflection at 1000-km depth of the seismically slow structures both regionally beneath the Iceland hotspot and globally. Indeed, examples of apparent deflected upwellings, such as the feature beneath the Macdonald hotspot in the South Pacific ([Figure. 3](#)), are globally not uncommon. In both studies, the apparent radius of plumes also decreases from the lower to the upper mantle. The decrease in radius appears to be coincident with the deflection at 1000-km depth. Upwelling structures in numerical simulations of mantle convection with an imposed increase in viscosity at 1000-km depth show similar behavior ([Figure. 3](#)).

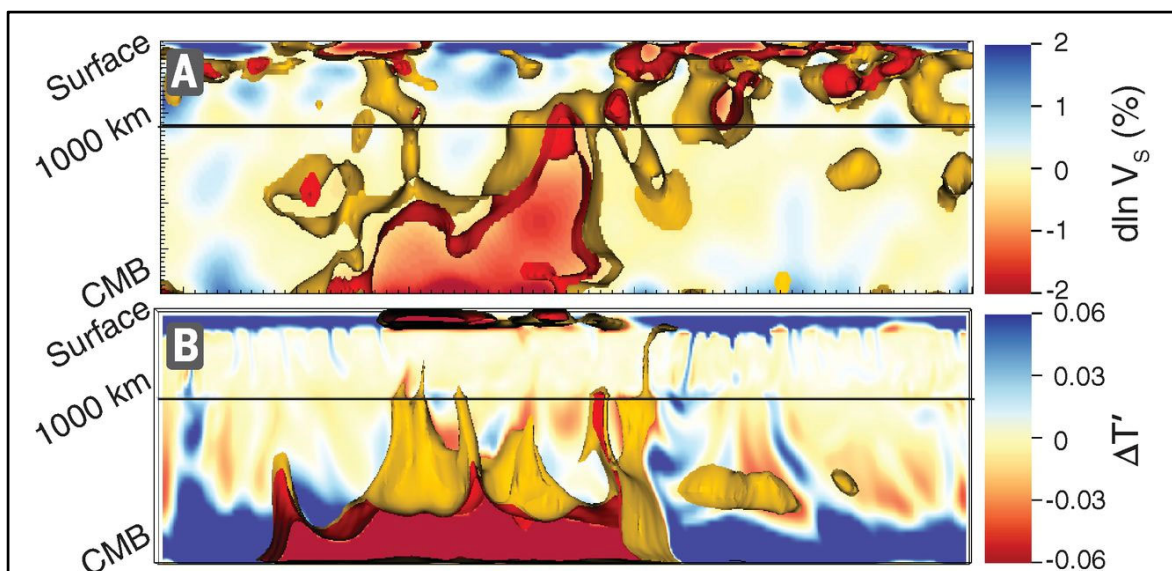


Figure. 3 Observed and modeled upwellings.

(A) Shear velocity anomaly isocontours delineate deflected downwellings at 1000-km depth (horizontal line) near McDonald hotspot in SEMUCB-WM1. (B) Dimensionless temperature (T') anomaly isocontours (and pseudocolor) show similar deflection and thinning of upwellings in a numerical geodynamic model with a viscosity increase at 1000-km depth. Cool and warm colors trace dimensionless temperature variations in (B) and denote seismically fast or slow regions in (A).

Other studies use the mantle radial correlation function to analyze tomographic models and to compare tomographic and geodynamic models. Radial correlation functions calculated for SEMUCB-WM1, as well as for the global P -wave tomographic model GAP-P4 for spherical harmonic degrees 1 to 3 ([Figure. 4, A and B](#)), show a high degree of correlation throughout the lower mantle at depths greater than 1000 km and a rapid decrease in correlation at 1000-km depth. Nearly identical behavior is also present in the average of S -wave tomographic models SMEAN (figure. S10). Other tomographic models show a change in radial correlation around this depth as well as a change in velocity heterogeneity, particularly at spherical harmonic degree 4, and an independent test based on voxel tomography favors a vertical coherence minimum around 800-km depth, below the base of the transition zone.



Viscosity Jump in Earth's Mid-mantle (Continued)

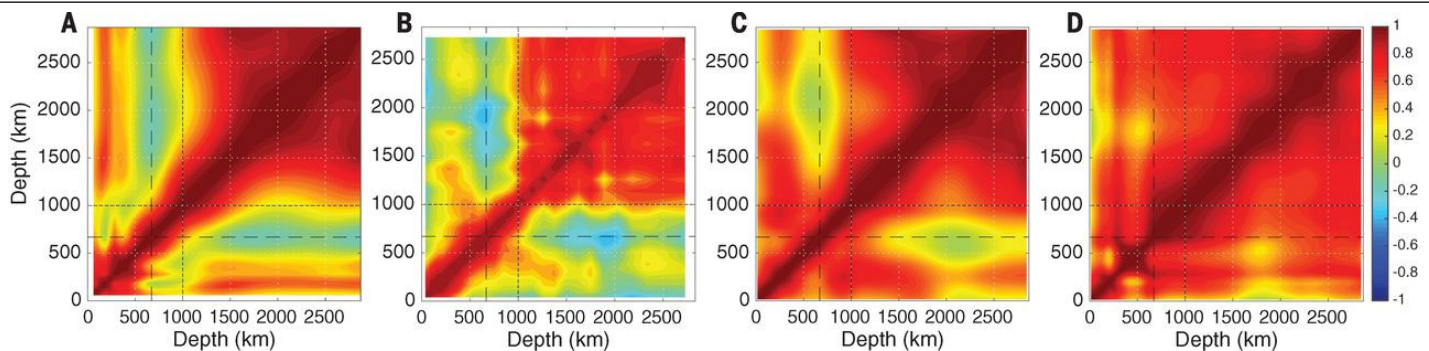


Figure. 4 Radial correlation functions of tomographic and geodynamic models.

(A) Radial correlation functions for spherical harmonic degrees 1 to 3 from SEMUCB-WM1 and (B) GAP-P4 show an abrupt decorrelation of structure across 1000-km depth. Very similar radial correlation functions are seen in the temperature field from numerical mantle convection simulations with imposed plate motions, including a viscosity contrast at 1000-km depth (C), but not when the viscosity contrast is smaller and shallower, at 670-km depth (D).

Changes in the radial correlation function may be related to changes in viscosity. Numerical simulations of convection in spherical shell geometry show that endothermic phase changes and depth-dependent viscosity can both cause corresponding changes in the radial correlation. We find that a viscosity increase at 1000 km (Figure. 4C) yields a radial correlation structure much more similar to that found in tomographic models (Figure. 4, A and B) than does a viscosity increase at 670 km (Figure. 4D). The rapid change in radial correlation at 1000-km depth in tomographic models thus suggests a contrast in viscosity, because no change in phase is known to occur at this depth. We emphasize that these models include simplified representations of mantle viscosity structure (fig. S7) and that a more gradual increase in viscosity may also be compatible with the observations. Other, more complex viscosity structures can also alter the behavior of upwellings and downwellings and consequently change the radial correlation structure. Convection simulations run with a “second asthenosphere,” a weak zone extending from 670- to 1000-km depth as suggested in some of our inversions (Figure. 1) as well as in inversions by Kido *et al.*, show a greater tendency toward layered convection, which promotes decorrelation.

The viscosity contrast at a 1000-km depth provides a physical mechanism for the observation that slabs, and plumes stagnate or become deflected deeper than the transition zone in the absence of a pervasive compositional barrier or another endothermic phase change. It may also reconcile observations of changes in seismic structure that led to a proposed hot abyssal layer, though this was originally placed at greater depths. Given the present state of understanding in mineral physics, no unique mechanism can be identified for this increase in viscosity, and our observation should motivate further experimental and computational studies. First principles calculations have indicated a continuous though gentle increase in the viscosity of bridgmanite due to greater vacancy diffusion starting at around 40 GPa (~1000 km) and continuing until the postperovskite phase transition. The increase in the strength of ferropericlase observed by Marquardt and Miyagi is the first positive experimental evidence for a possible change in rheology at these depths. Whether this effect, which is localized in high-strain-rate regions (surrounding slabs), should be expected to contribute to the viscosity inferred on the basis of the very-long-wavelength components of the geoid, remains to be determined. The spin transition in ferropericlase occurs at much greater depths, and first-principles simulations suggest that the higher-pressure phase (low spin) should have increased diffusion and



Viscosity Jump in Earth's Mid-mantle (Continued)

lower viscosity, with a viscosity minimum near 1500-km depth.

Two possible intriguing (though speculative) solutions remain. Changes in the relative abundance of ferric versus ferrous iron due to disproportionation at these depths or gradually over a depth range might change the bonding strength in bridgmanite enough to markedly strengthen it. Perhaps of greater interest and of more pervasive dynamical consequence might be the gradual drying of the bridgmanite perovskite as the solubility of water in the structure decreases with pressure, becoming more viscous at 1000-km depth.

Read more about this article at: <https://science.sciencemag.org/content/350/6266/1349?intcmp=trendmd-sci>

Toward Fire Safety Without Chemical Risk

Halogenated flame retardants are used widely in consumer products such as carpets, textiles, and electronics to reduce the risk of fire. It has been known for more than 20 years that these compounds can leach into the environment, with particularly high concentrations recorded in fish and marine mammals. Concerns have also been raised about carcinogenic and endocrine-disrupting effects in humans. Some brominated flame retardants—in particular, polybrominated diphenyl ether (PBDE) commercial mixtures and hexabromocyclododecane (HBCD)—have been banned or phased out in some jurisdictions, and the possible use of alternative flame retardants has been investigated. Yet, over the past 20 years, global production of flame retardants has continued to rise without a decrease in halogenated flame retardant production. It is time for a critical evaluation of flame retardant use.

In the late 1980s, scientists began to develop analytical methods and gather the first screening data on flame retardants in the environment in Europe, Japan, and North America. Concern among environmental scientists rose when Norén and Meyronité reported rising concentrations of PBDEs in human milk and de Boer *et al.* detected PBDEs in sperm whales stranded in the Netherlands. Soon after, more studies documented increasing PBDE trends in fish, sediment profiles, sewage sludge, aquatic birds, and human tissues.

Intensive discussions between scientists, regulatory authorities, and the international bromine industry, represented by the Bromine Science and Environmental Forum, followed but did not lead to reductions in the global use of halogenated flame retardants. Instead, repeated regrettable substitutions were made, in which one halogenated flame retardant was phased out and replaced by another halogenated flame retardant, for which less information on exposure pathways and potential environmental and health effects was available. All substitutes showed harmful effects, although these effects were sometimes slightly different from those of the compounds they had replaced.

In the meantime, a suite of other halogenated flame retardants was introduced; about 75 different brominated flame retardants are on the market, and many of them have been detected in the environment. For each of these compounds, scant information was available on their environmental behavior at the time of introduction, because years of research are needed to collect information and support a thorough risk assessment. Such risk assessments have been carried out in the past for single compounds or for well-defined mixtures but are much more difficult to conduct when the effects of multiple substances are cumulative.

Even after a detailed risk assessment of the flame retardant tris-(1,3-dichloro-2-propyl)phosphate (TDCIPP) found it to present a potential risk for children, the compound was not taken from the market but only



Toward Fire Safety Without Chemical Risk (Continued)

voluntarily removed from children's pajamas. More than three decades later, this same chemical became a popular replacement for pentabromodiphenyl ether (PentaBDE) in U.S. furniture, including baby and juvenile furniture.

Recent research has drawn attention to human exposure to flame retardants in indoor environments such as homes, with children receiving greater exposure than adults. Furniture and electronics appear to be substantial sources of flame retardants in indoor dust and air, as well as in cars. Scientists are now increasingly investigating the importance of dermal absorption and inhalation as primary uptake routes compared with diet.

Policy and Regulations

The European Union (EU) issued bans on the production and use of PBDEs and HBCD starting in 2002. More recently, several frameworks and directives have been developed in Europe, including the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), the Restriction of Hazardous Substances, and the Waste Electrical and Electronic Equipment directives. The current Community Rolling Action Plan of the European Chemicals Agency envisages further possible restrictions on a series of flame retardants, including TDCIPP. These are hopeful signs, but EU frameworks do not yet take account of mixture effects.

In 2004, the U.S. Environmental Protection Agency (EPA) and the manufacturers reached a voluntary phase-out agreement of PentaBDE and octabromodiphenyl ether (OctaBDE). Several U.S. states prohibited the use of these flame retardants in some products sold in their home states. In 2017, a group of organizations petitioned the U.S. Consumer Product Safety Commission (CPSC) to restrict the use of additive, nonpolymeric, halogenated flame retardants in children's products, furniture, and electronics enclosures on the basis of the Federal Hazardous Substances Act. This approach was unusual in that it requested a ban on an entire class of chemicals. The CPSC must now determine whether it considers halogenated flame retardants to be hazardous as a class. It is currently establishing a Chronic Hazard Advisory panel to make this determination.

Other parts of the world have seen far less regulation of halogenated flame retardants. In January 2018, China added decabromodiphenyl ether (DecaBDE) and HBCD to its list of priority substances, which may imply restrictions in productions or limitations of discharges. Taiwan and Japan have placed restrictions on the use of PBDEs and HBCD. Although India signed the United Nations Stockholm Convention on Persistent Organic Pollutants, in which PBDEs and HBCD are officially labeled as such, no comprehensive legislation for these and other flame retardants exists.

The recent United Nations Global Chemicals Outlook II predicts that the volume of chemicals used worldwide will double in the coming decade. It would be prudent to be more selective in the use of flame retardants and to potentially limit this increase. Flame retardants are needed in airplanes, cars, insulation, and electronics, but there are many questions around the need for flame retardants in furniture, children's products, and even products like flags. In the case of residential furniture, the use of flame retardants provides an additional ~30 s to escape from a flashover (the near simultaneous ignition of directly exposed flammable material in an enclosed area); however, this benefit must be considered against the increase of carbon monoxide and smoke produced by some flame retardants.



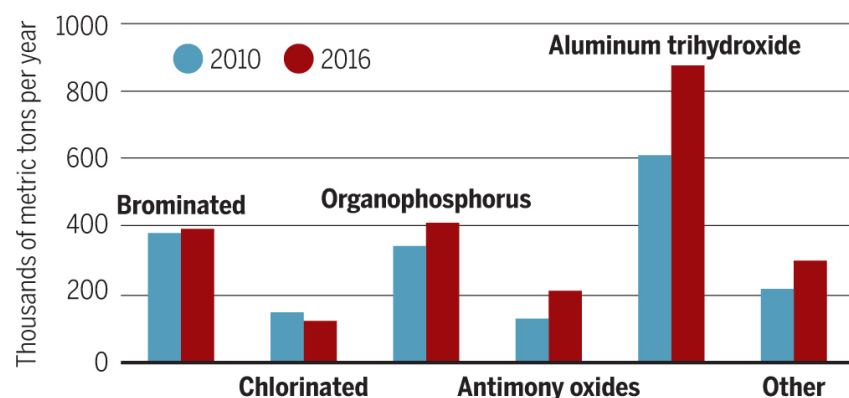
Toward Fire Safety Without Chemical Risk (Continued)

Production Developments

The production and sale of flame retardants is a billion-dollar industry. In 2016, the estimated worldwide consumption of flame retardants was 2.3 million metric tons (see the figure); the estimated annual growth rate is 3%. Overall production of halogenated flame retardants, excluding chlorinated paraffins used for other purposes, has been stable over the past 20 years at just over 500,000 metric tons.

Global production of flame retardants

Global flame retardant production increases by around 3% per year. Production of halogenated flame retardants is not decreasing, despite concerns regarding environmental and health impacts. Data from (12).



Global production of flame retardants

Global flame retardant production increases by around 3% per year. Production of halogenated flame retardants is not decreasing, despite concerns regarding environmental and health impacts.

Some changes have occurred over this time. For example, the bromine industry has started production of a brominated polybutadiene-polystyrene flame retardant, which should reduce exposure concerns because it is less likely to leach out of a polymer, compared with small-molecule flame retardants used as additives. The phosphorus industry is hoping to phase out the use of tris-(2-chloroisopropyl) phosphate (TCIPP) in isolating metal panels containing foam cores and to replace TDCIPP with phosphorus-substituted poly-ols (poly-P-poly-ols) in the automotive industry. However, production of many flame retardants that are harmful to human health and the environment continues.

The European research project ENFIRO has recommended alternatives for persistent, bioaccumulative, and toxic flame retardants. These alternatives have a better environmental profile and include metal-based compounds, such as zinc stannate, zinc borate, and aluminum diethylphosphinate, as well as melamine polyphosphate. The EPA has used the Design for the Environment program to provide information on alternatives for PentaBDE in polyurethane and DecaBDE in electronics.

A Better Way Forward

The production of potentially hazardous and environmentally unfriendly flame retardants continues even when better alternatives are available. Intense pressure from authorities, and sometimes the general public, can motivate industry to change, but governments have been slow to act. Any regulatory changes will likely raise concerns about impacts on fire-related fatalities and damages. However, environment- friendly



Toward Fire Safety Without Chemical Risk (Continued)

alternatives are available and just as safe as the halogenated flame retardants, and many applications do not require the presence of a flame retardant.

Authorities should ban persistent, bioaccumulative, and toxic flame retardants as soon as safer alternatives become available. It may be even better to only allow flame retardants on the market that have been adequately tested for human toxicity and environmental impacts. Such a focus on the design phase will be required to adhere to requirements for a circular economy, such as readiness of materials for recycling.

The need for flame retardants in some materials may not be as high as industry lobbyists suggest. The data used to support the implementation of flammability standards, particularly for furniture and televisions, may be flawed or misinterpreted. No one wants to compromise fire safety, but to protect human and environmental health, it is crucial that the use of flame retardants is critically evaluated to determine where they are needed and where they are not.

Read more about this article at: <https://science.sciencemag.org/content/364/6437/231>

Prospects for Harnessing Biocide Resistance for Bioremediation and Detoxification

Microorganisms in pristine ecosystems as well as those in anthropogenically disturbed habitats are constantly challenged by combinations of chemicals and physical stresses. Natural habitats can experience combinations of conditions from high salinity and osmolarity, desiccation, ultraviolet radiation, high pressure, or extremes of pH or temperature. Industrial, agricultural, and domestic activities lead to the release of organic and inorganic compounds toxic to a wide range of organisms in the environment. Microbes exposed to such conditions can rapidly develop physiological and/or genetic adaptations to resist environmental constraints. Harnessing the metabolic capacities of prokaryotes and their adaptive potential is of interest for a broad range of applications for environmental clean-up as well as for treatment of domestic and industrial waste.

Microbial tolerance and resistance mechanisms

The mechanisms that enable bacteria to survive typical environmental stressors, such as toxic concentrations of organic pollutants and changes in temperature or osmolarity, are well understood. Preventing damage to the cell envelope and cellular membranes are pivotal for prokaryote survival. Hence, one of the first responses to toxic assault is membrane repair to reestablish membrane fluidity and rigidity. In Gram-negative bacteria, this occurs with the insertion of saturated and *trans*-configured unsaturated fatty acids, whereas in Gram-positive bacteria, *iso*-branched fatty acids are inserted. Cell-surface properties can also be modified during exposure to stressors by the release of outer-membrane vesicles, which increase surface hydrophobicity. This phenomenon can stimulate biofilm formation, making bacteria yet more tolerant to environmental stressors. Bacteria can also change their morphology in the presence of toxic concentrations of organic pollutants, increasing their overall size and decreasing surface-to-volume ratio.

Many bacteria respond to stresses by inducing synthesis of specific membrane efflux pumps. This response is well understood in bacteria capable of withstanding high concentrations of organic solvents such as benzene, toluene, ethylbenzene, and xylene (BTEX). BTEX are excreted from membranes by energy-driven protein pumps belonging to the root nodulation (RND) family of membrane proteins. RND proteins are known in other bacteria to transport antibiotics and contribute to multidrug resistance. Cross-protection to different stresses is common. For example, bacterial cells that adapt to a given solvent also show increased tolerance



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to other solvents, heavy metals, antibiotics, and several forms of physical-chemical stress. Because bacterial adaptive physiological responses are inducible, it is therefore possible to pre-adapt the cells for potential applications at contaminated sites.

Role of environments in tolerance and resistance selection

Although any environment ultimately selects for the survival and proliferation of specific microbial genotypes, extreme and polluted environments showcase the power of such selective forces. Polluted environments are frequently characterized by high concentrations of toxic substances that can appear in sudden, infrequent, but ephemeral bursts such as oil spills, but equally, chronic pollution can arise from long-term input of pollutants. An influx of high concentrations of toxic compounds can lead to dramatic shifts in microbial community composition and diversity (Figure 1, top). Consequently, carbon and nutrients in the system that are no longer used by sensitive phenotypes can be used for growth by resistant phenotypes (Figure 1, top). Additionally, polluting compounds can become an exclusive source of assimilable nutrients or electron donors or acceptors for resistant microorganisms (Figure 1, bottom). For example, oil-degrading bacteria occur at typically low abundances in marine environments but respond with astonishingly rapid blooms during oil spills. Even for synthetic chemicals considered to be xenobiotic—such as chlorinated solvents, pesticides, and the plastic poly(ethylene terephthalate)—release into the environment, and long-term pollution selects for the appearance and proliferation of mutants with naturally recombined metabolic pathways, which profit from the exclusivity of the toxic compound for growth. Natural recombination is largely the result of abundant horizontal gene flow in prokaryote communities. Diverse mechanisms have been implicated in gene flow, such as plasmid conjugation, natural transformation, and integrative and conjugative or transposable elements. Extreme toxicity resistance as a result of RND-type efflux mechanisms may thus be a prerequisite for further adaptation by keeping the intracellular concentration of the toxicant low enough to permit its metabolism.

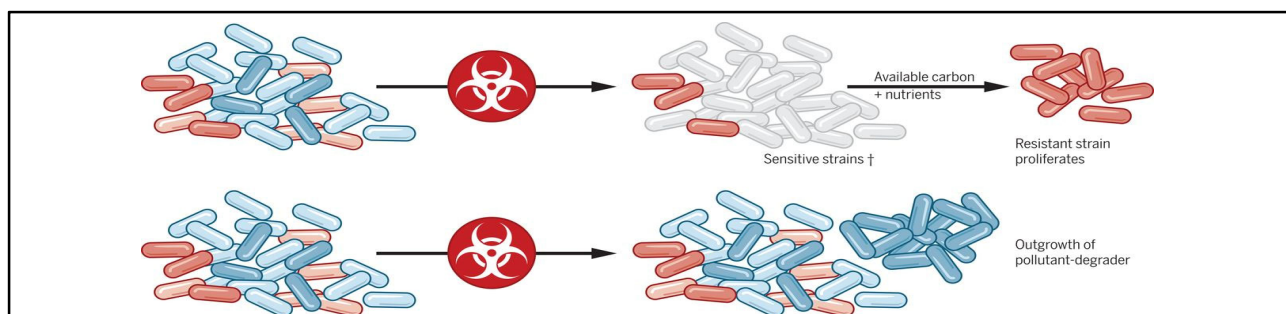


Figure 1 Environmental selection of adaptive phenotypes to toxic compound stresses.

(Top) Exposure of a diverse bacterial community to toxic concentrations of chemicals inhibits or kills sensitive individuals. Resistant organisms profit from the availability of unused carbon and nutrients in the system to proliferate. **(Bottom)** Toxic organic compounds themselves can be used as an exclusive growth substrate for low numbers of preexisting specialist bacteria in the community or for newly arising mutants. These lineages will proliferate by consuming the toxic compound, potentially leading to the spontaneous natural attenuation of a contaminated site. Specialist degrader bacteria may additionally profit from toxicity-resistance mechanisms.



Prospects for Harnessing Biocide Resistance for Bioremediation and Detoxification (Continued)

As worldwide environmental concerns shift from high contamination loads of legacy chemicals—such as oil, polycyclic aromatic hydrocarbons, and polychlorinated biphenyls—toward low concentrations of biologically very active molecules—including antibiotics, other pharmaceuticals, and ingredients of household and consumer care products—the question is what types of microbial resistance will be selected by low and chronic concentrations of these chemicals. Although low concentrations of chemicals can be toxic to some lineages and may result in selection of resistant phenotypes, as the widespread emergence of antibiotic resistances attests, the distinct proliferation of “compound-degrader” phenotypes may be more difficult to discern. Conceivably, micropollutant degraders might have more advantage in oligotrophic environments, where available nutrients are scarce and the ability to metabolize micropollutants may be particularly competitive.

Concepts for harnessing toxicant-tolerant or -resistant bacteria

An important outcome of adaptation and selection in contaminated environments is that sites chronically polluted with organic compounds naturally restore over time and diminish the pollution load. Such natural attenuation and restoration processes may, however, take decades. Nevertheless, they require little technical intervention or cost. The spontaneous adaptation and selection that has led to the appearance of (naturally recombinant) bacteria capable of resisting or degrading contaminants has since long attracted interest for potential applications elsewhere. The enrichment or isolation of promising pollutant-degrading bacteria, growth under laboratory conditions, and formulation for use in similar conditions and context—a process called bioaugmentation—could potentially shorten the long on-site adaptation process and accelerate remediation.

Bioaugmentation has been successfully applied at sites contaminated with organohalogen compounds. Organohalide-respiring bacteria (OHRB) such as *Dehalococcoides mccartyi*, *Dehalogenimonas* spp., and *Dehalobacter* spp. use chlorinated solvents and/or pesticides as their sole terminal electron acceptors for growth. Organohalide respiration is probably evolutionarily ancient, but traces of recent or even ongoing genetic adaptation are detectable in the genomes of these species. Precultured stocks of microbial consortia containing OHRB have been successfully applied so as to improve bioremediation of sites contaminated with chlorinated solvents such as tetrachloroethene (Figure 2). OHRB augmentation has been shown to be essential for on-site chlorinated solvent bioremediation because stimulation of the autochthonous OHRB frequently leads to accumulation of a more toxic transformation product, vinyl chloride.



Figure 2 Bioaugmentation with OHRB.

(Left) Injection of microbial cultures containing OHRB in an injection well or (Right) direct push injection without the use of wells in aquifers contaminated with chlorinated solvents. [Reprinted by permission from Springer Nature]



Prospects for Harnessing Biocide Resistance for Bioremediation and Detoxification (Continued)

Widespread pollution with hexachlorocyclohexanes (HCHs) arose around the world during production of the currently largely banned pesticide, the γ -HCH isomer lindane. Bacteria adapted to using HCHs as their sole carbon and energy sources have been discovered at HCH-contaminated sites as a result of natural recruitment and recombination of existing genes and subsequent mutations. Such bacteria have been isolated, cultured in larger quantities, specifically formulated, and successfully used in the bioaugmentation of HCH-contaminated areas.

Oil bioremediation

Crude oil is toxic to metazoan life yet is a supply of extremely energy-rich carbon sources for hydrocarbonoclastic bacteria. Hydrocarbonoclastic bacteria are ubiquitous and evolutionarily old lineages that have adapted to oil components released at natural oil seeps. Typically, their population size in the absence of oil spills is very small, but they bloom during oil contamination. For example, *Oceanospirillales* spp. can compose 90% of the local marine bacterial community after oil spillage. Two well-known species, *Alcanivorax borkumensis* and *Oleispira antarctica*, have evolved several adaptive strategies to optimize access to their poorly water-soluble aliphatic hydrocarbon substrates. These include an increase in cell surface hydrophobicity that is thought to favor partitioning of substrates into the cell envelope, as well as production of biosurfactants to increase the ambient solubility of the aliphatic hydrocarbons. Interestingly, *A. borkumensis* is also able to directly incorporate fatty acids, resulting from oxidation of aliphatic hydrocarbons, into its cell membrane.

“Although any environment ultimately selects for the survival and proliferation of specific microbial genotypes, extreme and polluted environments showcase the power of such selective forces.”

Although bioaugmentation of oil spills is often revisited, the application of large quantities of precultured marine hydrocarbonoclastic bacteria has not been very successful. A more effective measure for major spills seems to be through stimulation of the growth and activity of indigenous hydrocarbonoclastic bacteria with the application of lipophilic nitrogen-phosphorous-rich fertilizers, both in the open sea as well as on rocks and beaches contaminated with crude oil.

Oil spills in arid terrestrial environments are accompanied by the simultaneous occurrence of high pH, high salinity, and high loads of toxic organic compounds. In general, adaptation to osmotic stress under high salinity and pH requires increased intracellular salt concentration or accumulation of organic osmotic solutes. At elevated salinity, the microbial cell surface tends to become more hydrophilic, which will further limit physiological activity on hydrophobic hydrocarbons. High salt concentrations are also characterized by reduced dissolved oxygen, but some organisms can metabolize oil under these conditions, although the mechanisms are not well understood. Successful large-scale bioaugmentation has been implemented in a water pit (3600 m³) heavily polluted with crude oil in northern Oman, where the addition of halophilic cultures reduced hydrocarbon concentrations from 10 to 40% (w/w) to below 1% (w/w) within a year (Figure 3).

Resistance to low pH and high concentrations of heavy metals

Metal extraction and metal leachate decontamination offers contrasting examples of microbial resistance and



Prospects for Harnessing Biocide Resistance for Bioremediation and Detoxification (Continued)



Figure 3 Bioaugmentation with halophilic microorganisms.

A bioaugmented open-air bioreactor in northern Oman (**Left**) just before and (**Right**) 1 year after seeding, as an example of hypersaline oil remediation technology. [Reprinted by permission from Springer Nature]

its potential use for bioremediation. Bioextraction and recovery of valuable metals from sulfidic ores (biohydrometallurgy) depends on the activity of sulfur- and iron-oxidizing prokaryotes to solubilize the mineral pyrite (FeS_2) to H_2SO_4 and Fe^{3+} , during which protons and other metals trapped within the pyrite matrix are released. Biohydrometallurgic suspensions have extreme physicochemical characteristics, sometimes with negative pH values, and metal and sulfate concentrations between 10 and 100 g liter⁻¹.

Consortia of acidophilic prokaryotes used for biohydrometallurgy, mainly belonging to the genera *Acidithiobacillus* and *Leptospirillum*, are typically derived from natural acid rock drainage environments, such as the Tinto river in Spain, or from spontaneous enrichments derived from mine drainage. These acidophiles can grow at extremely low pH and high metal concentrations. Although growth at low pH has some advantages for cellular energy conservation because it builds a spontaneous pH gradient for the proton motive force across the cytoplasmic membrane, the protons still have to be neutralized within the cytoplasm. Some extreme acidophiles prevent ingress of protons by importing K^+ ions, which inverts the membrane potential (positive inside). They can also have highly impermeable membranes owing to the presence of tetraether lipids and specific membrane transporters, such as antiporters, symporters, H^+ -adenosine triphosphatases (ATPases), or metal-transporting P-type ATPases, which remove excess protons and metal ions from the cytoplasm. Additionally, specific chaperones have been reported in acidophilic bacteria that stabilize DNA and proteins, which would otherwise be damaged by the low pH.

Metal leachates from mines are highly problematic because of their low pH, high sulfate, and high dissolved metal content. Sulfate-reducing bacteria (SRB) release sulfide, which will increase the pH and will react with the dissolved metal ions to precipitate in the form of poorly soluble metal sulfides. Stimulation of sulfidogenic activity has been tested in pilot-scale treatment of metal leachate from the zinc smelter Nyrtar in the Netherlands, and also for leachates from the gold mine Pueblo Viejo in the Dominican Republic. Both applications, however, required prior neutralization of the leachates before biological treatment.

Nevertheless, acid- and metallo-tolerant SRB, such as *Desulfosporosinus acididurans*, have been isolated from low-pH environments and successfully deployed for initial biological leachate neutralization and subsequent metal detoxification in laboratory-scale reactors. The prior growth of acidophilic SRB in pH-controlled reactors may further improve the biological recovery of precipitated metallic sulphides and allow potential reuse in industrial processes.



Prospects for Harnessing Biocide Resistance for Bioremediation and Detoxification (Continued)

Resistance to antibiotics and nonantibiotic biocides

Application of antibiotics and nonantibiotic biocides has increased dramatically in recent decades and has resulted in widespread selection of resistant or tolerant mutants. Resistance to antibiotics by the selection of RND efflux pump mechanisms can provide cross-resistance to a wide range of other adverse conditions and compounds. Hence, antibiotic resistance also frequently co-occurs with resistance to biocides and heavy metals. This results from the colocalization and/or comigration of genes conferring multiple resistance mechanisms. Antibiotic resistance genes occur in microbes in natural environments without obvious anthropogenic exposure to antibiotics. This indicates that they confer additional biological advantages, such as resistance to other environmental stressors or to interspecies competition strategies, and metabolism of toxic compounds structurally similar to antibiotics. Several previously unknown dioxygenases have been retrieved from soil metagenomic libraries screened for resistance against β -lactam antibiotics. These enzymes were also shown to transform other aromatic compounds. Some microbes can use these antibiotics as substrates for growth, although the mechanistic basis for this antibiotic subsistence has not been identified unequivocally.

Nonantibiotic biocides can also select for proliferation of resistant microorganisms capable of their biotransformation, as has been shown for a river sediment microbial community degrading benzalkonium chlorides. Strains of *Pseudomonas putida* and *Alcaligenes xylosoxidans*—which are capable of resisting high levels of the polychlorinated antimicrobial triclosan and using it as a sole carbon source—have been isolated from soil. Biocide resistance could potentially be put to good use—for instance, for biocides removal from the filters of drinking water treatment plants (DWTPs). However, success has been limited so far. Augmentation of *Aminobacter* sp. MSH1 to sand filters in recent pilot-scale studies of DWTPs only temporarily increased 2,6-dichlorobenzamide degradation. The loss of activity was attributed to starvation of the introduced bacteria because the micropollutant concentrations were low, and metabolic competition occurred with more abundant assimilable organic carbon in the water.

Concluding remarks

The metabolic and stress-resistance traits that emerge in microorganisms in response to toxic compounds can be exploited for the bioremediation of spills of oil and chlorinated solvents, dissolution of valuable metals, and treating waste streams. However, designing sustainable bioremediation solutions, including those targeted at emerging micropollutants, is a major scientific challenge. The conceptual simplicity of bioaugmentation and attractiveness is deceptive, especially for single microbial strains. Microbiologists still have very little knowledge of the traits and conditions that need to be met to allow survival and population growth of non-native microbes introduced into foreign ecosystems. The few studies that have measured the metabolic activities of inoculated bacterial strains in complex ecosystems have unveiled how divergent the biochemistry becomes in field conditions compared with the laboratory. Transposon library selection and sequencing have further shown just how many specific traits determine survival and proliferation in, for example, soil compared with the well-controlled conditions in the laboratory. Detailed experiments will be crucial for unraveling stress and resistance responses in inoculated strains and consortia and will be necessary to understand how productive metabolic traits can be deployed in order to functionally complement and restore contaminated ecosystems.

Genomic and allied technologies will permit better characterization of the prevailing resident microbial



Prospects for Harnessing Biocide Resistance for Bioremediation and Detoxification (Continued)

community in contaminated sites and inform community composition, xenometabolic potential, and adaptive capacity to adverse conditions. Meta-omic site diagnosis will provide inputs for advanced biogeochemical models. Such insights could be applied to diagnosing microbial communities for xenometabolic function at contaminated sites and for forecasting the success of specific measures, such as biostimulation or bioaugmentation, for accelerated bioremediation. Models could be expanded to address the potential roles of protozoan grazers and phage parasites that regulate microbial populations. For example, although phages can infect and eradicate populations of key detoxifier strains, they can also facilitate horizontal distribution of genes essential for bioremediation and as such promote degradation capacity.

Read more about this article at: <https://science.sciencemag.org/content/360/6390/743?intcmp=trendmd-sci>

North Carolina girl finds megalodon shark tooth buried on beach: 'Is this a dream?'

A middle school girl stumbled upon a buried treasure while spending her spring break on a beach in North Carolina. Avery Fauth and her family love to scour the sand for shark teeth whenever they're on a beach. But Fauth attributes her recent prehistoric find — a megalodon shark tooth — on North Topsail Beach to luck. "I'm looking around and I see something buried in the sand," she told WECT. "I uncovered it and it keeps coming, and it's this big tooth, and then I hold it up and I'm screaming for my mom."

GREAT WHITE SHARK REVEALS RAZOR-LIKE TEETH AS IT ATTEMPTS TO CHOMP PHOTOGRAPHER'S CAMERA

Fauth's dad got the family interested in searching for shark teeth. "I was pretty surprised [that she found one]," he told the news station. "I've been looking for 25 years and I haven't found anything." "I was really shocked and excited for her that she found something that big," he added. Fauth was also surprised by the find. "I was just like, 'Is this a dream?' because I didn't believe I found it," she said. "They're really rare to find and they're some pretty big teeth and they're pretty cool."

GREAT WHITE SHARK WEIGHING 1,668 POUNDS SPOTTED OFF FLORIDA PANHANDLE, RESEARCHERS SAY

The megalodon, considered one of, if not the largest marine predator to ever live, had enormous teeth — some approaching nearly 8 inches in length. According to a study published in March, the giant shark spent millions of years sharpening its teeth to become a better predator. Another recent study, published in February, suggests the megalodon died off around 3.6 million years ago, roughly 1 million years sooner than initially thought. That study also hypothesized that competition from the great white shark contributed to the megalodon's extinction. Read more about this article at: <https://www.foxnews.com/science/megalodon-shark-tooth-north-carolina-beach>





April 2019 Atlanta Geological Society PG Candidate Workshop

Date: Saturday, **April 27, 2019**
Time: 10:00 am to 12:00 pm
Venue: Fernbank Science Center
(check-in with the receptionist for the specific classroom location)
156 Heaton Park Drive, N.E.
Atlanta, GA 30307
678-874-7102
<http://fsc.fernbank.edu/>

Speaker: Abigail Knapp

Subject: **Petrology**

Abigail graduated with MS in hydrogeology from UGA. Her interests include modeling, Hydrology and hydrogeology, and igneous petrology.

Abigail will present the basics of igneous petrology with a focus on major igneous rocks types and the minerals which define them. We will begin with the basic tectonic settings and processes of igneous rock formation as a foundation, after which we will link the lava types with the minerals which cool from them. We will go over the fundamental chemistry of growth rates, fractionation, and the Bowen's Reaction Series.

In addition to theory, we will review how to identify and classify igneous rocks in hand sample and thin section using their mineralogy and textures we will also review the use of phase diagrams and other useful tools for igneous petrology and geochemistry

Please join us and feel free to forward this announcement to anyone that might be interested.

Two Professional Development Hours will be offered and everyone is invited to attend. AGS Membership is not required, but certainly. Go to our web site (atlantageologicalsociety.org) or Facebook page for more info. An application form is attached

Atlanta Geological Society
Professional Registration/Career Development Committee
Ken Simonton, P. G., kws876@gmail.com
Ginny Mauldin-Kenney, ginny.mauldin@gmail.com



Fernbank Events & Activities

Geology Rocks

Monday, April 22, 2019 2:30 PM

Celebrate Earth Day and discover how the rocks of Georgia formed with hands-on experiments and touchable specimens.

Atlanta City Nature Challenge

Friday, April 26, 2019 12:00 AM

Join a city-wide initiative to document Atlanta's unique biodiversity.

Ranger Explorations

Friday, April 26, 2019 1:00 PM

Join a Fernbank Ranger for fun and informative outdoor activities in WildWoods, presented as part of the 2019 City Nature Challenge!

Atlanta City Nature Challenge

Saturday, April 27, 2019 12:00 AM

Join a city-wide initiative to document Atlanta's unique biodiversity.

Past Meets Presence: Yoga + Meditation with Elizabeth Rowan

Saturday, April 27, 2019 8:30 AM

Practice presence under the world's largest dinosaurs in Giants of the Mesozoic.

Ranger Explorations

Saturday, April 27, 2019 1:00 PM

Join a Fernbank Ranger for fun and informative outdoor activities in WildWoods, presented as part of the 2019 City Nature Challenge!

Atlanta City Nature Challenge

Sunday, April 28, 2019 12:00 AM

Join a city-wide initiative to document Atlanta's unique biodiversity.

Fernbank Forest Bird Walk

Sunday, April 28, 2019 9:00 AM

Join an Atlanta Audubon Society volunteer and discover more about the feathered inhabitants of Fernbank Forest, both permanent residents and visitors.

Tadpole Tales

Sunday, April 28, 2019 11:30 AM

Preschoolers will enjoy a story and special activity with a Fernbank educator.

Ranger Explorations

Sunday, April 28, 2019 1:00 PM

Join a Fernbank Ranger for fun and informative outdoor activities in WildWoods, presented as part of the 2019 City Nature Challenge!

Geology Rocks

Sunday, April 28, 2019 3:00 PM

Discover how the rocks of Georgia formed with hands-on experiments and touchable specimens.

Atlanta City Nature Challenge

Monday, April 29, 2019 12:00 AM

Join a city-wide initiative to document Atlanta's unique biodiversity.

Ranger Explorations

Monday, April 29, 2019 1:00 PM

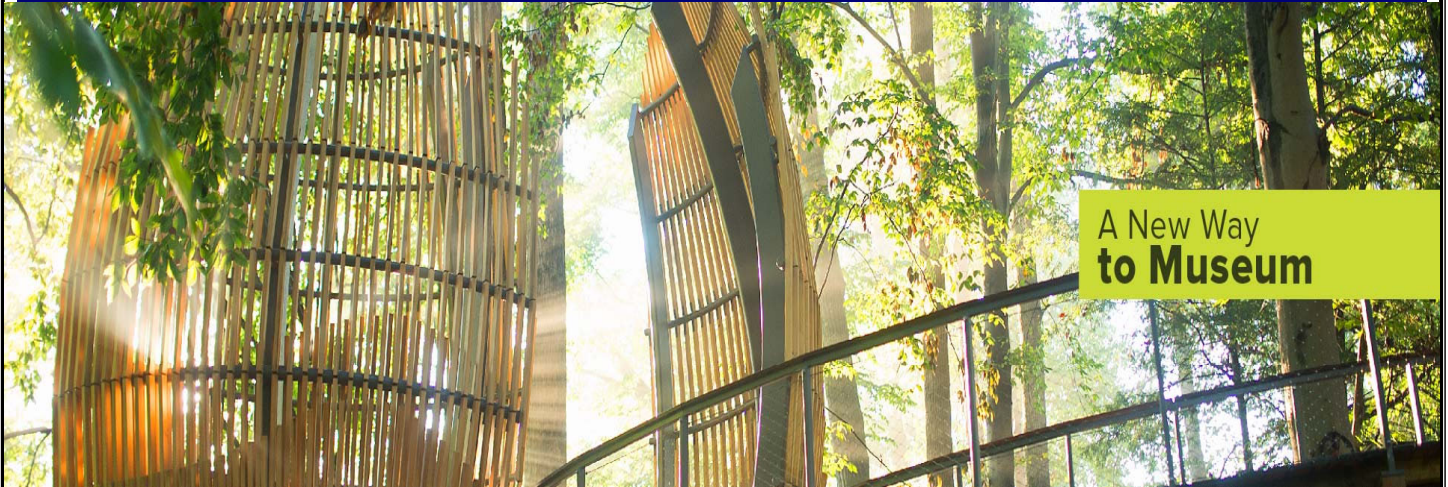
Join a Fernbank Ranger for fun and informative outdoor activities in WildWoods, presented as part of the 2019 City Nature Challenge!





FERNBANK MUSEUM

of NATURAL HISTORY



A New Way
to Museum



A New Way to Museum

Take a walk on the wild side as you explore 75 acres of new outdoor nature adventures. WildWoods and Fernbank Forest combine to highlight the natural world through immersive trails, educational programming, hands-on exhibits and beautiful scenery.

New for Summer! Experience the wonders of nature on Fernbank's giant 4-story screen with Backyard Wilderness 2D, and enjoy hands-on nature adventures outside in WildWoods.



Pterosaurs: Flight in the Age of the Dinosaurs

On view February 9 through May 5, 2019

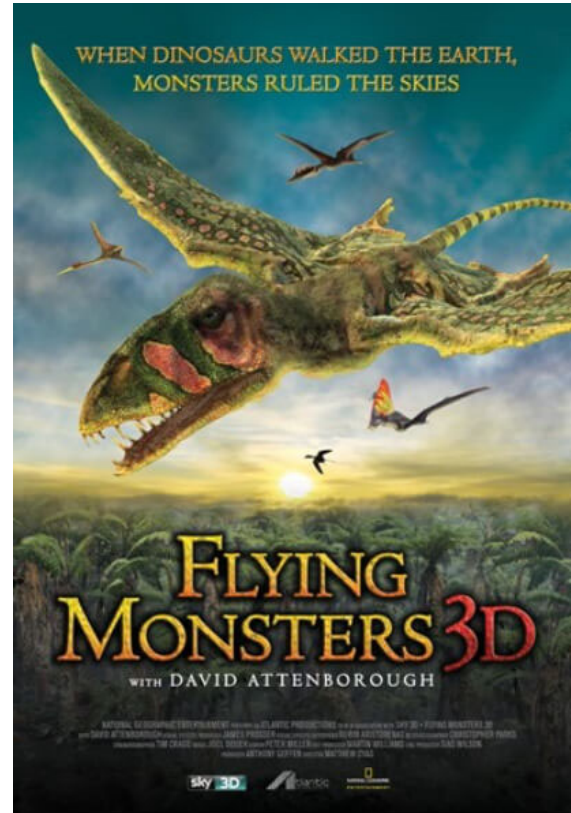
Neither dinosaur nor bird, pterosaurs flew with their fingers, walked on their wings, and ruled the skies. Journey through the Mesozoic Era with the largest flying animals that ever lived. This immersive exhibit includes remarkable rare fossils and casts, hands-on and digital interactives, enormous life-sized models, stunning dioramas and iPad stations with a custom app allowing guests to personalize their experience.



FERNBANK MUSEUM of NATURAL HISTORY

Fernbank Museum of Natural History
(All programs require reservations, including free programs)

Now showing in the Fernbank IMAX movie theater:



Superpower Dogs 3D

Opens May 17, 2019

Experience the life-saving superpowers and extraordinary bravery of some of the world's most amazing dogs. In this inspiring true story, our best friends are also real-life superheroes. Journey around the globe to meet remarkable dogs who save lives and discover the powerful bond they share with their human partners. *Run time: 45 minutes*

Flying Monsters 3D

Showing January 11 through May 30, 2019

Travel back in time to a world where pterosaurs ruled the sky. Naturalist David Attenborough takes viewers on a journey to explore why these prehistoric reptiles took flight, how they changed over time and why they went extinct. *Run time: 40 minutes | Assisted listening devices are available; Closed captions are not available.*



AGS Committees

AGS Officers

President: Ben Bentkowski

bbentkow@gmail.com

Phone (770) 296-2529

Vice-President: Steven Stokowski

sstokowski@yahoo.com

Secretary: Rob White

Phone (770) 891-0519

robeth@bellsouth.net

Treasurer: John Salvino, P.G.

Phone: 678-237-7329

johnsalvino@bellsouth.net

Past President

Shannon Star George

shannonsgeorge@gmail.com

AGS 2019 Meeting Dates

Listed below are the planned meeting dates for 2019. Please mark your calendar and make plans to attend.

2019 Meeting Schedule

April 30

May 28

June 25

PG Study Group meetings

April 27

May 25

June 29

July 27

AGS Publications: Open

Career Networking/Advertising: Todd Roach

Phone (770) 242-9040, Fax (770) 242-8388

tdr@piedmontdrilling.com

Continuing Education: Open

Fernbank Liaison: Miranda Gore Shealy

Phone (404) 929-6341

Miranda.Shealy@FernbankMuseum.org

Doug John

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Doug.John@FernbankMuseum.org

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kws876@gmail.com

Ginny Mauldin-Kenney,

ginny.mauldin@gmail.com

Teacher Grants: Bill Waggener

Phone (404) 354-8752

waggener80@yahoo.com

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Membership: Burton Dixon

Dixonburton1@gmail.com

Social Media Coordinator: Carina O'Bara

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Newsletter Editor: James Ferreira

Phone 508-878-0980

Ferreira.02767@gmail.com

Web Master: Ken Simonton

kws876@gmail.com

www.atlantageologicalsociety.org



ATLANTA GEOLOGICAL SOCIETY

www.atlantageologicalsociety.org

ANNUAL MEMBERSHIP FORM

Please print the required details and check the appropriate membership box.

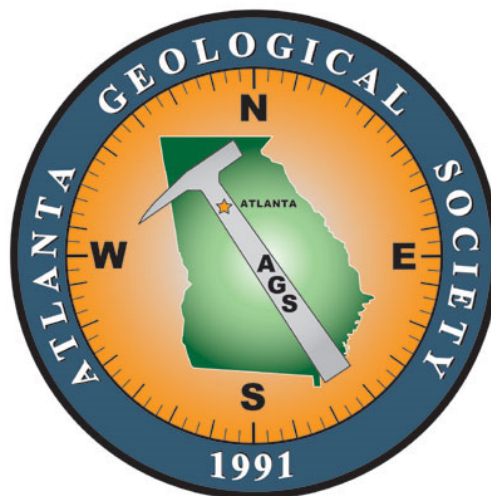
DATE: _____

NAME: _____

ORGANIZATION: _____

TELEPHONE (1): _____ TELEPHONE (2): _____

EMAIL (1): _____ EMAIL (2): _____



STUDENT \$10 ☐

PROFESSIONAL MEMBERSHIP \$25 ☐

CORPORATE MEMBERSHIP \$100 ☐

(Includes 4 professional members, please list names and emails below)

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

NAME: _____ EMAIL: _____

For further details, contact the AGS Treasurer:
John Salvino johnsalvino@bellsouth.net

Please make checks payable to the "Atlanta Geological Society" and bring them to the next meeting or remit with the completed form to:

Atlanta Geological Society, Attn: John Salvino
3073 Lexington Avenue
Woodstock, Georgia 30189

To pay electronically; click
<https://squareup.com/store/atlanta-geological-society>