LEAD LINGERS IN FOLK REMEDIES

NASA TURNS 60

INDONESIA TACKLES HAZARD PREPAREDNESS

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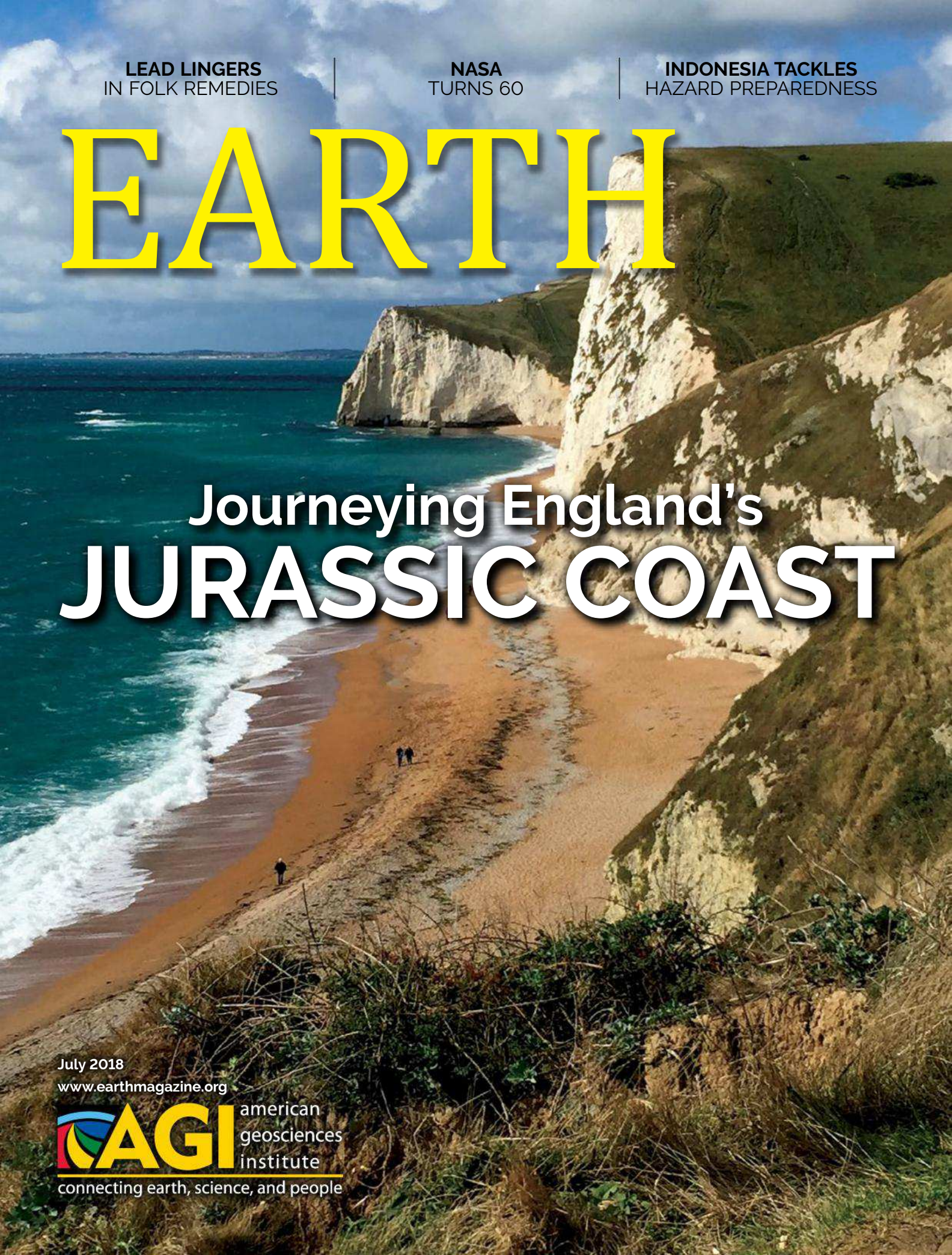

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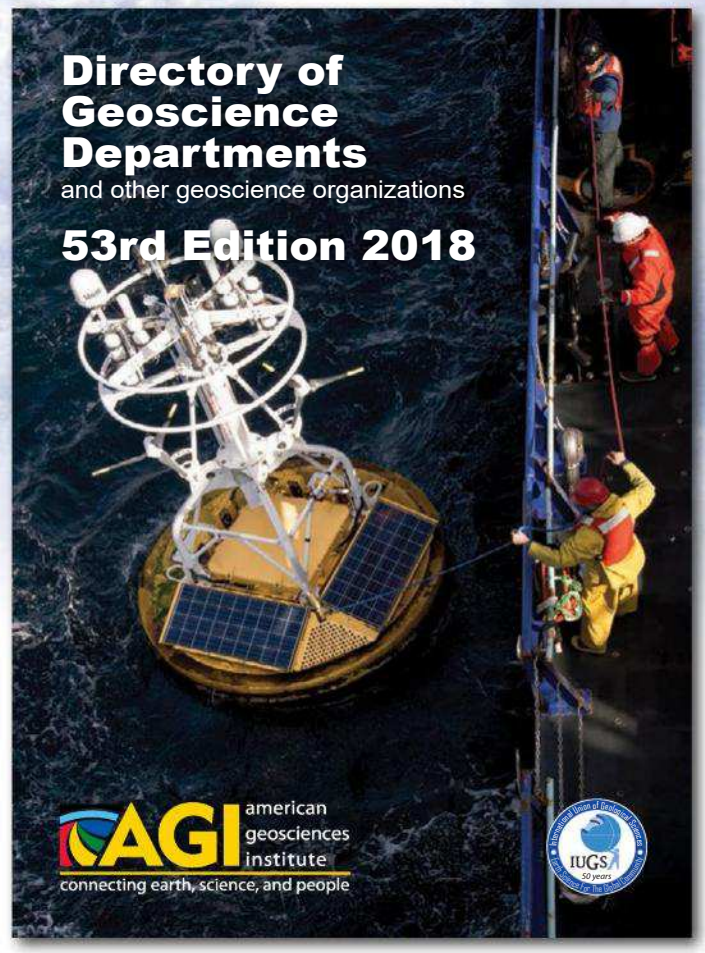

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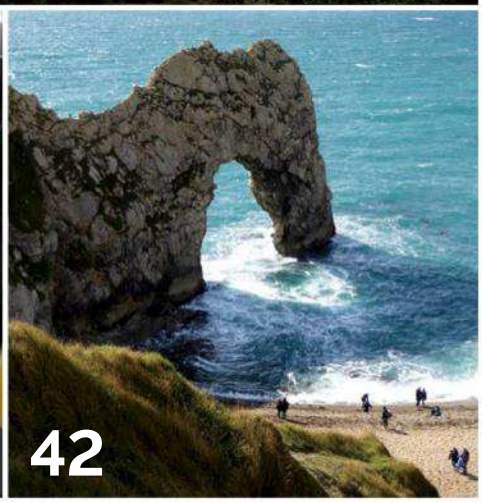

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ON THE COVER: The famous fossiliferous cliffs of England's Jurassic Coast. Credit: Terri Cook and Lon Abbott

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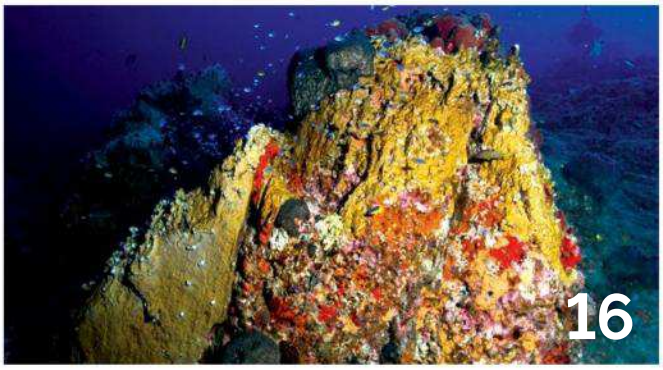

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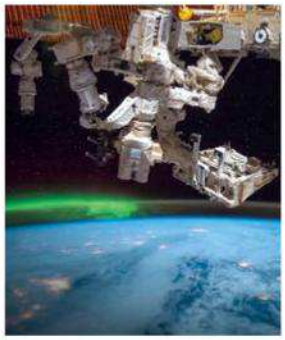

When I was an elementary school student in the 1970s, my family moved from an apartment into our first house. I was excited, as I would have a new bedroom and a wooded backyard in which to play — though I lost the ready crowds of kids at our apartment complex. But I was confused when, soon after the move, I was relocated to the basement for a couple of weeks. The decree came from my mother, who was worried that our decades-old house was slathered in lead paint. I recall being aware of the switch from leaded to unleaded gasoline around the same time, and I had heard about lead in paint. But the issue became real for me when my mother's concern grew. So, off it all came — layer after layer of chipping paint and peeling wallpaper — with my help. I guess my parents hadn't entirely thought through the lead hazard! Eventually, we applied new layers of latex paint to the stripped walls, and I could at last settle into my new life.

Credit: David Brodbeck, CC BY 2.0

In the U.S., the '70s were something of a cultural heyday for lead as a villain. It was a time when the dangers of lead ingestion, particularly to children, finally came to the fore, resulting in broad public health campaigns and a string of legislative efforts that, ultimately, were very successful in curtailing lead poisoning in the country.

So, it was with fascination that I read EARTH roving correspondent Mary Caperton Morton's feature, "Toxic Treatments: Lead Lingers in Folk Remedies," about "atypical" sources of lead exposure — namely, folk products used as cosmetics and medicines — that continue to impact the lives of people in this country and elsewhere. Today, the use of such treatments by those unaware of the risks they pose is no more malicious or neglectful than prior generations' unwitting uses of lead-laced products. In the past, society acted on evidence to change the culture of lead use, and it must continue to do so. It is heartening to see medical geology inform our own culture and others, and help bring about change for the better based on hard-learned lessons.

If you are looking for a different cultural journey this month, then venture down England's Jurassic Coast in this month's Travels in Geology, or read about how both official efforts and local wisdom are impacting disaster preparedness in Indonesia.

Christopher M. Keane, Ph.D.
EARTH Executive Editor

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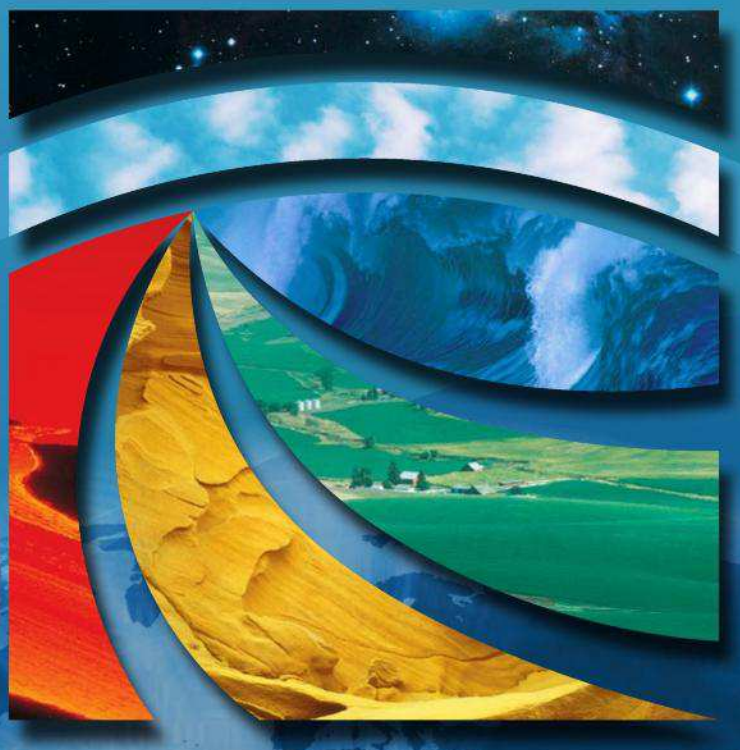

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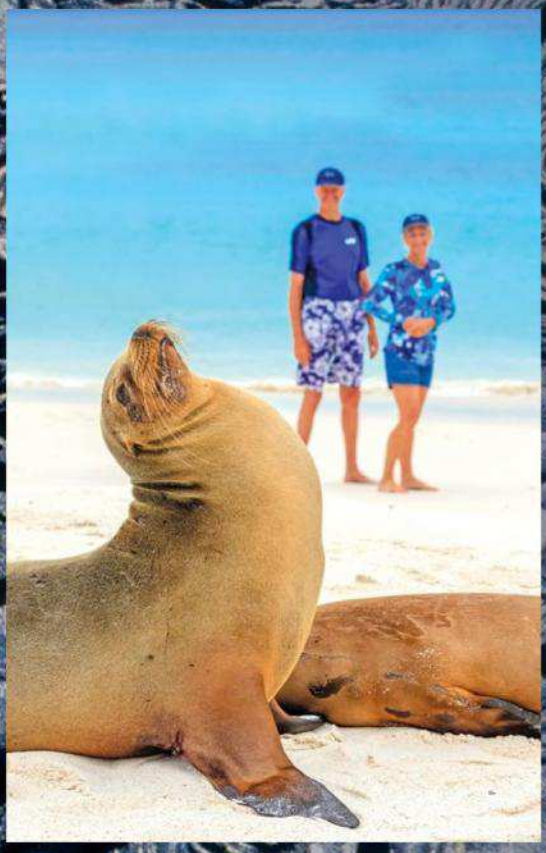

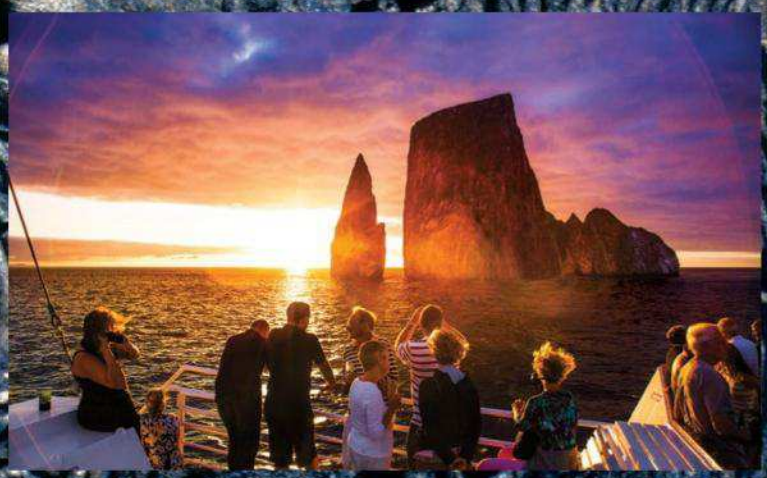

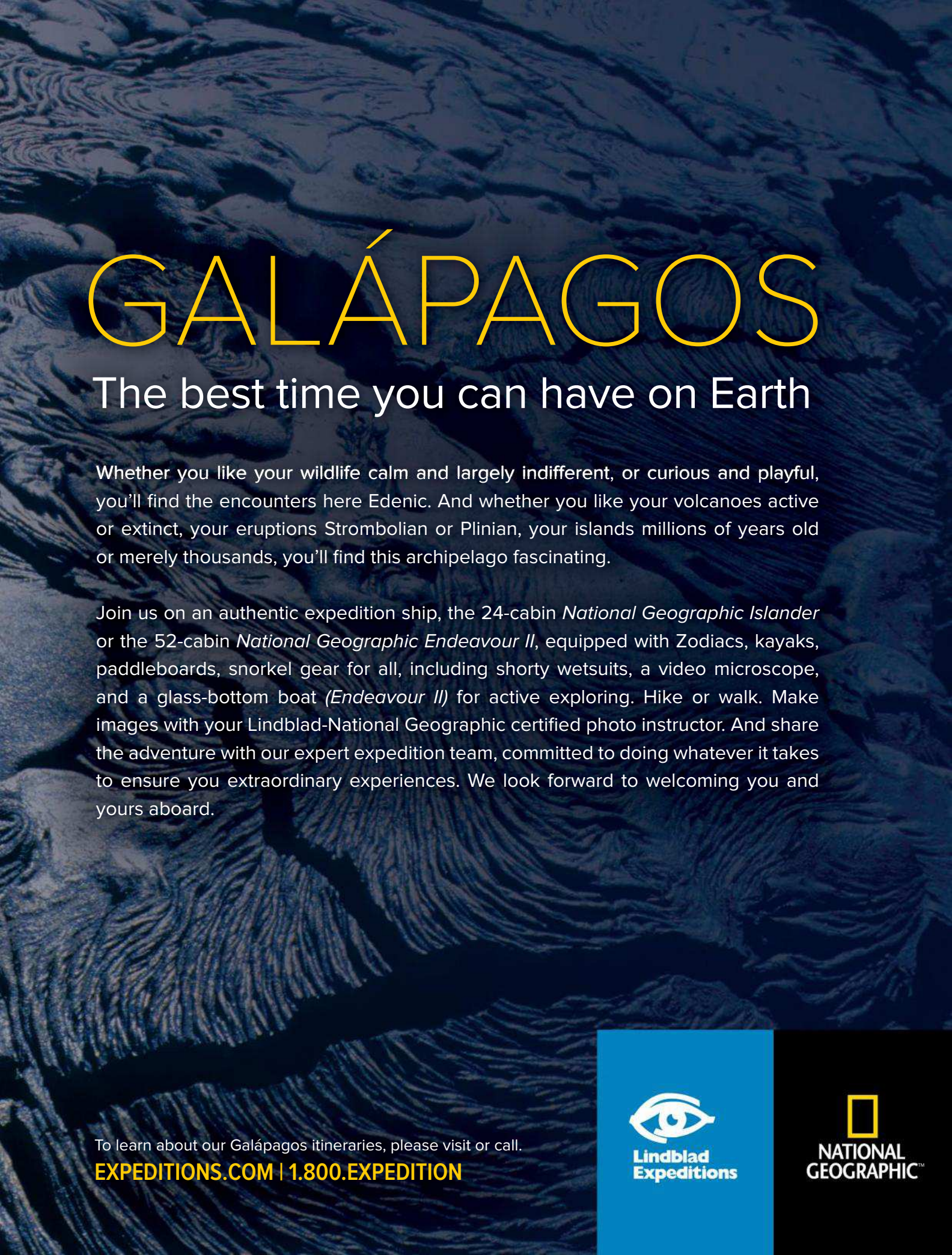

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The Changing Shape of Local Climates

David Stainforth

Earth's climate is changing. Increasing atmospheric greenhouse gas levels inevitably result in more heat being trapped in the lower atmosphere, the oceans and the land surface. But what does that mean where you are? What are the local consequences of global climate change? And what are the implications for decisions about how to adapt — decisions related to building design or flood protection measures, for example?

Most current efforts to understand and predict local consequences of global climate change use climate models. It is a challenge because local climates can respond in many ways to increasing global heat content, and such responses can vary considerably from one community to the next. Consequently, making reliable predictions about local climates places a high demand on the realism of computer models over a wide range of scales.

A complementary approach is to study historic changes using observational data. This is an approach that colleagues and I have pursued in recent years.

I don't want to imply that observational analyses can provide predictions.. Observations help us understand and assess models, but they also offer insights directly, potentially allowing us to make more robust decisions about adapting in the face of climate change.

The tricky part about using observational data to look at climatic trends is that we don't observe or experience climate directly; we experience weather. You can think of climate as the distribution of potential weather conditions. Different conditions have different likelihoods of occurring, with closer-to-average conditions — average temperatures, winds or precipitation amounts, for example — usually more likely than outlying conditions. So, overall, climate can be represented by distribution curves that describe the probabilities of different conditions; these curves might be simple if portraying a single facet of climate, like temperature (see Figure 1), or they can be complex if representing multiple facets simultaneously.

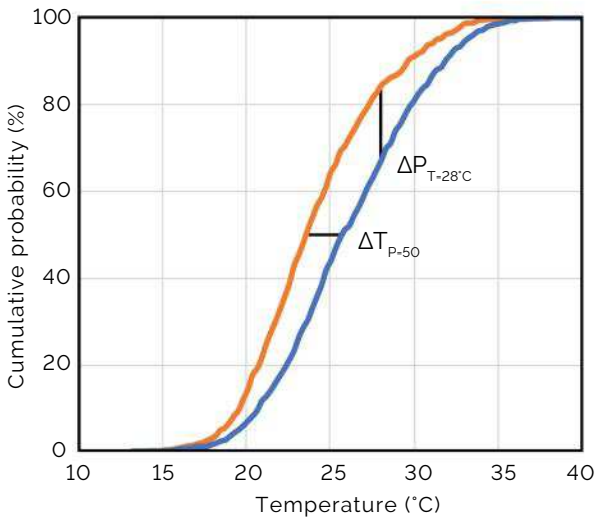

Figure 1. These cumulative distribution functions (CDF) represent the probability (P) of the maximum summer daytime temperature (T) around Bordeaux, France, being below a given temperature on the x-axis for the years 1950-1959 (orange) and 1993-2001 (blue). The separation between the two curves indicates a change in local climate between the two nine-year periods. For instance, median summer days (probability of 50 percent) warmed about 2 degrees Celsius (horizontal black bar), while the probability of the maximum temperature being below 28 degrees decreased from 83 to 66 percent (vertical black bar). Note that warmer days generally warmed more than cooler days (though the effect decreases for very hot days), indicating a change in the overall shape of the distribution rather than a consistent increase in temperature for all types of days.
Credit: K. Cantner, AGI; data courtesy of David Stainforth

Climate change alters the shapes of these distributions. For example, average daytime temperatures could increase. Or average nighttime temperatures could increase. Or both. The change could manifest as increased odds for extremely hot days and decreased odds of "typically" hot days, while the rest of the distribution stays pretty much the same. Each of these shifts would change the shape of a given climatic distribution in different ways, and changes to specific parts of a distribution are not necessarily related to a change in the average conditions. To understand if and how a local climate has changed, we need to quantify changes across the whole distribution, not just in the average.

One difficulty in using weather observations to look for signs of local climate change is that the relatively short timescale over which recent, anthropogenic climate change has been occurring fundamentally restricts how well we can resolve changes.

To construct a climatic distribution from observations, we want to use as much data as possible so as not to be misled by sampling biases or outlier conditions. For instance, an unusually hot summer, if not averaged together with a sufficient number of other summers, can skew the overall shape of a distribution, such that the conditions portrayed by that distribution are not truly representative of longer-term climate. That means we must combine data from observations over multiple years.

In many locations we have daily weather observations dating back to the 1950s, and some processed datasets spatially interpolate these observations to provide time series of daily data gridded on a scale of roughly 50 kilometers — not quite "local" perhaps, but getting close. By using data from these time series — from 1950 to present day — we can extract the

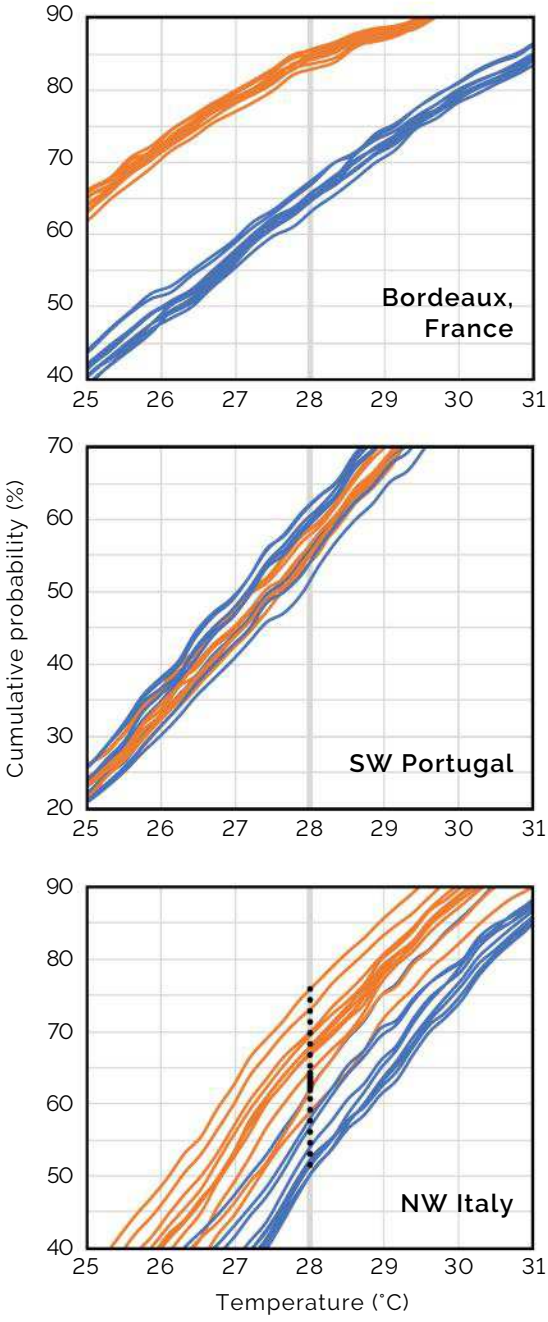

Figure 2. Comparing multiple pairs of CDFs offers a more robust picture of actual climatic change compared to any single CDF pair. Each curve again represents data from a nine-year period — orange and blue curves represent distributions from the 1950s-1960s and 1990s-2000s, respectively — and each pair is separated by 43 years, as in Figure 1. (Note that the x and y scaling is different relative to Figure 1.) Near Bordeaux (top), the climate at the 28-degree Celsius threshold has clearly changed. In southwestern Portugal (middle), the climate at this threshold has clearly not changed. In the Piedmont of northwestern Italy, there is no clear indication of the scale of any change because the smallest 43-year change is small (vertical solid black bar) while the largest change is large (vertical dashed black bar).
Credit: K. Cantner, AGI; data courtesy of David Stainforth

climatic distribution representative of that period for any available location. Or, we can extract distributions representing seasonal climates by only using data from certain months — say June, July and August if we want to look at the boreal summer climate.

If the climate weren't changing, then such distributions would represent the climate today as accurately as they represent the climate in the '50s or anytime in between, and they'd be a good basis for making climate-sensitive decisions today. But we know that climate is changing globally, so we expect that local climates in most locations are also changing. Thus, we do not expect distributions built from data from the last 60-plus years to be representative of climate today. The challenge is to figure out how to use the available data to reveal how and where local climates are changing.

As a starting point, instead of using a whole 1950s-to-today dataset, we can compare portions of the data — say the nine years beginning in 1950 and the nine years beginning in 1993. Figure 1 shows distributions of daytime summer temperatures around Bordeaux, France, for those two time periods. The fact that the two curves do not overlap suggests that the climate near Bordeaux — at least with respect to the distribution of daytime summer temperatures — did change significantly in the latter half of the 20th century. In fact, the figure indicates that warmer temperatures were more likely across all types of summer days, from relatively cool days to average days to warm days.

Comparing two discrete time periods like this — rather than comparing single years — gives us a more accurate idea of how a local climate has changed. But it's difficult to know just how accurate, in part because there is always the possibility that the sampled time periods still do not represent the underlying climate conditions because of natural variability. It would be nice to be able to compare conditions between two longer time spans — perhaps each 20 years long instead of nine, for example — but this is where the short overall timescale of recent global climate change bites us: the longer the time spans compared, the smaller the separation between them and the harder it is to identify signals of change.

One way to address this issue is to compare multiple pairs of distributions (Figure 2), with each pair separated by the same amount of time. In the example of Bordeaux, instead of just comparing two nine-year distributions beginning 43 years apart in 1950 and 1993, we can also compare the nine-year distributions beginning in 1951 and 1994, 1952 and 1995, and so on. Considering all these comparisons simultaneously shows us how much uncertainty there is among the distributions themselves, and gives us a more robust picture of the change that occurred compared to any single comparison between nine-year periods.

Unfortunately, the short duration of the last 60 to 70 years — the most interesting period to study with respect to climate change because it's seen the fastest recent increases in global average temperature and atmospheric carbon dioxide concentrations — creates friction between clarifying signals of change, providing the essential context of natural variability, and resolving the distributions. That's the challenge of observing local climate change.

So, what do the data reveal when we carry this exercise through? In Bordeaux

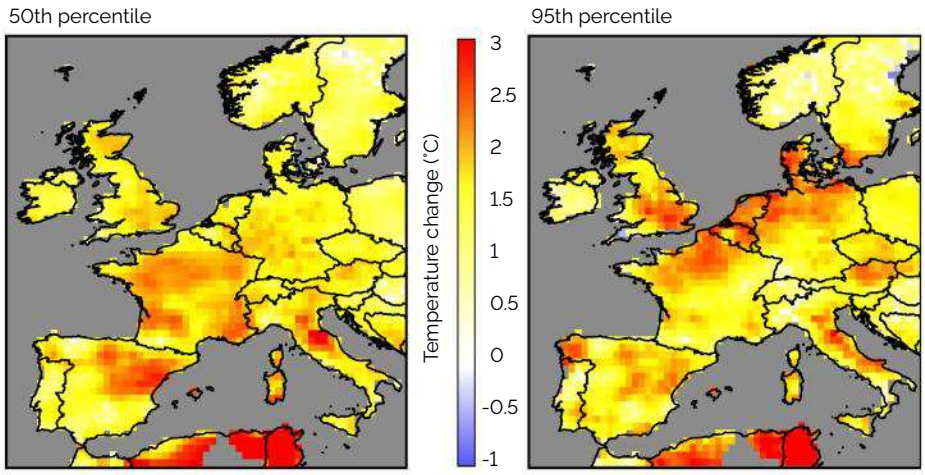

Figure 3. These plots show the smallest change in local summer daytime temperatures across 10 pairs of nine-year distributions (each pair is separated by 43 years) for average, 50th-percentile days (left), and for hot, 95th-percentile days (right). The character of climate change is different from place to place, but large-scale features can be seen. Identifiable warming of hot summer days, for example, is greatest in a band across Northern Europe, while for average summer days, warming is farther south, particularly in parts of France, Italy and Spain. The large changes indicated in North Africa are unreliable because the results are based on data from only a small number of observing stations. Credit: K. Cantner, AGI; data courtesy of David Stainforth from analysis of the E-OBS gridded datase

(Figure 2, top), we see that the increase in daytime summer temperatures in the late 20th century was not only large but also robust — all the sample pairs reveal the same message. For example, the probability of the temperature exceeding 28 degrees Celsius — a threshold in some countries relevant for building design and management — rose from about 16 to about 35 percent. The results were different elsewhere, however. The same comparison for southwestern Portugal (Figure 2, middle) showed a small or nonexistent increase in the likelihood of days above 28 degrees, but the picture was again robust. In Northwest Italy (Figure 2, bottom), meanwhile, some pairs of distributions indicated a large change and others showed a small change, so the picture of climate change there is less clear because the variability in the distributions is itself large. (But at least we know that we don't know, which is itself potentially useful.)

To support practical decision-making with respect to climate change adaptation on local scales, it's helpful for researchers to focus on specific thresholds — like changes in the probability of days above 28 degree Celsius — and locations. But it is nevertheless interesting to look at patterns of change over larger regions.

Figure 3 summarizes changes in summer daytime temperatures across Europe using the same sort of analysis as described above — that is, comparing multiple pairs of nine-year distributions from the mid- and late 20th century. The figure shows local changes in two different thresholds: how much temperature has increased on an average (50th percentile) summer day; and how much it has increased on hot (95th percentile) days, for which only one in 20 days is hotter. In each grid square on the maps, what's plotted is the smallest change seen from 10 pairs of distribution curves. This is a conservative approach: Where the change shown on the map is large (orange to red), we can be confident that there has actually been a significant change in summer daytime temperatures at that location (e.g., at least a roughly 2-degree increase on average summer days around Bordeaux in southwestern France). However, small changes on the map indicate either that there has been little change or that there is large variability in the differences between multiple pairs of distribution curves, so we can't identify the change clearly with this method alone. Despite that shortcoming, the maps reveal interesting patterns in the changes in local climates. For example, hot summer days are clearly warming most in a band across Northern Europe, with increases of more than 2 degrees Celsius common, while warming of average summer days is centered farther south. The maps indicate significant warming at both thresholds in eastern Spain and eastern Italy.

This approach to using observational data focuses on identifying the character of changes in local climate over roughly the last 60 years. It reveals how these changes vary substantially from one place to another, even within relatively small areas. And it could be used to support decision-making that's more robust and relevant to both today's climates and those of the future.

In practice, many climate-relevant decisions are based not just on temperature but also on other variables. The approach described here has already been extended to identify changes in rainfall, including how much, or what fraction of, rain comes from events of particular intensities.

Changing climate can be experienced in very different ways in locations that may be quite close to one another. Although there are fundamental challenges to deciphering information about changing local climates from climatic distribution curves based on observational data, it is nevertheless often possible to extract useful, threshold-specific information. An important next step in this line of work is to focus on decision-specific vulnerabilities so that these data analysis methods can be used to improve the robustness and resilience of our societies.

Stainforth is a professorial research fellow at the Grantham Research Institute on Climate Change and the Environment and co-director of the Center for the Analysis of Time Series at the London School of Economics and Political Science. He also holds a visiting position at the University of Warwick. The views expressed are his own.

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Cretaceous volcanic ash seeded U.S. oilfields

Petroleum and natural gas stores are often found amid rocks — particularly ashbeds — deposited during the Cretaceous, when dinosaurs roamed Earth and abundant volcanic arcs lined the edges of the continents.

"Some regions of the [U.S.], particularly areas where fracking happens, have a lot of ashbeds," says Cin-Ty Lee, a geochemist at Rice University in Texas. "Why is there this association?"

In a new study published in Scientific Reports, Lee and his colleagues suggest an answer: The abundant ash spewed by those many Cretaceous volcanoes fertilized the ocean, fueling the productivity of huge phytoplankton blooms that would later become crude oil and shale gas.

Lee and his team sampled ash layers from a 13-meter-thick section of the uppermost Eagle Ford Shale and lowermost Austin Chalk formations exposed in a roadcut along Highway 90 near Osman Canyon, Texas. Those rocks formed about 100 million years ago, when much of western North America lay beneath a shallow ocean. "There's so much ash there — these beautiful records of continuous ashfalls," Lee says.

A new study using samples from this outcrop — exposing the contact between the Cretaceous Eagle Ford Shale and Austin Chalk formations near Osman Canyon, Texas — suggests the abundant oilfields of the western United States may owe their existence to Cretaceous volcanic ash. Credit: Cin-Ty Lee

Lee's team analyzed the compositions of the ash and found that the rocks were missing a lot of iron, phosphorus and silicon. "The ashes are so altered that they don't look anything like when they originally left the volcano," Lee says, suggesting these elements, which are nutrients for plankton, likely leached from windblown ash that landed in the ocean.

To estimate the amounts of these nutrients that ended up in the ocean from mid-Cretaceous volcanic ash, Lee's team first needed to understand the composition of the parent material. The researchers measured titanium and zirconium to trace the ash they'd sampled back to its volcanic source. They could then calculate how much of the iron, silica and phosphorus in the original ash source was missing from the ash that ultimately deposited.

They determined that 75 percent of the iron, phosphorus and silicon originally in the ash never reached the ocean bottom, but instead leached into the water. During the Cretaceous, about 10 times more phosphorus was entering the ocean from volcanic ash than today.

"This is potentially a very large flux of nutrients into the oceans," Lee says. The high levels of nutrients would've led to blooms of phytoplankton, which, when they died, decayed and sank, would've sucked up much of the oxygen deep in the water column, potentially creating dead zones. Anoxic conditions at the seafloor would've then preserved much of the residual organic material, which was eventually buried and converted to oil and gas.

While many studies have focused on how volcanic activity during this time influenced the ocean, few have considered the specific impacts of continental volcanic arcs, says Timothy Lyons, a biogeochemist at the University of California at Riverside, who was not involved in the study. The findings offer new evidence for how ash impacted the ocean during the Cretaceous Period.

A hundred million years ago, the planet was much warmer and more volcanically active than it is today. This greenhouse Earth was characterized by a lack of glaciers and high atmospheric carbon dioxide levels. Additionally, up to 10 percent of the ocean was anoxic, compared to just 1 percent today.

All of these conditions mean that nutrients were abundant in the ocean, and the burial of organic material was favored. "It was an important time for petroleum source beds," Lyons says. "This work is an important and valuable piece of a larger puzzle."

Bethany Augliere

Giant ichthyosaur one for the record books?

A 205-million-year-old jawbone found on an English beach belonged to a Late Triassic ichthyosaur that might have stretched up to 26 meters long, comparable to one of the largest animals ever to exist: blue whales. Researchers could not identify the species of the aquatic giant from the jawbone alone, but comparisons of the fossil to bones in more complete ichthyosaur skeletons allowed them to approximate the animal's size.

Lomax et al., PLOS ONE, April 2018

India's urban areas punch city-shaped holes in fog

Air pollution boosts fog formation in some places, creating whiteouts that can affect air and ground transportation, air quality, and public health. In northern and eastern India, persistent fog often hovers over the Indo-Gangetic Plain, a vast region dotted with several densely populated cities, including Delhi, home to 19 million people. Over some of these cities, however, satellite imagery is revealing large holes in the fog.

In a new study in Geophysical Research Letters, researchers attribute the fog holes to the urban heat-island effect: Cities are often significantly warmer than surrounding rural areas because concrete and other building materials absorb more sunlight — and subsequently radiate more heat — than bare ground and plants. Heat islands warm the lowest zone of the atmosphere, called the boundary layer, and reduce humidity, leaving less moist air available to form fog, the researchers suggest. Drawing upon 17 years of satellite images of the Indo-Gangetic Plain, "we found a very strong correlation between … the population of the cities and the fog hole area [above them]," said lead author Ritesh Gautam of the Environmental Defense Fund in Washington, D.C., in a statement. "We found the largest and most frequent holes in fog over Delhi."

Mary Caperton Morton

Widespread fog blankets northern India in this image captured by the Moderate Resolution Imaging Spectroradiometer on NASA's Terra satellite on Dec. 7, 2016. Fog holes over several major cities are visible.
Credit: NASA

Rolling thunder portends remote eruptions

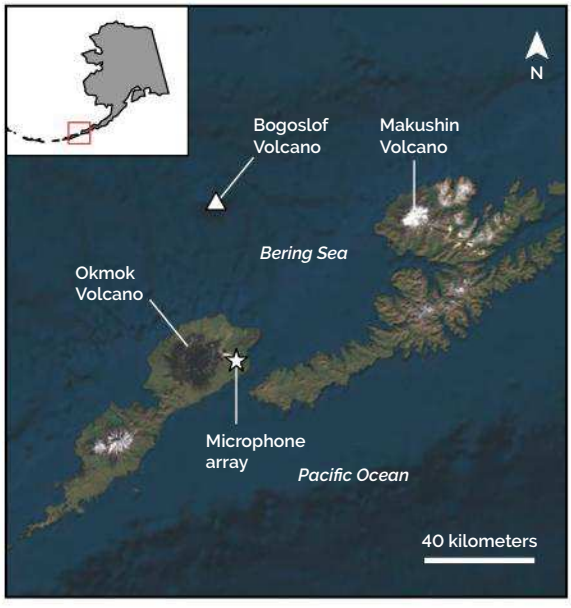
The logistics of monitoring volcanoes located in remote regions, such as Alaska's Fox Islands, can be prohibitive — but monitoring is necessary, as ash clouds billowing from even far-flung volcanoes can make their way into airplane flight paths. Researchers are now proposing an acoustic warning system to detect volcanic ash clouds that would rely on listening for the thunderclaps that often herald these eruptions.

Large, high-ash volcanic eruptions are frequently accompanied by impressive thunder and lightning displays sparked by friction between flying ash particles. Scientists discovered that the thunderous booms can be detected up to 100 kilometers away using an existing global network of very-low-frequency-detecting radio stations.

In a new study, Matthew Haney, of the Alaska Volcano Observatory in Anchorage, and colleagues detected volcanic thunder from two eruptions of Bogoslof Volcano — a predominantly submarine stratovolcano that breaches the ocean surface west of Alaska's Aleutian Islands — using a radio station 60 kilometers away.

In addition to providing a remote means for detecting eruptions, listening to bouts of volcanic thunder may also shed light on the dynamics of volcano plume evolution, since thunder is thought to occur mainly in the later eruptive stages of plume development, the team wrote in Geophysical Research Letters.

Mary Caperton Morton



Researchers detected volcanic thunder from two eruptions of Bogoslof Volcano, a predominantly submarine stratovolcano that breaches the ocean surface north of Alaska's Aleutian Islands.
Credit: K. Cantner, AGI

Yellowstone's Mexican mantle plume

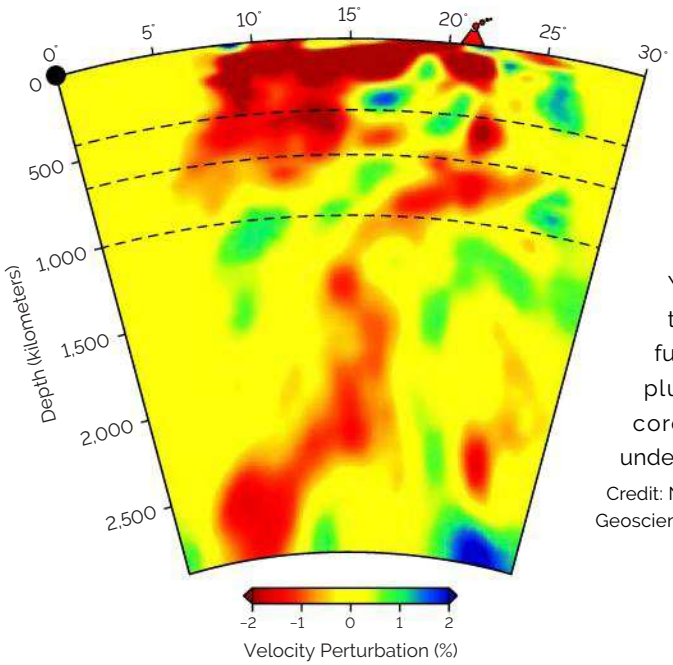
The volcanic activity at Yellowstone National Park is impressive, with thousands of active thermal features dotting a nearly 4,000-square-kilometer caldera. Scientists have long suspected that a massive mantle plume underlies the supervolcano. Now, new imaging has provided the clearest picture yet of the heat source that drives Yellowstone's volcanism.

The existence of mantle plumes under volcanic hot spots such as Yellowstone, Iceland and Hawaii continues to be debated among geologists, with detractors pointing to a lack of concrete geophysical evidence for the hot upwellings arising from deep in the mantle. Imaging Earth's interior is usually accomplished by tracking seismic wave velocities as they move through the crust and mantle — a technique called seismic tomography — but, so far, clear examples of mantle plumes haven't been seen in such imaging.

"Seismic waves travel faster through cold rocks than hot rocks, so if you have something really hot like a large mantle plume, you expect it to slow the waves," says Peter Nelson, a geophysicist at the University of Texas (UT) at Austin and a co-author of the new study in Nature Geoscience. But the type of seismic waves most commonly used in tomography studies — called surface waves, or S-waves — is only slightly slowed by plumes because of the respective orientations of the waves and plumes: S-waves mostly travel horizontally through the mantle and are not slowed down much by vertically oriented mantle plumes, Nelson says.

So, Nelson and co-author Stephen Grand, also at UT-Austin, turned to two other kinds of earthquake waves, called SKS and SKKS waves. (S stands for shear, K for compressional.) "These waves travel more vertically [through the mantle], so they will traverse a plume for a much greater distance than S-waves," thus revealing a lot more about the plume's structure, Nelson says.

Yellowstone is an ideal setting for this kind of study because it's located in the middle of a continent, where a dense seismic network, EarthScope's USArray, has been deployed in recent years. Drawing upon seismic data gathered from 71 earthquakes over a period of 48 months, Nelson and Grand identified a vertically elongated zone of the Earth's mantle where the SKS and SKKS waves traveled more slowly. This 400-kilometer-wide zone appears to be rooted at the core-mantle boundary beneath Mexico, running to the northeast beneath the western U.S. to Yellowstone as it rises through the mantle.



Yellowstone's many thermal features are fueled by a deep mantle plume rooted at the core-mantle boundary under Mexico.

Credit: Nelson et al., Nature Geoscience, 2018

The position of the plume's base south of the California-Mexico border came as a surprise, Nelson says, although previously published models had predicted that the prevailing convective currents of the mantle likely meant the Yellowstone plume would have its roots somewhere southwest of the park. "Why plumes form where they do is an open question. We found a much larger tilt (from southwest to northeast) than expected, but it aligns with what the models have predicted," Nelson says.

The study provides the best look yet at Yellowstone's mantle plume and foreshadows the scope of future work that will be possible with data from the USArray, says Barbara Romanowicz, a planetary seismologist at the University of California at Berkeley, who was not involved in the new study. Instead of focusing on just the S-wave part of earthquake seismograms, "the way of the future is to use the whole seismogram and the whole wave form to study the interior of the planet," she says.

This kind of work requires high-resolution datasets that can only be produced using dense seismic networks, such as the USArray. "Yellowstone presents a unique opportunity to image a plume under a continent. There's probably a plume under Hawaii, and another under Iceland, but we don't have the seismic coverage [from seafloor instruments] to image those," Romanowicz says. Plumes may also exist under Africa and Antarctica, but, again, the seismic detection coverage isn't adequate to produce the high-resolution data needed to image plumes in those locations, she says.

"At this point, I think we can say that the existence of mantle plumes is well established," Romanowicz says. "Now let's focus our efforts on addressing critical questions like: How wide are they? Do they have thermal boundaries, or are they thermochemical? Using the USArray to study Yellowstone, the possibilities are really endless."

Mary Caperton Morton

Weedy seeds gathered in once-green Sahara

Today, the vast and arid Sahara Desert seems an unlikely place to find early signs of seed gathering and plant cultivation in Africa, but new evidence shows that, 10,000 years ago, people were collecting, sorting and saving seeds near a rock shelter known as Takarkori.

Located in what is now southwest Libya in the central Sahara, the Takarkori rock shelter was occupied first by hunter-gatherers, and then pastoralists, between 11,500 and 8,500 years ago, when this region was more verdant. The archaeological site has been excavated for decades. "Takarkori has a unique archaeological record describing the last 10 millennia in a nearly continuous deposit, with fireplaces, penning structures, burials of human skeletons and decorated pottery," says Anna Maria Mercuri, a botanist at the University of Modena and Reggio Emilia in Italy and lead author of the new study, published in Nature Plants.

The Takarkori rock shelter in Libya, nicknamed the Archaeological Mission of the Sahara, was occupied for thousands of years by hunter-gatherers and, later, by pastoralists.
Credit: Archaeological Mission in the Sahara/Sapienza University of Rome

In a four-year-long study at Takarkori spearheaded by archaeologist Savino di Lernia from the Sapienza University of Rome, researchers uncovered millions of artifacts, including more than 200,000 seeds gathered in small circular concentrations. The team ruled out the possibility that the seeds were gathered by ants or other insects, leaving them as "the first unquestionable evidence of early Holocene seed collection in the central Sahara," Mercuri says. The carefully arranged seed assemblages also represent the earliest documented examples of seed selection, transport, planting, cultivation and harvesting — all behaviors associated with the shift from hunting and gathering to the more pastoral lifestyle that preceded the dawn of agriculture.

Analysis of the seeds showed that they were grouped by type and sorted by size, most likely by sieving through baskets, fragments of which were also found at the site. The researchers also found dried plant remains and microscopic pollen grains; some seeds and fruits were still colorful. "The state of preservation of this rock shelter is outstanding," Mercuri says. The team extracted ancient DNA from the grains of millets and wild sorghum. The grains "were so well-preserved that they look shiny and seem modern under the microscope," she says.

Most of the seeds came from wild cereals — a category of grass — that are now extinct in this region. But during the early Holocene, the area sprouted more savannah-like vegetation, including widespread grasses. The wild cereals identified by the team likely grew in clumps near waterways or ponds. Several of the species, including *Echinochloa colona*, *Panicum laetum* and *Dactyloctenium aegyptium*, are still grown elsewhere in Africa today for human consumption.

"In general, grasses are quite edible," says Regina Baucom, a botanist at the University of Michigan in Ann Arbor, who was not involved in the new study. "The bulk of the grain, or endosperm, consists of carbohydrates for the developing embryo, along with proteins, oils and some vitamins, making it a nutritious food source for humans."

Today, wild cereals are often dismissed as weeds — in competition with cultivated plants — but weedy traits would have been advantageous to the first farmers, Baucom says. "Most of the species this team found are highly prolific. They grow fast even in adverse soil conditions and produce a lot of seeds." Wild cereal seeds are also known to have high survival rates over periods of dormancy, so seeds could be saved from one rainy season to the next without germinating or dying.

Previously published paleoclimate studies have shown that the Sahara went through periods of rain and drought. "The wild cereals we identified in Takarkori can adapt very quickly to environmental stress, including climate change and also human interactions, which can also be considered an environmental stress," Mercuri says. "In times of change, these plants were chosen [for cultivation] because they were weeds."

Mary Caperton Morton

Fire coral (*Millepora alcicornis*) covers a rocky pinnacle in Flower Garden Banks National Marine Sanctuary. The reefs, which grow atop salt domes in the Gulf of Mexico, were discovered by fishermen in the early 1900s, and designated a marine sanctuary in 1992. Credit: NOAA

Tracking Hurricane Harvey's freshwater plume

On Aug. 25, 2017, Hurricane Harvey made landfall along the Texas coast as an unexpected Category 4 storm, with maximum sustained winds of 209 kilometers per hour. After rapidly intensifying over the Gulf of Mexico, it hovered over southeastern Texas for days, slowly weakening as it dumped 68 trillion liters of water onto the land — more than three times the volume of the Great Salt Lake in Utah.

That freshwater, potentially loaded with contaminants after flowing across the developed landscape, had to go somewhere. Researchers looking into where and how that immense amount of freshwater would impact the marine environment, including the delicate coral reef of the Flower Garden Banks National Marine Sanctuary about 185 kilometers offshore Galveston, presented their research at the 2018 Ocean Sciences meeting in Portland, Ore., in February.

There were two major concerns regarding this unprecedented amount of freshwater draining into the Gulf of Mexico, says Steve DiMarco, a physical oceanographer at Texas A&M University who led the recent research. First, the freshwater could potentially cause a low-oxygen dead zone, similar to the one that develops every summer off the Louisiana coast, which is fed by nutrient pollution from the Mississippi River. The dead zone would be exacerbated if the less dense freshwater formed a layer atop denser saltwater, resulting in stratification of the water column.

The second concern was whether the freshwater influx would reach Flower Garden Banks, one of the most northern coral reefs in the world. "It's a stunningly beautiful coral reef," DiMarco says. "If freshwater made its way out there, it could change the marine ecosystem and damage the coral reef."

Earlier in the summer, DiMarco and his colleagues had already been surveying and observing the continental shelf off Texas for ongoing projects related to tracking oil spills, water quality and ocean circulation. In June and August, they conducted two surveys from ships to collect salinity, temperature and depth data at 25 locations. After the hurricane, the team secured funding to conduct additional surveys for a study comparing conditions in the Gulf before and after the storm that would help track the freshwater plume.

The researchers found that wind-driven currents in the Gulf pushed the freshwater south toward Mexico, rather than toward the marine sanctuary. "The winds shifted right after the hurricane, as water was moving out [to sea from land]," DiMarco says. "That saved Flower Garden." The team tracked the plume as far south as South Padre Island, Texas' southernmost barrier island. DiMarco and his colleagues alerted ocean researchers in Mexico that the freshwater plume could continue south across the border.

North Korean nuclear test site collapsed

The site beneath Mount Mantap where North Korea has tested nuclear weapons since 2006 likely collapsed following the country's sixth and strongest test last September, according to a pair of studies. Both studies found a magnitude-4.1 earthquake that occurred eight and a half minutes after the nuclear detonation likely resulted from the near-vertical collapse of shattered rock overlying the buried test site.

Liu et al., Geophysical Research Letters, March 2018; Tian et al., Geophysical Research Letters, April 2018

The researchers also found that the water did indeed stratify, with oxygen levels in the saline waters beneath a 20-meter-thick freshwater cap falling to about 50 percent of normal — potentially damaging to bottom-dwelling marine organisms like fish and crabs. By November, however, those oxygen levels had returned to normal, as is expected in the fall when winds mix the water.

One of the big lessons from Hurricane Harvey, DiMarco says, is that a seemingly innocuous, loosely organized storm could become a Category 4 hurricane so quickly. Normally, a storm has to pass over a large, warmwater current — like the Gulf Stream in the Atlantic Ocean or the Loop Current in the Gulf of Mexico — to develop into a hurricane. For Harvey, however, "there was no real big current; the Loop Current was far to the east," he says.

Normally, the coastal Gulf waters in this region are warm on the top, but cold on the bottom, says co-author Henry Potter, an oceanographer at Texas A&M. In this case, the water was warm — 31 degrees Celsius — down to 50 meters depth. "Because the ocean was particularly warm, [it seems] the storm intensified very rapidly," Potter says.

The observation that hot shelf waters can produce an intense storm under the right circumstances should lead to new hurricane models that include data on oceanographic variables, in addition to atmospheric data, which has not typically been done, says Kevin Trenberth, a climate scientist at the National Center for Atmospheric Research in Boulder, Colo., who was not involved in the study. "Hurricanes are essentially coupled phenomena," he says. "The details of what's going on in the ocean actually matter."

Bethany Augliere

An aurora named Steve

In 2015 and 2016, more than 30 reports of odd, purple-hued ribbons of light over southern Canada popped up in forums on Aurorasaurus, a citizen science project funded by NASA and the National Science Foundation that tracks the aurora borealis through user-submitted reports and tweets. The amateur astronomers nicknamed the strange phenomenon "Steve," and in a new study, researchers have defined the new type of aurora.

Aurorae usually appear in dancing shades of green, blue and red as charged particles from the sun stream into Earth's atmosphere and interact with our planet's magnetic field, creating wavy light displays above the planet's polar regions that can last for hours. The aurora borealis — seen in the northern hemisphere — occurs at high latitudes in an area known as the auroral zone, but Steve's shorter-lived ribbons of purple light appeared at lower latitudes, as far south as southern Canada.

Using the European Space Agency's Swarm satellites to track changes in Earth's magnetic field, a team of scientists led by NASA's Elizabeth MacDonald detected unusual levels of electron activity and westward ion flow in the ionosphere during Steve events. These observations suggest that Steve is an optical manifestation of a phenomenon called subauroral ion drift, which occurs when a fast-moving stream of extremely hot, charged particles from the sun interacts with Earth's magnetosphere along lower-latitude magnetic field lines. Until recently, it had never been directly observed. "On the basis of the measured ion properties and original citizen science name, we propose to identify this arc as a Strong Thermal Emission Velocity Enhancement (STEVE)," the team wrote in Science Advances.

STEVE, a new type of lower-latitude aurora named by the citizen scientists who first observed it, appears with the Milky Way over Childs Lake in Manitoba, Canada.

Credit: Krista Trinder/NASA

More sightings are needed to track and better define Steve. Sightings of Steve and other aurorae can be reported at www.aurorasaurus.org or via the Aurorasaurus free mobile app available for Android and iOS.

Mary Caperton Morton

Geologic evidence of a 405,000-year Milankovitch cycle

Earth's rock record preserves evidence of numerous natural processes, from evolution and extinction to catastrophes and climate change, and sometimes even planetary configurations.

In a new study, a well-preserved sequence of Triassic lake sediments bearing evidence of cyclical patterns of climate change in the Newark Basin confirms the existence of a Milankovitch cycle — a periodic change in the shape of Earth's orbit caused by, in this case, Earth's gravitational interactions with Jupiter and Venus. The finding can be used to precisely date other events in the geological record, and inform climate and astronomical models.

Geologists previously suggested the patterns found in the Newark Basin, an ancient rift basin covering northern New Jersey, southeastern Pennsylvania and southern New York, could reflect the climatic effects of a predicted 405,000-year Milankovitch cycle, but the Newark Basin sediments were unable to be dated precisely enough to confirm the link.

Other Milankovitch cycles — a 23,000-year cycle related to the wobble of Earth's axis, a 41,000-year cycle related to the tilt of the axis, and a 100,000-year cycle related to orbital eccentricity — are relatively well established based on glaciological and sedimentary records. Such astronomical cycles influence how much solar energy the planet receives and thus alters climate, for example, by producing wet and dry periods, which leave their mark in the rock record.

In the study, published in Proceedings of the National Academy of Sciences, geologist Dennis Kent of Columbia University's Lamont-Doherty Earth Observatory and Rutgers University and colleagues assigned dates to the Newark Basin rock record by correlating it with rocks cored from the Upper Triassic Chinle Formation in Petrified Forest National Park in Arizona. Uranium-lead dating of zircons found in volcanic ash layers produced precise ages for the Arizona rocks, which the team then correlated to the Newark Basin rocks by matching the pattern of Earth's magnetic field reversals recorded in both places. The key is that "the Newark core has the [climatic] cycles. The Arizona core has the dates," Kent says.

Rocks from Arizona's Petrified Forest National Park helped scientists identify signals of a hypothesized Milankovitch cycle — a regular variation in Earth's orbit — that appears to have influenced the planet's climate as far back as the Triassic Period.

Credit: Kevin Krajick/Lamont-Doherty Earth Observatory

The researchers found that the dates of the climate cycles recorded in the Newark Basin rock record match the 405,000-year cycle predicted by astronomical models, providing the first empirical evidence for the cycle's existence and stability over the last 215 million years.

"This is the first time we can actually confirm the theoretical description of the 405,000-year cycle," says geologist Linda Hinnov of George Mason University, who was not involved in the study. "The astronomers have given us this model but we've never been able to establish that it's actually accurate until now."

However, a concern raised by Spencer Lucas, curator of paleontology at the New Mexico Museum of Natural History and Science, is that while the Newark record was deposited in an ancient lake, the Arizona sequence was deposited by a river, which makes it more likely to have gaps in the magnetic field history it records. "If you want a complete record of magnetic polarity, you have to have a complete pile of sediments. If you don't have that, then you're not going to get a complete record," Lucas says.

Such gaps are to be expected, and they are small compared to the overall length of time recorded in the section, which suggests that the overall pattern of magnetic field reversals is still likely to have been recorded accurately, says co-author Paul Olsen, a paleontologist at Columbia University's Lamont-Doherty Earth Observatory. Also, the gaps do not affect the precision of the zircon dating, he adds.

Confirming the existence of the regular astronomical cycle, which has been operating in the same way for more than

200 million years, provides astronomers reconstructing the history of the solar system with a predictable marker, much like the beat of a metronome, to calibrate their models.

Current astronomical models apply the laws of Newtonian dynamics and general relativity to reconstruct the solar system's past configurations, but model predictions fail beyond about 50 million years. That's because it is difficult to predict the motion of more than two moving bodies in space over very long periods of time. Astronomers are limited to computing the positions of the planets incrementally, and at each increment, errors accumulate.

"In addition, the physics of the solar system is chaotic," Olsen says, meaning that modern astronomical models are highly sensitive to initial conditions, and therefore, the picture of planetary positions hundreds of millions of years ago can vary widely depending on the initial assumptions and conditions input into a model.

However, because astronomers know the configuration of Earth, Venus and Jupiter when the 405,000-year cycle is at its minimum and maximum, and because those events are evident in the rock record and have now been well-dated, astronomers have more solid data on which to base estimates of planetary configurations going back more than 200 million years.

The discovery represents a linchpin in a hypothesis that Olsen and his colleagues have been developing for decades, called the "Geological Orrery," after the 18th-century mechanical models of the solar system. It holds that climatic change recorded in the geologic record could be used to infer the former positions and motion of planets in the solar system going back hundreds of millions of years.

Olsen suggests that careful examination of the geological record could help refine and point to gaps in astronomical models. The geological record "is a new world of empirical data that allows for tests of large-scale solar system theory," he says.

Viviane Callier

New ocean current found

Oceanographers using Doppler data collected on research cruises in the Mozambique Channel from 2007 to 2010 have identified a previously unknown ocean current: the Southwest Madagascar Coastal Current. The warm, salty surface current — less than 300 meters deep and 100 kilometers wide — flows south along Madagascar's southwestern coast, where it influences upwelling.

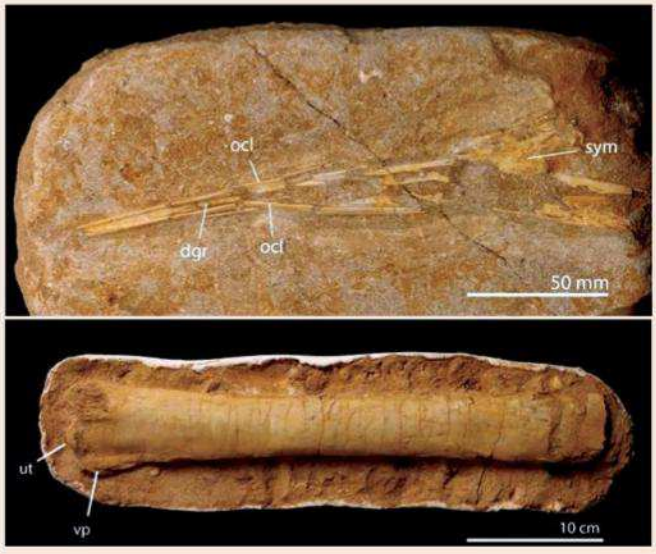
Ramanantsoa et al., Geophysical Research Letters, February 2018

Pterosaurs flew into the Late Cretaceous

Late Cretaceous skies might have been more crowded than previously thought. Until recently, scientists thought the dearth of pterosaur fossils found from the Late Cretaceous meant that the flying reptiles were in decline before the catastrophic end of the Mesozoic. But the recent discovery in Morocco of several new pterosaur species suggests this unique branch of reptiles may have been thriving just before the end-Cretaceous extinction.

The characteristics that made pterosaurs such fantastic fliers also explain why they are not well represented in the fossil record.

"To grow so large, and still be able to fly, pterosaurs evolved incredibly lightweight skeletons, with the bones reduced to thin-walled, hollow tubes like the frame of a carbon-fiber racing bike," said Nick Longrich, a paleontologist at the University of Bath in England and lead author of the new study, published in PLOS Biology, in a statement. "Unfortunately, that means these bones are fragile, and so almost none survive as fossils."



A lower jaw (top) and a forearm bone (bottom) from two species of pterosaur uncovered in Morocco.

Credit: Longrich et al., PLOS Biology, March 2018

Working in a phosphate mine in northern Morocco that dates to the Maastrichtian Age — the latest part of the Cretaceous, between 72 million and 66 million years ago — Longrich and colleagues recovered a handful of bones from specimens of at least seven different species representing three pterosaur families, making the assemblage "the most diverse known Late Cretaceous pterosaur assemblage," the team wrote. With wingspans ranging from 2 meters to more than 10 meters, the species "show a large range of variation in size and skeletal proportions, suggesting that they occupied a wide range of ecological niches," they added.

Mary Caperton Morton

Did a massive eruption spur Christianity in Iceland?

The 75-kilometer-long fissure that gave the Eldgjá "fire gorge" eruption its name is now a river valley in southern Iceland.
Credit: Clive Oppenheimer

The landscape and culture of Iceland, more so than any other country, have been shaped by volcanism. In a new study, researchers have refined the dates for the massive 10th-century Eldgjá eruption, which occurred just a few decades after the island was first settled. The findings may support a connection between the violent volcanism depicted in Iceland's most celebrated medieval poem and the island's conversion from paganism to Christianity.

The Eldgjá eruption originated under the Mýrdalsjökull Ice Cap on Katla Volcano in southern Iceland, and is estimated to have produced Iceland's largest known lava floods, with more than 20 cubic kilometers of lava gushing out of a fissure more than 75 kilometers long. "This was a colossal eruption that went on episodically for many months and would have involved spectacular activity at the fissure, including fire fountains and explosions," says Clive Oppenheimer, a volcanologist at Cambridge University in England and lead author of the new study, published in the journal Climatic Change. "It would have been very terrifying to witness."

Iceland was settled in about 874, so people were living on the island — and quite possibly near Katla — at the time of the eruption. But despite Eldgjá's massive size and widespread climatic impact, an exact date for the 10th-century event was not recorded. "This is pretty typical for eruptions in Iceland's early recorded history. There are written records but the pagans didn't keep track of years and record dates the same way we do," says Thor Thordarson, a volcanologist at the University of Hawaii at Manoa, who was not involved in the new study.

In previous studies of sulfur deposited in ice cores by the eruption, researchers identified a 10-year window when the Eldgjá eruption could have taken place: sometime between 935 and 945. Oppenheimer and his colleagues took a new approach to narrowing this window, focusing on the section of a Greenland ice core that contained tephra and ash markers for both the 946 eruption of Changbaishan Volcano, on the border between China and North Korea, and the Eldgjá eruption.

"Ice core dating is not always exact, but the recently dated major eruption of Changbaishan — known as the Millennium Eruption — gave us an anchor for the Eldgjá event," Oppenheimer says. The ice core record shows that the Eldgjá eruption started 7.5 years before the Millennium Eruption, pointing to its onset in the spring of 939. It persisted through the fall of 940. "This places the eruption squarely within the experience of the first two or three generations of Iceland's settlers. Some of the first wave of migrants to Iceland, brought over as children, may well have witnessed the eruption," he says.

Harsh winters and barren summers followed in the years after the Eldgjá eruption, due to the haze of sulfur that lingered in the atmosphere. "The effects of the Eldgjá eruption were likely devastating for people in Iceland, and the climatic effects of the sulfur emissions seem to have triggered famine in many parts of Europe, the Middle East and China in the years following the eruption," Oppenheimer says.

The new study lends support to a connection previously suggested by experts in medieval literature that Eldgjá and its aftermath may have inspired Iceland's most famous medieval poem, which dates to as early as 961: Völuspá — meaning "The Prophecy of the Seeress" — tells of a fiery end for Iceland's pagan gods and the rise of a new singular god, a story scholars have long associated with the conversion of Iceland to Christianity around the turn of the 11th century. "In the poem, the god Odin consults a prophetess and she describes the whole history of the world from beginning to end, with the death of all the gods and

Animals cannot foretell earthquakes

The common notion that animals can sense environmental changes presaging earthquakes is largely unfounded, according to researchers who reviewed available data. They found that the popular misconception is based almost entirely on anecdotal evidence of singular cases. Analysis of the few relevant time-series studies that do exist revealed that, in some instances, animals purportedly sensing future earthquakes were actually reacting to subtle shaking associated with foreshocks.

Woith et al., Bulletin of the Seismological Society of America, April 2018

Great Pacific Garbage Patch is growing

A three-year study of the Great Pacific Garbage Patch (GPGP) found that a staggering 80,000 metric tons of plastic — four to 16 times higher than previous estimates — now floats between Hawaii and California. Scientists surveyed and sampled the GPGP using 30 ocean-going vessels while two aircraft scanned and measured it from the sky. Researchers reported the patch covers 1.6 million square kilometers, three times the size of France, and has grown exponentially since the 1970s.

Lebreton et al., Scientific Reports, March 2018

giants. Interestingly, she describes this ending in terms of very vivid volcanic imagery," Oppenheimer says.

Written in Old Norse-Icelandic, the poem describes a magnificent eruption with fireballs lighting up the sky and explosions heard for great distances. The poem also chronicles darkened skies and woeful summers following the event: "The sun starts to turn black, land sinks into sea; the bright stars scatter from the sky. Flame flickers up against the world-tree, fire flies high against heaven itself."

"It's interesting to think about how pagans and Christians in Iceland would have viewed this eruption and interpreted it in terms of their cosmologies and world views," Oppenheimer says. "We can imagine that the eruption might have been rationalized by Christians as God's retribution for the sins of the people."

Still, the connections between the poem, volcanism and the conversion to Christianity remain speculative, Thordarson says. "This poem seems to be describing a volcanic eruption like Eldgjá, but my view is that a direct connection is a long shot. What I do accept is that Eldgjá and its fallout most likely ended the age of settlement in Iceland; it stopped people from coming to Iceland, since they couldn't grow enough food to sustain the existing population," he says. "Eldgjá had a huge impact on Iceland, there's no question about that."

Mary Caperton Morton

Trio of studies track stone tool technology in Kenya

About 300,000 years ago, East Africa was a hotbed of human evolution and innovation. Sweeping ecological changes contributed to the emergence of modern humans, and spurred the first long-distance trade routes and novel toolmaking technologies. Three new studies published in Science shine a spotlight on Kenya's Olorgesailie Basin, where the clunkier Acheulean tool technology gave way to the smaller, sleeker Middle Stone Age tool technology famously associated with *Homo sapiens*.

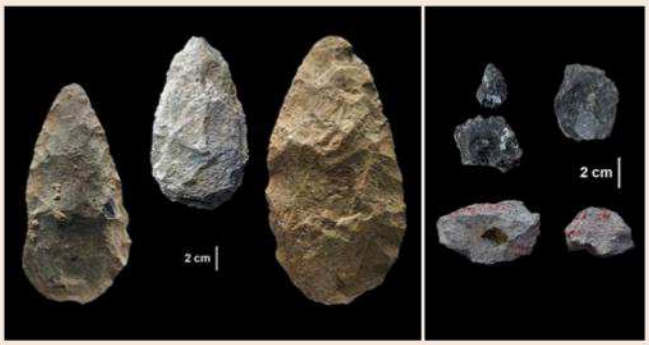
In the first study, Rick Potts, an anthropologist at the Smithsonian Institution's National Museum of Natural History in Washington, D.C., and colleagues analyzed artifacts and well-preserved sediments from Olorgesailie Basin to track ecological changes across the floodplains-turned-grasslands over a period of 1.2 million years. They found that grasslands spread across the region starting roughly 800,000 years ago, attracting smaller species of grazing animals that would have provided new hunting opportunities for early humans.

A second study, led by Alison Brooks, also of the Smithsonian Institution, cataloged stone tool artifacts found in the Olorgesailie Basin that are between 500,000 and 298,000 years old. They found that the older tools were bulkier and made from local volcanic rock, whereas the later tools were more refined and more often crafted from obsidian or chert from sources up to 90 kilometers away, suggesting trade routes had begun to spread across the landscape.

In the third study, detailed dating of the sites and artifacts was provided by geochronologist Alan Deino of the Berkeley Geochronology Center in California and colleagues. Using argon and uranium isotopic dating, Deino's team developed a timeline for the sites scattered throughout the Olorgesailie Basin. The study helped pinpoint the transition from the older Acheulean tools to the first Middle Stone Age tools at about 320,000 years ago, making the Middle Stone Age artifacts identified in the new studies the oldest examples found to date in eastern Africa.

Taken together, the trio of studies paints a picture of climate-driven innovation at one of the most pivotal times in human evolution, Potts and colleagues wrote in Science.

Mary Caperton Morton



New studies of Kenya's Olorgesailie Basin paint a picture of climate-driven innovation in toolmaking and trade about 320,000 years ago. People who had already been using large handaxes (left) for hundreds of thousands of years began making more specialized tools (right) like spearpoints, scrapers and awls.

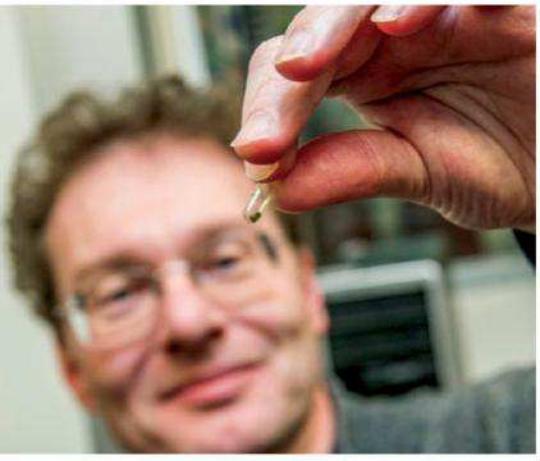
Credit: Human Origins Program, Smithsonian

Diamonds reveal water in deep mantle

Inclusions in diamonds often render them undesirable to consumers, but they can provide researchers with striking insights into Earth's composition. Recently, scientists probing diamond samples for the presence of carbon dioxide stumbled instead upon inclusions of ice-VII — a type of crystallized water that forms at very high pressures, and has never before been found in nature.

The discovery of the icy inclusions, reported in Science, could provide new insights into water in the deep mantle and its relationship to the global water supply. "Water-rich regions in Earth's deeper mantle are suspected to play a role in the global water budget," wrote Oliver Tschauner, a mineralogist at the University of Nevada, Las Vegas, and his colleagues in the study. Ice-VII "points toward fluid-rich locations in the upper transition zone [at a depth of about 410 kilometers] and around the 660-kilometer boundary."

"This study reveals something unusual," says Evan Smith, a diamond geologist at the Gemological Institute of America, who wasn't involved with the study. "We have seen a variety of different aqueous diamond-forming fluids trapped in lithospheric diamonds, but not in superdeep diamonds" — those that originate deeper than about 200 kilometers.



A new study analyzing the structural and chemical properties of diamonds from various locations in Africa and China found inclusions of ice-VII, a form of crystallized water created under very high pressure that has never before been found in nature. Credit: Marilyn Chung/Berkeley Lab

"Any evidence of water deep inside Earth, in the convecting mantle, is an important finding," Smith adds. "It is still unclear how much water is stored in the mantle, what its role is, and how it might relate to water at the surface."

Tschauner's team used hard X-ray diffraction and other techniques, including infrared analysis, to examine the structure and chemistry of diamonds from Africa and China and found inclusions of ice-VII in 13 of them. The discovery demonstrates that the inclusions aren't isolated to diamonds formed in only one region, and that deep diamonds may be more common than previously thought, Tschauner said in a statement. Until now, only about 60 diamonds originating from depths greater than about 300 kilometers had been found.

However, Smith notes that "compared to other superdeep diamonds, these ice-VII-containing diamonds do not seem to have the other typical inclusions representing high-pressure minerals like majoritic garnet. So, for now, the 'superdeep' origin of the ice-VII-containing diamonds is based entirely on pressure calculations from X-ray diffraction data," he says.

Ice-VII inclusions remain at high pressures within their host diamonds, allowing researchers to use knowledge of ice-VII's structure to determine the minimum pressures at which the diamonds formed. Chemical analysis, specifically the state of nitrogen inside the diamonds, revealed information about temperatures, which, along with pressure, was used by researchers to determine the depths at which the diamonds formed.

"Of 13 occurrences of ice-VII, eight fall into a narrow pressure interval from 8 to 12 gigapascals," with one other sample having formed at a pressure of about 6 gigapascals, and two more forming at about 24 to 25 gigapascals, they wrote.

These observations imply the diamonds were formed in "regions in the deep mantle where aqueous fluid was present during [their] growth," they add. The diamonds with the greatest retained pressures are thought to have formed up to 800 kilometers below Earth's surface.

Steven Shirey, a geochemist at the Carnegie Institution for Science in Washington, D.C., who studies deep diamonds but wasn't involved with the study, says he finds the research "quite novel, because preservation of such high residual pressure is unexpected."

However, Shirey says the diamonds in the study "are rather poorly characterized and difficult to understand. One is from a locality not known to carry such superdeep diamonds." In others, he says, the nitrogen chemistry is "hard to explain."

"It is not immediately clear how to connect these findings to other diamonds and other studies to date," Smith says. The study "has people scratching their heads," but it will prompt others to attempt to replicate and build on these findings.

Rachel Crowell

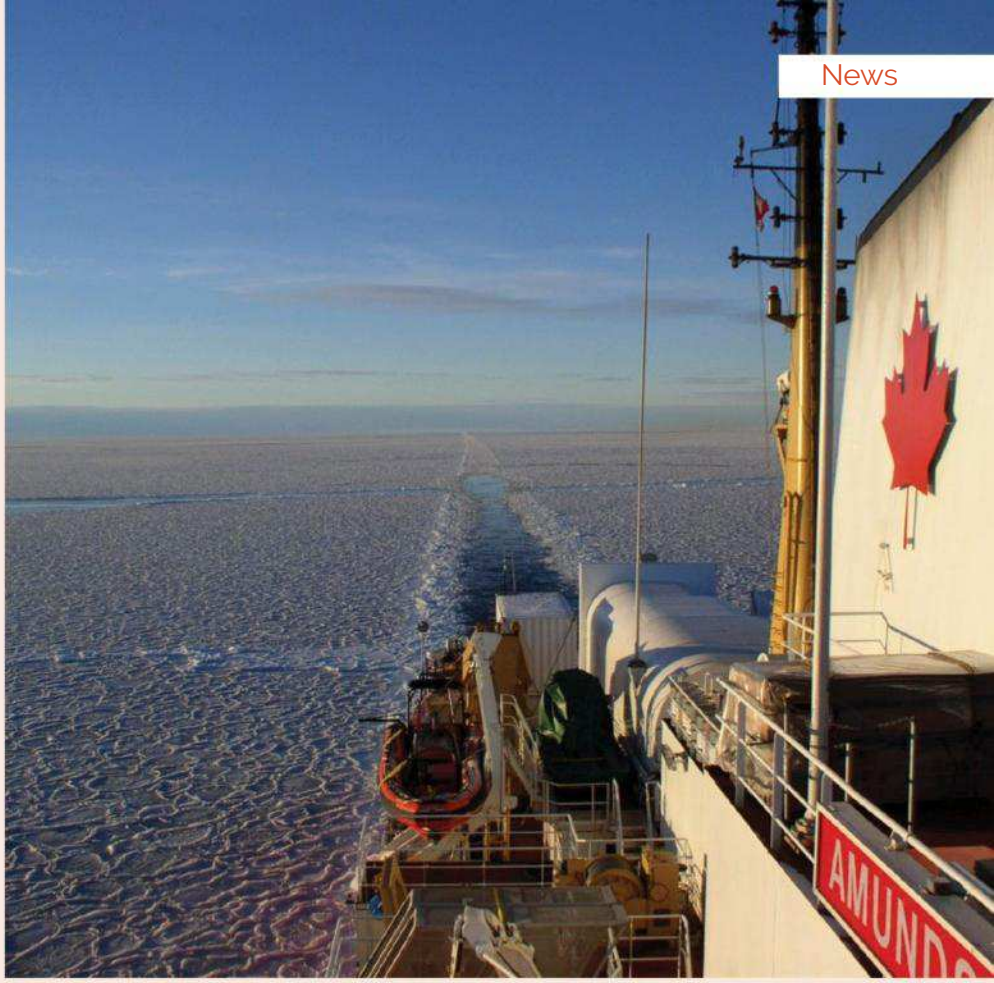
Trees recorded World War II chemical subterfuge

Pine and birch trees around Kåfjord, Norway, stopped growing for up to seven years after being exposed to chemical fog during WWII. The German battleship Tirpitz, anchored in Norwegian fjords during the war, was frequently targeted by Allied forces. To hide the ship, the German military pumped chlorosulfuric acid into the air, forming a mist that engulfed the ship within minutes. Nearby trees exposed to the gas stopped growing, creating a gap in the tree ring record. The research may be the first case of "war dendrochronology."

Hartl et al., European Geosciences Union General Assembly, April 2018

Ice (Re)Cap

From Antarctica to the Arctic; from polar caps, permafrost and glaciers to ocean-rafted sea ice; and from burly bears to cold-loving microbes, fascinating science is found in every nook and crevasse of Earth's cryosphere, and new findings are announced often. Here are a few of the latest updates.



The icebreaker CCGS Amundsen breaks a path through the Arctic in October 2010.
Credit: Canadian Coast Guard, CC BY-ND 2.0

- Warming global temperatures have produced an unexpected transit hazard in the Arctic: Increased amounts of sea ice are on the move. In 2017, an anomalous amount of sea ice along the eastern Canadian coast hemmed in the research icebreaker Amundsen near the east coast of Newfoundland. During the delay in the vessel's research mission, scientists aboard used the time to make observations and measurements of the large influx of ice. The team's findings, published in Geophysical Research Letters, showed that areas where ice arches normally form every winter — effectively damming sea ice — are faltering under warmer temperatures. "[More ice mobility] is counterintuitive to most people because it means you can have an increase in local ice hazards because of a changing climate in the high Arctic," said David Barber of the University of Manitoba in Winnipeg, in a statement. The transient sea ice phenomenon may last at least a couple more decades, he adds, causing hazards for shipping, ferries and fishing.

- Subglacial lakes sit in isolated darkness below the Antarctic and Greenland ice sheets, yet scientists have shown that these cold bodies of water can host microbial life. Using echo-radar sounding, a group of researchers has discovered the first subglacial lakes in Canada, lying in a bedrock trough under the Devon Ice Cap on Devon Island west of Baffin Bay. The results of the work, reported in Science, indicate that the base of the ice cap is likely colder than minus 10.5 degrees Celsius, and that the lakes are composed of hypersaline water. These isolated environments may show a unique habitat for microbial evolution. "If there is microbial life in these lakes, it has likely been under the ice for at least 120,000 years, so it likely evolved in isolation," said Anja Rutishauser of the University of Alberta in a statement. The team suggested their findings could be useful during upcoming space missions to places like icy Europa.

- A new study in Limnology and Oceanography Letters looks at how thawing tundra can release carbon trapped in the soil, and how it can affect surface waters. Over 15 years, scientists from Canada and Europe took samples during the summer months from 253 ponds in 14 different Arctic regions. Chemical, biological and optical analyses of the samples revealed a correlation between the extent of permafrost thaw in an area and the amount of dissolved organic carbon in nearby waters, including terrestrial carbon from land sources. The work is the first to examine the effect of rising temperatures on subarctic ponds. "The browning [from increased terrestrial organics] of these systems leads to oxygen depletion and cooler water at the bottom of the ponds, which can have a major impact on the microbial activity responsible for the production and consumption of greenhouse gases, particularly the production of methane, a powerful greenhouse gas," the authors said in a statement.

Sarah Derouin

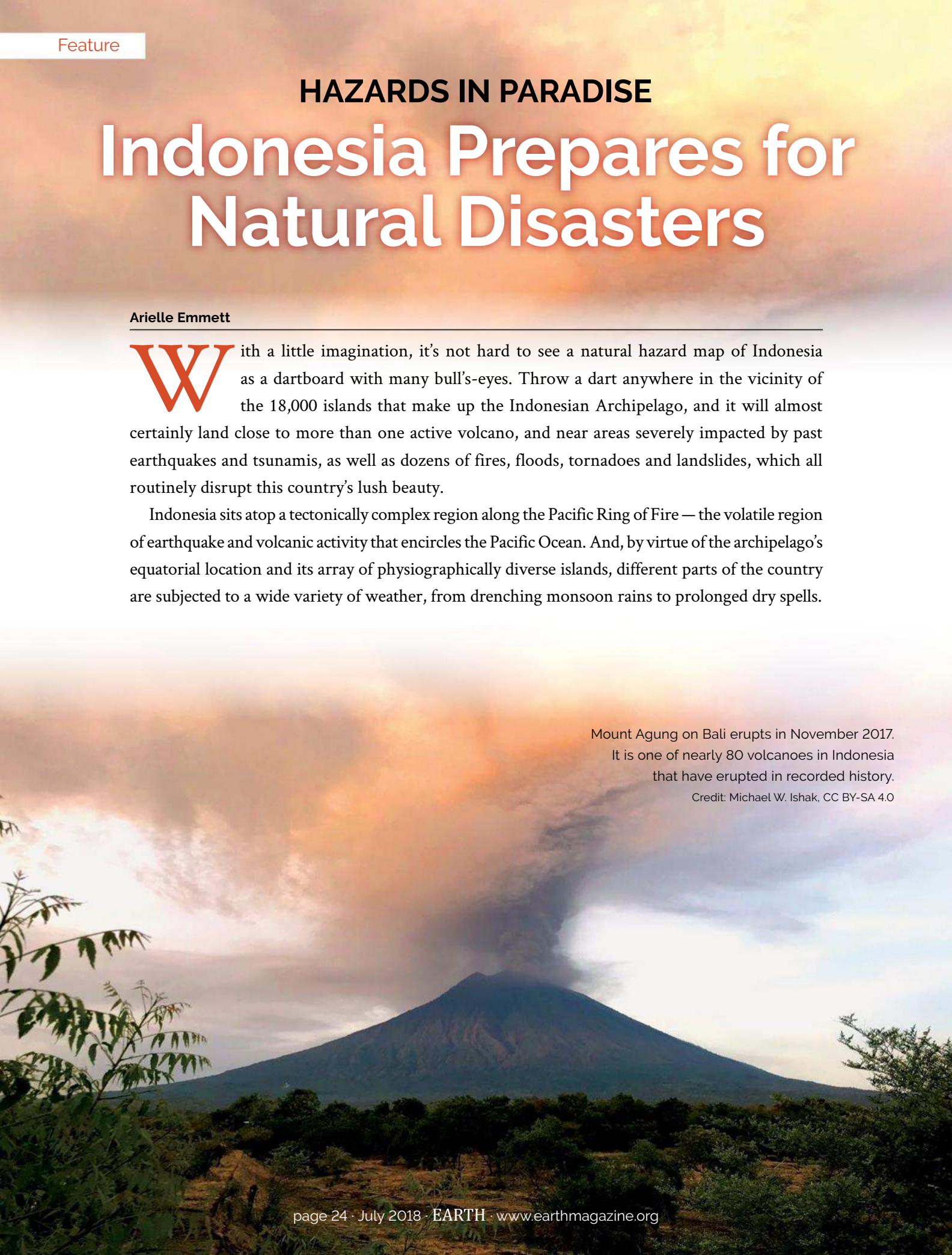
HAZARDS IN PARADISE

Indonesia Prepares for Natural Disasters

Arielle Emmett

With a little imagination, it's not hard to see a natural hazard map of Indonesia as a dartboard with many bull's-eyes. Throw a dart anywhere in the vicinity of the 18,000 islands that make up the Indonesian Archipelago, and it will almost certainly land close to more than one active volcano, and near areas severely impacted by past earthquakes and tsunamis, as well as dozens of fires, floods, tornadoes and landslides, which all routinely disrupt this country's lush beauty.

Indonesia sits atop a tectonically complex region along the Pacific Ring of Fire — the volatile region of earthquake and volcanic activity that encircles the Pacific Ocean. And, by virtue of the archipelago's equatorial location and its array of physiographically diverse islands, different parts of the country are subjected to a wide variety of weather, from drenching monsoon rains to prolonged dry spells.



Mount Agung on Bali erupts in November 2017. It is one of nearly 80 volcanoes in Indonesia that have erupted in recorded history.
Credit: Michael W. Ishak, CC BY-SA 4.0

I visited the islands of Java, Sumatra and Bali in December 2017 — my third visit to Indonesia in three years — eager to catch up on friendships and learn how carefully the country was monitoring its earthquake, tsunami and volcanic hazards. On my mind were the catastrophic 2004 Indian Ocean earthquake and tsunami that struck just west of Sumatra's Aceh Province, claiming the lives of more than 170,000 Indonesians and roughly 270,000 people around the region.

In recent years, the Indonesian government, along with other groups like the Earth Observatory of Singapore and the U.S. Pacific Tsunami Warning Center, has been introducing technologies to improve hazard forecasting, warning and mitigation. Among these technologies are GPS systems enabling precision geodetic measurements of plate tectonic movements and stresses; tidal gauges; gas-sniffing drones and temperature sensors for volcanic monitoring; and a new set of integrated databases and communications systems providing hazard detection and visualization, decision support, and earthquake and tsunami warning protocols.

But how effective are these technologies in helping safeguard the country's populace? Indonesia is a country with 55,000 kilometers of coastline and more than 266 million inhabitants living on 6,000 islands, many of which are among the most remote in the world, where cellphone and internet coverage is rare. I wanted to understand whether the government's efforts to communicate about hazards were reaching its far-flung residents, and if disaster preparedness based on folklore and "local wisdom" might be equally important — or more so — than monitoring and warning technologies.

Weather and Geology Hazards

Few people outside the region understand just how regularly natural disasters occur throughout Indonesia's 5,000-kilometer-wide archipelago. More than 2,000 serious disasters are reported each year, 90 percent of which are weather-related — mostly the result of flooding rains, tornadoes, fires and mudslides. In 2017, Indonesians reported 787 floods, 716 tornadoes, 614 landslides, and 96 forest and ground fires (burning peat lands and rainforests to make room for large palm oil plantations and smaller farms is a popular practice, especially in Sumatra). Indonesians also reported 19 regional droughts, two volcanic eruptions — at Mount Sinabung on Sumatra and Mount Agung on Bali — and 11 tsunamis. Overall, 3.4 million people were displaced that year by these natural disasters.

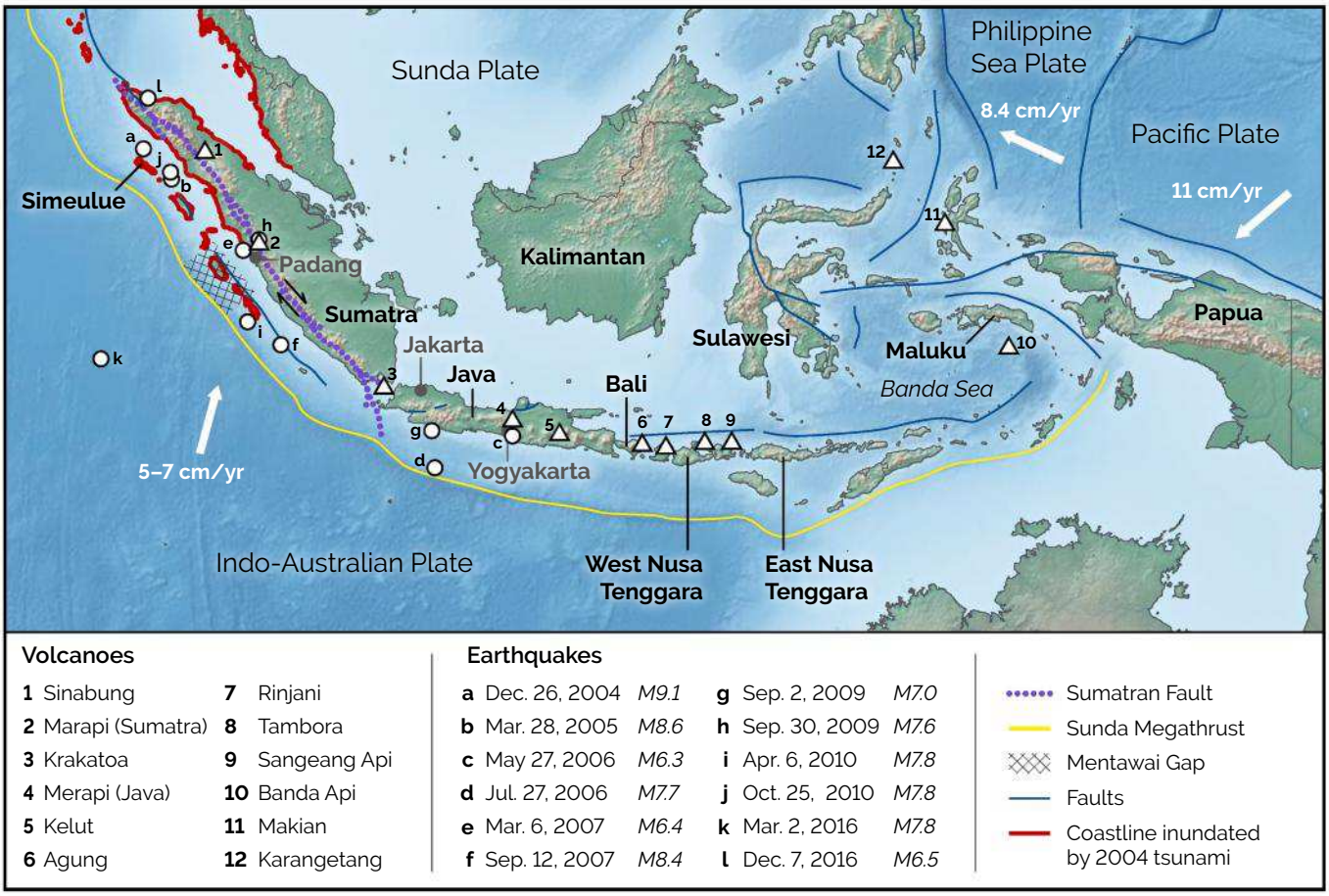
A flooded suburb of Banda Aceh, at the northwest tip of Sumatra, following the December 2004 Indian Ocean earthquake and tsunami, which inundated large swathes of coastline in Indonesia, Thailand and elsewhere around the region.

Credit: U.S. Navy photo by Photographer's Mate 2nd Class Philip A. McDaniel

Indonesia experiences roughly 4,000 earthquakes a year, 70 to 100 of which are magnitude 5.5 or higher, along with one or two highly destructive quakes, some reaching or exceeding magnitude 8. Hazard maps created by the Indonesian Agency for Meteorology, Climatology and Geophysics, known as BMKG (Badan Meteorologi, Klimatologi, dan

Volcanic ash covers a school and cemetery near Sinabung in January 2014. Sinabung began erupting in 2010 after a centuries-long dormancy, and has been very active since 2013.

Credit: Rendy Cipta Muliawan, CC BY 2.0



Earthquakes, volcanic eruptions and tsunamis often impact Indonesia as a result of the archipelago's location amid many colliding tectonic plates. This map shows some of the major earthquakes that have struck Indonesia in recent years, along with the inundation zone of the massive December 2004 tsunami and a sampling of the country's many active volcanoes.

Credit: K. Cantner, AGI

Geofisika), show that earthquakes and tsunamis are particularly frequent on those islands directly adjacent to the boundaries of the tectonic plates that meet in Indonesia's midst — specifically the Indo-Australian, Pacific, Philippine Sea and Sunda plates — which are continuously moving and straining against one another.

Off the western and southern coasts of Sumatra, Java and Nusa Tenggara, for example, the Indo-Australian Plate subducts under the Sunda Plate at a speed of 5 to 7 centimeters per year, building up stress that's occasionally released as large earthquakes. A chain of active volcanoes — including Sinabung and Krakatoa among others — traces this plate boundary. To Indonesia's northeast, meanwhile, the Philippine Sea Plate collides with the Sunda Plate to its west and the Pacific Plate to its east. And between all of these major plate collisions, just east of Java, a so-called "suture zone" up to 2,000 kilometers wide comprises several smaller plates that move against each other at relatively high speeds. Earthquakes happen along multiple subduction zones and other faults in the suture zone, too, especially around the "spice islands" of Maluku, Sulawesi, Papua, and smaller islands in the Banda Sea.

With all of this tectonic activity, the country also has 78 volcanoes that have erupted in recorded history. Most famous among them, perhaps, are Tambora in West Nusa Tenggara and Krakatoa, situated between Sumatra and Java, which erupted catastrophically in 1815 and 1883, respectively. In recent times, a 2010 eruption at Mount Merapi outside Yogyakarta in Java spewed plumes of ash, lahars and pyroclastic flows, along with a cloud of ash and sulfur dioxide that reached more than 15 kilometers into the atmosphere over the Indian Ocean, prompting the evacuation of 350,000 people. However, many chose to remain behind or return home while the eruption was still going on, and 350 people died.

In northern Sumatra, Mount Sinabung, which had been dormant for 400 years, began erupting in August 2010 and has been very active since 2013. Major eruptions in 2017, and again this past

Devy Kamil Syahbana, a volcanologist with the Indonesian Center for Volcanology and Geological Hazard Mitigation, talks about how the November 2017 eruption of Mount Agung forced the evacuations of rural residents living near the volcano.
Credit: Wibi Pangestu Pratama

February, chased residents from the mountain, and Indonesia's National Disaster Management Authority, known as BNPB (Badan Nasional Penanggulangan Bencana), determined that all residents had to be resettled permanently due to the volcano's volatility. Meanwhile, Mount Agung, on Bali, came to life in late November 2017 after a hiatus of more than 50 years since its last explosive eruption in 1963. Thanks to advances in monitoring near Agung, plenty of warning signs were detected, enabling disaster personnel to order evacuations before the volcano actually blew, and there were no casualties. In 1963, by contrast, 1,500 people perished as a result of the unexpected eruption.

Technical and Cultural Challenges

"Because of the technical changes in volcanic science, we have had fewer victims in the past 20 years," says Devy Kamil Syahbana, a field specialist with the Indonesian Center for Volcanology and Geological Hazard Mitigation (Pusat Vulkanologi dan Mitigasi Bencana Geologi Badan) who monitors Mount Agung on Bali. "Two decades ago, we didn't have broadband seismometers or multi-gas analyzer spectroscopy to give us insights into the physical processes inside a volcano," he says. GPS satellites and temperature sensors were also lacking in the toolkit of Indonesian scientists at that time. "Now, volcanic eruptions are among the most predictable of geological disruptions," Devy says. Seismic activity is another story. "You can't predict earthquakes, and that hasn't changed."

Tsunamis present a different challenge. Only short warning times are available with current tsunami monitoring setups: generally between 10 and 60 minutes. And although disaster forecasting and warning technologies can help, none are perfect. In an incident that attracted international media attention, a March 2016 magnitude-7.8 earthquake

Two men stand amid debris after their home in a village on the island of Nias, west of Sumatra, was demolished by ground shaking during a magnitude-8.6 earthquake in March 2005.
Credit: U.S. Navy photo by Photographer's Mate 2nd Class Jeffrey Russell

that struck in the ocean roughly 800 kilometers southwest of Padang, Sumatra, resulted in tsunami warnings for parts of Indonesia, but no tsunami ever arrived. The tsunami warning caused widespread panic in Padang, a coastal city in western Sumatra where tsunamis are a major threat. Thousands of citizens fled to higher ground before the warning was canceled two hours later.

While the temblor set off alarms in several different international tsunami warning systems, including Indonesia's own, both local disaster specialists in Sumatra and national specialists in Jakarta were confronted with conflicting reports. One of the big problems was a complete lack of data coming from 22 ocean buoys deployed between 2006 and

A tsunami hazard sign directs people toward high ground on Nusa Lembongan Island about 10 kilometers offshore Bali. Tsunami warning times in Indonesia are often short because of the close proximity of many islands to sources of major earthquakes, such as the Sunda Megathrust.
Credit: ©iStockphoto.com/urf

2010 west of Sumatra by a team of German and Indonesian scientists to detect oncoming tsunamis. All of these buoys reportedly failed to work properly during the March 2016 incident.

"There were 22 buoys, and as of [2016], the last of them were not working due to them breaking down, or from theft or vandalism," says Sutopo Nugroho, director of information for BNPB. Nugroho acknowledges the need for the buoys, but says the country doesn't "have funding for maintenance or to replace them."

When the buoys were first deployed, "they didn't work very well," says Jörn Behrens, a professor of mathematics at the University of Hamburg in Germany who was involved with the German-Indonesian tsunami warning system from 2006 to 2010. "Technically, the buoys did provide data, but they were placed too close to the potential tsunami sources," he says.

Indonesian islands are very close to earthquake sources like the Sunda Megathrust, the 5,500-kilometer-long subduction zone off Sumatra and Java that was the source of the cataclysmic 2004 earthquake and tsunami. The buoys' placement results in little delay between the detection of an earthquake and the potential generation of a tsunami wave. This makes it difficult for scientists to interpret two separate data streams coming from the buoys: one measuring seismicity (detected by ocean-bottom pressure sensors attached to the buoys) and another measuring anomalous wave heights at the water's surface. "We couldn't use the data except to say something severe had happened," Behrens says. In the Pacific Ocean, by contrast, tsunami buoys are placed farther out in the ocean and away from tsunamigenic faults, so there is a time delay between seismic activity and the detection of a tsunami. Behrens believes the current dysfunctional buoys need to be replaced with a better-designed tsunami warning system.

Although seismologists and disaster mitigation authorities in the country have hoped to procure new technology to more quickly detect incipient threats, an array of nontechnical factors impedes progress. Conflicting agendas among multiple disaster agencies sometimes get in the way, as do limited funding for disaster monitoring and response, which influences both technology choices and civic responses. And on some islands, local officials often ignore warnings from disaster agencies, thinking the government is too often "crying wolf."

"The challenge is the low capacity of local governments; they don't put disaster risk awareness into their agenda," Nugroho says. Many of Indonesia's most remote villages also lack reliable communications and road infrastructure, so that residents may not hear sirens or radio warnings.

Moreover, in some circumstances, individuals have motivations that — knowingly or not — are at odds with monitoring efforts. Off western Sumatra, for example, fishermen and pirates have reportedly stripped the tsunami buoys, which cost more than $300,000 apiece, of sensitive electronic parts to sell. Others, meanwhile, have used the buoys to anchor their boats, damaging the buoys and disrupting their data transmission.

"You have to face the situation that these fishermen have to make a living and support their families, while a tsunami might occur in their area every hundred years or so," Behrens explains.

Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG) earthquake and tsunami information specialists (left to right) Dr. Daryono, Weniza, and Ariska Rudyanto review data from the InaTEWS warning system.

Credit: Wibi Pangestu Pratama

BMKG specialist Weniza explains the agency's InaTEWS warning system to the author.

Credit: Wibi Pangestu Pratama

Efforts to Improve

Specific predictions of the timing and severity of natural disasters are not possible, but Indonesian disaster management agencies are making substantial progress in providing warnings of potentially dangerous events. Some critical system pieces are still missing in these efforts, however.

"Before 2012, even with the earthquake disasters of 2004 and 2009, Indonesia didn't have good monitoring or warning systems for disaster management," Nugroho says. "If we had an earthquake or volcano, and lots of citizens accessed our websites for information, too often the sites crashed," he says.

In the past half-decade, however, Jakarta adopted a single, internationally recognized platform for monitoring and responding to natural hazards of all sorts in near-real time. The high-tech installation is known as InAWARE 6, a variant of DisasterAWARE, a multihazard warning and risk assessment system created at the Pacific Disaster Center (PDC) in Hawaii with support from the U.S. Agency for International Development. It is also deployed in Thailand, Vietnam and Nepal. The Indonesian version of DisasterAWARE, however, has been modified for scenarios that take the dispersed Indonesian islands into account.

At BNPB headquarters in Jakarta, a constantly changing InAWARE touchscreen displays the size and severity of Indonesian natural hazards, with colored bull's-eyes indicating locations of earthquakes, volcanoes, fires, mudslides, tornadoes, storms and tsunamis. Using the platform, decision-makers can analyze data coming in from multiple regional and global feeds, such as seismic data from the U.S. Geological Survey, weather data from the National Oceanographic and Atmospheric Administration, and tsunami data from the Indian Ocean Tsunami Warning System and Indonesia's BMKG.

"The challenge that remains is getting information to people in the 'last mile' — people who need to know about it," says Chris Chiesa, deputy director of the PDC. "Even if the warning system worked perfectly and instantaneously, even if SMS [text messaging] works one second after the ground shakes, for a nearshore earthquake [and tsunami] event, you'd have trouble a couple of kilometers away getting out of the inundation zone," Chiesa says. "That wave is going to be there in five to seven minutes."

BNPB's companion agency, BMKG, which is in charge of all-island earthquake and tsunami warnings, relies on a separate warning system, known as InaTEWS (Indonesia Tsunami Early Warning System), which communicates some data to InAWARE but operates as a separate warning system for seismic hazards only. Built jointly with Germany and implemented over a three-year period in response to the 2004 Aceh-Andaman earthquake and tsunami, InaTEWS uses a network of 165 seismometers and accelerometers placed in the most seismically active island areas.

The interactive display of the InAWARE warning system at the headquarters of the National Disaster Management Authority (BNPB) in Jakarta shows natural hazards — volcanoes, earthquakes, flooding, landslides and other types — affecting Indonesia.

Credit: Wibi Pangestu Pratama

"We are now required to disseminate information and tsunami warnings to the country within five minutes after an earthquake," says Weniza (she has one name), a tsunami information specialist with BMKG. "Initial warnings are sent via internet, radio, cellphone SMS and TV," she says. Within 15 minutes, information from an accelerometer network helps the agency create a "shake map," at which point a second warning may be issued, and confirming messages exchanged with other disaster agencies.

Meanwhile, following the failure of the 22 previously deployed buoys, BMKG still lacks a functional network of ocean buoys and deep-sea pressure sensors called DARTs (Deep-ocean Assessment and Reporting of Tsunamis). These buoys and sensors can be linked with GPS systems to better measure seafloor displacement and detect tsunamis, but the InaTEWS system is not integrated at all with GPS networks configured for hazard warnings or for measurements of plate movement. It's a gap that could be hazardous. Of the 18 tsunami warnings that BMKG has issued since the system was set up in 2008, six have been false alarms, a success rate that could lead to skepticism about the reliability of future tsunami warnings.

The Mentawai Gap: The Next Big Threat?

The most functional GPS network in Indonesia is owned by the Indonesian Institute of Sciences (LIPI), a government research organization, and is jointly operated by LIPI's Research Center for Geotechnology and the Earth Observatory of Singapore (EOS). This research array consists of nearly

The city of Padang, on the west coast of Sumatra, could be severely impacted if a large earthquake occurs in the Mentawai Gap along the Sunda Megathrust.
Credit: Crisco 1492, CC BY-SA 4.0

Left: Iwan Hermawan (foreground) of the Earth Observatory of Singapore and his technical assistant Hafiz inspect a GPS station located near Padang, Sumatra. The outer casing of the station is broken, although the GPS unit itself is still operational. Right: Hafiz tests the electronics for the GPS station to make sure it's working properly.
Credit: both: Wibi Pangestu Pratama

five dozen satellite-linked GPS stations on Sumatra and on outlying islands, says EOS technical director Paramesh Banerjee. The array measures "movements of all the islands linked to the [Sunda Megathrust]" and other major faults, like the Sumatran Fault, Banerjee says. "GPS provides what is happening before an earthquake occurs — how the surface is deforming, and how the slip is occurring [on a fault] — and what happens after a quake."

The system could, in theory, be modified to work as part of a national earthquake and tsunami warning network, Banerjee suggests. "The best thing is to have one integrated warning system in the Indian Ocean … one that is as close as possible to earthquake sources." As president of the Asian Seismological Commission, Banerjee is organizing a conference in China to try to create that network out of the patchwork of systems that exist today. Indonesia has announced it will participate.

The Sunda Megathrust remains the most hazardous fault in the Indonesian archipelago. Many seismologists expect that the region's next great

earthquake and tsunami will likely happen in the Mentawai Gap, a portion of the megathrust about 90 kilometers west of central Sumatra. The gap hasn't seen a significant quake in more than 200 years.

"Mentawai is locked and loading with [seismic] energy, and there has to be an event that will release that stored energy," says Iwan Hermawan, a geodesist and research fellow at EOS who monitors Sumatra. Along the megathrust at Mentawai, the Eurasian Plate to the east has been shortening and bowing downward as the Indo-Australian Plate slides under it. At some point, the accumulated stress will be too great and a large earthquake — and, most likely, a tsunami — will occur.

The city most vulnerable to a potential quake in the Mentawai Gap and a resultant tsunami is Padang, the largest city on the western coast of Sumatra with a population of more than 800,000. "The risk is high," Hermawan says, adding that he and EOS director Kerry Sieh believe the Mentawai Gap rupture could happen within the next few decades, or possibly sooner.

"Much of the loss stemming from the great Aceh-Andaman earthquake and tsunami of 2004 could have been avoided," Sieh wrote in a 2007 Journal of Earthquake and Tsunami paper. "Similar future losses from earthquakes and tsunamis in South and Southeast Asia could, in theory, be substantially reduced." Sieh wrote that Indonesia can improve its survival rates in a future disaster by focusing now on scientific discovery, public education about hazards, emergency preparedness, and the design and construction of resilient coastal communities.

But whether Indonesia is adequately prepared today — technologically and in terms of public awareness and preparedness — remains an open question. Some local community organizers have been vigilant about educating the populace and persuading local government officials to act on evacuation plans, but infrastructure and budgets to support such efforts are spotty.

Local Wisdom

Patra Rina Dewi, a scientist and tsunami educator with a nongovernmental organization called Kogami, has been conducting hazard preparedness training for children and adults in Padang, and urging local and district governments to adopt evacuation and shelter plans. "After 2004, we struggled to get a program of training going for the first two years, and at one point in 2005, the Padang government asked us to stop because they thought we were frightening the tourists," she says. "But in September 2007, we had a magnitude-7-plus earthquake, and the government woke up and started trusting our organization."

By 2008, Padang had a tsunami evacuation plan and the city had built tsunami shelters resembling multilevel parking lots that can hold almost 5,000 people. But Dewi still worries that hundreds of thousands of people won't escape low-lying areas in time if a tsunami comes quickly and washes out key bridges and other infrastructure.

Patra Rina Dewi discusses tsunami education efforts in Padang.

Credit: Wibi Pangestu Pratama

A third-story deck atop this fortified shelter in downtown Padang can accommodate residents fleeing from tsunami floodwaters. The open design is intended to allow water to flow through.
Credit: Wibi Pangestu Pratama

Dewi tells people in Padang that the best way to avoid disaster is to recognize the signs for themselves — and as quickly as possible — because improved monitoring technology and communication won't necessarily help if a massive earthquake happens along a megathrust and forms a tsunami close to the Indonesian islands. She shares her experiences as a rescue worker on Simeulue Island, about 150 kilometers west of Sumatra, after the 2004 earthquake and tsunami struck. Unlike Aceh Province on Sumatra, where nearly 170,000 perished, only 7 people on Simeulue — out of 70,000 residents — drowned during the catastrophe, Dewi says, because locals recalled the stories of their ancestors who faced a tsunami in 1907. When the islanders saw the ocean receding, just before the giant tsunami waves came crashing in, they knew to run for higher ground.

"The children I saw afterward weren't traumatized; they knew what to do and they seemed happy, even though they saw their houses disappear," Dewi recalls. "After I returned to Padang, volunteers showed me a magazine saying Padang is the riskiest city in the world for tsunami," she says. That's when she discovered her calling. "I know something big will happen in the future if I don't contribute myself to save people."

And that's why rescue workers and organizers like Dewi and Nugroho believe that "local wisdom" is even more effective than GPS, seismometers or other technologies in warning Indonesians of coming disaster. "'Local wisdom' means people-to-people communication because, basically, disaster mitigation is from people to people," Nugroho says. "We are trying to develop and integrate local wisdom with technology, so that communities can build the capacity to cope with the disaster themselves," he says. "We call this the 'working together spirit.' This means the disaster belongs to us. It's our responsibility to deal with it."

Sutopo Nugroho (left), information director of BNPB, talks with Iwan Hermawan inside the BNPB museum, which is dedicated to natural disaster rescue efforts and the preservation of key artifacts. The sign above reads "Homeland Nation: Aware of Disaster."
Credit: Wibi Pangestu Pratama

"We've done the training," Dewi says. "We now tell our people that if the earthquake happens [and is] bigger than magnitude 7 … the authorities will make an announcement about a tsunami potential. If you feel a strong earthquake lasting 30 seconds or more and you can't stand properly, you must evacuate — but don't take your vehicles; just walk. Get quickly to higher ground — walk at least 3 kilometers away from the beach."

Emmett, who holds a doctorate in journalism and public communication, is an environmental and science journalist specializing in coverage of social and scientific issues in Asia and Africa. She received the 2018-2019 Fulbright Scholarship and will be teaching and researching Chinese-African labor policy issues in East Africa for 10 months. She is a contributing editor to Smithsonian Air & Space magazine.

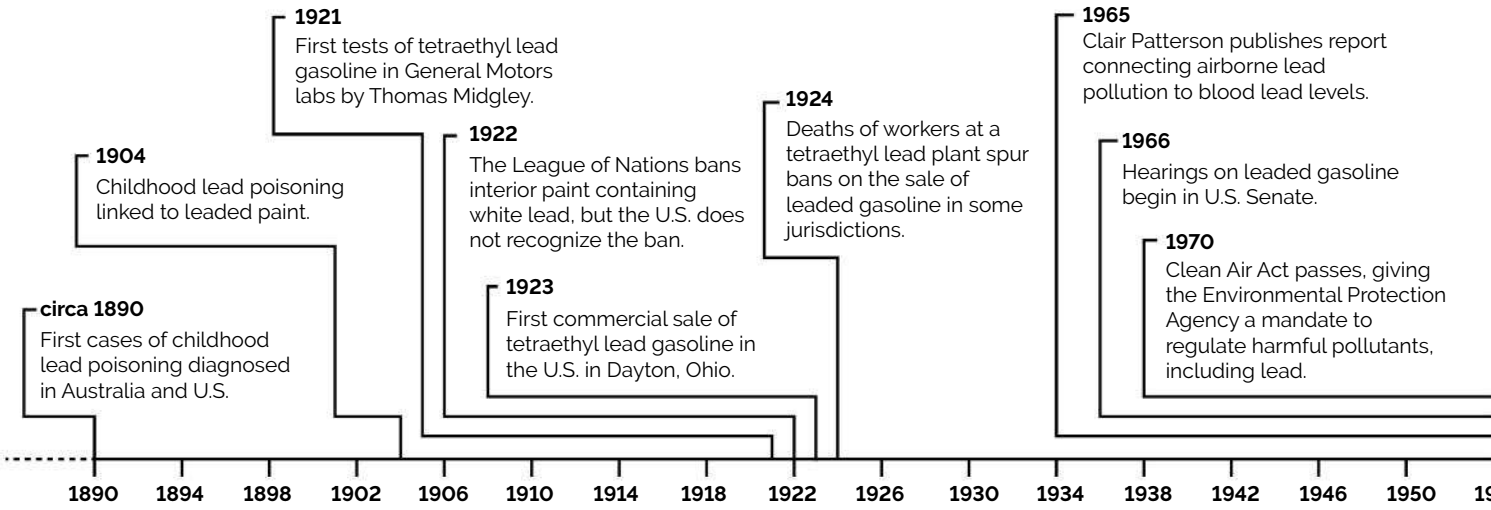
TOXIC TREATMENTS
Lead Lingers in Folk Remedies

Mary Caperton Morton

Lead is one of the most ubiquitous heavy metals in nature, and, for decades, it was a common ingredient in a wide range of consumer goods. After numerous studies detailed its toxicity and concluded there is no safe amount of lead in the human body — especially in children — new laws and regulations curbed its use dramatically. And yet, lead still appears in many products, particularly cosmetics, traditional medicines and folk remedies that are often lightly regulated.

Just a few decades ago, when leaded gasoline still flowed from gas pumps and lead paint brightened the walls of many homes, lead poisoning occurred across all socioeconomic classes in the U.S. The federal government banned the use of leaded paint in houses in 1978, and followed with a ban on the sale of leaded gasoline for on-road vehicles in the 1990s. Research conducted by the Centers for Disease Control and Prevention (CDC) found that, in the late 1970s, more than 77 percent of the U.S. population had elevated blood lead levels — some high enough to cause irreversible brain damage and death. But a follow-up study showed that, by 1994, the percentage of people with elevated blood lead levels had fallen to just 4.4 percent — a striking drop resulting from one of the most successful public health campaigns ever waged in the U.S. But the scourge of lead from other sources remains.

"We've made tremendous progress in this country against the traditional sources of lead," says Philip Landrigan, a pediatrician and epidemiologist at the Icahn School of Medicine at Mount Sinai in



Above: Leaded gasoline was developed in the 1920s to improve performance and reduce knocking in combustion engines. In the U.S., it began to be phased out in the 1970s due to the toxicity of tetraethyl lead.

Credit: above: David Brodbeck, CC BY 2.0; left and below: K. Cantner, AGI

New York City. But today, according to the CDC, more than half a million children in the U.S. are still affected by high blood lead levels, often from exposure to decades-old peeling paint, lead-polluted soils, or what scientists classify as "atypical sources," a group that includes cosmetics and folk remedies.

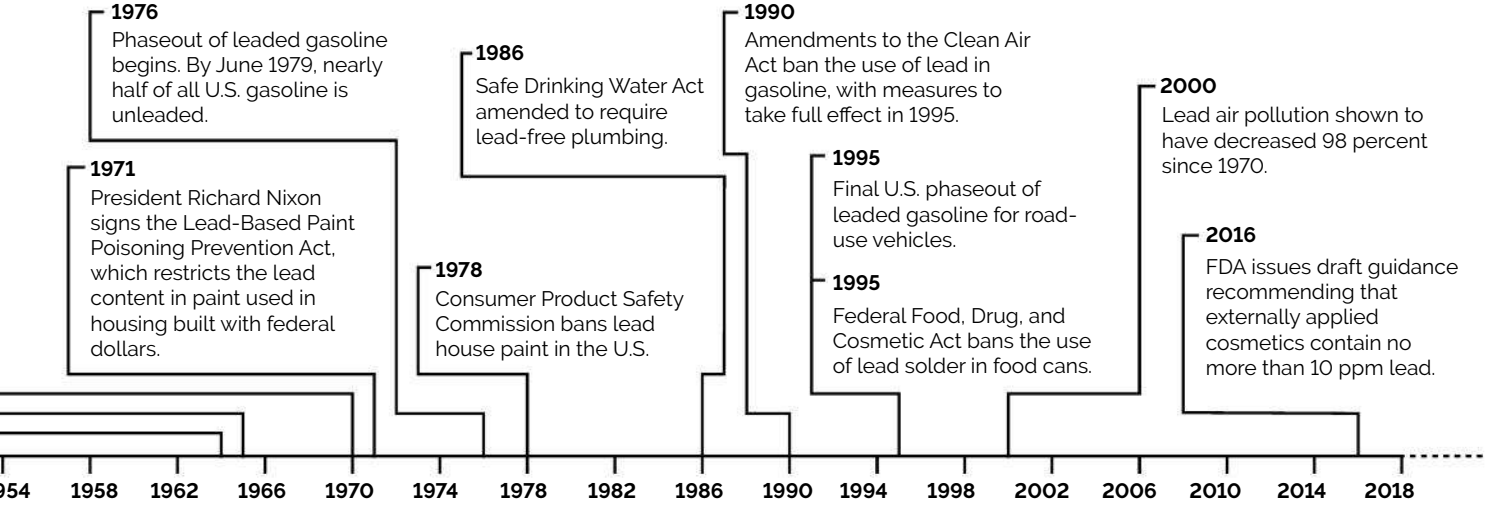
To continue making progress against lead poisoning, doctors and scientists need to determine where the metal is still slipping through the cracks into our everyday lives. Studying unique cases, or "sentinel events," in which individuals or small groups of people have been affected by lead from atypical sources, sheds light on how and where people are still coming into contact with lead with the hope of curtailing further exposure to these same sources.

A Slow, Silent Killer

Lead is toxic to people of all ages, but children are especially vulnerable, says Alan Woolf, a pediatrician and toxicologist at Boston Children's Hospital. "Children are more susceptible to lead poisoning because of their curious nature and tendency to put everything in their mouths," Woolf says. But their susceptibility also relates to physiology: "Kids absorb more lead through the gut than adults, and their immature kidneys cannot excrete lead as efficiently as adults," he says.

The primary pathway for lead intoxication is ingestion; lead does not readily enter the body through the skin. Once absorbed through the gut into the bloodstream, lead makes its way around the body where it tends to be mistaken for calcium because lead and calcium fit into the same cellular receptors. As "Trojan" calcium, lead moves into cells where it can wreak havoc. "Many cellular functions are calcium-dependent," Woolf says. Instead of facilitating metabolic reactions, lead torpedoes normal cellular functioning, sometimes killing the cell. When lead invades cells in target organs such as the liver, kidneys and brain, the fallout can lead to permanent tissue damage, organ failure and death.

Blood lead levels are used to assess how much lead is circulating in a person's bloodstream. The CDC recommends medical intervention for levels above 5 micrograms per deciliter (μg/dl). Medical interventions begin with identifying and removing the source of lead; acute cases — when blood lead



A 1919 advertisement for Dutch Boy "White-Lead" paint touted the product's "durability and resistance to weather."
Credit: Don O'Brien, CC BY 2.0

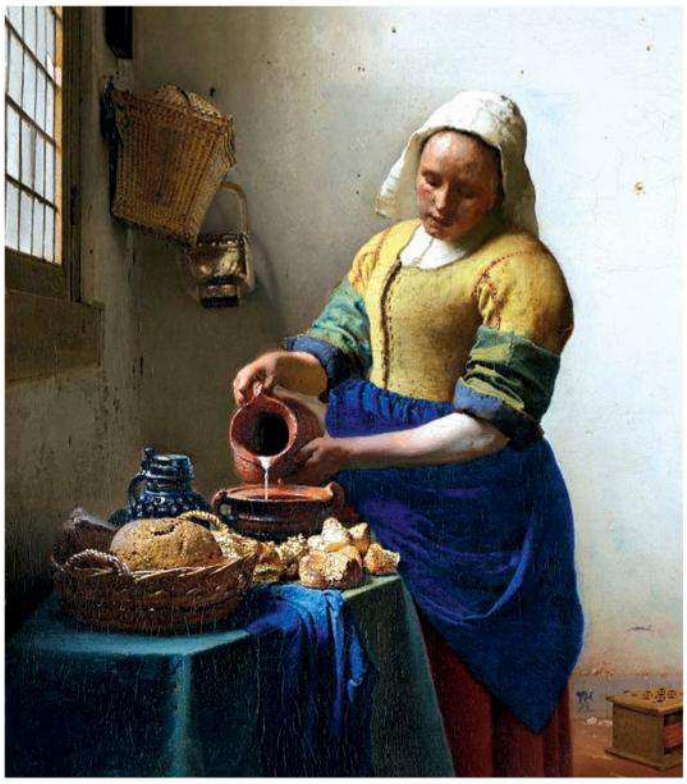
Peeling paint has long been a major pathway to lead exposure in the U.S. and elsewhere, even after leaded house paint was banned.
Credit: ©iStockphoto.com/XiFotos

levels rise above 45 µg/dl — warrant chelation therapy, in which chelating agents that bind lead and help clear it from the body are introduced into the bloodstream.

Left untreated, lead can make its way into storage reservoirs in the body. In adults, as much as 90 percent of residual lead is stored in bone tissue. Children tend to store less lead in their bones, but as children grow and their bones are remodeled, stored lead can be released back into the bloodstream, triggering new episodes of elevated blood levels and cellular malfunction.

The earliest diagnosed cases of childhood lead poisoning emerged in the late 19th century. In 1892, for example, doctors at the Brisbane Children's Hospital in Australia noted that 10 children initially misdiagnosed with meningitis turned out to have acute lead poisoning. The lead was traced to paint in the children's homes, and the product was subsequently banned in Australia in 1914. That year also saw one of the first recorded cases of childhood lead poisoning in the U.S., documented in a case study published in the American Journal of Diseases of Children. Decades passed, however, before doctors realized the severity of long-term effects from lead poisoning.

"When colleagues and I first started working on lead poisoning in the late 1960s, the view at that time was that high doses of lead could cause acute poisoning, which made children horribly sick," Landrigan says. "We used to see children who had eaten paint chips in comas, in convulsions. Many died; and the ones that survived were left with obvious brain damage." As devastating as acute lead poisoning can be, the long-term effects of lead



Lead-tin-yellow, a yellow pigment composed of lead tin oxides, was a popular choice among artists of old, including 17th-century Dutch painter Johannes Vermeer, who used it in "The Milkmaid."
Credit: public domain

exposure are equally sobering: Lead is a neurotoxin that targets both the central and peripheral nervous systems, capable of causing permanent brain damage even in low doses.

"Over the last few decades, we've learned that lead is the worst kind of gift that keeps on giving," Landrigan says. Children exposed to even low doses of lead tend to exhibit reduced IQ, shortened attention spans, disruptive behaviors, dyslexia and other learning disabilities. "When we track their long-term development, we find that these kids are more likely to drop out of school and have run-ins with the law in adulthood," he says. "We now know from studies done on low-dose lead toxicity that even small doses of lead can be very harmful, especially to young children and unborn children in the womb."

Why Use Lead in Anything?

"Heavy metals like lead, arsenic, mercury, aluminum, zinc, chromium and iron are found in a wide variety of cosmetics and personal care products, including lipstick and other lip products, whitening toothpaste, eyeliner, nail color, foundations, sunscreens, eye shadows, blush, concealer, moisturizers and even eye drops," says Janet Nudelman, director of the Campaign for Safe Cosmetics organized by the nonprofit Breast Cancer Prevention Partners. But if ingested lead is so toxic, why does it appear in products like lipstick? "Some metals are intentionally added as ingredients, while others are contaminants of the raw materials or are present in the colorant," Nudelman says.

"Like asbestos, lead has certain properties that make it attractive to people and manufacturers," despite its known hazards to public health, Landrigan says. Lead has been mixed into pigments since antiquity because it reacts with elements such as oxygen, sulfur, manganese and iron to produce chemical salts with brilliant colors. For example, lead oxide was long used in both interior and exterior house paints because of its bright white tone and resistance to weathering.

In 2012, scientists at the U.S. Food and Drug Administration (FDA) published a study in the Journal of the Society of Cosmetic Chemists in which they tested more than 400 lipsticks sold in the U.S. for total lead content. The researchers found that almost all of the lipsticks tested contained small amounts of lead, with an average lead concentration of 1.1 parts per million (ppm). Just over a dozen of them had lead levels of about 3 ppm, and the highest concentration observed was 7.2 ppm.

The lipstick study revealed that, in most cases, the lead was not intentionally added to the lipstick but instead was naturally present in trace amounts in some ingredients. "Based on our surveys, we determined that manufacturers are capable of limiting lead content in cosmetic products to 10 ppm or less if they are careful about selecting their ingredients and follow good manufacturing practices," the FDA team wrote in the study. As lead is mainly absorbed through the digestive tract, not through the skin, lead exposure from lipstick and other topical cosmetics is minimal, the researchers noted, reporting that they "determined that exposure to 10 ppm lead from incidental ingestion of cosmetic lip products is very small and cannot be measured in routine blood testing."

The FDA issued draft guidance to the cosmetics industry in 2016 recommending that externally applied cosmetics, including lipstick, should contain no more than 10 ppm lead. On its website, the agency notes that "most cosmetics on the market in the United States generally already contain less than

In a 2012 study by the U.S. Food and Drug Administration (FDA), researchers tested 400 lipsticks commercially available in the U.S. and found lead concentrations ranging from near zero up to 7.2 parts per million (ppm), with an average of 1.1 ppm. A draft guidance to the cosmetics industry issued by FDA recommends that externally applied cosmetics contain no more than 10 ppm.

Credit: ©iStockphoto.com/TheCrimsonMonkey

10 ppm of lead," but that "some cosmetics from other countries contain lead at higher levels."

In a 2016 study published in Environmental Science & Technology, scientists tested lipsticks commercially available in China and found lead concentrations up to 10,185 ppm. The average concentration was 497 ppm, with lower-priced products tending to contain more lead. "A woman may ingest 1.8 kilograms of lipstick inadvertently over a lifetime," the team wrote, "which represents a significant exposure pathway depending on [lead] concentration in lip products."

The Case of the Nigerian Eyeliner

Traditional products and folk remedies, which are often produced with untested ingredients and distributed without labels or ingredient lists, can be even more perilous than commercial products, particularly for children.

"A lot of these folk products are imported informally, through families, often by well-meaning grandparents who are trying to pass on their native cultural traditions to their children and grandchildren," says Suzette Morman, a geochemist with the U.S. Geological Survey in Denver, Colo. "These remedies are perceived as healthy, and not at all hazardous, but they're generally not regulated and they can turn out to be nightmares from a toxicology standpoint."

When a child or adult presents with high blood lead levels, atypical sources like traditional medicines and folk remedies must be considered once common sources, such as paint, occupational exposure and industrial pollution, are eliminated. "If a child comes in with an elevated blood lead level and they are living in an apartment that was built in 2016, and nobody in the family works in lead-related occupations, we then have to play detective and delve into other sources of lead that might not be so routine," Woolf says.

In 2011, Woolf and a team of doctors from Boston Children's Hospital — one of the leading treatment centers for heavy metal poisoning in the U.S. — published a case study involving a six-month-old boy of Nigerian descent. The boy — who arrived to a well-child physical with eyeliner on his eyelids — appeared healthy, but a routine blood test revealed a blood lead level of 13 μg/dl, more than twice the CDC's recommended action limit.

When the child's case came to the attention of Woolf and his colleagues, they suspected the eyeliner could be to blame for the lead in the boy's system. A form of eyeliner traditionally used in parts of the Middle East and Africa is so notorious for its high lead concentrations that it cannot be legally imported into the U.S. Known in different places as kohl, kajal, al-kahal, surma, tiro, tozali or kwalli, the eyeliner is used cosmetically to enhance the eyes, even of very young children, and is also thought by some cultures to ward off evil spirits.

A man applies eyeliner around the eyes of a boy in Kolkata, India. Known variously as kohl, kajal, al-kahal, surma, tiro, tozali and kwalli, such eyeliners are sometimes composed of crushed galena, or lead sulfide, which is toxic, although less bioavailable than some other forms, such as lead oxide or lead carbonate.

Credit: ©Shutterstock.com/clicksabhi

Kohl is applied in many cultures to enhance aesthetic appearance, or as a medicine purported to strengthen eyes and protect against disease or evil.
Credit: Ako Mahmoodi, CC BY 3.0

Unfortunately, the material is often composed of galena, the mineral form of lead sulfide.

Lead displays different degrees of bioavailability — a measure of how readily a substance makes its way into the bloodstream and throughout the body — so hazards from lead-containing products often depend on the type of lead involved.

"When we looked at the eyeliner under a scanning electron microscope, we found it was almost pure galena," says Geoffrey Plumlee, a geochemist with the U.S. Geological Survey in Reston, Va., who, along with Morman, has collaborated with Woolf and his colleagues on several atypical lead poisoning cases. "Of all the lead minerals, galena is one of the least bioaccessible. That explained why the infant's blood lead levels were [elevated] but not screaming high."

Further investigation revealed that the eyeliner had been purchased from a street vendor in the Nigerian city of Ilorin, where it's called tiro, and imported to the U.S. by the infant's grandparents. The parents had applied the eyeliner to the infant's eyelids three to four times a week since he was 2 weeks old to "improve attractiveness and promote visual development," Woolf's team wrote in the report, published by the CDC.

Lead sulfide is not readily absorbed through the skin or the mucus membranes, Woolf says. But as young children often rub their eyes and put their fingers in their mouths, the lead from the tiro likely entered the infant's bloodstream through ingestion, he says, although some could have also been absorbed through the conjunctival surfaces of the eyes or from ingested tears.

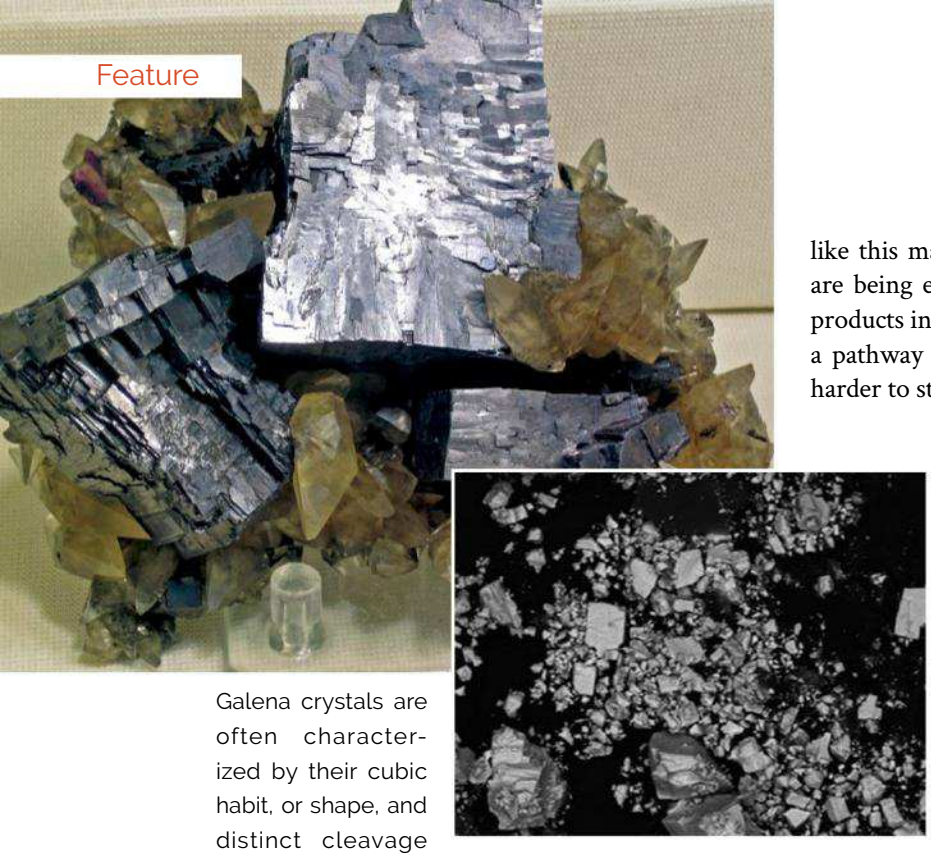
After applications of the tiro on the infant ceased, his blood lead levels gradually dropped over a matter of months, and the child never showed outward signs of illness. The case led Woolf's team to reach out to the Nigeria Center for Disease Control (NCDC) about lead poisoning. The NCDC subsequently began working with tiro vendors to look into safer alternatives to using galena, and also initiated public health outreach efforts to raise awareness about lead in tiro and other sources. "The problem is not unique to Nigeria," Woolf says. "Many countries in Africa and the Middle East lack formal systems for regulating or labeling cosmetics. When we saw the eyeliner, there was no label, no warnings, and no way to trace where it came from."

The Case of the Malaysian Diaper Powder

In 2017, Morman, Plumlee and Woolf collaborated on a sentinel case of a 9-month-old girl with blood lead levels as high as 18 μg/dl. "After [the medical investigation team] checked the family's house and yard and found no lead, they asked the girl's parents to bring in all the products they were using on the child for testing," Plumlee says. "Sure enough, they were applying some kind of unlabeled, unbranded diaper powder the child's grandparents had sent over from Malaysia. When we analyzed [the powder] we found it was very high in lead, and mineralogical studies showed that it was primarily lead oxide."

The primary pathway for lead intoxication is via ingestion into the digestive system, where the metal is absorbed into red blood cells and circulated throughout the body. Woolf and his colleagues were curious whether urine could solubilize the lead in the diaper powder such that it might be more readily absorbed through the skin.

"In vitro bioaccessibility studies are a relatively easy and inexpensive way to identify how lead is being absorbed in the body," Morman says. In such studies, researchers take samples of simulated gastric fluid or lung fluid and test the solubility of the particular type of lead involved. In the case of the Malaysian diaper powder, Morman developed a novel simulated urine bioaccessibility test, which revealed that the lead oxide was highly bioaccessible in simulated gastric fluids, but only slightly so in simulated lung fluids and even less so in simulated urine. The results suggested that the primary lead exposure routes for the 9-month-old were ingestion via hand-to-mouth transmission and ingestion of



Galena crystals are often characterized by their cubic habit, or shape, and distinct cleavage planes at both macroscopic and microscopic scales. Scanning electron microscopy (inset) confirmed that the tiro eyeliner applied to a Nigerian boy and analyzed in a 2012 study was composed largely of tiny galena crystals (field of view is about 0.1 millimeters).

Credit: James St. John, CC BY 2.0; inset: U.S. Geological Survey, Crustal Geophysics and Geochemistry Science Center

inhaled dusts cleared from the respiratory tract, rather than absorption of dissolved lead through the skin.

Four weeks after discontinuing use of the powder, the infant's blood lead level had dropped to 8 µg/dl. The team followed up with Malaysian authorities, but the lack of identifying information on the unlabeled powder stymied efforts to track it to the source. "Cases like this make you worry about how many people are being exposed to lead through these unlabeled products in the country of origin," Plumlee says. "It's a pathway that's very difficult to follow, and even harder to stop."

The Case of the Asian Tongue Powder

In some instances, enough information can be gleaned about a lead-containing product to stop its distribution at the source. In a case at Boston Children's Hospital, a 12-month-old child of Thai descent presented with a blood lead level of 61 µg/dl, which warranted immediate chelation therapy. The alarmingly high levels were tracked to the daily application of a black tongue powder called Ya Kward Pak (meaning "medicine to be applied to the mouth" in Thai) for the first seven months of the child's life.

"This ethnic remedy was applied to the tongue to absorb toxins … and preserve the infant's health," Woolf's team wrote in a 2008 study in Clinical Toxicology. Spectrometric analyses of the tongue powder showed lead in excess of 109,000 ppm, in the form of lead oxide.

The team contacted two poison control centers and government agencies in Thailand to launch a public health inquiry and recall. The Ramathibodi Poison Center, the Siriraj Poison Control Center, and the Thai Food and Drug Administration tracked the powder to a Chinese traditional medicine shop in Bangkok. Testing of several kinds of tongue powders and other remedies for sale in the shop revealed that many of the products had lead levels in excess of 9,500 ppm. The shop was ordered to stop selling the contaminated powders and was later closed for additional violations. The Thai FDA also conducted a press conference alerting the public in Bangkok to the dangers of lead and other heavy metals in traditional products, and the poison control centers opened a 24-hour hotline to handle cases of suspected infant poisoning.

In one sentinel case, a container of unlabeled diaper powder sent from Malaysia was found to consist largely of lead oxide.

Credit: ©iStockphoto.com/ThitareeSarmkasat

Traditional products that have tested high for lead include cosmetics as well as folk remedies meant to improve health, such as tongue powder and the "tonic pills" for infants seen here.

Credit: Alan Woolf

Working Toward Lead Literacy

The public health campaign that began in the 1970s to combat lead poisoning has dramatically reduced the incidence of childhood lead poisoning and cultivated widespread knowledge about the dangers of lead in the U.S. "These days, most Americans are familiar with the pitfalls of lead," Landrigan says. This lead literacy is also due in part to the work of pediatricians and family doctors who "make a point to talk to parents about the common and uncommon sources, and the warning signs, of lead poisoning," he says.

But while many parents are generally aware of the dangers posed by lead, the metal still lurks in unexpected places. And people who have immigrated to the U.S. in recent years may not have had the same experience with public health campaigns about the dangers of lead. A limited amount of research has shown a greater incidence of elevated blood lead levels in immigrant children. And, at least anecdotally, lead literacy seems less widespread among immigrant populations, although few studies have sought to quantify this knowledge gap.

"I do think there's a gap in understanding in many international cultures that haven't had the benefit of decades of public health campaigns," Woolf says. "As physicians, we have to stay vigilant and remember that not everybody is well versed in the dangers of lead or the threat that unlabeled or mislabeled products might [pose] to children."

Atypical lead poisonings sometimes spark international ripple effects, with dangerous products being tracked back to their place of origin and distribution stopped at the source. "Earth scientists can play an important role in these cases by helping doctors figure out what forms of lead somebody has been exposed to and pinpoint the pathway of intoxication," Plumlee says. "Collaboration is key to solving these medical mysteries and figuring out how to keep them from happening again."

A circa 1970 poster from the U.S. Department of Health, Education and Welfare (now the Department of Health and Human Services) warns of the hazard to children from lead paint. Nowadays, while many parents are generally aware of the dangers posed by lead, the metal still lurks in unexpected places.

Credit: public domain

Morton (www.theblondecoyote.com) is a freelance science writer based in Big Sky, Mont. Her first book, "Aerial Geology: A High-Altitude Tour of North America's Spectacular Volcanoes, Canyons, Glaciers, Lakes, Craters, and Peaks," was published by Timber Press in 2017.

England's Jurassic Coast records 185 million years of Earth history in its spectacular scenery, including one of its most iconic sights: a natural arch called Durdle Door.
Credit: Terri Cook and Lon Abbott

Travels in Geology

MESOZOIC MASTERPIECE: ENGLAND'S JURASSIC COAST

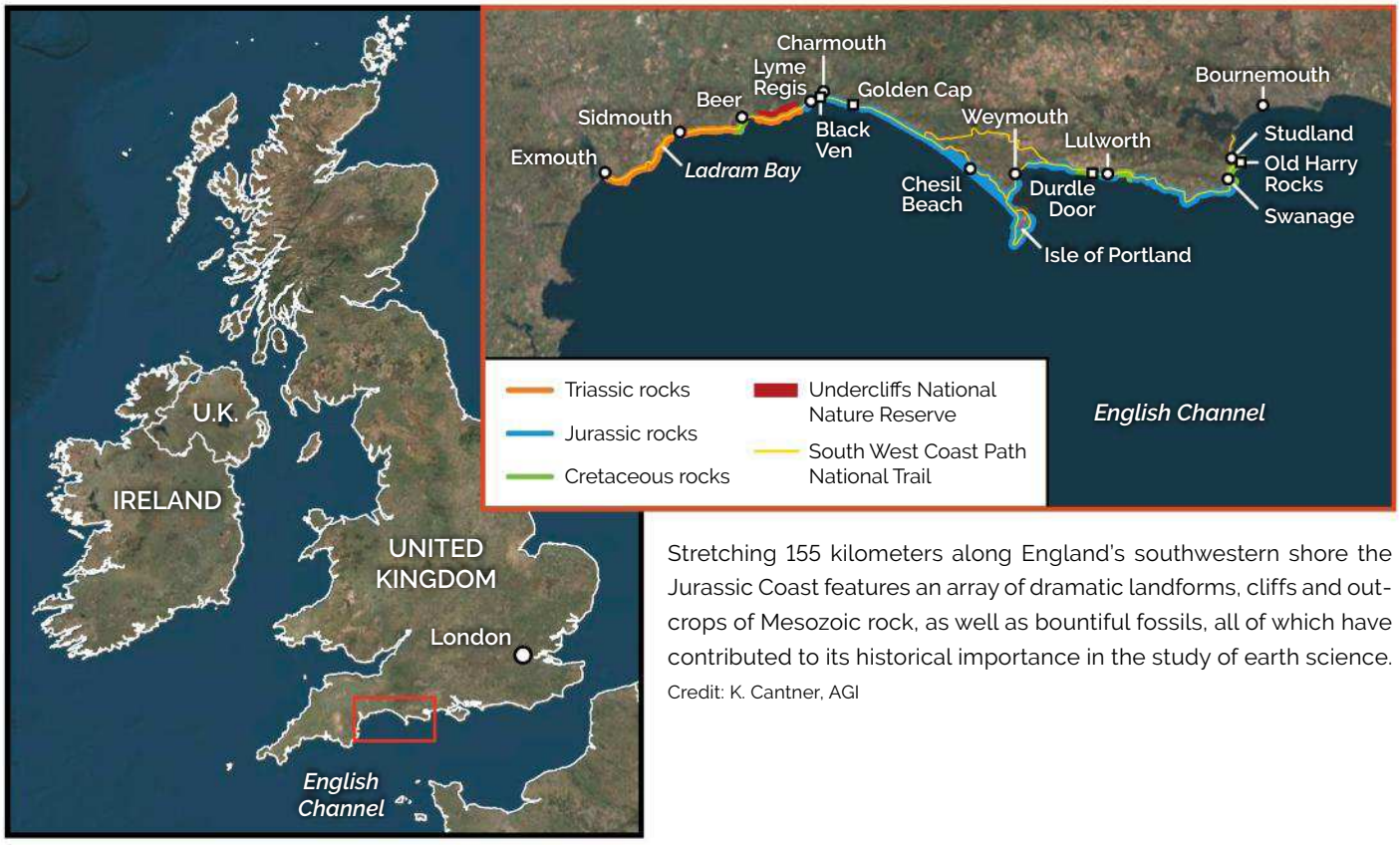
Terri Cook

Just a few hours' drive from London, along England's southwestern shore, stretches a stunning expanse of coastline with a geologic story as captivating as its scenery. Thanks to a wide variety of landforms, impressive cliffs ranging in color from ochre to lily-white, and layered rocks representing all three periods of the Mesozoic Era, this 155-kilometer-long coastal strip has long been recognized as an important place in the study of earth science. But it's the rich cache of fossils entombed within these colorful rocks, particularly those of Jurassic age, that led UNESCO to declare this singular shoreline a World Heritage Site in 2001. Exploring the "Jurassic Coast" — from its pebbly beaches, windswept walking paths and cozy pubs, to the various museums detailing the area's long tradition of groundbreaking fossil discoveries — is a timeless and fun-filled adventure.

A Journey Through Time

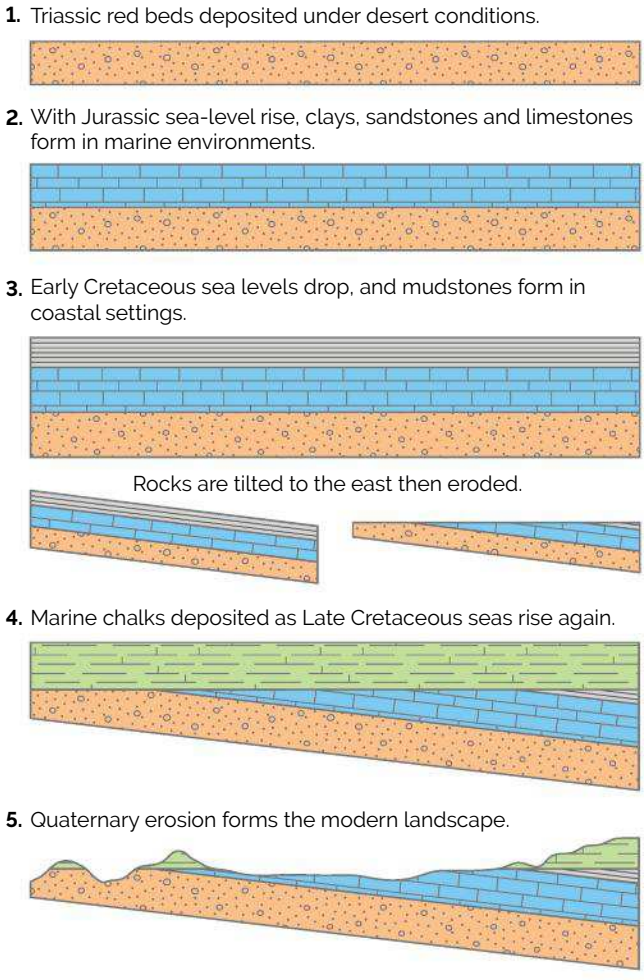
Situated along the undulating shoreline between the towns of Exmouth in East Devon and Studland in West Dorset, the Jurassic Coast is renowned for the nearly continuous 185-million-year record of Earth's history exposed in its sensational seacliffs. These vibrant sedimentary rocks record one of the world's best stratigraphic sequences from the Mesozoic Era, which lasted from 252 million to 66 million years ago and was distinguished by a rapid diversification of life as well as several major extinctions.

Throughout this era, a series of sedimentary basins existed in the vicinity of the modern English Channel. In one of these, the Wessex Basin, whose rocks today cover more than 20,000 square kilometers of southern England, layer upon layer of sediment accumulated from the late Permian to the Paleogene. The sediments that filled the basin are several kilometers thick along



Stretching 155 kilometers along England's southwestern shore the Jurassic Coast features an array of dramatic landforms, cliffs and outcrops of Mesozoic rock, as well as bountiful fossils, all of which have contributed to its historical importance in the study of earth science.

Credit: K. Cantner, AGI



portions of the Dorset Coast, and form three broad rock groups: a basal stack of Permian to Triassic "red beds"; a middle sequence of Jurassic to Early Cretaceous marine mudstones, sandstones and limestones that accumulated as the basin deepened in response to the rifting of Pangea; and an uppermost group primarily composed of Upper Cretaceous to Paleogene chalks.

In the mid-Cretaceous, tectonic activity gently tilted the Mesozoic sedimentary layers down to the east. Then, sea level rose and Upper Cretaceous chalks, sands and clays accumulated atop the inclined layers. The contact between the top of the tilted section and these Upper Cretaceous layers is thus an unconformity. The time gap is larger to the west, where the underlying rocks are older than those to the east. Thanks to this fortuitous geologic happenstance, visitors can journey through 185 million years of Earth history while exploring the beautiful Jurassic Coast.

The rocks of the Jurassic Coast formed from layers of sediment that were deposited, tilted and eroded during the Mesozoic. More recent erosion, in the Quaternary, formed the coastal landscape as we know it today, leaving outcrops that represent roughly 185 million years of geologic activity.

Credit: K. Cantner, AGI

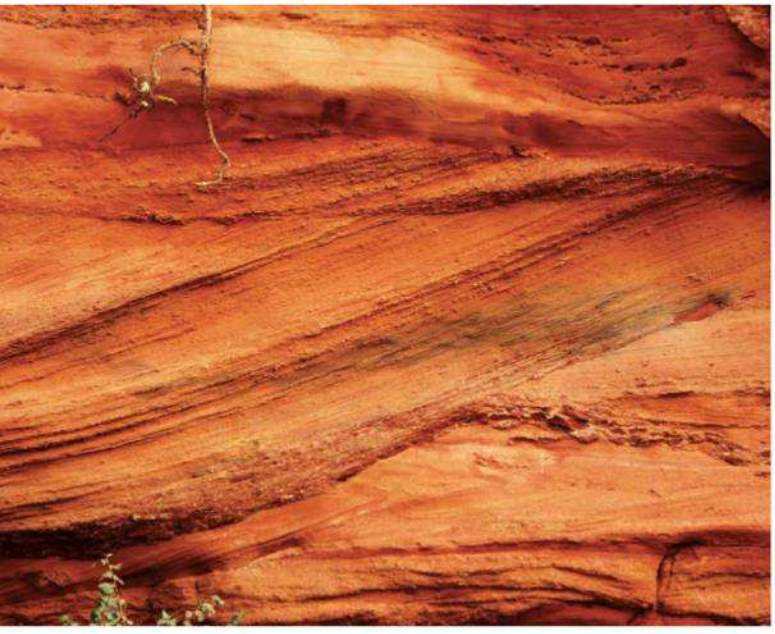
Sidmouth's seafront buildings contrast sharply with the ochre-colored cliffs of Triassic rocks that rise nearby.
Credit: ianwool/istockphoto.com

Tour de Triassic

Triassic rocks extend eastward from the World Heritage Site's western boundary at Exmouth, where seasonal Jurassic Coast Cruises provide excellent views of the coastal exposures. Between this port and the resort town of Sidmouth, the sinuous shoreline is distinguished by dramatic, ochre-colored cliffs that rise sharply from the restless English Channel to form rugged promontories and isolated sea stacks.

A great place to see the Triassic portion of this coastline up close is at Ladram Bay. About 4 kilometers southwest of Sidmouth, a holiday park offers boat rentals, a clifftop restaurant with lovely views, and beach access to the Pangean red beds. Whether you view these sandstones from land or sea, their most distinctive characteristic is a deep crimson color, imparted by the relatively large amount of ferric iron oxide minerals in the rock. The red beds and other clues, including the presence of evaporite minerals like gypsum and halite elsewhere in the Triassic section, indicate these sediments were deposited in a hot, arid environment when the region lay locked in the middle of the supercontinent.

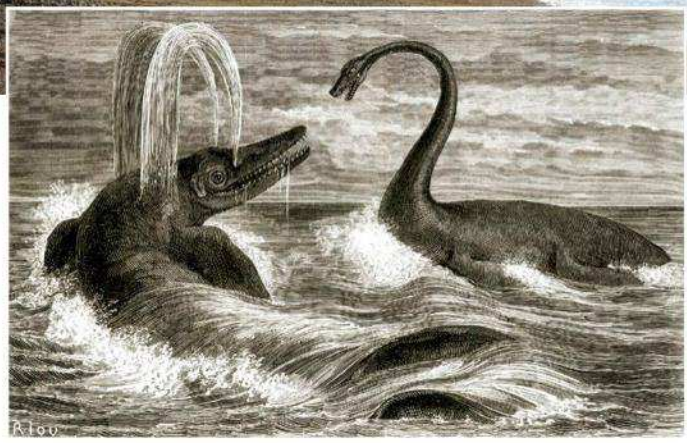
Pangea's center, however, was far from homogenous; lakes, lagoons and fields of sand dunes created a shifting patchwork of depositional environments where the more than 1,100-meter-thick Triassic section accumulated for tens of millions of years. Despite the overall dryness of the environment, crossbeds visible in the colorful cliffs and sea stacks at Ladram Bay provide evidence that large rivers periodically flowed across this region. These rivers drained a tall mountain range to the west that was uplifted roughly 100 million years earlier during the Carboniferous Period as the assembly of Pangea was finalized. Due to their terrestrial origins, the Triassic rocks host relatively few fossils, but those that have been found in this region — including 10 species of reptiles, fish and amphibians discovered in mid-Triassic rocks west of Sidmouth — are of international importance.



Crossbeds visible in the seacliffs at Ladram Bay are one clue that large rivers draining a Pangean mountain range flowed through this area more than 200 million years ago.
Credit: Terri Cook and Lon Abbott

East of Charmouth you can walk in the footsteps of both Mary Anning, one of England's greatest fossil hunters, and prehistoric creatures like *Scelidosaurus*, an armored herbivorous dinosaur.

Credit: Terri Cook and Lon Abbott



This whimsical 1863 engraving depicts an ichthyosaur and a plesiosaur, both apex predators in Jurassic seas.

Credit: Edouard Riou, engraved by Laurent Hotelin and Alexander Hurel

The Charmouth Heritage Coast Center is one of nearly two dozen museums, quarries, visitor centers and wildlife reserves located along the Jurassic Coast.

Credit: Terri Cook and Lon Abbott

Jurassic Fossils

The most famous — and namesake — portion of the Jurassic Coast is its central segment, which stretches east from the historic town of Lyme Regis and showcases one of the world's most complete marine sequences from the Jurassic Period. Deposited in the depths of the Wessex Basin in environments ranging from deep water to coastal lagoons, this stratigraphic section consists of rhythmic layers of mudstone, sandstone and limestone that preserve six cycles of rising and falling sea levels.

The Jurassic section is best known for its remarkable fossil record, which is inextricably linked with the story of Mary Anning. Born in Lyme Regis in 1799, Anning overcame her low social status, lack of formal education and poverty to become one of England's greatest fossil hunters. In her book, "Jurassic Mary," author Patricia Pierce narrates how, as a child, Anning accompanied her father, a carpenter, on coastal walks in search of fossils he could sell to supplement his meager income. After her father's death in 1810, Anning continued to walk the shoreline near Lyme Regis, where frequent landslides and harsh winter storms would often expose new fossils.

At age 12, Mary Anning unearthed the first complete skeleton of a "sea monster" that at first was thought to be an enormous crocodile. Upon further examination, the 5.2-meter-long, dolphin-like creature was named *Ichthyosaurus*, or "fish lizard."

The "Drinking Bowl" by Jonathan Sells is one of more than 60 sculptures carved in the Isle of Portland's historic Tout Quarry.
Credit: Ajsmith141, CC BY-SA 3.0

Eleven years later, in 1823, Anning made a second major discovery: the first nearly complete fossil of *Plesiosaurus giganteus*, a marine reptile with a long, curving neck, paddle-like flippers and a relatively small head. In addition to previously discovered marine crocodiles, these creatures were the apex predators in the relatively warm and shallow Jurassic seas that covered what is now southern England.

You can learn more about Mary Anning and walk in her footsteps in the village of Charmouth, a few kilometers east of Lyme Regis. There, the free Charmouth Heritage Coast Center has informative exhibits about her and other locals' many fossil discoveries, including *Scelidosaurus*, the "Charmouth Dinosaur." This armored herbivorous dinosaur, which roamed the region about 190 million years ago, grazed on grasses that grew on islands sticking out of the tropical Jurassic sea. The fossil cast on display at the museum was fashioned from the best preserved of the eight *Scelidosaurus* skeletons found in this area.

Because the soft, gray cliffs that line the sea near Charmouth are chock-full of fossils, the beach by the heritage center is considered the best place in the World Heritage Site to go fossiling. When the weather and tides cooperate, it's fun to stroll near the pounding surf, searching among the "shingles" (beach stones) for bullet-shaped belemnites, coiled ammonites and other strange-looking creatures that once swam in the Jurassic seas. You're allowed to keep your finds as long as you follow the local fossil collecting code.

Frequent landslides have shaped the Jurassic Coast, creating inspiring scenery and important wildlife habitat — and sometimes causing considerable destruction.
Credit: Terri Cook and Lon Abbott

Landslides and Quarries

The combination of alternating layers of soft mudstone and more resistant sandstone, the wet weather, and erosion of the base of the seacliffs have made the coast's Jurassic section notorious for landslides. Major mudslides have occurred repeatedly just west of Charmouth at Black Ven, where Anning found the famous *Plesiosaurus* skeleton. She also witnessed the aftermath of the "Great Landslip" of Christmas 1839, which occurred west of Lyme Regis along the stretch now preserved as the Undercliffs National Nature Reserve. The slide involved the breakaway of a large, intact block of land, which also formed a small temporary harbor. The changes dramatically reshaped the local landscape and attracted attention from tourists as well as the eminent scientists William Buckland and William Conybeare, who studied the 1839 event in detail and penned some of the earliest known scientific descriptions of landslides.

Repeated landslides in this area have created a mosaic of habitats that constitute one of Britain's most crucial wilderness areas. And slides continue to reshape this coastline today, frequently damaging portions of the 1,014–kilometer-long South West Coast Path, the U.K.'s longest national trail. Nine segments of this popular route, which follows the South West Peninsula coastline, traverse the Jurassic Coast World Heritage Site.

East of 191-meter-high Golden Cap, the highest cliff on England's south coast, exposures of Jurassic rocks continue past the town of West Bay and

The pale cliffs of Old Harry Rocks formed from the remains of microscopic algae that thrived in the ocean that covered this region during the Late Cretaceous.

Credit: milangonda/istockphoto.com

along Chesil Beach, a beautiful barrier beach, to the Isle of Portland, the primary source of the famous Portland Stone. Quarried since Roman times, this high-quality limestone is composed of oolites — round grains of concentrically layered calcium carbonate — deposited near the end of the Jurassic in balmy, lime-rich waters similar to those found today near the Bahamas. This durable material has been used to construct a number of prominent buildings in London, as well as the United Nations' headquarters in New York City.

Isle of Portland is also a famous fossil locality for Late Jurassic fish, turtles and ammonites, and it hosts a Fossil Forest that once grew alongside a hypersaline lagoon that existed during a time of sea-level regression. Boat trips from Portland Harbor and the small city of Weymouth are seasonally available to the island, where you can visit the historic Tout Quarry, which has been converted into a sculpture park and nature reserve. The isle also boasts several lighthouses; outdoor recreation including rock climbing, kayaking and hiking; and opportunities to view native butterflies and orchids, which bloom from late spring through early summer.

Cretaceous Chalk

East of the Isle of Portland, between the towns of Weymouth and Lulworth, the seacliffs are composed of Late Jurassic to Early Cretaceous rocks. Sea levels fluctuated during this time, and the region hosted a variety of coastal environments, including sabkhas — coastal lagoons covered in salt flats like those found today around the Persian Gulf — as well as verdant swamps inhabited by *Iguanodon* and other dinosaurs. As sea levels rose later in the Cretaceous, the region was submerged beneath a sea teeming with microscopic algae. When these organisms died, their calcium carbonate shells gradually accumulated on the ocean floor, forming a thick layer of carbonate-rich ooze that later lithified into snow-white chalk.

This porous chalk forms the spectacular scenery at Old Harry Rocks, a trio of rock formations that mark the Jurassic Coast's easternmost point. These rocks, which erosion has isolated from the narrow coastal headland, are best viewed from boats departing out of Swanage or Bournemouth, from along the South West Coast Path, or from the shores of South Beach. South Beach is reached by a short path that heads downhill from the Bankes Arms, a cozy stone pub that serves up pints of house-brewed ale to customers gathered around a crackling fire.

Scraps of Upper Cretaceous rock overlying the unconformity are also present in several other locations along the coastline, including the upper cliffs east of Sidmouth, where the white limestone contrasts sharply with the underlying Triassic red rocks. Some Upper Cretaceous rock is also present near the town of Beer, where downward faulting of a large block of chalk protected it from erosion. In this area, a layer composed primarily of shell fragments has been extensively quarried to provide building material for 24 cathedrals and Windsor Castle. Although active quarrying ceased in 1920, visitors can still tour the extensive Beer Quarry Caves from late March through late September.

Two more iconic Jurassic Coast sites are Durdle Door, a classic sea arch, and horseshoe-shaped Lulworth Cove, both located, geographically, about 15 kilometers east of Weymouth, and geologically, near the Jurassic-Cretaceous stratigraphic transition. The features owe their origin to an especially resistant band of Portland Stone, which has better resisted the waves' erosional onslaught than the adjacent softer rocks. Lulworth Cove formed after a stream eventually broke through the resistant band of Portland Stone, which had formed a bulwark against the sea. This breach then allowed waves to hollow out the soft clays inland of the strong limestone, creating the famous embayment. Similar processes formed Durdle Door, creating yet another site where visitors can relish the Jurassic Coast's tantalizing combination of gorgeous scenery, landmark attractions, and 185 million years of incomparable evolutionary history.

Cook (www.down2earthscience.com) is a science and travel writer based in Colorado and an EARTH roving correspondent.

Getting There & Getting Around

From North America, the cheapest and most convenient access to the Jurassic Coast is via one of London's major airports. Nonstop service to Heathrow (LHR) and Gatwick (LGW) airports is available from many major U.S. cities.

In addition to views of Old Harry Rocks, visitors to South Beach on the eastern Jurassic Coast can also enjoy a pint of hearty ale next to a crackling fire at the Bankes Arms pub.

Credit: Terri Cook and Lon Abbott

From London, the easiest way to get to (and around) the Jurassic Coast is by renting a vehicle, assuming you're comfortable driving on the left side of the road. Because Gatwick is located on London's southern outskirts, it offers the best escape to England's southern coast from the hustle and bustle of the city. National Express offers convenient and inexpensive bus shuttles between Heathrow and Gatwick. You can also catch a quick flight to Bournemouth or Exeter and either rent a vehicle or hop aboard a bus traveling one of the five routes that regularly ply the southwest coast. It's also possible to reach the area via rail. If you decide to rent a vehicle, any airport will offer a good selection of international and local carriers.

In Charmouth, visitors can search the beach for the fossilized remains of ammonites and other creatures that swam in the shallow sea that covered southwestern England during the Jurassic.

Credit: Terri Cook and Lon Abbott

During the busy summer season, it's best to book accommodations ahead of time. These range widely in price, services and quality. Websites such as bedandbreakfast.com and historic-uk.com highlight the many quaint bed and breakfasts and cozy inns scattered along this stunning coast.

The United Kingdom's official currency is the British Pound. ATMs are widely available, and most restaurants and accommodations accept credit cards. The weather along the coast is often wet, so it's best to bring along good rain gear and walking shoes, especially if you're planning on hunting for fossils or hiking the coast.

TC

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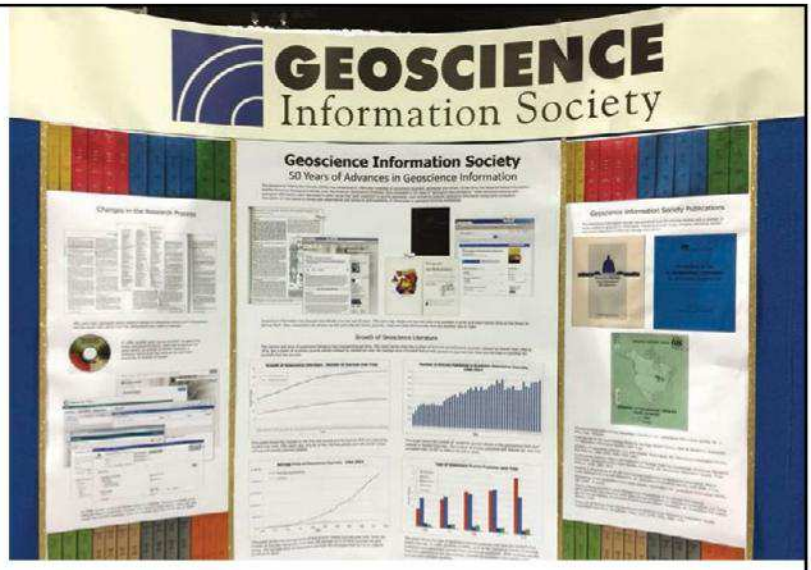

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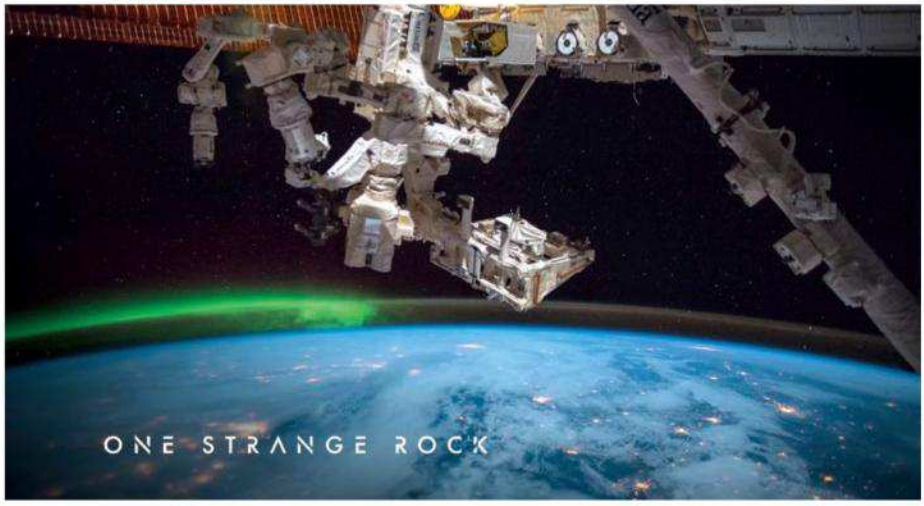
Television: "One Strange Rock" Is Superlative

Mark Oscar McAdam

If I only had one word to describe the 10-part National Geographic documentary series "One Strange Rock," directed by filmmaker Darren Aronofsky, it would be "superlative." But don't misunderstand me: The series is not remarkable because it's the best nature documentary I've ever seen. It's not, although it does feature gorgeous footage and state-of-the-art, digitally generated animations, and perhaps covers a wider range of earth science topics than other documentaries in the genre. Instead, it is superlative in the way that Americans make many things superlative — with hyperbole.



"One Strange Rock," a 10-part documentary television series, features gorgeous footage — much of it shot in space — and state-of-the-art digital animation as it brings together natural phenomena and human interest. It aired on the National Geographic Channel this spring.

Credit: NASA/National Geographic

In "One Strange Rock," every fact and facet of nature is presented as utterly astounding. In the breathlessly titled first episode, "Gasp," about Earth's unique oxygen-enriched atmosphere, host Will Smith tells viewers: "I am going to tell you about the most incredible place ... and you know what? You're walking on it." He later adds: "We're walking a tightrope, with death on either side."

In the second episode, titled "Storm," Smith ominously intones: "Here comes the sun, it is the fuel of life. But it is not our friend. The sun is a planet-killer." He also notes that "for 4.5 billion years our planet has been battered and bruised and punched and pummeled, but we're still standing. It's actually the battle that's built us, and this is the tale of the tape," Smith says.

Fans of David Attenborough's calm dictation in the BBC documentary series "Planet Earth" may find Smith's energetic sensationalism a little jarring. For me, though, the poetic and expressive language works. Smith's excitement is palpable — a constant grin tugs at his mouth during interludes, shown in simple black and white filming, when he narrates directly to the camera. The same close-up, black-and-white aesthetic is used with the 10 astronaut presenters featured in the series — Chris Hadfield, Mae Jemison, Mike Massimino and Peggy Whitson, to name a few. An array of international geoscientists also take part, helping narrate the episodes through voice-overs and on-location reports. Many of these scientists explain their work in their native languages, something not often seen in science documentaries produced in the U.S.

These moments of narration are useful devices, offering viewers momentary reprieves from the frenetic pace. After all, there's a lot to take in, with stunning cinematography filmed across 45 countries and six continents as well as in outer space, where Italian astronaut Paolo Nespoli and NASA astronaut Whitson shot footage from the International Space Station.

The series focuses on the perspectives of those few humans who have left Earth and seen the planet from space.

Credit: NASA

Researchers sample microbes from an acidic lake in Ethiopia in an episode of "One Strange Rock."
Credit: National Geographic

The first episode of "One Strange Rock" features many photos taken from space, such as this shot of an impact crater on Earth taken from the International Space Station.
Credit: NASA

National Geographic bills the 10-episode series — which began airing weekly on Nat Geo TV in late March — as "an epic journey across the globe and into outer space" that "promises to be a thrilling, mind-bending trip within and beyond planet Earth, affirming that there really is no place like home." To that end, the series focuses on the perspectives of those few humans who have left Earth and, having seen it from space, possess, we are told, more objective opinions about it. The astronauts' experiences are contrasted with perspectives of earthbound humans, with footage cutting between views of Earth from space and views from the surface to reveal what is hidden from the astronaut's viewpoint. These back-and-forth shifts are frequent in each episode, forming an interwoven storyline from different perspectives.

Throughout the series, Earth is portrayed as odd, rare, unique and special. It's no wonder, since "strange" is right there in the title. This characterization allows the series to range over a plethora of issues, threading together what might seem like disparate topics into a coherent narrative. For example, the first episode begins with Will Smith playing with his dogs on Earth, which he notes is made possible by oxygen, then leaps to an interview with Hadfield about a scary incident he had during a spacewalk that necessitated having to evacuate the oxygen from his spacesuit. From there the show jumps to scientists dressed in protective suits collecting samples from an acidic lake occupied by oxygen-producing microbes that may have been similar to the early inhabitants of Earth.

That episode goes on to cover fumaroles, dust storms, diatoms, clouds, glaciers and why the atmosphere is blue, and juxtaposes these features and phenomena with the human experiences of astrobiologists, salt traders, climatologists, glaciologists and Buddhist monks.

I expected the second episode ("Storm") to be about weather, but it soon became clear that the title refers to the space environment that Earth weathers. "Every day the Earth plows through about 40 tons of material in space," astronaut Nicole Stott tells viewers.

"Storm" pings around the universe, touching on topics as diverse as asteroids and comets (including everything from dust particles to protoplanets), cenotes, deserts, circumstellar habitable zones, ice caves, frozen waterfalls, tides, Europa, and the Theia and Gaia hypotheses. Along the way, we hear from free divers, Bedouin meteorite collectors, astrophysicists and Inuit elders.

By dovetailing these various natural phenomena with diverse representations of humanity, the series shows that good science should also acknowledge its resultant philosophical implications. For example, "Gasp" addresses the notion that humanity takes for granted the unique conditions on Earth that have allowed humans to survive, and also that we often ignore that the spread of humans around the globe has constrained other species, shrinking their habitats and sometimes eliminating them altogether.

We are also shown that many scientific findings that the western world only recently accepted were intuited long ago by other cultures. In "Gasp," Buddhist monk Pra Chayanon recounts: "All life is interconnected. Nothing exists in isolation."

Ultimately, "One Strange Rock" is not so much about Earth itself as it is about how humans have managed to survive and thrive on a once inhospitable, and yes, very strange, planet. Perhaps that is something worthy of a little hyperbole.

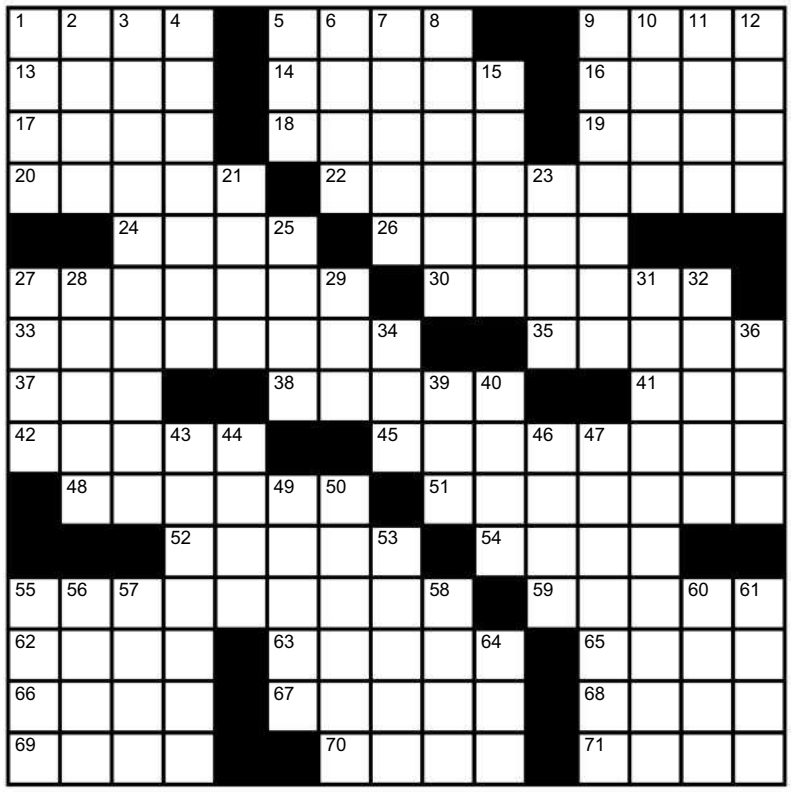
McAdam holds a master's degree in geology and is technology manager at the American Geosciences Institute. He is based in Flagstaff, Ariz.

Across

1. An Avenger
5. Bandy words
9. Hair goops
13. Burrow
14. Holding one's piece
16. "Absolutely!"
17. Soprano's song, maybe
18. Short tale
19. Part of the Hindu trinity
20. Fireplace
22. Can be virtual
24. Goals
26. Church part
27. Not real?
30. In arrears
33. Inside a growth
35. Cast member
37. ___ power
38. Decree
41. Bemoan
42. Chamber groups
45. Chemist
48. Eyepiece
51. Marched
52. ___ bar
54. Bowline
55. Nose color
59. Cast out
62. Jewish month
63. Bartender on TV's Pacific Princess
65. 10^5 in India
66. Energetic
67. "Likewise"
68. Biblical birthright seller
69. High-five, e.g.
70. Home, informally
71. Adjusts, as a clock

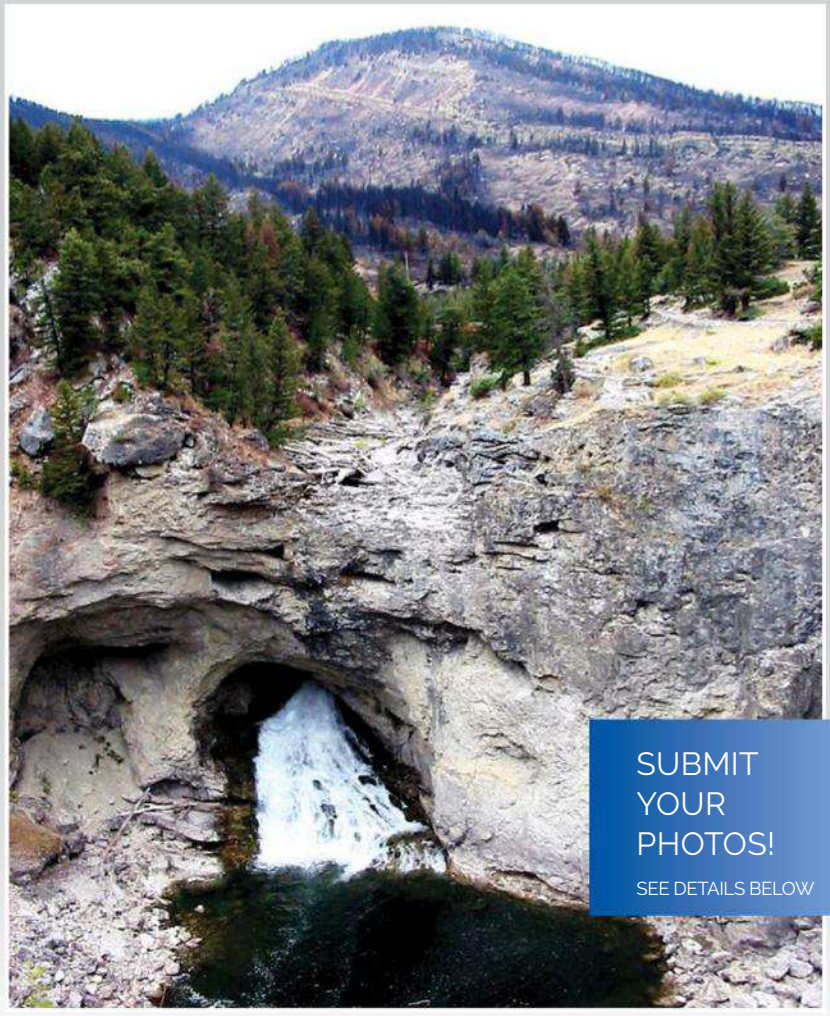
Down

1. Asian tongue
2. Game ender, perhaps
3. Controlled by a few
4. In person or virtual
5. Amniotic ___
6. Doc
7. Embryo sac
8. Repeat yarn
9. Of the stomach
10. Arabic for "commander"
11. ___ Strauss & Co.
12. Become unhinged
15. Atlanta-based airline
21. Flightless flock
23. Computer info
25. Fill
27. Blow off steam
28. Foreword, for short
29. Certain digital watch face, for short
31. Erotic dance
32. Put up
34. "___ not!"
36. Abbr. after many a general's name
39. Computer monitor, for short
40. Istanbul native
43. Field trip target
44. Cole ___
46. Departed
47. Searches
49. Greenfly, e.g.
50. Cereal fruit
53. Affirm
55. Not zigs
56. "American ___"
57. Mythical serpent
58. Beanery sign
60. 32-card game
61. As a result
64. Bunk



Puzzle solution appears in the Classifieds section.

WHERE ON EARTH?



SUBMIT YOUR PHOTOS!

SEE DETAILS BELOW

CLUES

- At times of low runoff (as in this picture), the river drains through a solution cavity in Paleozoic limestone. During times of high runoff, however, water fills the dry channel above the cavity, spilling over the cliff and creating a 30-meter-high waterfall.
- The waterfall, located about 60 kilometers north of a colorfully named national park, was named after a nearby natural feature that collapsed in July 1988.
- This river is the better known of two in the state with the same "rocky" name, and is a popular destination for hiking, camping and fishing.

NAME THE WATERFALL & ITS HOST STATE.

April 2018 Answer:

Lake Oeschinen (or Oeschinensee in German) has been part of the Swiss Alps Jungfrau-Aletsch UNESCO World Heritage Site since 2007. Photo by Matteo Rolfi.

April 2018 Winners:

Heike Alberts (Oshkosh, Wis.)
Claude E. Bolze (Sapulpa, Okla.)
Rena M. Bonem (Waco, Texas)
Edith Chasen-Cerreta (Woodhaven, N.Y.)
Trina Dey (Irving, Texas)

Editor's note: Abraham J. Padilla, a February winner, was incorrectly listed in the May issue as Anthony J. Padilla. We apologize for the error.

HOW TO PLAY

Where on Earth was this picture taken? Use these clues to guess and send your answer via Web, mail or email by the last day of the month (July 31). Subscribers can also view contest photos and clues in EARTH's monthly digital editions. From those who answer correctly, EARTH staff will randomly draw the names of five people who will win a prize from AGI. Enter the contest at www.earthmagazine.org/whereonearth.

You can also submit entries to Where on Earth? EARTH, 4220 King Street, Alexandria, VA 22302 (postmarked dates on letters will be used). EARTH also welcomes your photos to consider for the contest. Find out more about submitting your photos at www.earthmagazine.org/whereonearth/submit, and send them to earth@earthmagazine.org. If we print your photo in EARTH, you'll receive a free one-year subscription or renewal.

With Highway Paleontologist Shane Tucker

Bethany Augliere

When roads are built in fossil-rich states, paleontologists sometimes follow the trucks and bulldozers to make sure that the buried treasure that construction crews occasionally uncover — namely, remnants of ancient animals and plants — get out of the ground safely and into a museum to be cataloged and studied.

The first state to establish such a highway paleontology program, in 1960, was Nebraska, where, today, the role of state highway paleontologist is held by Shane Tucker.

A native of the state, Tucker grew up stashing rocks and clamshells into his dad's tackle box during fishing trips. "I wanted to be a paleontologist since I was a kid," Tucker says. "It sounds kind of goofy, but I am living out my dream."

Tucker earned a bachelor of science in geology with minors in biology and math at the University of Nebraska–Lincoln in 1997. While in college, he worked as an intern at Ashfall Fossil Beds State Historical Park in northeastern Nebraska. After graduation, he continued at the university, earning a master's degree in geosciences with an emphasis in vertebrate paleontology.

In 2000, Tucker started working as a preparator for the Nebraska Highway Paleontology Program, which is a collaboration between the University of Nebraska State Museum, where Tucker is based, and the Nebraska Department of Transportation. Seven years later, he assumed the role of state highway paleontologist. During the Nebraska program's 58 years, fossils ranging in age from 20,000 years to 290 million years have been recovered in 91 of the 93 counties in the state. Over the years, Tucker has helped recover specimens of primitive horses, camels, rhinoceroses and even marine reptiles like mosasaurs.

Tucker recently spoke with EARTH contributing writer Bethany Augliere about how he got started as a paleontologist, some of his exciting discoveries, and what he enjoys about Nebraska rocks.

Nebraska highway paleontologist Shane Tucker monitors road construction projects to recover the state's valuable paleontological resources, including many of the mammal fossils for which Nebraska is famous.

Credit: Gary Hochman

BA: What exactly does a highway paleontologist do?

ST: I review road construction projects that are going on around the state, and analyze potential impacts on fossil resources. Based on the rock units that will be exposed in an area, we determine which projects are more likely to produce fossils. Then we go out and monitor those projects. If there are any fossils that are uncovered, we'll excavate them, bring them back, and then curate them into the paleontology research collection here at the museum. Nebraska is extremely rich in fossil resources, and our natural history museum has more than a million-and-a-half vertebrate fossils from throughout the state.

We often walk behind equipment like scrapers or bulldozers. If we find bones, we'll flag down a worker or get in touch with a project manager. Then the construction just shifts a little while we do exploration. The good thing is it doesn't stop or get in the way of the road construction.

BA: What kinds of fossils do you find in Nebraska?

ST: There are fossil invertebrates and vertebrates from the Paleozoic, Mesozoic and Cenozoic eras. Depending on where you go in the state, you'll find different ages of fossils. In the far southeastern portion of the state are the oldest rocks, between 290 million and 320 million years old.

There's a pass in the eastern third of the state that has exposures of rocks from 100 million to 70 million years ago, when

Digging can be temporarily stopped or moved if fossil discoveries are made during road construction projects. Here, Tucker samples late Pleistocene sediments for microfossils on a highway project near Kearney, Neb. At this site, he recovered fossil snail shells and gopher remains.
Credit: Gary Hochman

Nebraska was mostly covered by oceans. The fossils we find there are from the end of the Age of Dinosaurs, including fossil fish, invertebrates, mosasaurs and plesiosaurs.

What Nebraska is really known for, though, are its mammals. Our fossil mammalian record is second to none, and many museums from across the country have collected here over the years. We have things like four-tusked elephants, rhinos, three-toed horses, lions, horned rodents that are like prairie dogs with horns on their noses, and dogs that had bone-crushing jaws.

BA: You have to be able to recognize many fossils for this job; what makes you successful in this position?

ST: Lots of on-the-job experience, in addition to the training as an undergraduate and graduate student. The two internships I did at Ashfall Fossil Beds really helped me, as did my mentors who had decades of experience studying Nebraska geology and paleontology.

Much of the background research for individual highway construction projects is done in the office. Prior to monitoring a project, we know which rock layers will be impacted and the fauna from this unit. There are features on individual bones that identify them as being from a horse, a rhino, a camel or a bison, for example. The more detailed identifications down to species level are done in the paleontology research collections at the museum, by curators, students, outside researchers and myself.

BA: I can't say I'd ever heard of a highway paleontologist before meeting you. Is this what you thought you'd be doing?

ST: No, my plan originally was to work toward a doctorate, do research and teach as a professor. Then I saw how difficult it was to get a position in paleontology and I had this opportunity to work at the museum that I had visited so much as a kid. I thought, "I get to study the rocks in Nebraska, I get to study the fossils, I'm part of our natural history museum, and I'm being paid." All that made the opportunity worth it. I absolutely feel lucky.

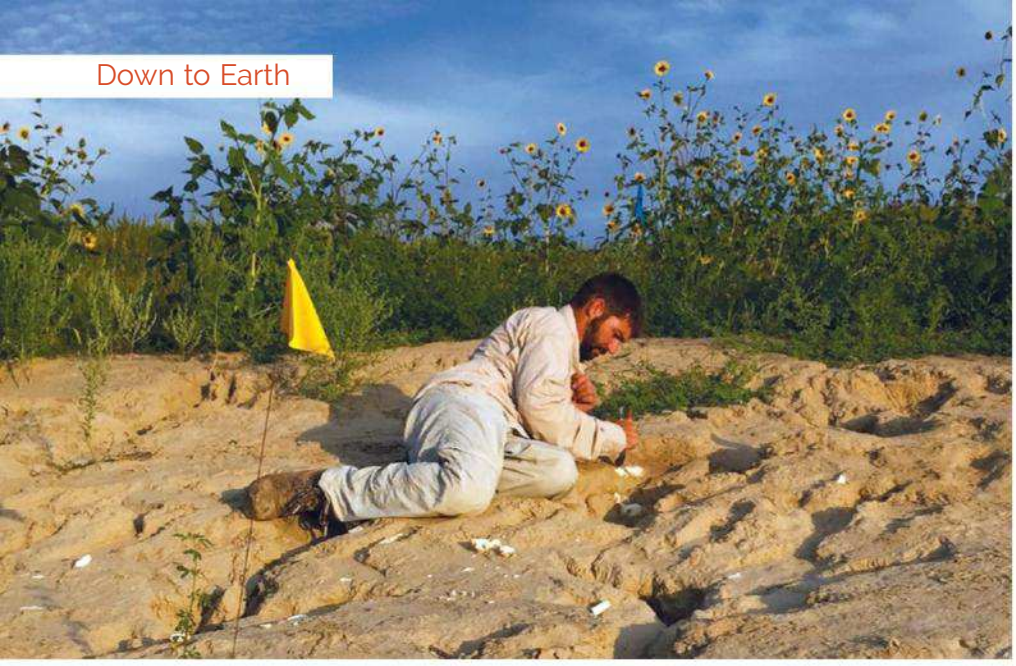
BA: What about paleontology, and your job specifically, excites you?

ST: First, it's the sense of discovery. When I'm out in the field, for example, I could work all day shoveling sand and not find anything. But, the next scrape could expose a jawbone that I'm the first person to ever see, and it might be millions of years old. That's extremely exciting.

I also get to interact with the public, which is exciting because everybody has a different story. Everybody has found something. I've seen people's eyes light up like a kid's when you identify something they've found that's millions of years old.

I also get to be outside and see beautiful parts of the state. People think Nebraska is flat because they travel on Interstate 80. We have buttes, 150-meter-tall sand hills, and deep river valleys. We have beautiful sunrises and sunsets in four different seasons, and I get to see that. A lot of people don't know this, but the largest sand sea in the Western Hemisphere — the Sand Hills — is in Nebraska, it's just covered with grass. That's why I love the job.

Tucker excavates an 8-million-year-old giant tortoise shell alongside a highway in western Nebraska.
Credit: Mark Harris



Tucker explores an area where a few bone fragments were discovered at the surface in Custer County, Neb., which led to the recovery of a skull and partial skeleton from an extinct species of bison (*Bison antiquus*).

Credit: Gary Hochman

BA: What did you study for your master's research?

ST: It was actually a highway construction project, in Keya Paha County in north-central Nebraska, called the Rick Irwin Site. The museum and my advisor knew of this site but its age was unknown — the goal of my project was to narrow down the age.

Some of the bones discovered by Rick Irwin, a state highway employee, were from taxa that were extremely rare in the Niobrara River Valley. There are hundreds of fossil localities [represented] in our museum collection, as well as at the American Museum of Natural History collection, from time intervals older than 9 million years ago and younger than 3 million years ago. The rare fossils suggested that the [Irwin] site filled a portion of this missing time slice. By using the known temporal ranges of certain carnivore and rodent taxa, we determined the age of the site to be between 6 million and 6.6 million years old. This site is one of the most diverse spots for carnivore faunas of its age in North America. We've identified 17 different carnivore taxa.

BA: A common misperception about paleontologists is that they all dig up dinosaurs. Nebraska doesn't have many dinosaur fossils. Did you originally want to study dinosaurs?

ST: I liked dinosaurs as a kid and had dinosaur toys. "Jurassic Park" had just come out after I graduated high school, and I was thinking I was going to study dinosaurs in Nebraska in college.

When I had the chance to do an independent study project with Mike Voorhies, the curator of vertebrate paleontology at the museum and a geologist at the University of Nebraska, I wanted it to be on dinosaurs. He took me to the museum and showed me a shelf with the two dinosaur fossils from Nebraska. One is a broken limb and the other is a small section of a tooth. And I thought, "Well, that is pretty disappointing."

Then he showed me the mammals. He showed me a full skeleton of a rhino with every bone. The hook, line and sinker was a saber-toothed cat skull. I thought, "This is so much cooler than the dinosaur fossils!"

BA: What is the coolest fossil you have found?

ST: That's hard to say; there have been a lot. I was working on a project in the Wildcat Hills in the western region of the state, and the last fossil we found before we finished the project was the skull of a slingshot-horned deer called *Prosynthetoceras*. It isn't a true deer but an extinct family that resembled deer. That's the only skull from that genus that I'm aware of that's ever been found in Nebraska — it's extremely rare.

The crazy part is that I'd first found the fossil two days before. The animal has a horn that is kind of curved like a rib, so I thought I'd just found a rib. It wasn't until I came back to the site, dug more and saw the eye socket that it popped into my head that this was the skull of a slingshot-horned deer. I was so excited, I was visibly shaking. It's on display now at the museum.

When we collected it, we put it in a plaster field jacket and took a lot of extra sand [from around the skull], so we didn't have anything fall out when flipping the jacket. This could happen in loose sand if you aren't careful. Back at the lab, we realized there were about six other partial skulls and jaws in the same field jacket — including one from a primitive three-toed horse called *Archaeohippus*.

BA: Is there a particular fossil you are hoping to find someday?

ST: In the old rocks of the far southeast corner of Nebraska, we have fossil lungfish. Today, they're found in Africa, South America and Australia, so you wouldn't necessarily expect them to be in Nebraska. But when these fish were alive, Nebraska was part of the supercontinent Pangea. Geologists collected lungfish from one site during a past road project, and our museum went back and collected a few more, but I've never encountered any of those. There's just a lot of cool stuff here; Nebraska is a great state for a paleontologist.

Augliere is a freelance writer and photographer and a former editorial intern at EARTH. She is a graduate of the science communication program at the University of California, Santa Cruz, and holds a master's degree in marine biology from Florida Atlantic University. For more of her work visit http://www.bethanyaugliere.com.

July 29, 1958: The Birth of NASA

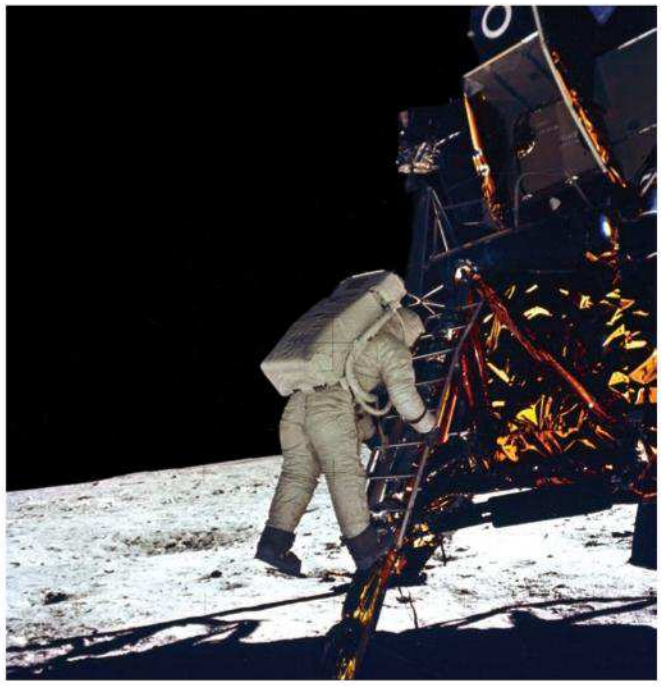
Bethany Augliere

Growing up in the suburbs of Washington, D.C., meant that my house was often frequented by guests who wanted to visit our nation's capital. Without fail, this meant my family and I would be taking a trip to one of the Smithsonian's most popular attractions, the National Air and Space Museum. I can't count the number of times I visited the museum before I left for college, but it was a lot. Although glimpsing the museum's collection of aircraft and spacecraft was cool at first, I would much rather have spent those afternoons wandering the halls of the National Museum of Natural History.

But my journey through space history didn't stop in my own backyard. In middle school I took a private tour at the John F. Kennedy Space Center in Florida because my cousin worked there as an aerospace engineer. Although this behind-the-scenes tour would be riveting for some, the truth is, the giant alligators soaking up the sun on the grassy banks nearby stole my attention.

It wasn't until I was a young adult that I developed an interest in stars and space. My grandfather, with whom I first began stargazing, shared his awe of space with me. Until his death in 2016, he would always call to tell me if there was a conjunction in the sky. As I learned to recognize the night sky, my curiosity for the entire field grew. Eventually, I peered through telescopes to learn the features of the moon or glimpse Jupiter's moons, and researched the things I was seeing, like red giants and nebulae. Now, as a science writer, I regularly explore space, covering topics such as the 20-year-long Cassini Mission.

Sixty years ago this month, on July 29, 1958, President Dwight D. Eisenhower signed the National Aeronautics and Space Act, officially establishing NASA. In the ensuing years, NASA has regularly pushed the boundaries of scientific and technological achievements in air and space, as with the moon landings of the Apollo Program, the deployment of the Hubble Space Telescope, and exploration of Mars with increasingly intelligent spacecraft. The agency has also made countless discoveries about the cosmos, and continues to do so — the recent launch of TESS (Transiting Exoplanet Survey Satellite) to survey our space neighborhood, likely discovering thousands of new planets outside our solar system.



U.S. astronaut Edwin "Buzz" Aldrin climbs down the ladder of the lunar lander during the July 1969 Apollo 11 moon landing, which effectively ended the space race.

Credit: NASA

For the American public — and perhaps worldwide — the mention of NASA likely brings to mind popular figures like astronauts Alan B. Shepard, Buzz Aldrin and Neil Armstrong. Yet, if the 2016 biographical drama "Hidden Figures" taught us anything, it's that there are many important figures who worked behind the scenes throughout the agency's history.

The Race Is On

In the late 1940s, the United States worked to establish itself as a world leader in technological development. Coming out of World War II, the Department of Defense pursued research and rocketry. Other nations followed suit, and in 1952, the International Council of Scientific Unions designated the International Geophysical Year (IGY) from July 1, 1957, to Dec. 31, 1958. The IGY was part of a collaborative effort among 69 countries, including the U.S., to further understanding of Earth's gravity, aurorae, ionosphere and geomagnetism, among other characteristics.

In July 1955, President Eisenhower announced a plan to launch a scientific satellite into orbit as part of the IGY. The president put out a call for proposals, and ultimately chose the Naval Research Laboratory's Project Vanguard on Sept. 9, 1955. In response, the Soviet Union also announced plans to put its own satellite into orbit, sparking the space race. On Oct. 4, 1957, the Soviets launched Sputnik I.

Sputnik I was the world's first artificial satellite. About the size of a beach ball and weighing a mere 83.6 kilograms, it spent a total of 98 minutes orbiting Earth. Then, just one month later, the Soviets launched Sputnik II, carrying a stray dog from Moscow named Laika into space.

The successful launch of Sputnik I caused widespread concern in the U.S.

and among its allies, about a perceived technology gap between the U.S. and the Soviet Union. There was also fear that the Soviets could send missiles with nuclear weapons to Europe and America. Rumblings that the Eisenhower administration had neglected the American space program emerged among the general populace. The so-called "Sputnik Crisis" even prompted the Democratic governor of Michigan, G. Mennen Williams, to write a poem:

Oh little Sputnik, flying high
with made-in-Moscow beep.
You tell the world it's a Commie sky
and Uncle Sam's asleep.
You say on fairway and on rough
the Kremlin knows it all.
We hope our golfer knows enough
to get us on the ball.

Ultimately, in response to Sputnik, the U.S. poured more funding and resources into aerospace endeavors, technical and scientific educational programs, and the chartering of new federal agencies to manage air and space research and development.

After the moon landing, NASA's mission expanded to include the shuttle and space station programs, Earth observation, and the exploration of other planets in our solar system — missions on which many women worked behind the scenes. In 1972, Patricia "Patsy" Conklin assembled a mosaic of Mars' surface from photos taken by Mariner 9.
Credit: NASA/JPL-Caltech

The U.S. was determined to pull ahead in the space race, but the initial attempt to send a satellite into space failed on Dec. 6, 1957, when the Vanguard launch rocket exploded shortly after takeoff.

Eisenhower then directed the U.S. Army Ballistic Missile Agency to orbit a satellite using a Jupiter-C rocket under the leadership of Wernher von Braun, often considered the father of American rocket science. The Jet Propulsion Laboratory (JPL) in Pasadena, Calif., received the assignment to design, build and operate the artificial satellite that would serve as the rocket's payload, an effort directed by William H. Pickering. In less than three months, JPL completed the job.

On Jan. 31, 1958, the U.S. successfully launched the Jupiter-C rocket, carrying the country's first satellite, Explorer I, into outer space. It was also the first satellite to carry a scientific instrument, which had been designed by James A. Van Allen of the University of Iowa. That instrument helped scientists discover the radiation belts — now named for Van Allen — that encircle Earth.

In July 1958, about a year after Sputnik entered space, Congress passed legislation establishing NASA, which absorbed the earlier National Advisory Committee for Aeronautics. NASA started with 8,000 employees, an annual budget of $100 million, and three research laboratories: Langley Aeronautical Laboratory, Ames Aeronautical Laboratory and Lewis Flight Propulsion Laboratory, as well as two small test facilities. Within three months of its creation, the agency began space missions.

NASA's first administrator was Thomas Keith Glennan, who had previously served as president of the Case Institute of Technology (CIT) in Cleveland, where he was credited with turning CIT into one of the nation's top 20 technical institutes and where he'd planned to spend the remainder of his career. However, in August 1958, Glennan was flown to the nation's capital, where Eisenhower asked him to consider becoming administrator of the new agency. "The meeting with President Eisenhower was brief and very much to the point," Glennan wrote in his diary. "He said he wanted to develop a program that would be sensibly paced and vigorously prosecuted." Glennan took the job.

Trailblazing Women

Since NASA's inception 60 years ago, the list of people who have contributed to its success is lengthy, from engineers to pilots to research scientists and beyond. Although astronauts capture most of the limelight, it is the work of many unseen heroes that also drives successful missions.

Nancy Roman joined NASA in 1959 and started the agency's astronomy program shortly thereafter. She was the first chief of astronomy in the Office of Space Science at NASA's Headquarters in Washington, D.C., and the first woman to hold an executive position in the agency.

Throughout her career with NASA, Roman worked on the planning and development of various programs, including the Hubble Space Telescope, which earned her the nickname "Mother of Hubble."

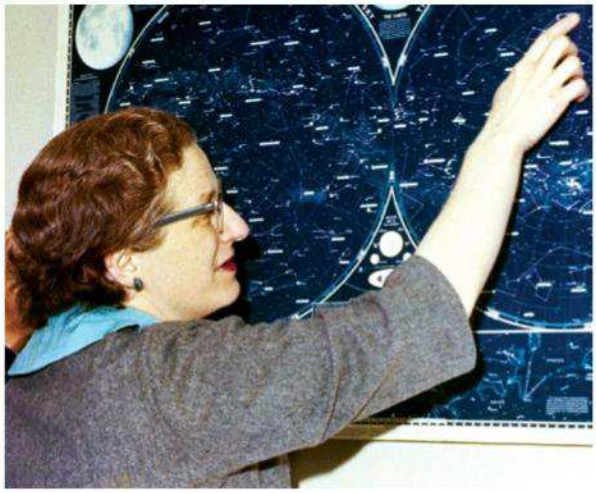
"What I liked most about being the chief of these programs was the many contacts I had with researchers that were on the forefront of astronomical research and with the broad astronomical community in this country and abroad," Roman said in an interview posted on NASA's website.

Her observations led to the knowledge that common stars are not all the same age — a discovery that was a favorite moment in her career, she recalled. Roman credits her parents for inspiring her, including her mother, who "took me out at night and showed me the constellations and the aurorae."

In 1962, Roman was listed by Life magazine as one of the 100 Most Important Young People. She has an asteroid named in her honor and, in 2017, the "Women of NASA" LEGO set included a mini figurine of her, as well as four other women.

Humanity's knowledge of the cosmos has expanded exponentially since the founding of NASA in 1958. This image of an active star-forming region in the Eagle Nebula, named the Pillars of Creation, was taken by the Hubble Space Telescope, which launched in 1990.

Credit: NASA, ESA and the Hubble Heritage Team (STScI/AURA)



NASA's first chief astronomer, Nancy Grace Roman, was nicknamed "Mother of Hubble" for her work on the Hubble Space Telescope.

Credit: NASA

Another important woman in NASA's history is Anngienetta Johnson, whose career with the agency spanned 40 years. Johnson received a bachelor of arts in mathematics with a minor in chemistry from Texas Woman's University in 1971. While in school, she began working with NASA through a cooperative education program at the Johnson Space Center (JSC) in Houston. "Every emotion one can think of welled up inside of me — fear being the most prominent. How could I work with those geniuses?" she recalled about her start with NASA during a speech at her 40th high school reunion.

Yet, she thrived. Despite lacking formal training in computer science, Johnson, early in her NASA career, taught herself FORTRAN, a programming language developed by IBM in the 1950s, which she used to write programs for, and process data from, the Apollo missions.

In 1981, Johnson worked as a payload officer on the second NASA Space Shuttle mission, STS-2. The historic second flight of the orbiter Columbia marked the first time a manned orbital vehicle returned to space. Johnson was the first African-American to manage a console position in mission control, and she later became the information technology lead for the International Space Station.

For her accomplishments, Johnson was recognized by NASA and the federal government, and named Woman of the Decade in 1977 and Volunteer of the Year in 1996. In 2005, Johnson co-authored a chapter in "Success Strategies for Women in Science," and today, she remains an advocate for women and minorities in science and technology.

Johnson capped her time at NASA as the senior advisor for safety and mission assurance, but also worked as the assistant associate administrator for education. After retiring from NASA in 2011, Johnson became the senior disaster program manager for the American Red Cross, where she had previously volunteered for years.

The Space Race Ends, But the Mission Continues

Today, NASA employs more than 18,000 people and comprises 10 field centers and many other facilities around the country, which carry out different aspects of research and development. The successful landing of Apollo 11 team members on the moon in July 1969 — 11 years to the month after NASA had been established — may have ended the space race that Sputnik started, but NASA's mission has long outlived its Cold War origins.

The next 20 years will surely bring more NASA discoveries, thanks to advancing technology in human and robotic exploration of both space and Earth. For example, the agency will explore deeper into space than ever before with spacecraft like the James Webb Space Telescope, set to launch in 2020; and it will continue investigating how the space environment affects humans and other life by conducting experiments and observing astronauts living in space for prolonged periods. The Mars 2020 mission will send a new rover to the Red Planet to conduct the agency's most in-depth search yet for signs of life, and a mission to visit Jupiter's ocean-bearing moon Europa is also in the works.

Each of these endeavors may well capture the wonder of a new generation. The moon landing made a lasting impression on everyone who witnessed that momentous event — including my mother. She recalls watching the landing with her parents while camping in the Smoky Mountains — some neighbors at the campground hooked up a little black-and-white television outside their recreational vehicle so everyone could watch.

As I look up at the night sky now, it occurs to me that those visits to the Air and Space Museum as a kid might have left a bigger impression on me than I thought.

Augliere is a freelance writer and photographer and a former editorial intern at EARTH. She is a graduate of the science communication program at the University of California, Santa Cruz, and holds a master's degree in marine biology from Florida Atlantic University. For more of her work visit: http://www.bethanyaugliere.com.

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Tarnish on the Golden State

Fred Schwab

For the 10th straight year, my wife, Claudia, and I were "California Snowbirds" last winter, leaving our snow shovels behind in Virginia for the good life in Southern California. While the winter sun there remains wonderful, California is changing.

From the end of World War II until the turn of the century, California was the "end of the rainbow" for many folks. The population exploded from 10 million in 1945 to 40 million today. The state's economic output — which, at about $2.7 trillion annually, accounts for about 14 percent of the U.S. gross domestic product — just took over fifth place worldwide, only trailing the U.S., China, Japan and Germany. Nevertheless, for the last three decades, California has seen negative net migration — that is, more people are fleeing the state than settling there. Unreasonably high living costs and numerous natural threats cloud its rosy image as the paradise by the Pacific.

Cost of Living: In the nine-county Bay Area, the median price for a single-family home in 2017 rose to $850,000. The California Association of Realtors projects the median statewide home price will reach $561,000 in 2018, roughly double the national average and a price only one-third of households in the state can afford. Additionally, a third of renters spend half their income on housing; and four in 10 residents live near or below the poverty line. Recent changes to the federal tax code, which cap amounts of deductible state and local taxes and mortgage interest, will almost certainly exacerbate cost-of-living issues.

Drought: As the state emerges from a severe multiyear (2012-2016) drought, projections suggest another drought may be imminent. Heavy March snows gave the 2018 Sierra Nevada snowpack, which produces much of California's water, a late boost, but it was still below its long-term average. In addition to reduced accumulation and accelerated melting thanks to warmer-than-average temperatures, persistent high-pressure ridges over the state (arguably linked to climate change) have blocked some of the tropical moisture that normally streams into California.

Fires: Climate plays an important role in why California is a tinder box. Low soil moisture and parched vegetation result from low precipitation and warm temperatures. And the dry, seasonal Santa Ana and Diablo winds, which can gust upwards of 100 kilometers per hour, fan fires and allow them to jump both natural barriers and multilane highways. In October 2017, wildfires struck the Napa and Sonoma areas in Northern California, killing dozens and destroying almost 5,000 buildings, including 2,800 houses. And in December, shortly before we arrived in Santa Barbara, wildfires forced mass evacuations and destroyed more than 1,000 buildings in the Los Angeles region. Wildfires occur annually, but their intensity and frequency have grown.

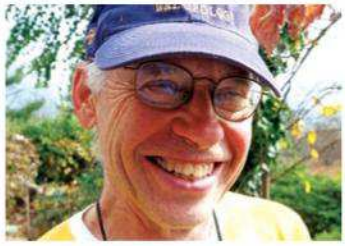
Beyond direct risks to lives and property, wildfires also present health hazards: In particular, dangerous levels of particulate matter — specifically particles 2.5 microns across or finer — are occurring more often. Inhalation of these particles can cause serious cardiovascular and respiratory problems. In December 2017, PM2.5 concentrations in Santa Barbara's air jumped from background levels of about 10 micrograms per cubic meter of air to as high as 140 micrograms per cubic meter — well into the "severe" range.

Flooding: Flooding is often triggered by brief bouts of heavy rainfall that aren't absorbed by paved urban and suburban landscapes, or by hard-packed surface soils. The devastating debris flows and mudslides I saw in Montecito — where multimillion-dollar homes and small cottages were indiscriminately buried — were triggered by a mere 1.3 centimeters of rain that fell in five minutes.

Rising sea levels will inevitably bring severe long-term flooding along the coast. The rise in sea level anticipated by the end of this century — as little as 75 centimeters or as much as 300 centimeters — would destroy California's signature attraction: its beaches. Major commercial ports like San Pedro and Long Beach would also be significantly impacted.

Earthquakes: California has long been a laboratory where geoscientists can observe the causes and effects of seismicity and investigate how to minimize risks to life and property. Improved fault maps help formulate regulations related to building near seismic zones, sometimes even requiring the demolition of badly sited or poorly constructed buildings. And California has rules for designing quake-resistant highways and buildings, and for retrofitting existing structures. Still, the risks from the next "Big One," or of smaller but still damaging quakes, are ever present and make for common coffeehouse conversation.

An Uncertain Future: Since 2010, California has lost about two million people aged 25 or older. People flee for different reasons — among them, the high cost of living, overcrowding and the sometimes dysfunctional government. Natural hazards are increasingly becoming a decisive factor as well, particularly after the calamitous past few years. California's state motto, "Eureka" — Greek for "I've found it!" — might soon be, "I'm out of here!"



Credit: Washington and Lee University

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Visit www.envirotechonline.com ◆ Call Toll Free **1-800-468-8921**

EnviroTech's Quality Guarantee on Rentals

- If we fail to provide any accessory equipment as ordered, your rental is free
- If any rental doesn't work, your rental is free

RENTAL RATES
25/60/200
DAY WEEK MONTH
Also a Certified Repair Facility

Solinst 101
Water Level Meter

RENTAL RATES
75/200/725
DAY WEEK MONTH
Also a Certified Repair Facility

RAE Systems
MiniRAE 2000 PID

RENTAL RATES
75/200/600
DAY WEEK MONTH
Also a Certified Repair Facility

AMS Basic Soil Sampling Kit

RENTAL RATES
w/Controller
165/495/1485
DAY WEEK MONTH
Also a Certified Repair Facility

Geotech
Low Flow Sample System

RENTAL RATES
60/180/560
DAY WEEK MONTH
Also a Certified Repair Facility

Solinst Levelogger

RENTAL RATES
75/210/600
DAY WEEK MONTH
Also a Certified Repair Facility

YSI 556
System

We accept P.O.s ◆ Call Toll Free **1-800-468-8921**