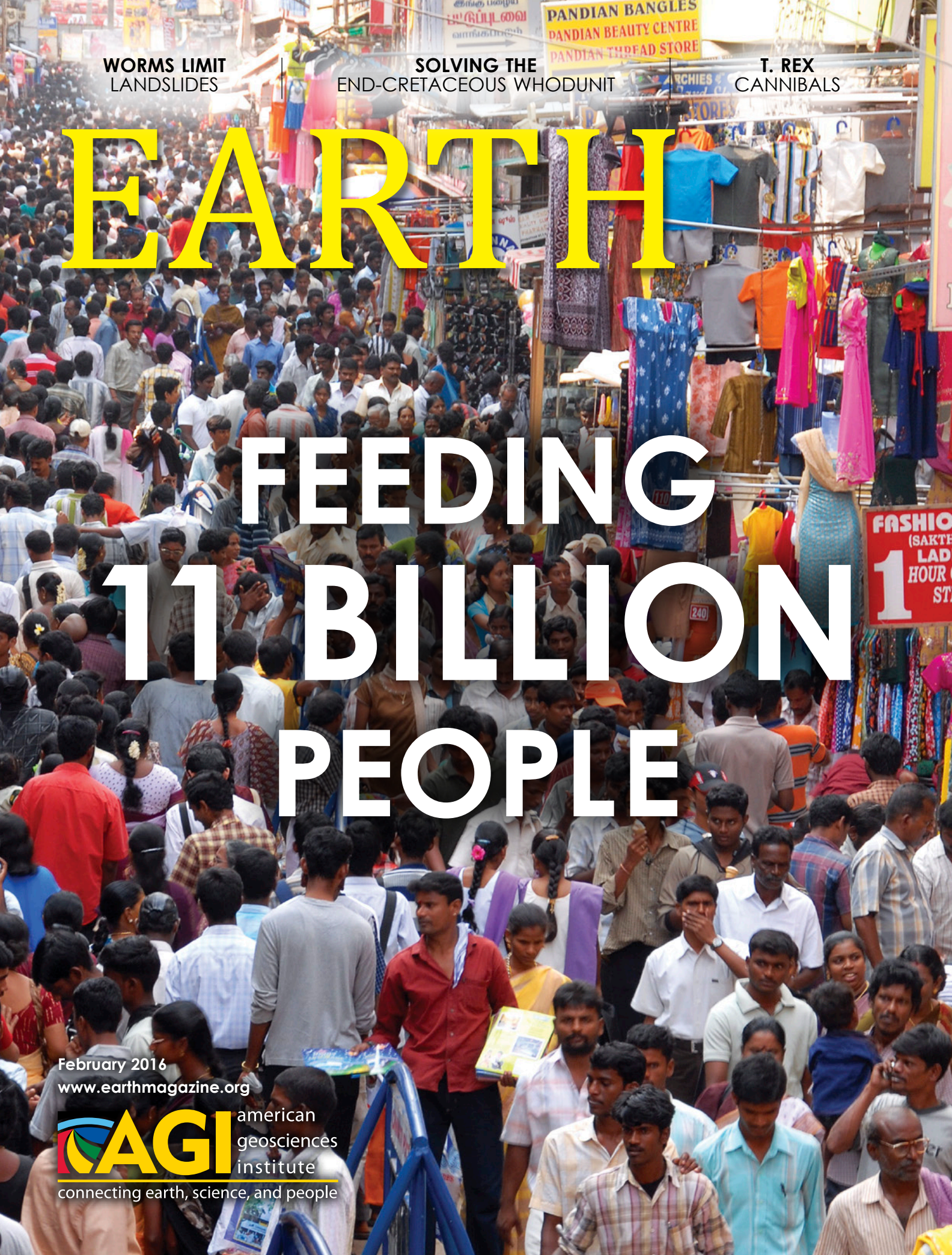

WORMS LIMIT LANDSLIDES

SOLVING THE END-CRETACEOUS WHODUNIT

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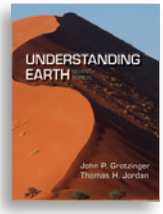

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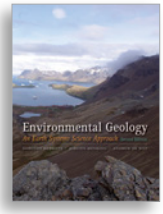

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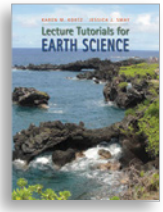

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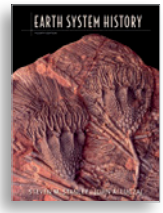

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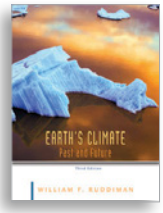

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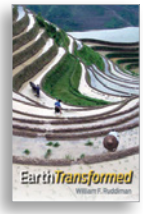

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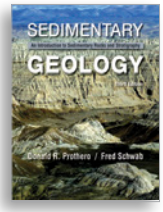

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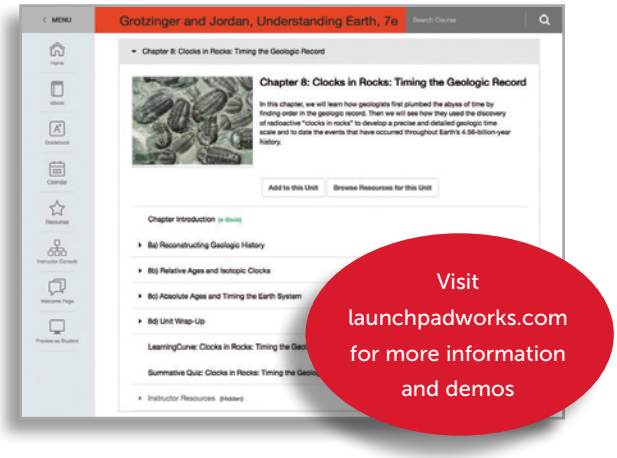

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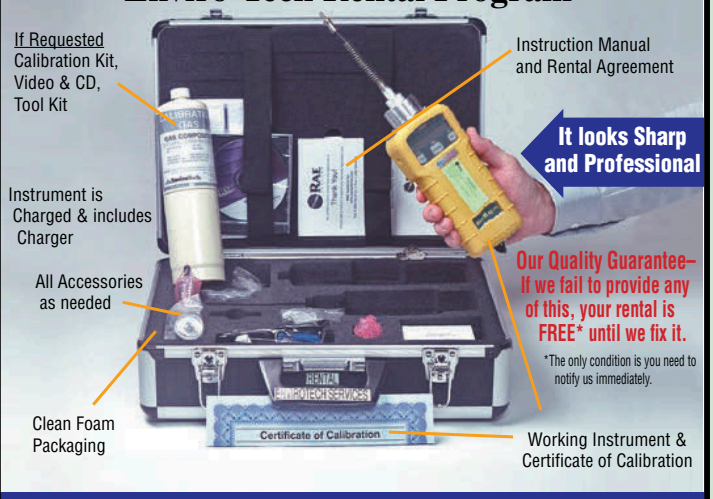

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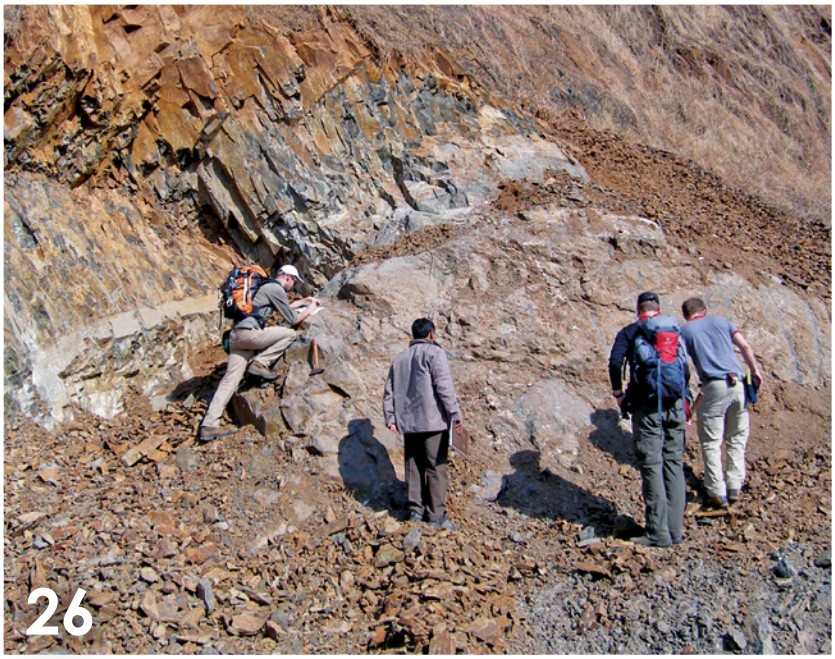
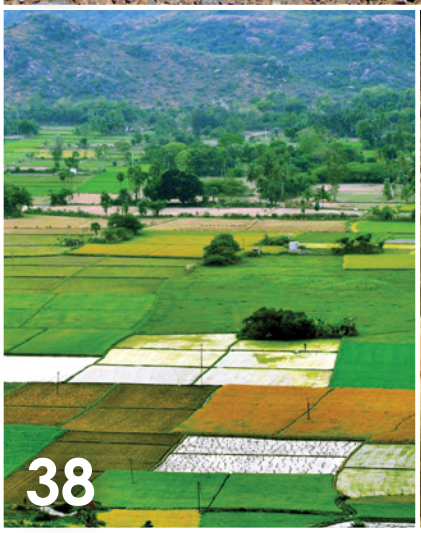
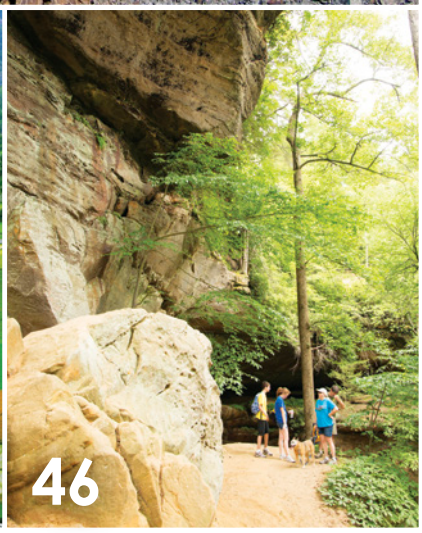


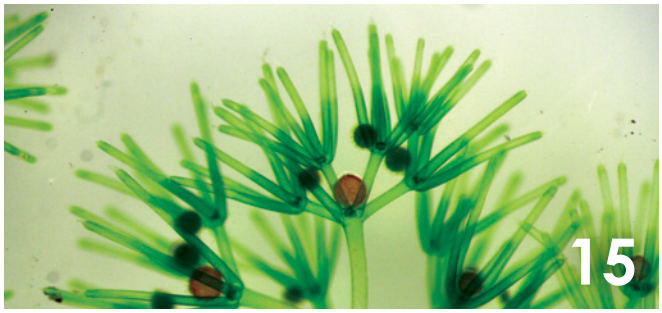




VOICES

ON THE COVER: Ranganathan Street in Chennai, India, is often called the world's most crowded place.
Credit: Yoga Balaji, CC BY-SA 3.0

NEWS



DEPARTMENTS

Credit: NASA Goddard, CC BY 2.0

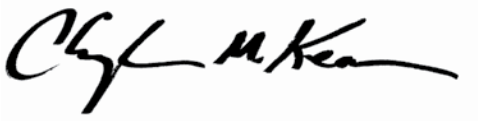
Certainty is a comforting concept. Whether in crime stories, where we crave the proverbial smoking gun, or in sporting events, where we seek the clarity of victory, certainty — especially when it comes with a straightforward explanation — provides the most satisfaction. This is true in science as well: Witness the use of Occam's Razor in helping prioritize hypotheses — simple and direct explanations are favored. But just ask individuals who work on the forensics of system failures, such as airline crashes, and they will tell you that big problems are almost always the result of multiple causes — rarely is the explanation simple and direct.

Earth is a massively complex system, and, here too, when big things happen, usually a lot of smaller events interacted to lead to the dramatic results. But solving mysteries through the gauze of deep time, including discerning all the players involved, can be challenging, and it's inevitable that thoughts and opinions evolve. And so it is with the demise of the dinosaurs and other species at the end of the Cretaceous.

In the 1980s, the Alvarezes built the case for the Chicxulub impact as the cause of the mass extinction event, and they presented a relatively uncomplicated story supported by compelling evidence and a nice temporal linkage. Yet there were always questions to be found in the details: things like the precise timing of events; proposals that the dinosaurs were already dying off before the impact; and the observation that a several-million-year-long episode of volcanic eruptions was progressing at roughly the same time.

Over the last couple of decades, the public has come to accept the direct and simple impact hypothesis. The idea of flaming balls of rock falling from space and causing global calamity is an exciting one to be sure, and the nice TV visuals certainly don't hurt. It's the lingering uncertainty, however, and the potential that multiple factors contributed to a planetary system collapse, that led EARTH News Editor Timothy Oleson to explore the issue in his feature, "Impact or Eruptions: Are Both to Blame in the Great End-Cretaceous Whodunit?" I won't spoil the end, but it is an outstanding journey through the story of how the Mesozoic ended.

And for those wanting more, we have coverage of how in the world we might be able to feed 11 billion people in the future, as well as a piece on touring and rock climbing in Kentucky's Red River Gorge. We hope you enjoy perusing this month's issue of EARTH and the variety it provides — sometimes the most interesting journey is neither simple nor direct.



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

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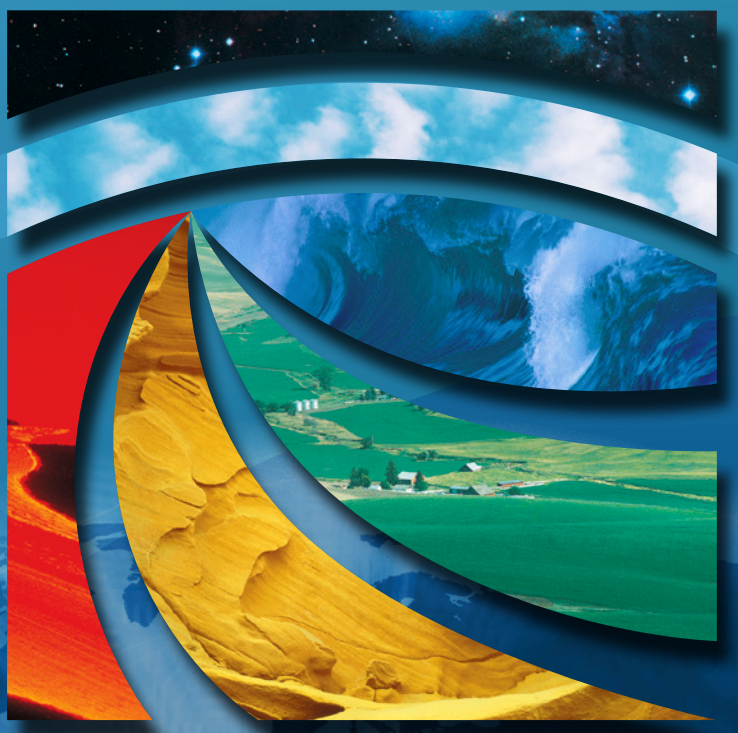

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SAY GOODBYE TO 400 PPM

Every spring, plants in the Northern Hemisphere unfurl new leaves. Chlorophyll soaks in sunlight and begins suturing atmospheric carbon dioxide to water brought up from the plants' roots. This chemical reaction is photosynthesis, and the carbohydrates it makes are the foundation for most of Earth's food chains. It's also so efficient that each summer, plants draw down atmospheric carbon dioxide levels by close to 2 percent globally. In the boreal winter, the situation reverses. As deciduous photosynthesis ends and is overwhelmed by the carbon dioxide-emitting processes of respiration and decay, carbon dioxide levels climb back up. This seasonal cycle lends a distinctive saw-tooth pattern to the carbon dioxide records.

But since the Industrial Revolution, humans have been dropping more carbon dioxide into the mix each year by combusting long-dormant carbon in fossil fuels. The energy we've gotten from that fossil carbon has been a boon for our standard of living and the development of our civilization. But it also means that despite the annual ups and downs, instrumental records of global carbon dioxide — kept since 1958 at Mauna Loa, Hawaii, for example — have been climbing over time. We've gone from about 280 ppm to 400 ppm in 150 years.

The winter peak of carbon dioxide first hit 400 ppm in 2013, then dropped below that threshold again as the photosynthesis "trough" kicked in. For the next two years, it went up and down again cyclically, each time with the summer's minimum at a higher level than the year before. It now appears that even the summer low point won't touch 400 any time in the foreseeable future, unless something radically changes in our attitudes or our technology.

In November 2015, we left 400 ppm behind, probably for the final time in any of our lives. We may bounce off that nice round number again in September, but with the extra carbon dioxide loading that comes with El Niño-induced forest fires, it's unlikely. So, welcome to the greater-than-400 ppm world. You and I grew up in the less-than-400 ppm world, but we don't live there anymore.

Four hundred is just a round number — it's no more inherently significant than 399 or 401. But as we pass it, it feels like we're zooming by a highway sign reading, "Last chance to exit before toll." How do we pump the brakes? - **Callan Bentley, EARTH contributor and cartoonist and assistant professor of geology at Northern Virginia Community College in Annandale, Va. Follow his blog at http://blogs.agu.org/mountainbeltway.**

Credit: Virginia Community College System

EARTH welcomes letters to the editor. All letters are subject to editing for length and clarity. Send letters to: earth@earthmagazine.org.

Visit our polls online at www.earthmagazine.org

POLL: CONFLICT-FREE ELECTRONIC DEVICES

In November, we asked our readers: Would a company's claim that their personal electronic device (e.g., tablet or cellphone) is free of conflict minerals be a factor in your purchasing decision? Here are the results:*

Yes, I would try to buy conflict-free devices no matter what.....39%

No, it wouldn't make any difference to me 25%

No/Don't know, because it's hard to tell if conflict-free claims are true 18%

Yes, but only if there's little or no price difference.....11%

Maybe 7%

*This poll is not scientific and reflects the opinions only of those Internet users who have chosen to participate.

Weathering a Perfect Storm From Space

Jeffrey J. Love

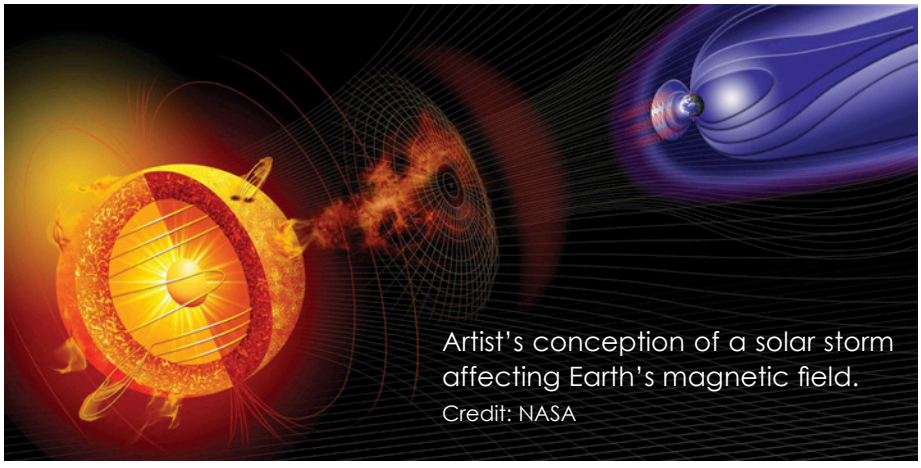
Extreme space-weather events — intense solar and geomagnetic storms — have occurred in the past: most recently in 1859, 1921 and 1989. So scientists expect that, sooner or later, another extremely intense space-weather event will strike Earth again. Such storms have the potential to cause widespread interference with and damage to technological systems. A National Academy of Sciences study projects that an extreme space-weather event could end up costing the American economy more than $1 trillion. The question now is whether or not we will take the actions needed to avoid such expensive consequences. Let's assume that we do. Below is an imagined scenario of how, sometime in the future, an extreme space-weather event might play out.

They were first seen through telescopes on Earth: A closely packed group of sunspots on the eastern limb of the sun had formed when a bundle of magnetic field lines was buoyantly disgorged from the seething solar interior. A week later, the sun's rotation had brought the inky blemishes into the center of the solar disk. Intricate in detail, slowly shifting in shape, the spots had grown large enough to be seen by residents on Earth at sunrise and sunset. Some even said that the sun resembled a giant ominous eye, staring down at us from outer space.

In ages past, fortune-tellers and prophets might have interpreted sunspots as portending a bad future. In some respects, things haven't changed. This time, speculation about the sunspots was anonymously posted on the Internet; some of it was serious and informed, most of it was not. The mainstream media were more cautious, interviewing expert space scientists. But the fact was, nobody knew exactly what would happen. In the United States, NOAA and the Air Force prudently issued warnings of potentially serious space-weather disturbances.

Soon after the sunspots emerged, satellites monitoring the coronal atmosphere detected a powerful solar flare. Ultraviolet and X-ray radiation abruptly enhanced the ionization of Earth's upper atmosphere, temporarily rendering high-frequency radio communication impossible across the dayside of our planet. Civilian aviation and shipping were affected, as were emergency rescue and military operations. To avoid exposing passengers and equipment to dangerous levels of radiation, flights across the northern polar cap were rerouted to lower latitudes. In the several space hotels that now orbit Earth, and on the moonbase that NASA had recently established, space tourists and astronauts took shelter in shielded capsules.

But this was only the beginning. Following yet another flare, a concentration of electrically conducting solar-wind plasma was tossed into space following a rapid rearrangement of sunspot magnetic field lines. Hours later, this coronal mass ejection (CME) was measured by a new system of sentinel satellites in orbit between the sun and Earth; they indicated that the CME, packed with energy, was headed straight for Earth. Like that which caused the infamous "Carrington Event" of 1859 — disrupting telegraph systems around the world — this CME would traverse the distance between the sun and the Earth in a mere 12 hours. NOAA scientists responded immediately, issuing an alert that an extremely intense magnetic storm would soon commence. In the United States, the Federal Emergency Management Agency prepared for the possible widespread interference with electrical power, navigation, and communication systems. Critical industries, security and emergency services, and decision-makers across the nation and around the world were notified.



Artist's conception of a solar storm affecting Earth's magnetic field.
Credit: NASA

When the CME arrived at Earth, an influx of high-energy ions and electrons in Earth's magnetosphere temporarily disabled several communication satellites. Heating of Earth's upper atmosphere resulted in increased atmospheric drag experienced by satellites, and several fell from orbit. Disruption of Earth's ionosphere degraded GPS accuracy, and the interruption of GPS timing signals brought rapid financial transactions between global stock markets to an abrupt halt.

Like many magnetic storms, this one lasted three days. Its detailed evolution was closely monitored from a network of ground-based observatories operated by the U.S. Geological Survey (USGS) and allied geomagnetic agencies around the world. Airborne magnetic surveys routinely undertaken for geologic mapping

and mineral assessment had to be canceled. At high latitudes, the magnetic storm caused compass needles to swing by tens of degrees in a matter of minutes. In Alaska and the North Sea, oil and gas companies that use magnetic orientation as a guide for directional drilling received real-time magnetometer data, allowing for automatic compensation of changing magnetic direction and enabling drilling operations to continue without interruption.

As the storm reached almost unprecedented intensity, geomagnetic activity induced electric fields in Earth's conducting crust and lithosphere, interfering with the operation of electrical power grids. Utility companies had to tap into reserve generating capacities. A high-voltage transformer was damaged, resulting in a temporary blackout in a mid-size metropolitan area. Otherwise, widespread damage to vital electrical power infrastructure was minimal. All the while, auroral displays were spectacular, with beautiful undulating curtains of green and red light seen in the night sky from the poles to tropical latitudes.

As dramatic as all this was, the effects of the storm could have been worse. Much worse. Fortunately, back in 2015, the U.S. government began planning for an extreme space-weather event. Led by NOAA and the Department of Homeland Security (DHS), and acting under the auspices of the White House's Office of Science and Technology Policy, numerous federal departments and agencies worked together to identify priority projects that needed to be pursued in order to stave off the consequences of extreme space weather. The release of a strategic plan was followed up with a detailed implementation plan. A mind-boggling set of issues needed to be addressed. The U.S. Congress even passed appropriation bills so the work could get done.

The National Science Foundation (NSF) and NASA supported the pursuit of fundamental scientific research into the nature of the heliosphere and the space that surrounds Earth, and improved fundamental understanding led to improved space-weather prediction capabilities. NOAA and the USGS worked together to support the development of real-time geophysical monitoring capabilities in space and on the ground. The USGS and NSF cooperated to complete a national magnetotelluric survey of the lower-continental United States, needed to estimate the electrical conductivity of Earth's interior. The Department of State worked with governments around the world to promote the rapid exchange of data and the sharing of knowledge and technical skills.

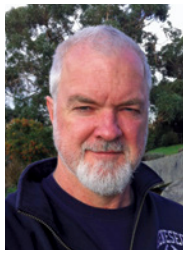
Numerous engineering and operational standards were addressed. The Department of Energy and its Federal Energy Regulatory Commission worked with utility companies within the North American Electric Reliability Corporation to improve the resilience of electrical power grids. NSF, NASA and the Department of Defense worked with aerospace companies to harden satellite systems against harsh space-weather conditions. The Federal Aviation Administration worked with the airline industry to consider issues of pilot and passenger safety, and the Federal Communications Commission worked with broadcast, telephone and Internet companies to improve the reliability of communication systems.

NOAA, DHS and the other government entities participating in the National Space Weather Program organized scenario exercises in which hypothetical, extreme space-weather events were considered in order to test and practice response plans with emergency managers in state and local governments, industry and the public. The State Department promoted similar exercises on an international level. All of this provided insights into how operational space-weather services needed to be improved. And this, in turn, highlighted needs for additional space-weather monitoring systems and geophysical surveys, and it helped to prioritize federal investments in research. More generally, the public became better informed about space weather and the hazards it poses to our technologically dependent society.

Looking back to 2015 and the years that followed, we recognize it as a time of remarkable cooperation: scientists, engineers, economists, managers and leaders worked together for the benefit of society. Investments were made for the sake of the future. And work on this multidimensional project brought many fringe benefits. Fundamental understanding of the natural environment of the sun, space and solid Earth increased. Technological systems became more reliable; government, academic and commercial sectors became more communicative and cooperative. National and international economic security improved.

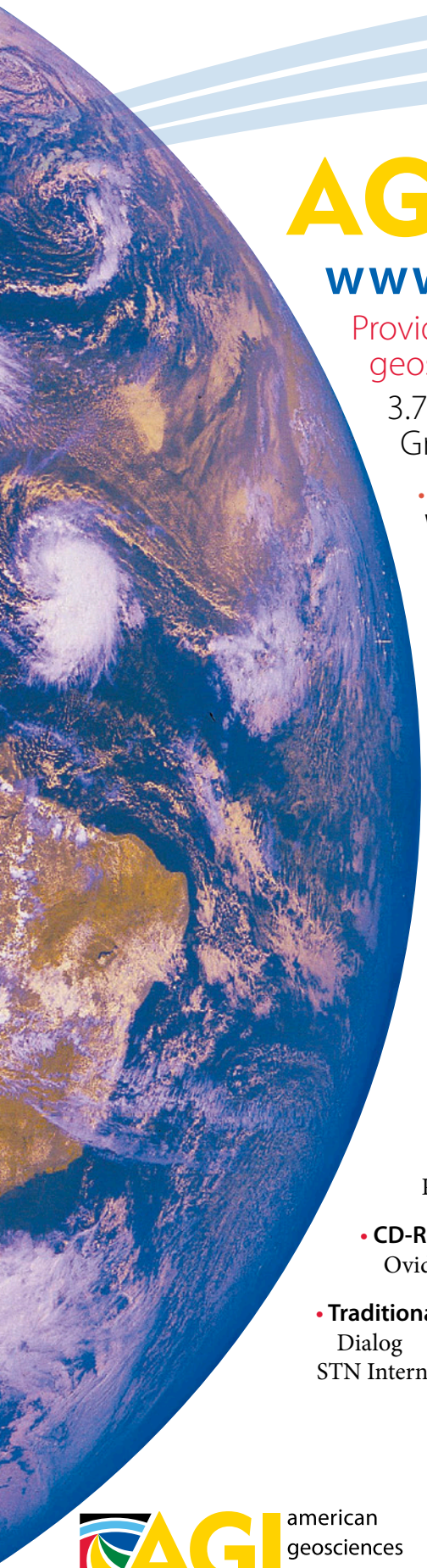
Severe space-weather events can affect electrical grids on Earth.
Credit: Dreamstime LLC

So, there we have a scenario of a space-weather event sometime in the future. Obviously, as you read this, the U.S. national space-weather plans have only just recently been released. The cooperation needed to prepare for an extreme space-weather event is, at this stage, only an optimistic aspiration. It is, however, reasonable to expect an extreme space-weather event in the future. Let us hope that the space-weather plans will be successfully implemented so that the next extreme space-weather event has minimal negative effects on our society and its important infrastructure.



Credit: Jeffrey J. Love

Love is the advisor for geomagnetic research at the U.S. Geological Survey.



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Permian-Triassic extinctions timed differently on land and at sea

Life on land and in the sea was nearly eradicated about 252 million years ago in the largest-known mass extinction. The cataclysm, known as the Permian-Triassic (P-T) mass extinction, was likely driven by extensive flood basalt volcanism in Siberia and is thought to have affected global biodiversity simultaneously. However, based on analyses of rocks deposited around the time of the P-T boundary in the Karoo Basin of South Africa, scientists suggest in a new study that the terrestrial turnover in vertebrates occurred earlier than the marine extinction. If true, a second trigger — other than Siberian volcanism — might need to have occurred to explain both events.

Sandstones and volcanic deposits at Old Lootsberg Pass in South Africa's Eastern Cape Province preserve fossil and geochronometric evidence suggesting that the Permian-Triassic terrestrial and marine extinctions were not simultaneous.
Credit: Robert A. Gastaldo

Terrestrial rocks on both sides of the P-T boundary show a turnover in vertebrate ecosystems, says Robert Gastaldo of Colby College in Maine, lead author of the new study in Geology. In particular, fossils of *Dicynodon* — a genus of small, herbivorous therapsids — disappear from the Karoo Basin, while other taxa, namely *Lystrosaurus*, a different type of herbivorous therapsid, become pervasive. This turnover is thought to have been caused by volcanism-induced climate change that drove massive die-offs of plants like *Glossopteris* and, in turn, sparked the extinction of many Permian herbivores, including *Dicynodon*, which could not adapt to the new vegetative landscape.

However, Gastaldo says, "from our fieldwork in the Karoo, we've found discrepancies in this traditional model of the terrestrial response to the extinction." Along with collecting paleomagnetic measurements from a stratigraphic section previously reported to surround the P-T boundary in the basin, he and his team discovered volcanic ash deposits in the same part of the section where the vertebrate turnover is observed. Using radiometric dating, the team dated the ash layer to about 253.5 million years old. "This means the turnover was in the early Changhsingian [Age]," Gastaldo says, and thus not even close to the time when the marine ecosystem was destroyed at roughly 252 million years ago.

Further evidence also indicates that the terrestrial P-T extinction occurred before the marine extinctions. In China, just below where the marine extinction event is seen in the stratigraphic record, paleomagnetic data from previous studies have indicated that the planet's magnetic field flip-flopped from a reverse orientation, meaning magnetic north and south were opposite from how they're oriented today, to a normal orientation. And earlier studies of the Karoo have shown a magnetostratigraphy that's similar to what is seen in China, Gastaldo says. "But our paleomagnetic data differ considerably because the [transition] zone that's supposed to be just below the extinction event is now about 55 meters below the last appearance of *Dicynodon*."

This, along with the team's new date for the vertebrate turnover, implies that an extinction on land predated the marine extinction. Gastaldo says the results of previous magnetostratigraphic work in the basin might differ from what his team found due to sampling differences: For each of about 90 stratigraphic horizons he and his colleagues examined, they retrieved roughly 10 samples, he says, providing paleomagnetic data at a higher resolution compared to previous efforts that typically only retrieved one core per horizon from widely spaced beds.

But measuring paleomagnetism in the Karoo is complicated, says Spencer Lucas, a paleontologist at the New Mexico Museum of Natural History and Science who was not involved in the work. "It was long believed that you couldn't get reliable magnetic data from these rocks, because the magnetic signatures from when the rocks initially formed had been reset" by volcanism, he says. This is cause for skepticism over the team's magnetic data, Lucas says, adding, however, that he otherwise agrees with the interpretations presented in the study.

Lucas notes that accurate dating is essential because "this study goes after the most important question about the land extinction: Did it occur exactly when the extinction occurred in the sea?" If the two were simultaneous, "then you could argue that there was one cause for both extinctions," he says. "If their findings are correct, though, then they must have had different causes."

Part of the difficulty in studying the boundary, says Sylvie Bourquin, a sedimentologist at the University of Rennes in France who was not involved in the work, is that "precise, absolute time constraints in continental paleoenvironments [from the period] are difficult to establish due to a general [scarcity] of dateable rock." Additionally, there has been little study of the interactions between marine and terrestrial environments that existed at the time, she says. "Researchers tend to work on either marine or on terrestrial rocks, so it is very hard to understand the real response to the crisis at a global scale."

Because the types of environments can contain subtle differences, Bourquin says, studying P-T boundary sedimentary basins where marine and terrestrial environments were interconnected should help to further refine the relative timing of the land and sea extinctions.

Lucas Joel

Bite marks offer best evidence yet of *T. rex* cannibalism

Tyrannosaurs were not the most discerning of carnivores. In addition to dining on other dinosaurs, like *Triceratops* and duck-billed hadrosaurs, it appears the fearsome apex predators weren't averse to making a meal of their own kind. A series of deep bite marks on a 66-million-year-old leg bone uncovered recently in eastern Wyoming may be the best evidence yet of *Tyrannosaurus rex* cannibalism.

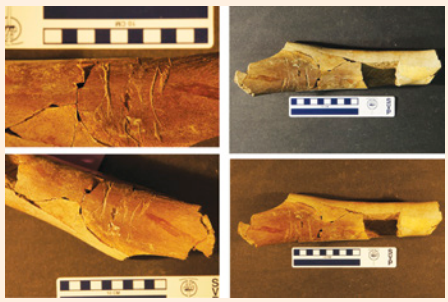
Upon noticing the bite marks on the bone, "we knew that we had something really special," says Matthew McLain, a graduate student at Loma Linda University in California who presented an analysis of the features in November at the annual meeting of the Geological Society of America in Baltimore. For example, there are indications on the bone of a tooth "re-entering the same groove," an indication that the animal that did the biting was "really trying to strip flesh off," he says. "It really looks like feeding [behavior]," McLain told EARTH.

The bitten bone fragment, pulled from the rocks of the Lance Formation in Wyoming and dating to the Maastrichtian Age shortly before the mass extinction that finished off the nonavian dinosaurs, was large and hollow, indicating it had belonged to a big theropod; *T. rex*, the largest theropod found in the Lance, was the only animal that fit the bill. And the bite marks suggested the attacking animal was probably as big as or bigger than the victim, McLain says.

To further confirm the aggressor's identity, McLain and his colleagues turned to studies of bite marks left on bones by modern Komodo dragons, which, like tyrannosaurs, have serrated teeth. That work showed that if a Komodo dragon dragged the serrated edge of its tooth sideways along a bone, as it might if it turned its head abruptly while feeding, it would carve parallel grooves — each no bigger than the size of the tooth serrations — into the bone. "You can measure the distance between those [grooves] and then compare it to the distance between the serrations on the teeth themselves," McLain says. "And then you can match up which tooth made this mark."

The bone that McLain and his team found had such parallel grooves, among other marks gouged by teeth, suggesting the animal that left them indeed had serrated teeth and ruling out other possible culprits, like ancient crocodiles, that did not. When the researchers measured the striations and the distance between them, they found that the grooves were too big and too widely spaced to have come from any other dinosaurs that inhabited the area at the time. But they were a match for an adult *T. rex* tooth.

This isn't the first evidence that tyrannosaurs in general, and *T. rex* specifically, might have had cannibalistic tendencies. Previous studies have described tyrannosaur bones — from 75-million-year-old *Daspletosaurus*, for example — bearing bite marks that could have come from kin. The difference between most of the earlier indications and this new work is the number of markings found on a single bone, McLain says, and thus the strength of evidence for *T. rex* cannibalism. Instead of one or two bite marks per bone, "on this [bone] we have something like eight to 10, and they're all concentrated in one spot in the same direction." This reinforces the notion that the one dinosaur was actually eating the other, rather than the marks simply representing injuries sustained during combat.



Bite marks on this large theropod bone, which was found recently in Wyoming, offer strong evidence that *Tyrannosaurus rex* wasn't averse to making a meal out of its own kind.

Credit: Matthew McLain

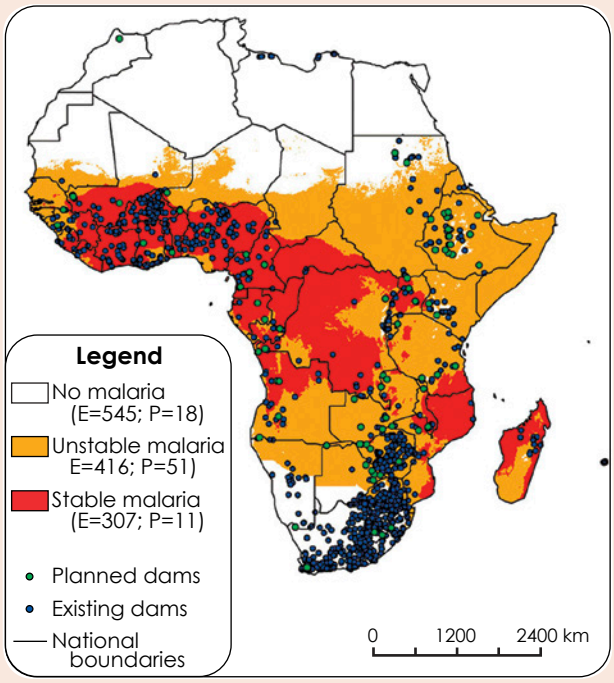
Although the prospect of two *T. rexes* locked in an eat-or-be-eaten battle is thrilling, McLain says there's no way to tell in this case if the dinosaur that did the biting actually killed its fallen companion before chomping away or if it was simply scavenging the carcass of an animal that died by other means. He says, however, that continuing efforts may help confirm what part of the animal the bone came from — the researchers suspect it's a lower leg bone — as well as the size difference between the two animals. "There might be a story to tell there too about relationships between bigger and smaller tyrannosaurs."

Timothy Oleson

Widespread malaria risk from African dams

Large dams cause more than 1 million cases of malaria annually in sub-Saharan Africa, according to the authors of a new study published in Malaria Journal.

Reservoirs and shallow pools impounded by dams offer breeding grounds for the parasite-carrying mosquitoes that transmit the disease, which can be life-threatening if not treated. Although previous work had identified increased rates of malaria infection in populations living close to particular dams, none had mapped the risk broadly across the region.



Map of existing and planned large dams considered in a new study that analyzed rates of malaria infection near the dams in areas where malaria transmission is stable (perennial) versus unstable (seasonal).
Credit: Kibret et al., Malaria Journal, 2015

Researchers compared malaria infection rates in people living within 5 kilometers of 723 dams located in areas of sub-Saharan Africa where malaria occurs with background rates in people living more than 5 kilometers away. (Five kilometers is assumed to be the distance limit of a dam's influence on malaria infection based on the limited flight ranges of mosquitoes.) Of the 15 million people in the malarial zone, 1.1 million cases of malaria per year are associated with the dams, the team, led by Solomon Kibret of the University of New England in Australia, reported. The increased risk from dams was especially high in areas where malaria transmission occurs only seasonally, possibly, the authors suggested, due to a proportionally greater significance of dammed water reservoirs as mosquito breeding grounds in these areas compared to areas of year-round transmission where breeding habitats are common.

The researchers also noted that their estimates may be conservative considering that hundreds of large dams were not included in the analysis, and that many new dams are in development. "While dams clearly bring many benefits — contributing to economic growth, poverty alleviation and food security — adverse malaria impacts need to be addressed or they will undermine the sustainability of Africa's drive for development," Kibret said in a statement.

Timothy Oleson

Three new species of extinct baleen whales found

The evolution of baleen whales from toothed whales was gradual, with intermediate fossil species found that possess both teeth and baleen. Now, the discovery of three new whale species on New Zealand's South Island is filling in the evolutionary story of baleen whales.

The newly-described species — *Waharoa ruwhenua*, *Tokarahia kauaeroa* and *Tokarahia lophocephalus* — are all eomysticetids, a family of baleen whales dating to the Late Oligocene between about 35 million and 25 million years ago. *Waharoa* appears to be a fully baleen whale, but the two *Tokarahia* species may be transitional animals between primitive toothed baleen whales and modern baleen whales, Robert Boessenecker of the University of Otago in New Zealand and colleagues reported in the journal PeerJ.

"The skulls of these three specimens were spectacularly preserved, revealing that eomysticetids had unusually long and delicate surfboard-like snouts, with blowholes placed far forward on the skull, and enormous attachment areas for jaw muscles," Boessenecker said in a statement. The delicate nature of the jaws and skulls indicates that the 5- to 6-meter-long whales were likely not lunge feeders like humpback whales, but were adapted for skim feeding like right whales — "they would have been a sort of slow-cruising vacuum cleaner for krill," he said.

Isotopic analyses of the bones suggested that the whales were undertaking north to south migrations in the Southern Ocean, around the continent of Zealandia, which at the time existed as a collection of small islands surrounded by shallow seas. The area may have been a calving ground; at least one small juvenile was recovered. The whales represent three of the five known members of the Eomysticetidae family to have been identified in the Southern Hemisphere.

Mary Caperton Morton

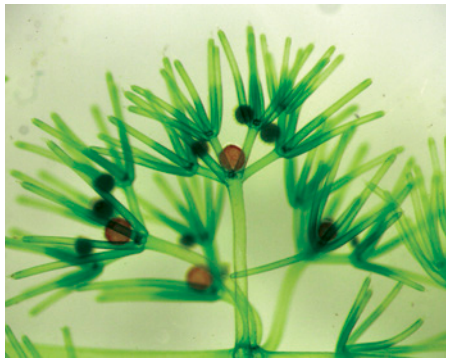
Land plants came prepared for terrestrial life

Plants colonized land between 450 million and 420 million years ago, and, once there, they drastically altered terrestrial landscapes and provided resources for animals leaving the oceans around the same time. One adaptation that helped plants gain a foothold on land is a symbiosis with fungi known as arbuscular mycorrhizae (AM), which help plants acquire water and key nutrients from the soil and are still associated with most land plants today. In return, plants provide the fungi with bioavailable carbon produced during photosynthesis. When this symbiosis evolved has remained unclear, but researchers recently discovered that it likely has roots in a group of freshwater algae ancestral to land plants.

For the symbiosis to work, a chemical communication pathway that helps fungi connect to and colonize plant root cells is needed, says Pierre-Marc Delaux of the Plant Sciences Research Laboratory in France, and lead author of the new study published in Proceedings of the National Academy of Sciences. "We found that this pathway ... existed before plants colonized land," Delaux says, and then "land plants built on this pre-existing pathway."

Delaux and his team uncovered the origins of the pathway — in which a specific plant enzyme acts as a beacon that helps the fungi find their way into the plant — by studying genomes from a group of modern-day freshwater green algae called charophytes, which are thought to be ancestral to land plants.

"These structurally simple organisms have remarkably complex developmental and regulatory pathways analogous to those of plants," says Charles Delwiche, a botanist at the University of Maryland who was not involved in the study. "It's extraordinary to realize how many key plant systems, like this [communication] pathway, are present within their close charophyte relatives."



Nitella hyalina is a stonewort and a member of the charophyte green algae family. No known charophyte alga has symbiotic associations with mycorrhizal fungi, but *N. hyalina* and other stoneworts do develop root-like rhizoids that anchor the thallus in sand and mud, and probably frequently interact with fungi. The frame is about 5 millimeters tall.

Credit: Charles F. Delwiche, University of Maryland, all rights reserved

Why the pathway evolved in charophytes is still uncertain, as they have no known symbiosis with fungi. "There are many possibilities, but without knowing more about the biology of the algae — which remains a relatively understudied group overall — it is difficult to identify the nature of the trait's origins," Delwiche says.

What is clear, though, is that while the pathway did not initially evolve as an adaptation for terrestrial life, it has proven abundantly useful for land plants.

When plants began colonizing land, the symbiosis was one of the main features that helped plants survive in terrestrial environments, Delwiche says. In the rock record, he says, the plant-fungus association is discernible in fossils from the 410-million-year-old Rhynie Chert in Scotland, for example, which preserves fossils of AM fungi in a very similar association to what occurs in modern plants.

Today, more than 80 percent of land plants rely on the AM symbiosis. Studying the symbiosis and revealing its origins have potential economic benefits, says Jean-Michel Ané of the University of Wisconsin at Madison and a co-author of the study. "By understanding the building blocks of symbiotic associations, we can engineer our own beneficial associations between organisms like cereal [grains] and bacteria," Ané says, which could help increase cereal crop yields.

Lucas Joel

How to survive when your dinner goes extinct

Using fossils from before, during and after the Permian-Triassic mass extinction event, researchers ran extensive models to put together 100 possible food webs for the extinction event. They found that the structure of the ecological communities — the species' "jobs" in the food web — was a key factor in how well a community fared through the extinction.

Roopnarine and Angielczyk, Science, October 2015

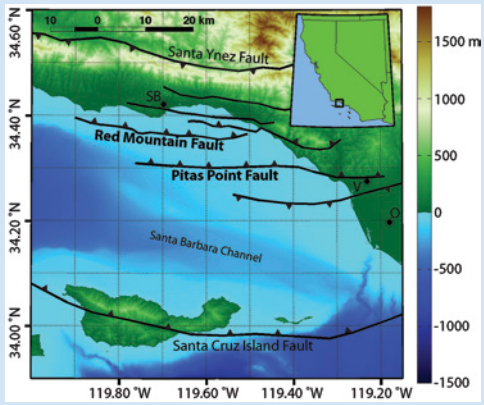
Sea levels and storms magnify East Coast flooding potential

A new study that combines current and projected sea-level rise with projected flooding from intense tropical cyclones indicates that the height and duration of coastal flooding associated with such storms could increase several hundredfold by 2100 along the U.S. Gulf and East coasts. Scientists not only projected how sea-level rise and storms would individually affect flooding but how likely they were to be correlated.

Little et al., Nature Climate Change, September 2015

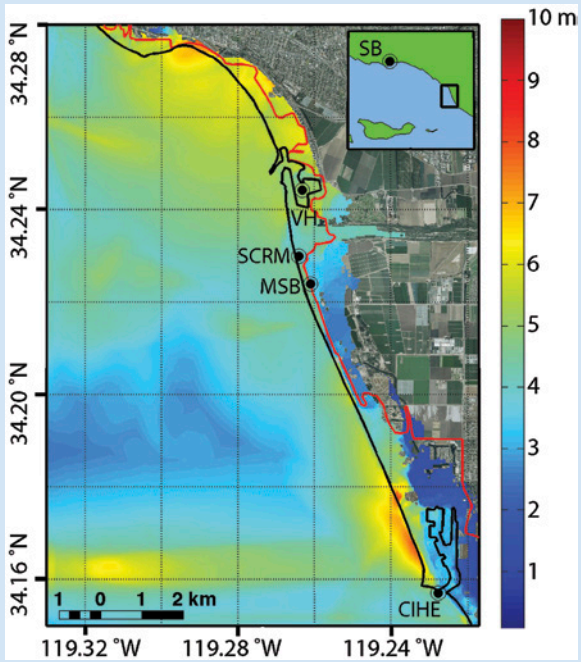
Revealing potential tsunami inundation on California coast

Earthquakes are well known along Southern California's coast, and existing hazard maps indicate where quake-triggered tsunamis could flood the coastline. But in a new modeling study published in Geophysical Research Letters, researchers found that an earthquake-generated tsunami northwest of Los Angeles may reach farther inland than is currently projected.



Map of the localized peak tsunami amplitude (below) due to a simulated earthquake on the Pitas Point and Lower Red Mountain fault systems (shown above), which extend east-west offshore of Santa Barbara (SB) and Ventura (V), Calif. The black and red lines indicate, respectively, the coastline and the extent of tsunami inundation based on maps put out by the California Emergency Management Agency. Inundation following the modeled earthquake exceeds the state prediction, particularly in the vicinity of Ventura Harbor (VH).

Credit: both: Kenny Ryan, UC Riverside



Recent studies of Southern California's Ventura Basin, which straddles the coastline around the city of Ventura, have suggested that faults there are able to generate larger earthquakes than previously thought, says co-author David Oglesby, a geophysicist at the University of California at Riverside. Those realizations have spurred geologists to question whether "the earthquake and tsunami hazard in this region may have been underestimated in the past," and to try to assess the actual scope of the hazards, Oglesby says.

To address the questions, Oglesby and his colleagues created a computer model of the geometries and other physical properties of the Pitas Point and Lower Red Mountain faults, which lie mostly offshore. They then physically simulated an earthquake with a magnitude of roughly 7.7. The model yielded estimates of seafloor deformation, which when combined with fault location, seafloor bathymetry and coastal topography, offered information about the resulting tsunami's scale, direction and extent of inland inundation, Oglesby says. Integrating these modeling techniques in this way to simulate an earthquake and resulting tsunami had not been done before, he adds.

The team found that, soon after forming, the modeled tsunami split into two separate waves. One traveled north toward Carpinteria and Santa Barbara, where damage would be limited by seaside cliffs and hills that would partially block tsunami inundation, note Oglesby and lead author Kenny Ryan, a graduate student at UC Riverside. The surprise, Oglesby says, was that the southbound wave was refracted 90 degrees to the east toward flatter and lower-lying Ventura and Oxnard, which produced wide-ranging inundation in those areas. "We find that in many places [the modeled tsunami] goes inland farther than the existing State of California tsunami inundation" maps predict, Oglesby says. Modeled inundations exceed those mapped by up to a kilometer, Ryan says, with much of this added inundation occurring around Ventura Harbor.

Oglesby notes that the modeled earthquake is "a severe but plausible event. That doesn't mean that we think it's going to happen next year, or even in the next hundred years necessarily."

Although further work is needed to understand this fault system, the team's "preliminary results show how important it is to study ... tsunamigenic earthquakes, and the potential consequences should one of these large earthquakes occur on the Pitas Point-Ventura Thrust System," says seismologist Thomas Rockwell of San Diego State University, who wasn't involved in the research.

"This is one of the first studies to model potential tsunamis" in this system, Rockwell says. "We are still working out the details of the structural geology of this fold and thrust system, so this will not be the last model."

Indeed, Oglesby says, further modeling is in the offing. Many of the

assumptions about fault conditions and parameters that went into the models "are not terribly well-constrained," he says.

This research also provides a template for studying other tsunami-prone locales, Oglesby says, noting that the "methodology could be applied to any number of places around the world to look at potential earthquakes and tsunamis from lots of different faults."

Lauren Milideo

Subducting seamounts blocked a big quake in Chile

Chile, which lies above a massive subduction zone fault, is one of the world's most earthquake-prone countries, experiencing nine temblors of magnitude 7 or greater since 2010. In April 2014, a magnitude-8.1 earthquake struck 95 kilometers northwest of the city of Iquique, but despite its large size, the event failed to release all the stress thought to have built up along that portion of the fault. A new study reveals that a ridge of ancient underwater volcanoes may have blocked the 2014 earthquake rupture from propagating farther, thus limiting the size of the quake.

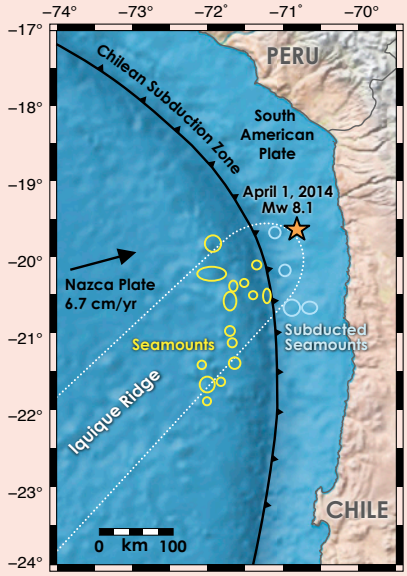
Off the coast of Chile, the Nazca Plate is subducting beneath the South American Plate. Friction between the two plates creates stress along the contact area between them, which is occasionally released in the region's frequent earthquakes. But the section of the megathrust fault near Iquique has been locked and accumulating stress since the last big event to strike that part of the fault in 1877.

"In northern Chile, there is a gap 550 kilometers wide that has not seen a major earthquake since 1877," says Jacob Geersen, a geophysicist at GEOMAR Helmholtz Center for Ocean Research in Kiel, Germany, and lead author of the study, published in Nature Communications. For decades, experts have thought Chile's next major earthquake would strike in this gap and that it would need to reach a magnitude greater than 9 to release all of the stress accumulated in this region of the fault. Indeed, the April 2014 quake did strike within this gap, but it only reached magnitude 8.1 and it only affected the central part of this gap, leaving the sections to the north and south unruptured.

To investigate why the Iquique quake didn't rupture the entire gap, Geersen and colleagues combined topographic images of the seafloor around the subduction zone with seismic images showing the deeper structure of the fault. They found that a ridge of seamounts on the downgoing Nazca Plate may be impeding subduction and deforming the interface between the two plates.

The volcanic features, some up to 2.3 kilometers high and 15 kilometers wide, are no longer active, Geersen says. "The seismic data show that several seamounts have already been subducted into the fault zone, while others are pushed up along the interface" — the surface fault trace — "of the two plates, thereby actively deforming the interface and the overlying South American Plate," Geersen says.

The seamounts on the exposed portion of the Nazca Plate had been previously mapped at low resolution, but the subducted seamounts revealed by the seismic reflection data are a new discovery, says Roland Bürgmann, a geophysicist at the University of California at Berkeley, who was not involved in the new study. "People have thought for a long time that seamounts might affect the subduction earthquake process," he says. But the data presented in this study make "the nature of this connection, and the apparent arrest of the Iquique rupture, much more concrete."



Map of Chile's coastline showing the locations of the April 2014 earthquake and the seamounts that may have prevented the rupture from propagating farther.

Credit: K. Cantner, AGI, adapted from Geersen et al., Nature Communications, 2015

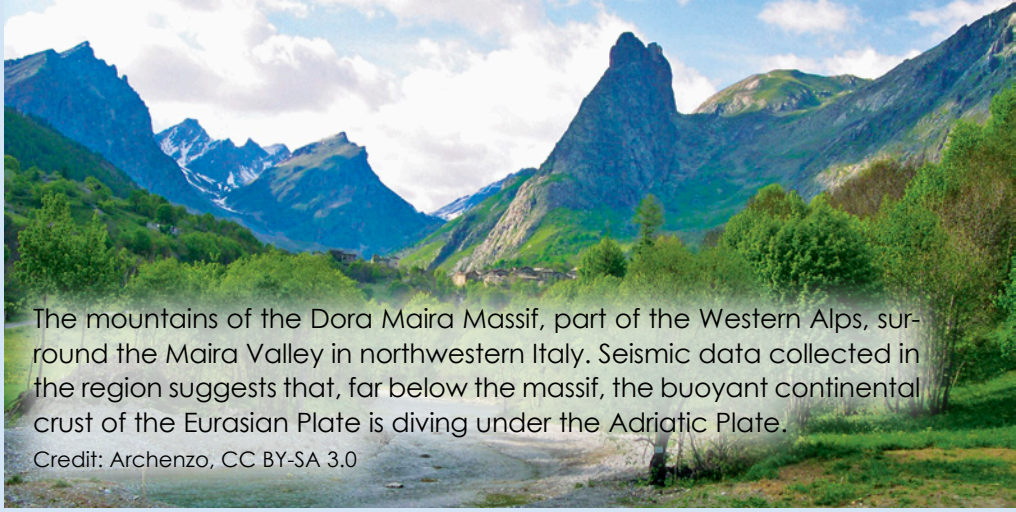
"When you bring topographic features into a subduction zone, they tend to fracture the area around the plate boundary so it's not one continuous fault, but more of a fractured network" of many smaller faults, Geersen says. It seems this fractured network cannot build up or efficiently transmit seismic energy, thus preventing rupture along the entire length of the seismic gap, he says.

But that doesn't mean that this section of the fault is safe from more damaging quakes, Bürgmann notes. "We should always be careful not to overinterpret and overextrapolate from one such observation," he says.

In 2014, the Iquique quake broke the middle 150 kilometers of the 550-kilometer-wide gap, leaving sections to the north and south with enough stored seismic energy to produce an earthquake larger than magnitude 8.5, Geersen says. The team is now installing geodesic instruments on the seafloor near the subduction zone to monitor the fault. "The more information we have, the closer we get to being able to manage the risks and mitigate the effects of potentially large earthquakes," he says.

Mary Caperton Morton

How deep do the Alps go?



The mountains of the Dora Maira Massif, part of the Western Alps, surround the Maira Valley in northwestern Italy. Seismic data collected in the region suggests that, far below the massif, the buoyant continental crust of the Eurasian Plate is diving under the Adriatic Plate.
Credit: Archenzo, CC BY-SA 3.0

Continental crust was long thought to be too buoyant to subduct into the mantle, unlike denser oceanic crust, which descends into the mantle in many locations around the world. But the discovery of coesite — a type of silica formed at the extreme pressures present in subduction zones — in the Alps in 1984 challenged that long-held idea. Seismic evidence backing up claims that continental crust has indeed been subducted beneath the Alps has been scant, however, until now.

The European Alps are part of the Tethys Orogen, the largest ongoing continent-continent collision belt in the world, which extends from the Alps in the west to Tibet and Southeast Asia in the east. "The geology of the Western Alps has been studied for 200 years, which makes it one of most well-studied tectonic areas in the world," says Liang Zhao, a geophysicist at the Chinese Academy of Sciences in Beijing and lead author of a new study in Geology presenting seismic data from beneath the mountain range. Despite the long history of geologic study, producing seismic profiles of the Western Alps has been difficult due to a strong seismic velocity discontinuity at a depth of 10 to 20 kilometers. "This is the reason why previous studies could not image the subduction of Eurasian [continental crust]," Zhao says.

In a new approach, Zhao and colleagues gathered data from the China-Italy-France Alps seismic survey, the first passive seismic transect of the entire Dora Maira Massif in southern France and northern Italy, where the coesite samples were originally found. The team reported evidence of the continental crust of the Eurasian Plate diving under the Adriatic Plate and extending to a depth of 75 kilometers, deep enough to produce the extreme pressures and temperatures needed to form coesite. "Our data demonstrate that the Eurasian lower crust underthrusts the Adriatic mantle," he says, providing the first seismic evidence of subducted continental crust. The Adriatic Plate is made up of mostly continental crust that broke off from the larger African Plate during the Cretaceous.

The findings may have applications elsewhere along the Tethys Orogen, Zhao says. "We are not only interested in the Alps; we are also interested in improving the understanding of how a continent-continent orogen evolves. This project is part of a [larger project to] deploy several seismic arrays across the Tethys tectonic area."

Mary Caperton Morton

Irrigation drives rain away in East Africa

Researchers have found that large-scale agricultural irrigation, intended to supplement precipitation, may actually drive rainfall away, potentially exacerbating conditions in some areas while improving them in nonirrigated lands.

In addition to adding moisture to the ground, irrigation affects local air temperature, humidity and winds, all factors that contribute to weather patterns. Previous modeling has suggested that large-scale irrigation can shift where rain falls, particularly in arid regions like the African Sahel — the transitional zone between the Sahara Desert and wooded savanna farther south — where small changes in moisture levels may have outsized effects on weather. But little has been done to verify model results for Africa with observations of actual conditions.

Ross Alter of MIT and colleagues used a regional climate model to investigate part of the East African Sahel surrounding what's known as the Gezira Scheme, a nearly 9,000-square-kilometer area of irrigated land in central Sudan, between 1979 and 2008. The model suggested that during the summer months when the Sahel receives most of its annual precipitation from the African monsoon, precipitation levels fell by as much as 2 millimeters per day over the irrigated area while they increased over nonirrigated areas farther east. The researchers then looked at trends in a historical precipitation dataset covering the region, as well as in separate observations from six weather stations in and around Gezira. They found that the relative patterns were consistent with their model results. Shifts in surface air temperatures and streamflow over the same time period were also consistent, they noted.

A "causative link between irrigation development and rainfall modification may have numerous implications for agricultural, hydrologic, economic and political interests both inside and outside these irrigated areas," the researchers wrote in Nature Geoscience.

Timothy Oleson

Ancient eggshells may reveal dinosaur body temperatures

Whether dinosaurs had metabolisms more like slow, cold-blooded reptilians or fast, warm-blooded birds has long been a mystery. Fossilized bones, which don't preserve the delicate cell membranes that facilitate heat production in warm-blooded animals, are not likely to answer the question. Fossilized eggshells, however, might be just the ticket to determining the past body temperatures of egg-laying females, which, scientists say, might help address whether the dinosaurs' metabolisms were warm or cold.

Reptiles, like lizards and crocodiles, are cold-blooded animals, or ectotherms, that are at the mercy of external heat sources to warm their bodies. These animals are usually confined to warmer climates where they absorb heat from sunlight. But dinosaurs' widespread distribution across many climate zones suggests that they might have had higher body temperatures than modern-day reptiles, and scientists have long wondered whether dinosaurs were endotherms — more similar to modern-day birds than crocodiles.

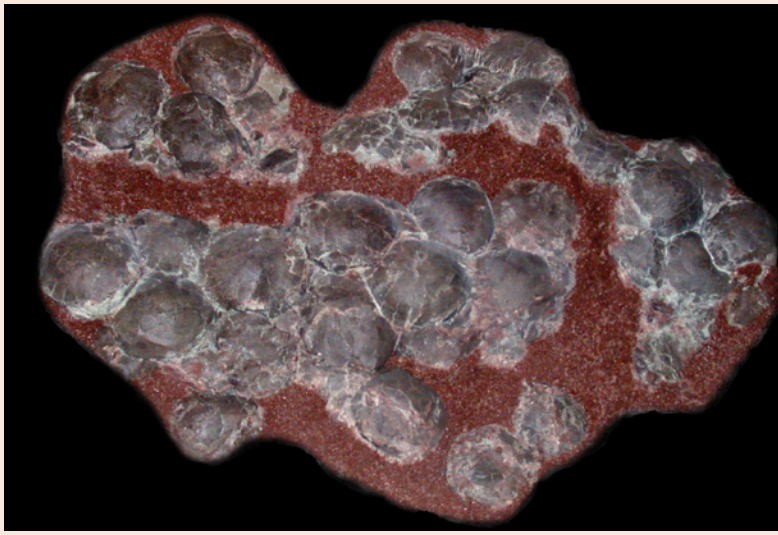
To test the feasibility of calculating ancient dinosaur body temperatures from fossil eggshells, a team led by Robert Eagle, a geochemist at UCLA, measured carbon-13 and oxygen-18 isotopic ratios in eggshells from 13 modern bird species and nine species of reptiles using a mass spectrometer. The researchers determined the mineral formation temperatures recorded in the calcium carbonate of the eggshells, which matched up with the internal body temperatures of the mothers at the time the eggshells formed.

"We were able to quite clearly distinguish the birds from the reptiles and predict the known body temperatures to within 1 to 2 degrees Celsius," Eagle says. "We were also able to distinguish among different species of birds," he says, differentiating, for example, "small songbirds with high metabolisms from large flightless birds like ostriches."

Next, the team turned to eggshells found in Argentina belonging to a large sauropod called *Titanosaurus* that lived about 80 million years ago, as well as shells from Mongolia that were laid by a small theropod called *Oviraptor* and dated to about 75 million years ago. "We picked these two species because fossil embryos had been found inside some of the eggshells, so we could assign a specific species to the eggshell," Eagle says.

The team selected three well-preserved eggshells from each species and analyzed the shells' chemistry to determine the temperature at which they'd formed. They found that the large sauropods were warm, roughly 37 degrees Celsius, while the smaller theropods were slightly cooler, about 32 degrees Celsius.

While this study, published in Nature Communications, presents some of the first direct body-temperature measurements for theropods, the sauropod results match up with findings from previously published work in which Eagle and colleagues measured isotopic ratios preserved in sauropod teeth. That work indicated that sauropods had body temperatures between 36 and 38 degrees Celsius. Modern mammals run between 36 and 39 degrees Celsius; reptile body temperatures vary widely, with crocodiles being between 26 and 37 degrees. Birds are typically warmer, closer to 40 degrees Celsius.



A fossilized clutch of titanosaur eggs.
Credit: Luis Chiappe

"These temperatures suggest that at least some species of dinosaur fell somewhere in between reptiles and modern birds," Eagle says. "They were not full endotherms yet but they likely had faster metabolisms than reptiles."

But not everyone agrees that eggshells are a reliable source of 80-million-year-old temperature data. "Body temperature is a problematic subject to study because it's affected by many internal and external variables. It's hard to find information that is solely dependent on temperature, and is not affected by other variables," says Eva Maria Griebeler, a biologist at the Johannes Gutenberg University of Mainz in Germany, who was not involved in the new study. The isotopic ratios could have been altered over the time they were buried and may not accurately reflect the body temperatures of the females when the eggs were formed, she says.

Furthermore, Griebeler notes, studies on modern animals suggest that although isotopic ratios can sometimes provide records of body temperatures, they typically only reflect the body temperature during mineralization, which could be deceptively high in, for example, an ectothermic animal that warms itself in the sun. "A high temperature doesn't automatically mean the animal was endothermic," she says.

Mary Caperton Morton

Sulfur radicals better at concentrating gold

A new study combining lab experiments and modeling shows that trisulfur radicals are 10 to 100 times more effective at leaching gold from rocks and concentrating the precious metal in ore deposits than hydrogen sulfide and chloride — the chemical species long thought to be most responsible for transporting gold in the crust.

Pokrovski et al., PNAS, October 2015

Life on Earth 4.1 billion years ago?

Researchers analyzing a 4.1-billion-year-old zircon crystal from the Jack Hills of Western Australia have found that the carbon isotopic signatures of bits of graphite encased within the crystal are "consistent with a biogenic origin," suggesting that life on Earth might have been around at least 300 million years earlier than previously proposed.

Bell et al., PNAS, October 2015

Marine animal diversity at all-time high

Marine animal diversity on Earth has been on the rise for the last 200 million years, according to an analysis of available records in the Paleobiology Database. On average, twice as many genera called the ocean home in recent geologic history as did during the Paleozoic.

Bush and Bambach, Geology, October 2015

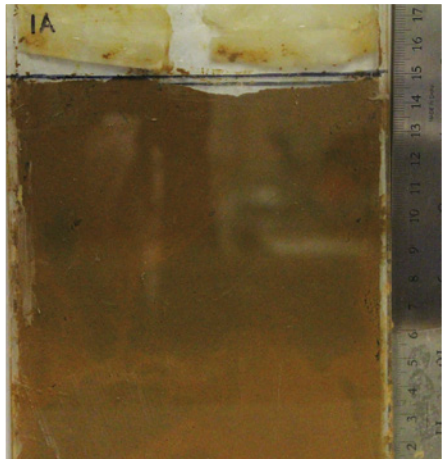
Wormholes may limit landslides

Scientific investigations sometimes take unexpected twists and turns. When Emma Harrison, a graduate student at the University of Pennsylvania, began digging trenches in the mountains of Puerto Rico to study how the soil mantle responds to rapid changes in erosion, she couldn't help but notice the worms.

The thick Puerto Rican soils were chock-full of the wriggling creatures: endogeic worms, which spend their lives burrowing through the soil and feeding on bits of decaying organic matter underground, as well as much larger anecic worms, which in the Luquillos are typically 2 millimeters wide and as long as a human forearm. Anecic earthworms live deeper in the soil profile but build long, vertical burrows so they can feed on organic litter at the surface.

Harrison had gone to northeastern Puerto Rico's Luquillo Mountains, which rise steeply from sea level up to 1,075 meters in elevation, to look into why erosion rates aren't as high as it seems they should be. Uplifted between about 37 million and 28 million years ago, this range is the first barrier on the island encountered by the prevailing easterly winds, which carry moisture from the Caribbean Sea. The resulting orographic effect produces copious rainfall, exceeding 5 meters per year at higher elevations, where a dense rainforest thrives. "With the amount of precipitation [the area] gets, you should be eroding the range at a much quicker rate," Harrison explains. Whereas erosion rates in the Luquillos range from about 0.05 to 0.18 millimeters per year depending on elevation, rates are typically much higher in other high-precipitation tropical environments, she says; the mountains of Taiwan, for example, lose between 2.2 and 8.3 millimeters per year.

At the Luquillo Critical Zone Observatory — one of 10 such National Science Foundation-funded observatories focused on studying the so-called critical zone between the treetops and the base of weathered rock — researchers like Harrison are working to understand why these mountains are still as high as they are. Intrigued by the worms' abundance and prodigious activity at her field site, Harrison wondered whether their presence could influence weathering in the Luquillos. Previous studies had found that landslides account for most of the erosion in the lush, tropical and steep environment of the Luquillos, and that removing earthworms from an experimental plot in the mountains



An experimental worm nest on day one, prior to noticeable burrowing by endogeic worms.
Credit: Emma Harrison

A worm nest after 12 days. Endogeic worm burrows are denoted with black coloration added with image processing software.
Credit: Emma Harrison

greatly increased surface runoff and the downhill transport of fine organic matter.

What were the earthworms doing to the soil to create such a difference? Along with undergraduate Aria Kovalovich, Harrison constructed several clear earthworm nests that were thin enough to allow the team to observe worm tunneling in two dimensions. After placing endogeic worms and soil native to the Luquillos in the nests, the researchers stored them in a dark room, pulling them out once per day to photograph the worms' progress. Using image-processing software, the researchers then quantified changes in the amounts of material excavated in the tunnels from day to day. After two weeks, they also measured the nests' bulk densities and their permeability to water.

On average, the soil in the experimental nests was compacted by 4.3 percent, the team reported in November during the annual meeting of the Geological Society of America in Baltimore. "It's very rare to see [levels of] compaction like that," Harrison says. "It was really surprising; we had actually thought that there would be an increase in the volume of the soil," she adds, because worms are often observed to churn up and aerate soils.

There could be several reasons for the compaction, Harrison explains. First, as the earthworms burrow, they push the dirt surrounding the tunnels together, reducing pore space between soil particles. In addition, when soil particles are ingested and later excreted by worms, the particles tend to be compacted, she says. The soil is also compacted when earthworm tunnels collapse.

Based on the experiments, the researchers concluded that earthworms are significant biological agents that actively restructure the Luquillo soils, and that the worms' tunnel networks increase the rate at which precipitation filters through the soil. This allows water to drain more rapidly from the clay-rich surface where landslides most frequently occur. The end result, according to the team's hypothesis, is fewer landslides and a slower rate of erosion in the Luquillo Mountains.

Ultimately, Harrison says she hopes the study will stimulate new ideas about erosional processes. She also would like to expand the research to include the anecic earthworms, whose longer, straighter burrows could be even more effective conduits for draining precipitation. "A landscape is a composite of all of its component parts, including the life that lives within it," Harrison says, adding that studying the interactions among all these components is an exciting new direction in landscape geomorphology.

Terri Cook

Rising Star cave hominid walked its own way

After dozens of human-like fossils were discovered in a cave in South Africa last summer, they were declared distinct enough to be classified as a new species: *Homo naledi*. Two recent studies looking in detail at the new hominid's hands and feet are revealing how different they were from other early humans.

Human feet have more than two dozen bones, the shape and structure of which reveal a lot about a species' locomotion and lifestyle. Close examination of 107 foot bones belonging to at least five individuals suggests that *H. naledi* was well-adapted for standing and walking on two feet, but that it also was likely adept at climbing trees, according to a study in Nature Communications.

"*Homo naledi*'s foot is far more advanced than other parts of its body, for instance, its shoulders, skull, or pelvis," said William Harcourt-Smith, a paleoanthropologist at the American Museum of Natural History in New York and lead author of the new study, in a statement. "Quite obviously, having a very human-like foot was advantageous to this creature because it was the foot that lost its primitive, or ape-like, features first. That can tell us a great deal in terms of the selective pressures this species was facing."

Analysis of the foot bones showed that they appear to be closer in shape and size to modern human bones than chimpanzee bones, except that *H. naledi*'s toe bones were more curved and the arch of the foot was flatter than modern humans.

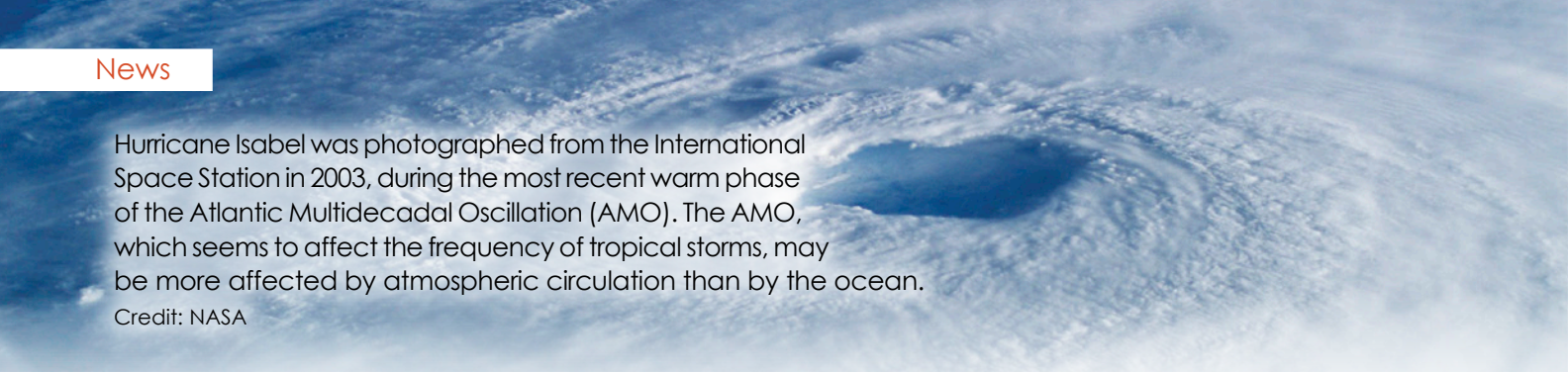
The rest of *H. naledi*'s anatomy — including its long, curved fingers and a more ape-like shoulder girdle — suggests they moved in their own unique way, somewhere between chimps and full bipeds. A study of the hominid's hands, led by Tracy Kivell of the University of Kent in England, was published in the same issue of Nature Communications.

The hand and foot of the newly discovered hominin species, *Homo naledi*.

Credit: Peter Schmid/Will Harcourt-Smith

"This species has a unique combination of traits below the neck, and that adds another type of bipedalism to our record of human evolution," Harcourt-Smith said. "There were lots of different experiments happening within hominins — it wasn't just a linear route to how we walk today."

Mary Caperton Morton



Hurricane Isabel was photographed from the International Space Station in 2003, during the most recent warm phase of the Atlantic Multidecadal Oscillation (AMO). The AMO, which seems to affect the frequency of tropical storms, may be more affected by atmospheric circulation than by the ocean.
Credit: NASA

Atmosphere, more than ocean, might drive Atlantic climate variation

Atmospheric, not oceanic, circulation may be the main driver of climate variations over the North Atlantic Ocean, potentially complicating future hurricane and drought predictions, according to the authors of a new study.

The climate variations — in air temperatures, precipitation patterns and cloud formation — result from the Atlantic Multidecadal Oscillation, or AMO, a phenomenon in which ocean surface temperatures swing by up to half a degree Celsius. The AMO affects the sea surface between the equator and Greenland, and warm and cool phases can last 20 to 40 years.

"These slow changes in the Atlantic have an impact on the climate on land around the Atlantic, where people are living," says Amy Clement, an atmospheric scientist at the University of Miami and lead author of the study, published in Science. For example, "the hurricane frequency and the number of storms seem to co-vary with the AMO," Clement says, and rainfall patterns in Florida and throughout much of the northeastern United States appear to be influenced by the AMO.

Similar to El Niño, the AMO accompanies natural changes in sea-surface temperature. Ocean circulation is a critical driver of El Niño, leading many scientists to assume the ocean is also driving the AMO, Clement says. However, when her team ran climate simulations over the North Atlantic with and without ocean circulation, they found that both yielded similar variations in droughts and hurricanes, among other weather events. That suggested that the atmosphere, rather than the ocean, is driving the AMO in the models.

"We know the climate is going to warm in the future, with or without oceanic circulation," Clement says. "But fluctuations about that warming trend, which matter for multiyear and multidecadal changes in rainfall patterns, could be harder to predict" if her team's simulations are accurate, she says, because the more-chaotic atmosphere, instead of the more-predictable ocean, is driving the changes on those timescales.

But not everyone agrees that the atmosphere is solely responsible for driving the AMO. Tom Delworth, a research scientist at NOAA's Geophysical Fluid Dynamics Laboratory who was not involved in the study, says the atmosphere probably contributes to the AMO on short timescales, but that the ocean is a key driver of decadal-scale changes.

"The ocean is sluggish — it takes a lot of energy to move the ocean and change the ocean," Delworth says. So, he adds, ocean circulation doesn't usually respond quickly to shifting winds. But on longer timescales, it does respond to atmospheric circulation changes.

Delworth also notes an inconsistency between the new modeling and physical observations. Changes in the North Atlantic Oscillation, or NAO — the dominant pattern of wind variability over the Atlantic — determine how much energy cycles between the ocean and atmosphere, which adjusts the ocean's thermostat, Delworth says. In the new study's models, when the NAO is "positive" — with stronger westerly winds in subpolar regions of the North Atlantic and stronger trade winds in the tropics — winds remove heat from the ocean surface and cause it to cool, he says. "However, what we see in reality on long timescales is the opposite relationship in the Atlantic," Delworth says. The NAO was strongly positive at times in the 1990s and early 2000s, and that led to strong warming of the North Atlantic, attesting to the influence of ocean circulation, he notes.

Gerard McCarthy, a research scientist at the National Oceanography Center in England who was not involved in the study, also says that ocean circulation plays a role in the AMO. In his view, the NAO controls the temporal pattern of the AMO while ocean circulation drives its spatial pattern in the North Atlantic. To capture the ocean's role in setting the AMO's spatial pattern, the study's models need additional high-resolution data to accurately portray circulation patterns over small regions of the ocean. This will help the simulations better account for the shape of the Gulf Stream, which flows north from Florida and eastward to Europe, among other features, McCarthy says.

Clement says it's possible that her team's models are overlooking a role for ocean circulation in explaining the multidecadal fluctuations of the AMO, and that higher-resolution ocean data could help resolve this role if it exists. If you can simulate the ocean at high resolution, then you can start to see smaller-scale features in its circulation, like eddies, and perhaps then "the ocean may start to have more of an impact" in the model, she says.

Understanding how the climate system, particularly in the Atlantic, evolves

today is important for predicting how it's going to change in the future, Delworth says. And the reason researchers are so interested in the AMO is because "there are real impacts of it," Clement says. Storms are twice as frequent during warm years of the AMO compared to cold years, she says. If the steadier ocean takes a backseat to the atmosphere, "we don't have a lot of ability to predict that switch."

Elizabeth Goldbaum

Fossilized melanin reveals bats' true colors

Studies of pigments preserved in fossil feathers have changed our perception of how colorful dinosaurs were. Now, researchers have revealed the true colors of some of the first flying mammals as well. Two species of bats that lived during the Eocene about 50 million years ago were likely reddish-brown in color, according to a new study published in Proceedings of the National Academy of Sciences.

Scientists led by Caitlin Colleary, a doctoral student now at Virginia Tech University, studied how melanin pigment is preserved in fossils over time. For decades, the organelles that produce melanin, called melanosomes, have been observed in well-preserved fossils of a number of species, but scientists long suspected the structures might instead be fossils of bacteria that invaded the specimens after burial.

By replicating the conditions under which the fossils formed using high-pressure, high-temperature experiments, the researchers determined that some exceptionally preserved fossils do indeed contain remnants of melanin, which can be used to determine coloration. Melanin comes in two distinct colors: reddish-brown phaeomelanin and black eumelanin. The bat fossils — both found in Germany and belonging to the species *Palaeochiropteryx* and *Hassianycteris* — were found to be colored by phaeomelanin.

"Importantly, we see that the different melanins are found in organelles of different shapes: reddish melanosomes are shaped like little meatballs, while black melanosomes are shaped like sausages," said co-author Jakob Vinther of the University of Bristol in England in a statement. Because this pattern is also seen in fossils, we can "easily determine color from fossils by simply looking at the melanosome shape," he said.

The team plans to continue studying coloration of ancient fossils from a number of lineages. "We have now studied tissues from fish, frogs and tadpoles; hair from mammals; feathers from birds; and ink from octopus and squids," Colleary said in a statement. "They all preserve melanin ... Now, we can confidently fill in some of the original color patterns of these ancient animals."

Mary Caperton Morton

Jupiter's shrinking Great Red Spot

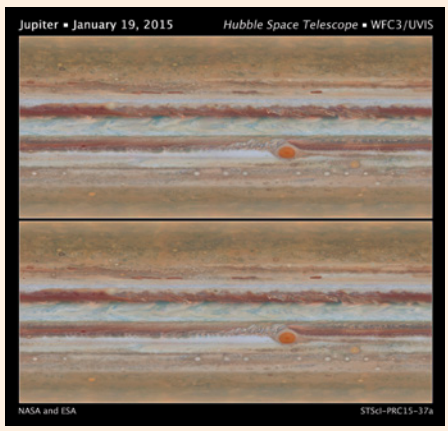
Like a kid sitting for her annual school portrait, Jupiter lines up with the Hubble Space Telescope for a series of photographs once a year. The images capture a broad range of features, including winds, clouds, storms and atmospheric patterns, and are used to create yearly maps of the gas giant to study how it changes over time.

"Every time we look at Jupiter, we get tantalizing hints that something really exciting is going on," said Amy Simon, a planetary scientist at NASA's Goddard Space Flight Center in Greenbelt, Md., and lead author of a new study detailing analyses of images taken in 2015, in a statement. "This time is no exception."

The images confirm that the planet's Great Red Spot, a giant storm spinning in Jupiter's atmosphere, is continuing to shrink and become more circular, trends that have been observed during previous years. At its widest point, the storm is about 40,000 kilometers across, but the most recent photos indicate that it shrank by 240 kilometers since 2014, a rate consistent with long-term trends.

The most striking changes seen in the recent images were the appearance of a unique filamentary feature in the eye of the Great Red Spot not previously seen and a rarely observed atmospheric wave just north of the planet's equator, the researchers reported in Astrophysical Journal. The filament spans the width of the Great Red Spot and was seen twisting and rotating throughout the 10-hour duration of the image sequence. The wave, thought to be a baroclinic wave similar to those that occur in Earth's atmosphere when cyclones are forming, was last observed in 1979 by Voyager 2.

"Until now, we thought the wave seen by Voyager 2 might have been a fluke,"



New images of Jupiter show some key changes in the gas giant's atmosphere and storm systems.

Credit: NASA, ESA, A. Simon (GSFC), M. Wong (UC Berkeley), and G. Orton (JPL-Caltech)

said co-author Glenn Orton of NASA's Jet Propulsion Laboratory in Pasadena, Calif., in the statement. "As it turns out, it's just rare!"

Mary Caperton Morton

In 2015, D.C. Water, which treats wastewater from Washington, D.C., and the Maryland and Virginia suburbs, began using a thermal hydrolysis treatment system to convert sewage into electricity.
Credit: D.C. Water

D.C. wastewater no longer going to waste

D.C. Water & Sewer Authority, which treats sewage from Washington, D.C., as well as from the Maryland and Virginia suburbs ringing the city, is the biggest consumer of electricity in the U.S. capital. But last September, D.C. Water began creating its own power, becoming the first utility in the country to convert sewage into electricity.

The system behind this conversion was originally developed in Norway and involves a dewatering building, 32 sleek thermal hydrolysis vessels, four 24-meter-tall anaerobic digesters that each hold about 14,000 cubic meters of solids, and three turbines the size of jet engines. Together, the technology works like a giant pressure cooker that breaks down solid waste, producing copious amounts of methane gas, which is combusted to drive the electricity-generating turbines. At the end of the process, the leftover solids are cooked down into a bio-solid that can be used as compost in urban gardens.

D.C. Water officials say the $470 million system, which took four years to build, will save the city about $10 million annually and shrink the plant's overall carbon footprint by one-third. It may find application in other major cities as well; on average, water and sewer utilities account for about 4 percent of the country's overall energy usage, and they're the single largest energy consumers in most communities.

"This project embodies a shift from treating used water as waste to leveraging it as a resource," said D.C. Water CEO and General Manager George S. Hawkins, in a statement. "We are proud to be the first to bring this innovation to North America for the benefit of our ratepayers, the industry and the environment."

Mary Caperton Morton

UNESCO adopts Global Geoparks Program

On Tuesday, Nov. 17, 2015, the 195 member states of UNESCO formally adopted the Global Geoparks Network, designating the inscribed parks as UNESCO sites during the organization's 38th General Conference in Paris.

Global Geoparks are areas that conserve geological features of international significance and capitalize upon those features to attract visitors. The new UNESCO Global Geoparks designation recognizes "the importance of managing outstanding geological sites and landscapes in a holistic manner," according to a press release from the organization.

Together with the Burren, the striking Cliffs of Moher on the Republic of Ireland's west coast were first designated a Global Geopark in 2011.
Credit: Terri Cook and Lon Abbott

Although UNESCO facilitated efforts during the late 1990s to create a global network of geoparks, in 2001 the executive board chose to support a voluntary ad hoc member-based geopark effort over a formal program. The Nov. 17 decision upgrades this informal approach to an official program comparable to the World Heritage and Biosphere Reserve programs. Collectively, this trio represents the most significant international framework to promote sustainable development of the world's outstanding geological, biological and cultural sites.

Biosphere reserves and global geoparks are first established by individual countries, then later recognized by UNESCO. The host nation and, if applicable, private landholders retain complete control over the land, although each park must be protected by national land policies and comprehensively managed in order to retain its Global Geopark label.

After adding nine new sites in September 2015, the Global Geopark Network now includes 120 sites in 33 countries, including Canada, which hosts both the Tumbler Ridge and Stonehammer global geoparks. The United States is not currently represented in the network.

Terri Cook

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.

- Two new 300-year-long ice-core records suggest that snowfall over part of coastal West Antarctica increased dramatically through the 20th century compared to the preceding two centuries, when it was stable. From 1900 to 2010, annual snow accumulation rose roughly 30 percent in Ellsworth Land, near the Bellingshausen Sea, reported Elizabeth Thomas of the British Antarctic Survey and colleagues in Geophysical Research Letters. The researchers attribute the increase to the strengthening of a long-lasting regional low-pressure system, called the Amundsen Sea Low, which pushes warm, moist air onshore. The extra snow has not compensated for the loss of glacial mass measured in recent years, however. "The same [storms] that have driven increased snowfall inland have brought warmer ocean currents into contact with West Antarctica's ice shelves, resulting in rapid thinning," Thomas said in a statement.

- Deep fjords, rocky moraines and streams clouded by fine sediment are all reminders of glaciers' ability to shape Earth's surface through erosion. Decades of study and modeling, however, have yet to provide a consistent picture of how different physical factors govern glacial erosion. In a study published in Science, Frédéric Herman of the University of Lausanne in Switzerland and colleagues propose a novel numerical law governing glacial erosion rates, suggesting that such rates are proportional to the square of the velocity at which ice slides over the ground below it; the velocity, in turn, primarily depends on ice thickness and topographic steepness. The researchers determined the new erosion rate law based on a five-month study of the Franz Josef Glacier on New Zealand's South Island, during which they measured ice velocities and bedrock erosion rates across the glacier through remote sensing and sediment-load monitoring in glacial outwash streams. The wide range of erosion rates observed in the study suggests the rate law may be globally applicable, the researchers noted. Additionally, the law "may explain why glacial erosion rates span several orders of magnitude, from polar dry regions to temperate alpine glaciers and from soil-mantled hillslope landscapes to steep, tectonically active mountain ranges."

- A new study investigating an interior portion of the Greenland Ice Sheet (GIS) indicates that levels of snow-darkening particles, which absorb sunlight and decrease the albedo (the ability of a surface to reflect sunlight) of snow and ice, have not risen significantly in the last few years, relative to recent decades. Based in part on satellite observations from NASA's MODIS instruments indicating that the albedo of the interior of the GIS has declined since 2001, scientists had blamed black carbon and other dusts settling out of the skies for contributing to the recent rapid loss of mass from the ice sheet. In the new work, published in Geophysical Research Letters, a team led by Chris Polashenski of Dartmouth College and the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory sampled near-surface snow that had fallen between 2012 and 2014 in 67 locations in the northwestern interior of the GIS. The researchers reported finding "no evidence that would support a hypothesis that observed inter-annual to decadal trends in albedo are being caused by changes in the deposition" of black carbon or dust. Rather, they concluded, the albedo decline seen in the satellite data is likely an artifact of degradation of MODIS sensors. Polashenski and colleagues noted, however, that the albedo of the GIS overall, including the ice sheet's periphery, is still declining due to increased melting at lower elevations.

Based on a study of New Zealand's Franz Josef Glacier, researchers have developed a novel numerical law to describe glacial erosion rates on Earth.
Credit: Frédéric Herman

Timothy Oleson

IMPACT OR ERUPTIONS

Are Both to Blame in the Great End-Cretaceous Whodunit?

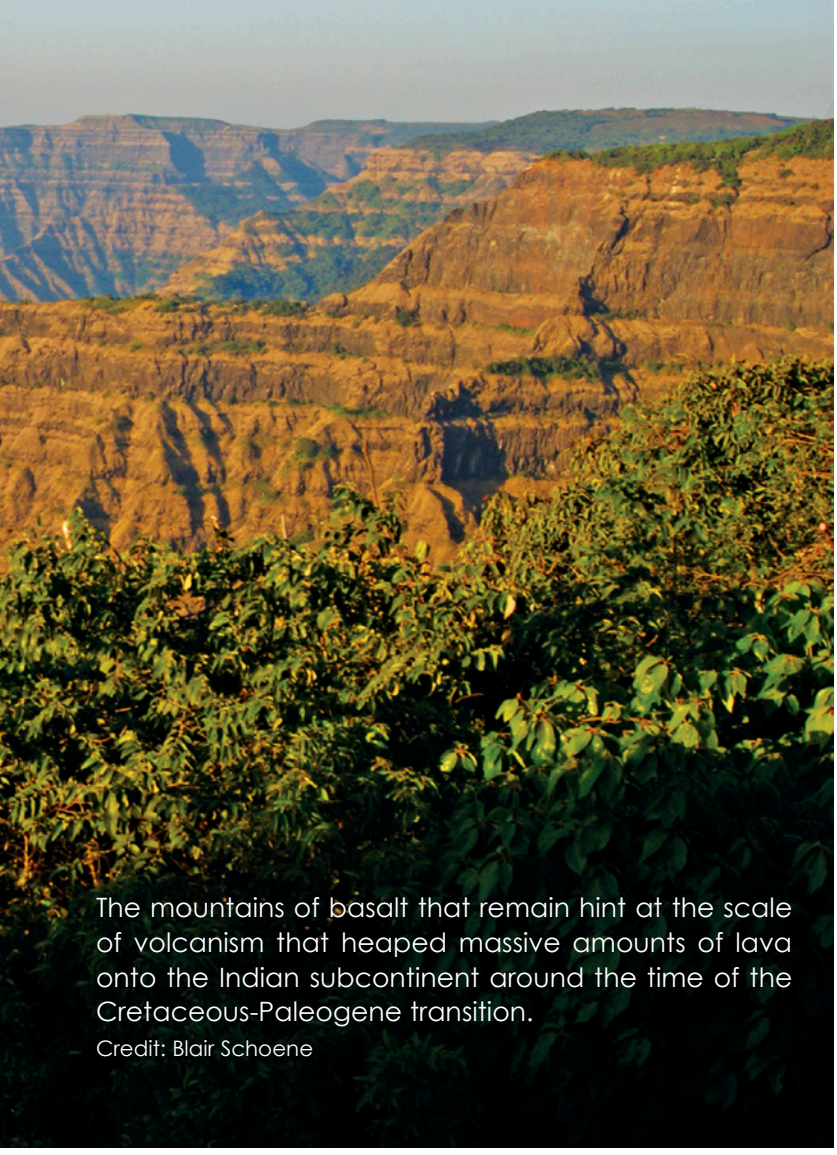
Timothy Oleson

Few episodes in geologic history are as widely recognized as the Cretaceous-Paleogene, or K-Pg, boundary 66 million years ago. Utter "K-Pg," "K-T" (for Cretaceous-Tertiary, as it's still commonly known) or "end-Cretaceous" to any geoscientist and you're virtually assured of a knowing glance as he or she recalls at least the textbook basics of a large bolide impact and mass extinction that finished off the dinosaurs and gave rise to the Age of Mammals. Mention it to science-interested laymen, meanwhile, and they may conjure images of tyrannosaurs peering over their shoulders in anguish as they flee from streaking meteors.

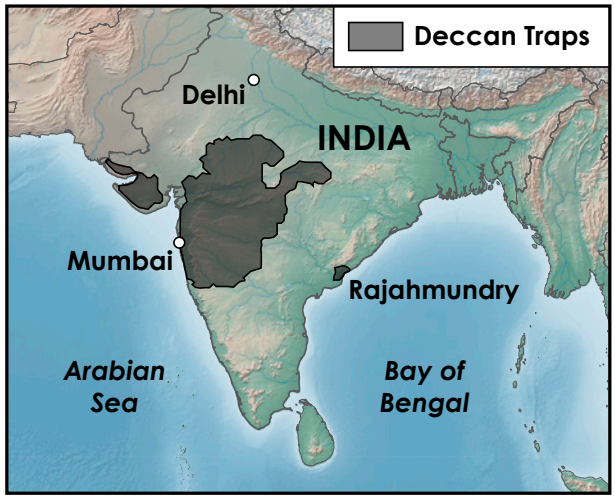
These catastrophic events make for a compelling and, aside from artistic liberties taken in some recountings, mostly truthful tale. Paleontologists have long recognized from the fossil record that more than half of the species inhabiting Earth perished at the end of the Mesozoic — the most emblematic of course being the remaining nonavian dinosaurs, like *T. rex* and *Triceratops*. And for the last quarter-century, since the identity and approximate age of the roughly 200-kilometer-wide Chicxulub crater on Mexico's Yucatán Peninsula were confirmed, the impact's devastating blast, and resulting fallout, has been the favored explanation for the K-Pg extinctions.

But before the impact's ascendance in both the scientific and popular psyches, another prevailing hypothesis invoked to explain the mass die-off described an altogether different global calamity: massive volcanism that heaped layer upon layer of basaltic lava onto the Indian subcontinent and belched climate-modifying gases and aerosols into the atmosphere. Possibly totaling more than 1 million cubic kilometers, these lava flows — known as the Deccan Traps — erupted over several million years, beginning before and ending after the mass extinction.

The debate over the cause of the K-Pg extinction has continued to simmer through the years, boiling over at times as proponents of each explanation traded barbs in the literature and at scientific meetings. But as researchers have continued amassing relevant data — geochemical, geochronological, paleomagnetic, paleontological, sedimentary



The mountains of basalt that remain hint at the scale of volcanism that heaped massive amounts of lava onto the Indian subcontinent around the time of the Cretaceous-Paleogene transition.
Credit: Blair Schoene



The Deccan Traps sprawl over more than half a million square kilometers of India.
Credit: K. Cantner, AGI

Setting the Stage

Fossil records of marine plankton and terrestrial plants suggest that, in the last million years or so of the Cretaceous, the warm global climate that prevailed through the period was cooling in fits and spurts: Earth experienced a series of brief cold snaps, with average annual temperature swings of 2 to 8 degrees Celsius possibly accompanied by large sea-level fluctuations. These same records, combined with those of mammals from the well-studied Hell Creek Formation in Montana, show that many of Earth's ecosystems faced on-again, off-again environmental stress, resulting in shifts in biodiversity and loss of species.

The scale of change leading up to the K-Pg boundary pales in comparison, however, to what happened during the main pulse of extinction, when an estimated 60 to 70 percent of Earth's species died off in a geological instant. In addition to the dinosaurs, many other large land animals and terrestrial plants, as well as marine reptiles, mollusks and numerous ocean-dwelling microorganisms, succumbed. Other evidence from the geologic record also points to a major disturbance on Earth at about the same time as this huge pulse of extinction: A sudden shift in carbon isotopic ratios and a decrease in the amount of calcite observed in marine sediment cores indicate drastic drops in biological productivity and carbonate sedimentation in the oceans — markers traditionally taken to define the K-Pg boundary.

and stratigraphic — explanations for the extinction involving both the impact and volcanism have emerged.

It's not certain whether a definitive picture of exactly what happened is even possible. However, improvements in rock-dating techniques and in understanding the complex and sprawling stratigraphy of the Deccan Traps and the Chicxulub impact deposits have offered the clearest views yet of the timeline of events. Shoring up this critical part of the story would be a major step, scientists say, in revising our perception of this extraordinary episode in Earth history.

The Cretaceous-Paleogene boundary can be seen at Gubbio, Italy. Here, drillholes are visible from coring in the 1980s.
Credit: Terri Cook and Lon Abbott

Images like this one of an asteroid hurtling toward Earth are often what come to mind when people think about the Cretaceous-Paleogene mass extinction that ended the Age of the Dinosaurs.
Credit: K. Cantner, AGI

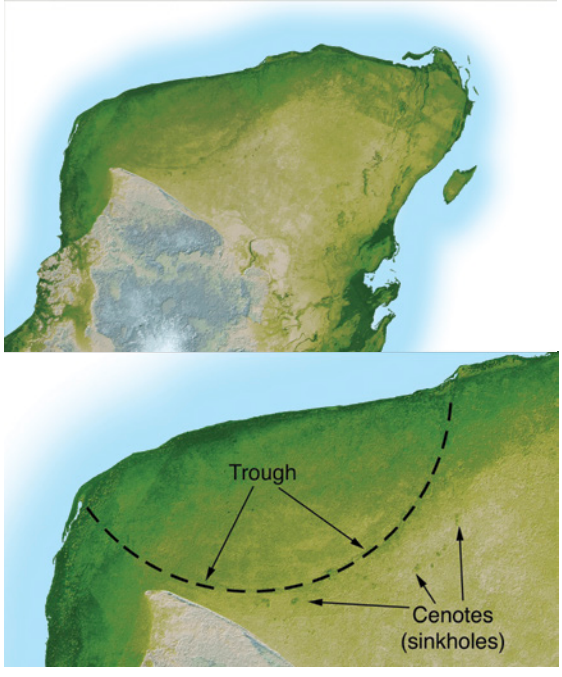
Suspect 1: The Impact

At certain locations on land, layers of sediment enriched in iridium and other rare metals, as well as bits of shocked quartz and droplet-shaped particles called tektites — which form when melted rock resolidifies quickly as it flies through the air — indicate that something big struck the planet around the same time that the extinctions were occurring. It was these terrestrial deposits, particularly at Gubbio in Italy's Apennine Mountains, that prompted a group led by University of California at Berkeley physicist Luis Alvarez and his son Walter, a geologist also at UC Berkeley, to lay out the first detailed hypothesis in 1980 that a bolide about 10 kilometers wide had slammed into Earth, sending large amounts of rocky debris and gases into the atmosphere and perhaps sealing the unfortunate fates of so many species.

Eleven years later, researchers announced evidence of a massive crater in the carbonate rock buried beneath Mexico's Yucatán Peninsula. The position and inferred age of the crater — named after Chicxulub Puerto, the coastal town near its center — matched up with the patterns and timing of fallout observed at Gubbio and a host of other such sites. The Chicxulub crater and its debris quickly became the keystone argument of impact hypothesis proponents.

Despite the popularity of the impact hypothesis, limitations of impact modeling and geologic dating techniques at the time left the door open to uncertainty about Chicxulub's size and exact timing relative to the extinctions seen in the fossil record. Could it have affected global climate enough on its own to account for the scale of the extinction episode seen at the K-Pg boundary? And was it actually contemporaneous with the major pulse of extinction, or did it happen sometime before or after?

Additionally, no other mass extinction is known to be associated with a major impact. Four out of five extinctions in the last half-billion years, however, are broadly correlated in time with huge inundations of flood basalts. The Siberian Traps erupted about the time of the end-Permian extinction, for example, which is thought to have knocked off about 90 percent of Earth's species some 252 million years ago. And the basalts of the Central Atlantic Magmatic Province emerged roughly 200 million years ago, about the time of the Triassic-Jurassic extinction. So there would seem to be more of a precedent for a volcanic culprit at the end of the Cretaceous.



This shaded relief map (and labeled inset) of the Yucatán Peninsula indicates the location of the buried Chicxulub crater.
Credit: both: NASA/JPL

Layer upon layer of Deccan lava is exposed in the Western Ghats mountain range east of Mumbai, India.
Credit: Mark Richards, UC Berkeley

Suspect 2: Volcanism

Questions have remained about the impact's lasting effects, but it at least was a discrete single event that's relatively well delineated in the sedimentary record (although there has been disagreement over just how clear this delineation is in some locations) and whose size is constrained by the size of the crater it carved. And over the years, repeated studies of impact deposits have led to updated understandings of when the meteorite struck: Ages of 65 million years and then 65.5 million years were once favored, but current consensus puts the impact at about 66 million years ago.

Meanwhile, the complex, tangled pile of Deccan lava flows defies "classical stratigraphic methods," says Mike Widdowson, a volcanologist at the University of Hull in England. Flows of varying sizes erupted at different places at different times; the basalts look similar to one another to the naked eye; and there aren't any obvious marker horizons, Widdowson says. These factors complicate efforts to correlate the timing and size of the different flows. It's also unclear how much lava lies underwater offshore, and how much lava was once on land that has now eroded away.

Although the traits of the Traps are far less constrained than those of the impact, it is clear that an enormous amount of lava — the Traps sprawl over roughly half a million square kilometers and are still piled more than two kilometers deep in places today — erupted toward the end of the Cretaceous or early in the Paleogene. The sheer volume of sulfur dioxide, carbon dioxide and other gases that vented to the atmosphere would have been staggering — far greater in total than what was kicked up by the impact. Then again, the Traps didn't erupt all at once, but, rather, in pulses. The major climate-altering gases have limited residence times in the atmosphere — on the order of years for sulfur dioxide to hundreds or thousands of years for carbon dioxide — so the environmental and ecological impacts of Deccan volcanism would have been tied to the size, duration and pacing of individual eruptive episodes. "The most important question right now with regard to the Cretaceous-Paleogene extinction … is exactly what the timing was for

Fresh lava spews from Iceland's Holuhraun lava field in 2014. During Deccan Traps volcanism, the landscape near eruptive vents likely would have looked similar.
Credit: Peter Hartree, CC BY-SA 2.0

these large eruptions in India," says Mark Richards, a geophysicist at UC Berkeley.

Starting in the 1980s, Widdowson and other researchers began studying the Traps' geochemistry. "We found that each batch of magma that produced lava flows was unique in that it was fingerprinted in a slightly different way," he says. "If you look at certain geochemical fingerprints ... you can tell where you are in the stratigraphy, and that amazingly holds true for most of the Deccan." The work allowed scientists to begin mapping the flows, which they classified into distinct, albeit discontinuous, "subgroups" — each of which comprised multiple formations and numerous individual flows — based on their geochemical similarity.

A rough outline of the sequence of different eruptive episodes of the Deccan Traps slowly emerged, but there was still little indication of the actual timing and duration of each episode — crucial factors in establishing potential correlations between the eruptions and extinctions. If much or most of the volcanism occurred soon before the extinctions, for instance, the case could be made for a causal link. If, on the other hand, the volcanism occurred after the main extinction pulse, such a link could be essentially ruled out.

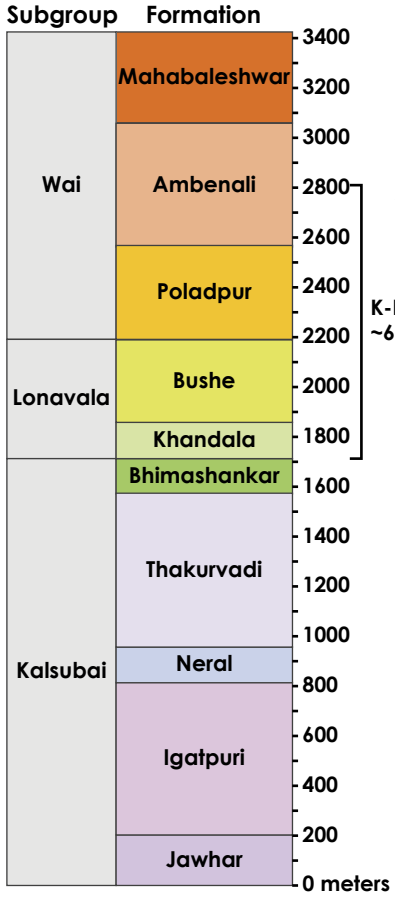
Through the 1990s and 2000s, several groups worked to refine the timeline of the Traps by applying geochronological techniques — particularly potassium-argon and argon-argon dating — to the Deccan lavas. The work combined to suggest that the vast majority of the erupted lava spewed from the ground in less than 1 million years. Additionally, this interval seemed to overlap with the timing of the Chicxulub impact.

In the late 2000s, studies led by Anne-Lise Chenet and Vincent Courtillot of the Institute of Global Geophysics in Paris offered further clarification on the timing and pacing of Deccan volcanism. Through geochronological and paleomagnetic analyses of minerals in the lavas and comparison with an established geomagnetic age timeline, they proposed that the volcanism occurred in discrete phases. A small initial phase dating to about 67.5 million years, well before the main K-Pg extinction, preceded a massive second phase, which Chenet, Courtillot and their colleagues thought had peaked about 65 million years ago. The researchers found that nearly all of the lavas of this phase, which account for about 80 percent of known Deccan lava volume, erupted within a portion of the geomagnetic timeline known as chron C29r — a roughly million-year-long period thought at the time to have ended shortly after 65 million years ago.

As the K-Pg boundary and extinction were thought to date to late in this chron, the team concluded that the large second phase occurred at least partly during the lead-up to the boundary, strengthening the case for a role of volcanic emissions in the extinctions. Further, they found that the lavas of this phase likely erupted in a series of about 30 eruptive events, each lasting only a hundred years or so. These punctuated eruptions could have thus spewed high concentrations of ash and gas into the atmosphere over short periods of time, potentially compounding environmental degradation from the volcanism. "The chemical input of the Chicxulub impact would have been on the same order as that of a very large single [eruptive event]," the researchers wrote in a 2009 study in the Journal of Geophysical Research – Solid Earth, concluding: "The impact, therefore, appears as important but incremental, neither the sole nor the main cause of the Cretaceous-Tertiary mass extinctions."

Other studies — both prior and since — have countered the group's notion that there were discrete pulses of Deccan eruptions, however, suggesting instead that relatively low levels of volcanism beginning as early as 69 million years ago likely continued unabated until activity rapidly accelerated closer to the K-Pg boundary.

Still, from the paleomagnetic work of Chenet, Courtillot and their colleagues, "we knew clearly that the main phase of the Deccan Traps was quite short," beginning



Composite stratigraphic column showing the lava subgroups and formations — which all erupted during the main phase of Deccan volcanism — present in India's Western Ghats mountain range. Formation thicknesses, which vary from location to location, are approximations based on Schoene et al. Science, 2014. The vertical bracket at right indicates where the K-Pg boundary might lie within the stratigraphy based on data from that study and from Renne et al., Science 2015.
Credit: K. Cantner, AGI

Thierry Adatte (left) and colleagues take a close look at a layer of weathered lava, called a red bole, in the Deccan Traps.
Credit: Mike Eddy

"maybe a little bit before the K-T [boundary]," says geologist Thierry Adatte of the University of Lausanne in Switzerland. But the timing still "was not very clear in terms of absolute dating," he says. Even the best radiometric ages for the lavas and the geomagnetic timeline came with error estimates of several hundred thousand years, confounding efforts to determine whether the largest Deccan eruptions — and their accompanying bursts of climate-altering gases — actually happened shortly before or shortly after the main extinction.

Researchers climb scree-covered slopes in India looking for suitable sites to sample for zircons.
Credit: Gerta Keller

When the Traps Were Set

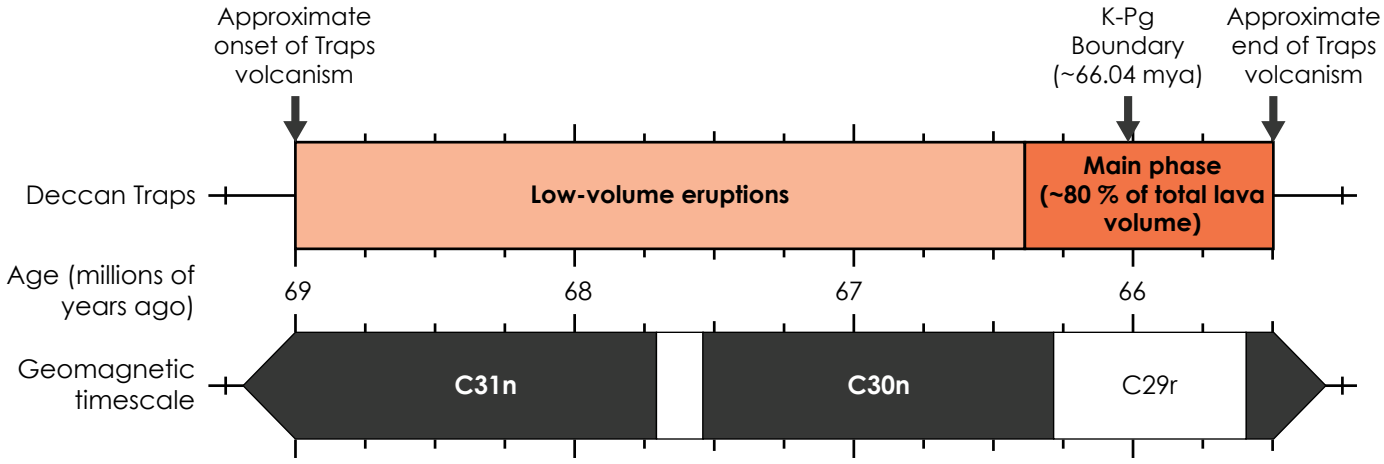
"The existing geochronology was not adequate to answer the questions people were asking" about the eruptions, says Blair Schoene, a geologist at Princeton University. Beginning in 2013, he teamed up with Adatte and others to collect zircon crystals from the Traps to analyze with high-precision uranium-lead dating.

Zircons very rarely form in the basaltic lavas of the Deccan, so the researchers searched in layers called red boles that occur between some of the flows. These layers represent quiescent periods, likely lasting thousands of years or more, between Deccan eruptions, during which natural weathering converted fresh, exposed basalt into soils. As the soils formed, debris — including tiny zircons — from explosive volcanic eruptions elsewhere in the world rained down and mixed into the red boles.

Although previous efforts had failed to locate datable zircons, Schoene's team pulled a handful of the crystals from boles situated near the bottom and top of the massive lava stack from the second phase of Deccan volcanism. "We were able to date precisely the onset of what's considered the main eruptive package of the Deccan," as well as the end, Schoene says.

The dates, reported in Science in late 2014 and bearing uncertainties of about 30,000 years — instead of 300,000 years or more — showed that this main phase lasted 750,000 years in total and started about 66.3 million years ago. "The most important thing is that it looks like [this phase] started about 250,000 years before the K-T boundary," Adatte says.

In parallel with efforts to detail the Deccan eruption timeline, Adatte and colleagues, including Gerta Keller of Princeton, have also been working to understand the varied responses of life in India and elsewhere to the eruptions. Among other sites, they've studied sediments found between some of the longest Deccan lava flows — called the Rajahmundry Traps — which stretched up to 1,000 kilometers southeast from the main eruption center in western India to low-lying areas flooded by seawater. In those sediments, deposited during quiet periods between individual eruptions, they've found signs of ocean acidification and, based on microfossil remains, evidence that ocean surface-dwelling plankton suffered severe losses. Similar to other locales around the world, including North America and New Zealand, pollen data from India also suggest a shift in terrestrial flora about the same time as plankton were dying off, with trees and



The main phase of Deccan volcanism is thought to have initiated several hundred thousand years prior to the Cretaceous-Paleogene (K-Pg) boundary and continued for about half a million years beyond the boundary. Note that the arrow in this figure only denotes the timing of the boundary, not its physical position within the stratigraphic sequence illustrated on page 30, as Deccan eruption rates varied through time. Earlier, smaller lava flows are thought to have mostly erupted in the northern portion of the Deccan expanse mapped on page 27. Shaded portions of the geomagnetic timescale, such as chron 30n (C30n), denote times when Earth's magnetic field had a "normal" orientation, as it does today; unshaded portions denote times when the field had a "reverse" orientation.

Credit: K. Cantner, AGI

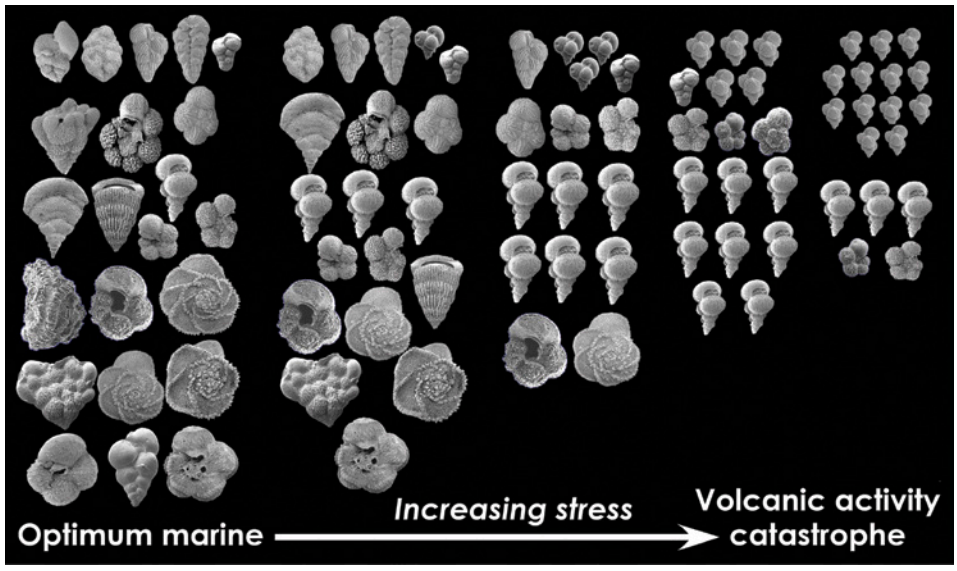
Blair Schoene studies a section of Deccan basalt in India in 2013.

Credit: Kyle Samperton

flowering plants giving way amid environmental stress to hardier spore-forming fungi.

Overall, Adatte says, "sediments before the K-T boundary show a decreasing diversity in a lot of species," including not just land plants and plankton but mollusks like ammonites and rudists too — and, of course, dinosaurs. With the new geochronology from the zircon study, "we clearly see that there is a huge coincidence between the maximum activity of the Deccan Traps and the K-T boundary," he says. "This may explain the decrease in biodiversity that you can see slightly before [the K-T boundary], and it also may explain the main part of the extinction."

The biostratigraphic data from India confirm that the main K-Pg extinction occurred while Deccan volcanism was ongoing, but gauging the Traps' possible role in the extinction is still complicated. For one thing, volumes of different Deccan eruptive episodes are still only roughly known, with estimates based mainly on the stratigraphic thicknesses of lava flows in a few well-studied parts of India and on assumptions about the original extents of the flows. Although it's clear that some formations are larger than others, the volume estimates come with big uncertainties. Yet, those eruptive volumes are "what you really want to know if you want to understand whether the basalts played an important role in the extinction," Schoene says. If, for example, 90 percent of Deccan lavas were erupted leading up to the boundary, he notes, "that would [suggest] a much different interpretation than if



Paleontological analyses of sediments that accumulated between Deccan lava flows in India during quiescent periods in the volcanism have suggested that the diversity of planktic foraminifera declined progressively, possibly as a result of environmental changes wrought by the volcanism.
Credit: Gerta Keller

90 percent erupted after the boundary." Additionally, he says, with recent improvements in the dating of the impact and extinction from other sites around the world, "where exactly that date sits within the package of basalts is not known yet."

The improved resolution of the timing of the Chicxulub impact came in a 2013 study in Science led by Paul Renne of the Berkeley Geochronology Center in California. Using an updated argon-argon dating methodology, he and his colleagues pegged it at 66.04 million years ago, roughly half a million years earlier than the prior estimates. By comparing this date, obtained from analysis of a thin coal layer in Montana's Hell Creek area — a layer associated with both the Chicxulub iridium anomaly and ecosystem turnover at the K-Pg boundary — with dates obtained for impact tektites found in Haiti, the researchers also concluded that the impact and K-Pg extinction were effectively synchronous. The work showed that both "the main pulse of extinctions and far-field impact signals — like the iridium anomaly, the shocked quartz and

Paul Renne samples volcanic ash from a thin coal bed in the Hell Creek Formation of northeastern Montana. Based on analyses of these and other samples, Renne and his colleagues concluded that the Chicxulub impact and K-Pg mass extinction were synchronous.
Credit: Courtney Sprain

other indicators — were in fact related to the Chicxulub structure," Renne says.

But neither a clear iridium spike nor layers of tektites or shocked quartz have been found in the Deccan Traps. The iridium anomaly is really the "golden spike" that everyone would love to find in the Deccan, Widdowson says. "If you could do that, it would solve a lot of problems because you could then use that as a datum against which we could pin all of these events, and also the changes of biota and extinctions."

Although an impact-related iridium anomaly in the Deccan might be found in the future, both Renne and Widdowson say it would take a lot of looking and a fair bit of luck. In the meantime, instead of going after the golden spike, researchers are trying to home in on the K-Pg boundary's position by continuing to fill out the Deccan timeline in more detail.

Key Evidence: The K-Pg Boundary in the Deccan

The main sequence of Deccan volcanism has long been divided, based on differences in geochemistry, into three subgroups called the Kalsubai (earliest), Lonavala and Wai (latest), each of which is composed of multiple formations and numerous individual flows. The most expansive flows — and some of the thickest — found on the subcontinent compose the Wai subgroup, suggesting it's the single largest contributor to the Deccan's total lava volume. In past work, researchers have postulated that the K-Pg boundary lies somewhere in the Wai, citing clues such as the increasing frequency of red boles between lava flows (indicative of a large-scale shift in the pattern of eruptions), or biostratigraphic changes seen, for instance, in the Rajahmundry Traps.

Renne examines a red bole, which formed during a prolonged period of weathering between successive Deccan eruptions.
Credit: Mark Richards, UC Berkeley

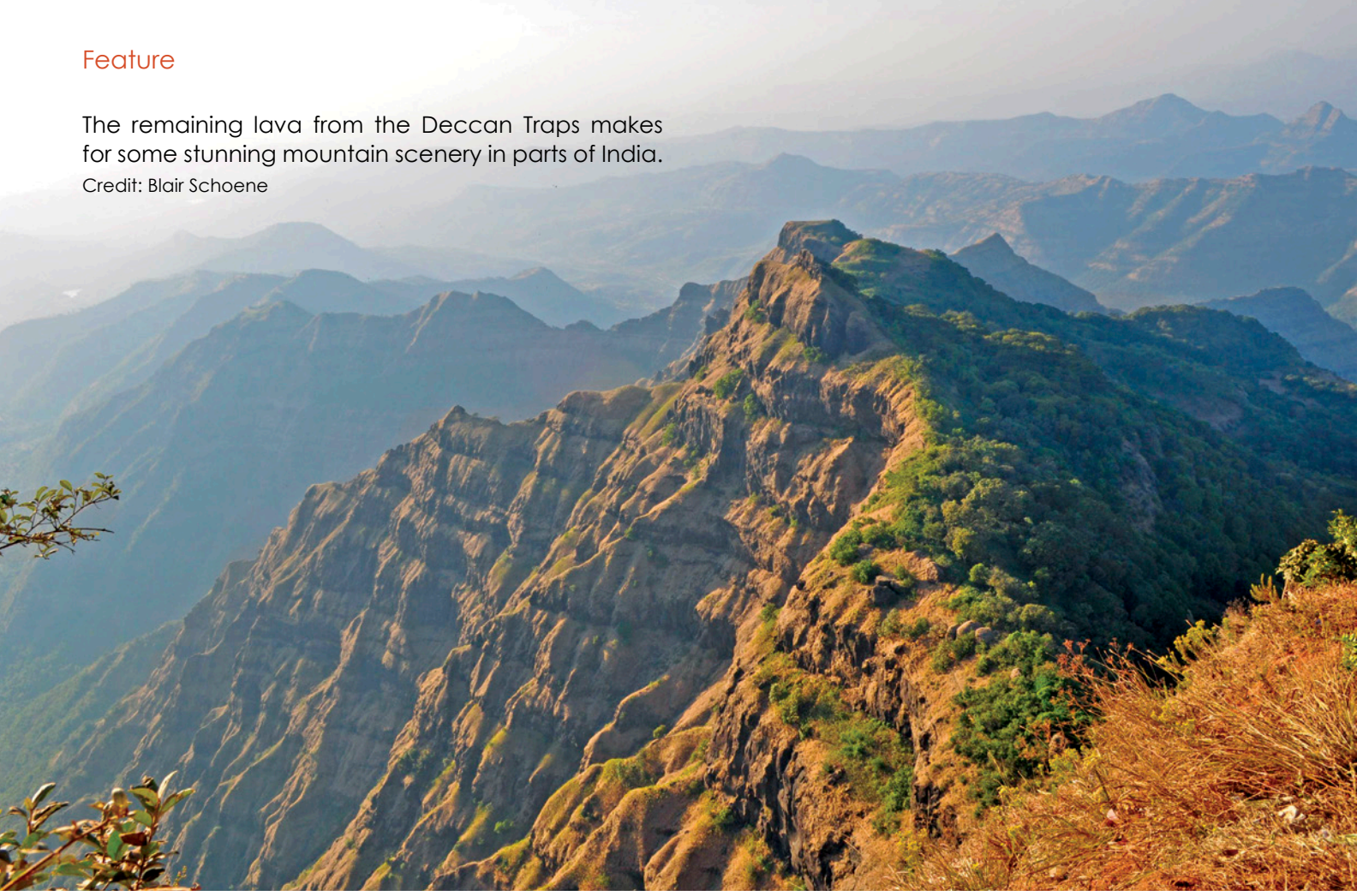
Adatte and fellow team members dig into a hillside in India to expose Deccan sediments.
Credit: Gerta Keller

"But only recently have we started to bring in high-precision geochronology tools on the question of the pace and history of volcanism," Richards says. The zircon study from Schoene's team was one of the first such efforts. Their dates are the most precise of any published so far, but "they are, for the most part, dates that are well before and well after where we think the actual K-Pg boundary is within the Deccan lavas," Richards says. "They kind of squeeze things down a little bit, but they still leave several hundred thousand years of uncertainty about exactly what happened in this critical period when we think that the lava flows became much more voluminous."

In hopes of adding some needed data points to the timeline, Renne, Richards and several colleagues ventured to India in 2014 to collect feldspar crystals from the lavas that they could analyze using the same improved argon-argon technique that produced Renne's updated age for the impact and the K-Pg boundary. The resulting dates from their samples — pulled mostly from the Kalsubai subgroup as well as one from high up in the Wai — jibe with Schoene's group's data, Renne says. And while they still all fall before (for the Kalsubai samples) or after (for the Wai sample) the 66-million-year-old date for the boundary, he says, "we've been able to … nail down much more closely where in that [main lava] sequence the K-T boundary would be."

In a study in Science published in October 2015, Renne and his colleagues reported that the boundary must lie either in the Lonavala subgroup or in the bottom half of the Wai. Interpolation of the data across the remaining gap in the geochronological dataset, combined with their own updated estimates of the lava formation volumes, suggested the boundary may lie at the transition between the two subgroups, and that this transition probably occurred within about 50,000 years after the Chicxulub impact. "It's looking increasingly probable that that transition was exactly coincident with the K-T boundary and the Chicxulub impact," Renne says.

If that's the case, it opens the door to the possibility that the impact might have actually kicked the ongoing volcanism into high gear and implies that the majority of Deccan lavas, composing the voluminous Wai subgroup, weren't erupted until after the impact and the K-Pg boundary — a hypothesis Richards, Renne and others first laid out in a 2015 study in the Geological Society of America Bulletin. In that study, the researchers noted that large earthquakes are known to trigger volcanic activity at times. Thus, they suggested, the dramatic shifts seen in various geochemical and structural traits of lava flows from one side of the Lonavala-Wai boundary to the other, along with obvious changes in the size, rate and pacing of eruptions, could have been



The remaining lava from the Deccan Traps makes for some stunning mountain scenery in parts of India.
Credit: Blair Schoene

triggered by the impact, which would have jolted the planet with seismic energy possibly equivalent to a magnitude-11 earthquake.

"It's an interesting idea," Schoene says. "If it turns out that we see a big pulse of volcanism right at the impact, that's going to be really fascinating." But until the geochronology is tighter, he says, "I don't think … we can really say whether that model is true or not."

The timing of the boundary in the Deccan Traps "is better constrained than it was," Renne says, but he agrees that the existing data still leave room for other interpretations. "That's exactly why we still need to constrain the ages" even more.

Co-conspirators?

In addition to continuing to improve the geochronology and volume estimates of the Deccan lavas relative to the K-Pg boundary and the impact, there is plenty of other work left to be done in the effort to understand what happened — and why — during the mass extinction. Fleshing out the global picture of when different plants and animals went extinct with more paleontological data is very important, Schoene says. Additionally, although rough estimates of the amounts of gases and aerosols emitted by both the impact and volcanism have been made, getting a better handle on these emissions for use in paleoclimate models is key. Ultimately, these emissions — and not the impact or eruptions themselves — are the drivers of the complex mix of environmental changes and feedbacks that likely did in so many species.

Regarding the quarter-century debate over whether the Chicxulub impact or Deccan volcanism caused the K-Pg extinction, "as the evidence mounts, it becomes more convincing that both could've played a role," Schoene says. "We know both things happened and that both are potentially devastating," he says.

It's an increasingly popular point of view.

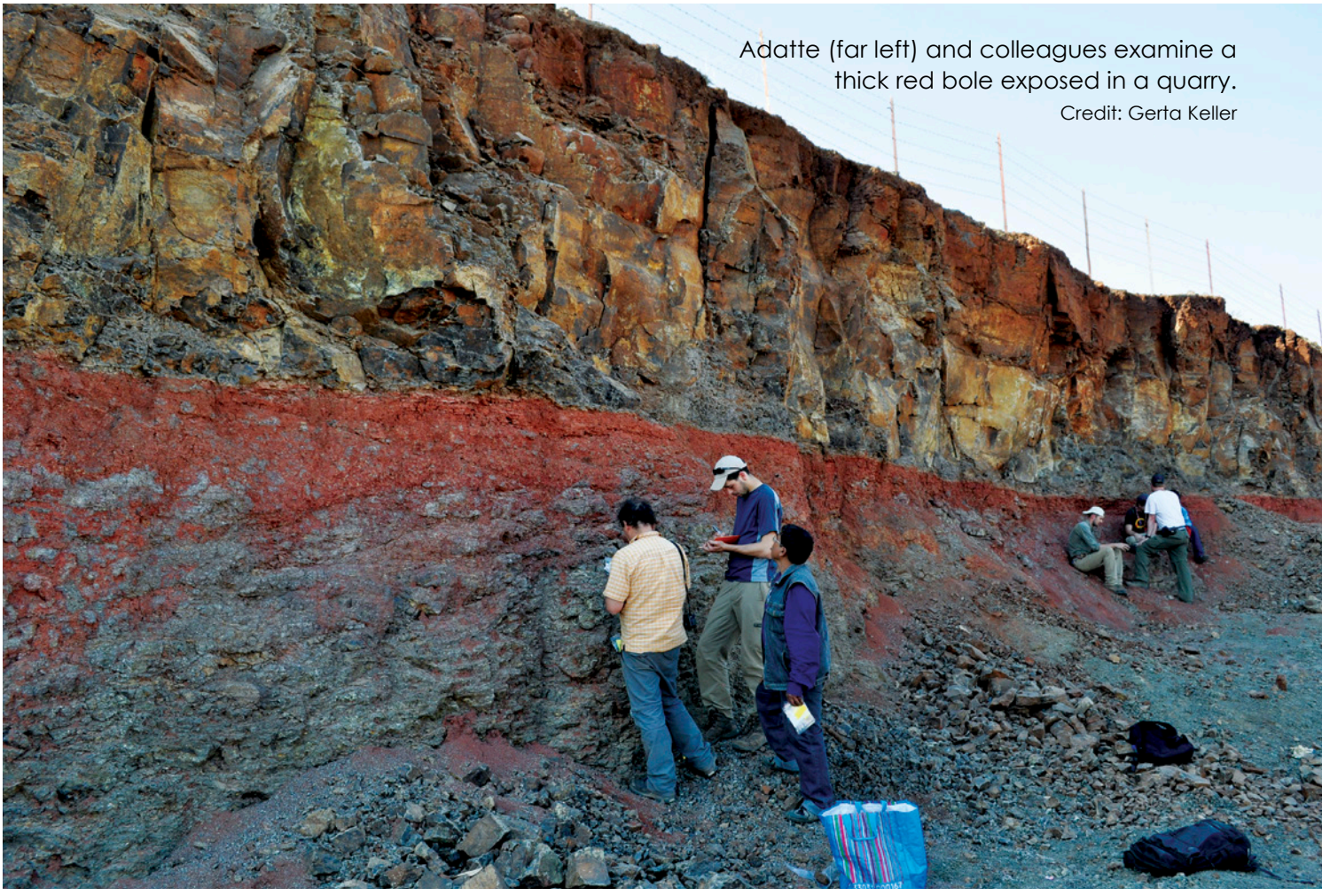
"If our results are telling us anything, it's that we can't look at the impact and the acceleration of volcanism as individual unrelated things," Renne says. "They're closely related in time and their effects probably cannot be totally disentangled." For example, he notes, it took about 500,000 years after the extinction "for marine communities to begin to recover in a meaningful way," which is also how long the main phase of Deccan volcanism lasted after the impact. So, it's possible "that the volcanism, once it was really boosted, suppressed the recovery [of marine life] until it began to wane."

On the hunt for zircons that can be radiometrically dated, Schoene (left) and Mike Eddy of MIT collect material for later analysis.
Credit: Kyle Samperton

There is still no unanimity of opinion among scientists studying the K-Pg. But a "growing body" of researchers has taken up a pragmatic middle ground, Widdowson says, acknowledging that both events likely contributed to the extinctions and suppressed the recovery of life to some extent. Whether the blame can actually be parsed between the two events — "50-50, 80-20 or whatever" — is difficult to say, he says.

"I think everyone is trying their best to understand what is perhaps a more interesting scenario than any of us had imagined," Richards says. "Nature seems to have thrown a real curveball at us on this one, and it has taken a long time to get close to figuring it out. So it's pretty exciting."

Oleson is the news editor at EARTH.



Adatte (far left) and colleagues examine a thick red bole exposed in a quarry.
Credit: Gerta Keller

A market in Delhi, India.
Credit: Christian Haugen, CC BY 2.0

HOW TO FEED 11 BILLION PEOPLE

Addressing the 21st Century's Biggest Challenge

Terri Cook

In April 2008, violent protests erupted across the impoverished Caribbean nation of Haiti. Enraged by soaring food prices and all-too-frequent hunger pangs, protesters smashed windows, looted shops, barricaded streets with blazing cars and stormed the presidential palace in the capital, Port-au-Prince. The week of violence, during which five people were killed, flared after the cost of staples like beans and cooking oil spiked dramatically and the price of rice nearly doubled in four months, increasing hardships in a nation where 80 percent of the population survives on less than $2 per day.

So-called "food riots" aren't restricted to the Caribbean. Between 2006 and 2008, as the cost of food, fuel oil and other commodities surged to levels not experienced in almost three decades, disturbances erupted around the planet. Large — and frequently violent — protests broke out in Latin America, Asia, the Middle East and Africa.

Although many factors, like high unemployment, political frustration and poverty, contribute to social unrest, the timing of the 2007–2008 turbulence correlated clearly with peaks in global food prices. According to a study published in 2011 by the New England Complex Systems Institute, when the United Nations Food and Agriculture Organization's (FAO) Food Price Index rose above 180, food riots occurred in 30 countries. When the index decreased later that year, social unrest also declined.

In the past, price spikes like these have usually been short-lived, wrote Joel Bourne Jr. in his 2015 book, "The End of Plenty." Things typically evened out quickly as global trade shifted grain from countries with surpluses to those with deficits, and farmers responded to higher prices by increasing planting. But in 2007–2008, the world's grain harvests were close to record-setting levels. Unlike in the past, Bourne wrote, this time the increased prices — and the ensuing violence — were due to the fact that the world was running out of food.

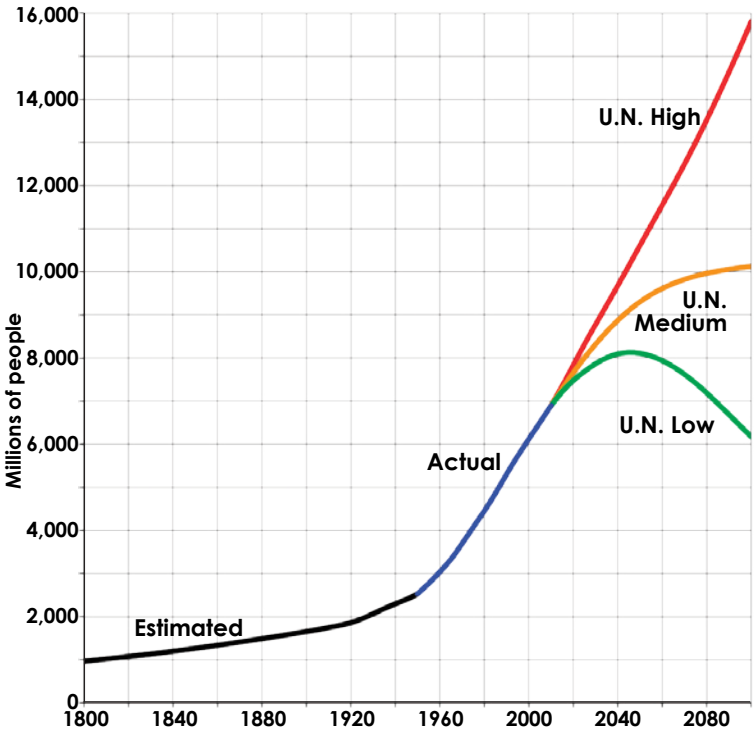
Feeding the world today is a daunting challenge; in the future, as global population skyrockets, it is likely to be a Herculean task. But researchers around the world are working on the problem, including how to implement the many changes that must happen locally at the farm level to effect large-scale change. But first, farmers need information. And that's where science comes in.

A Herculean Task

Last summer, the planet's population reached 7.3 billion. Of these, 795 million people lack enough food to lead healthy, active lifestyles, according to the United Nations World Food Program. In addition, more than 2 billion people currently suffer from "hidden hunger" — deficiencies in micronutrients such as iodine, vitamin A and iron — that can lead to blindness, stunted growth and restricted cognitive development.

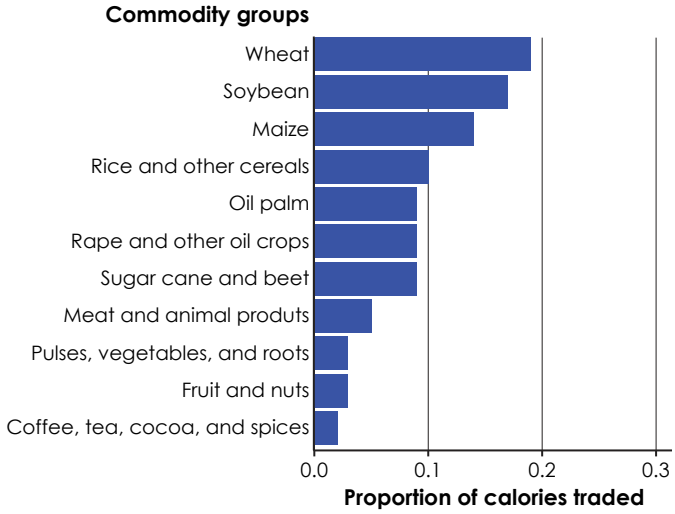
The world's population is projected to reach 8.5 billion by 2030, 9.7 billion by 2050 and 11 billion by 2100, according to the United Nations World Population Prospects report released last July. Unlike previous estimates, which generally agreed that the planet's population would peak at 9 billion to 9.5 billion people in about 2070, a statistical analysis published in 2014 in Science concluded that the planet's population is unlikely to stabilize this century. There is now an 80 percent chance, the authors reported, that, by 2100, the planet will host between 9.6 billion and 12.3 billion people.

These numbers add up to roughly 75 million more mouths to feed each year. Add to that the increasing demand for grain from livestock to feed increasingly meat- and dairy-rich diets, as well as from biofuels, particularly in the U.S. and Europe, and all told, the FAO estimates that by 2050, the global food demand will rise more than 60 percent above 2005 levels. Other estimates suggest that number may be as high as 110 percent, says Deepak Ray, a senior scientist at the University of Minnesota's Institute on the Environment.



World population estimates from 1800 to 2100, based on high, medium and low United Nations projections in 2010 (red, orange and green), U.S. Census Bureau historical estimates (black), and recorded population figures as of 2010 (blue). Statistical analysis suggests an 80 percent chance that by 2100, the population will be between 9.6 billion and 12.3 billion people.

Credit: Tga.D based on Aetheling's work, UN Data, CC BY-SA 3.0



Although family farms or smallholder farms make up the bulk of agriculture worldwide, much agricultural production is still traded across international borders. This graph shows the breakdown of global agricultural trade in terms of calories — for example, wheat makes up 20 percent of the total calories that are traded internationally. The graph incorporates commodities from 139 different crops and 10 livestock animals, sorted into 11 commodity groupings.

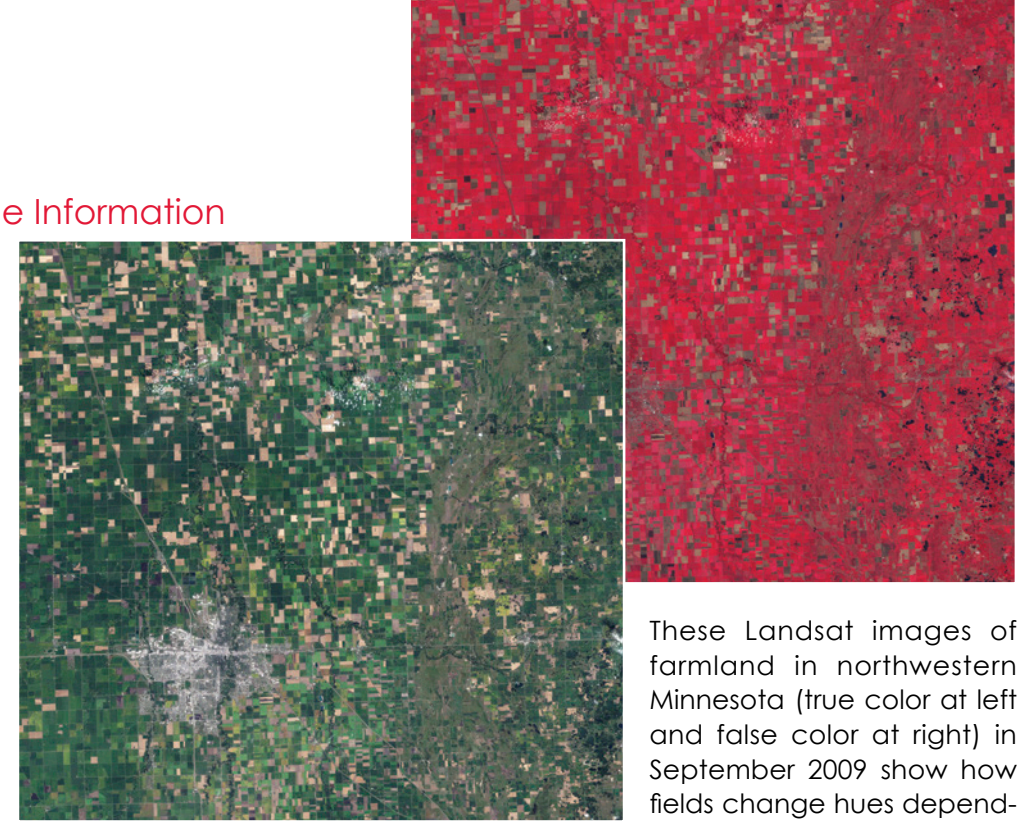
Credit: K. Cantner, AGI, after MacDonald et al., Bioscience, 2015

Rapidly increasing productivity is a big challenge, which will only be made more challenging by a changing climate that could bring increasing temperatures, changing precipitation patterns, rising water levels along coasts, and larger and more frequent extreme-weather events, according to a report issued last August by the joint U.S.-U.K. Taskforce on Extreme Weather and Global Food System Resilience.

A 2012 study by the Consultative Group for International Agricultural Research found the global food system contributes nearly one-third of anthropogenic greenhouse gas emissions. As a driving force behind climate change, it creates a vicious cycle that will be difficult to break. Compounding these issues is the fact that agricultural production also impacts the environment through loss of biodiversity, degradation of soils, and pollution and use of sparse freshwater resources. How we meet the planet's growing demand for food, while simultaneously mitigating agriculture's environmental impacts, will be one of the 21st century's greatest challenges.

Gathering Global-Scale Information

Fortunately, the number of tools and technologies available to help humanity tackle this challenge is increasing. In 1999, Navin Ramankutty, now an agricultural geographer at the University of British Columbia in Vancouver, fused satellite data with census reports, creating the first realistic global maps of agriculture. Since then, Ray says, scientists and managers have had access to increasingly detailed geospatial datasets like global crop yields and harvest frequencies, and insights from these data have transformed the field. "They revolutionized agronomy," he says.

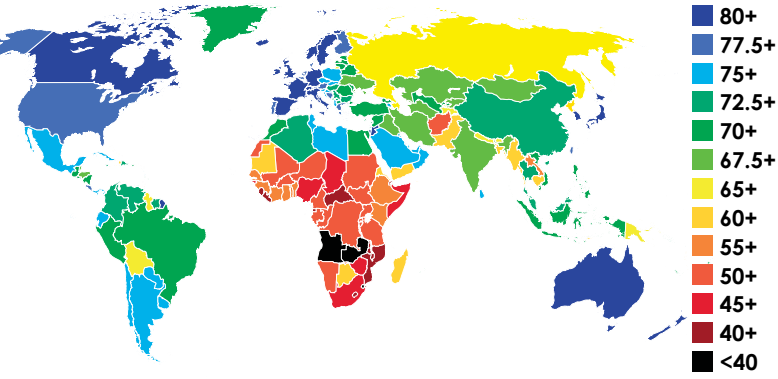


These Landsat images of farmland in northwestern Minnesota (true color at left and false color at right) in September 2009 show how fields change hues depending on crop conditions. The true-color image shows that most fields are doing well; brown squares are fields that either have been harvested already or are damaged. The false-color image provides further information: Farmers are trained to see yellows where crops are infested, shades of red indicating crop health, black where flooding occurs, and brown where unwanted pesticides land on chemical-free crops.

Credit: both: NASA Earth Observatory, Jesse Allen

Since the launch of the Landsat program in 1972, remote sensing has played an integral role in agricultural mapping and monitoring. And the rapid improvements in Earth observation technologies in recent decades have offered opportunities to boost agricultural productivity and address critical issues in the world food system.

One of the leaders in this realm is the Group on Earth Observations (GEO), a voluntary partnership of governments and international organizations working to integrate Earth observations into resources that can guide policy decisions. In 2011, the Group of Twenty Agriculture Ministers tasked GEO with using remote sensing tools to strengthen agricultural monitoring. The goal of the resulting GLobal Agricultural Monitoring initiative (GEOGLAM) is to improve the international community's capacity to both generate and disseminate timely, accurate forecasts of agricultural production at regional to global scales.



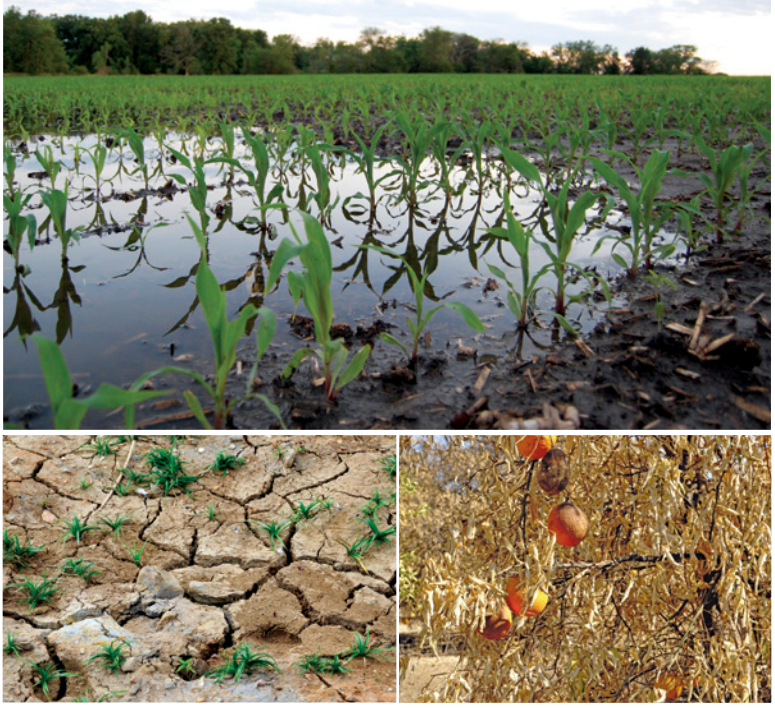
In 2012, the average global life expectancy was 70.5 years, according to the World Health Organization. This 2012 map shows average life expectancy by country. Increasing life expectancy adds to the number of mouths to feed.

Credit: Fobos92, CC BY-SA 3.0

One GEOGLAM partner is CropWatch, a program sponsored by the Chinese Academy of Sciences that relies heavily on remote sensing data to monitor global crop production. CropWatch issues quarterly bulletins that report global agroclimatic conditions as well as the status of major producers of maize, wheat, rice and soybeans — the "big four" crops that provide about 80 percent of all calories consumed by humans.

A 2013 review of CropWatch's remote sensing products in the International Journal of Digital Earth found its estimates of crop conditions and acreage, and its predictions of crop yields and food production, to be highly accurate. Such data can offer early warnings of potential shortages so that timely interventions — such as the delivery of food aid — can be planned and implemented.

Ray and other researchers are also working on global production numbers. He and his colleagues have developed an extensive crop statistics database filled with satellite data that they use to analyze how crop yields are changing. Specifically, they're interested in whether or not the world is on track to double global food production by 2050 to meet the projected



Satellite data can indicate months ahead of time if a crop is likely to fail due to drought, pests, floods or other hazards. Advance knowledge of food shortages allows for timely interventions, such as the delivery of food aid as shown above in Ethiopia.

Credit: clockwise from top left: Sonya Green, CC BY 2.0; Tony Hall, CC BY-NC-ND 2.0; USDA photo by Cynthia Mendoza; Neil Palmer, CIAT, CC BY-SA 2.0

demands without clearing additional land, which has widely acknowledged drawbacks due to greenhouse gas emissions and loss of biodiversity. How the productivity of the big four crops is increasing on existing agricultural land will determine whether we can meet these growing demands.

In a 2013 analysis in PLOS One, Ray and his team concluded that most recent yields of the four major crops are increasing at 0.9 to 1.6 percent per year — nowhere near the annual rate of 2.4 percent necessary to double production by 2050. At current rates, only about a 38 percent increase in wheat, a 42 percent increase in rice, a 55 percent increase in soybeans and a 67 percent increase in maize production will be possible by 2050.

The situation, Ray says, is that "most of the lands that could potentially be brought under crop cultivation have already been brought into production."

If increasing crop yields and expanding the area under cultivation aren't possible or desirable, a third strategy is to increase the frequency of harvests on existing croplands, wrote Ray and ecologist Jonathan Foley, now executive director of the California Academy of Sciences, in a 2013 study in Environmental Research Letters. This could be accomplished by planting multiple crops per year, reducing crop failure and leaving less land fallow.

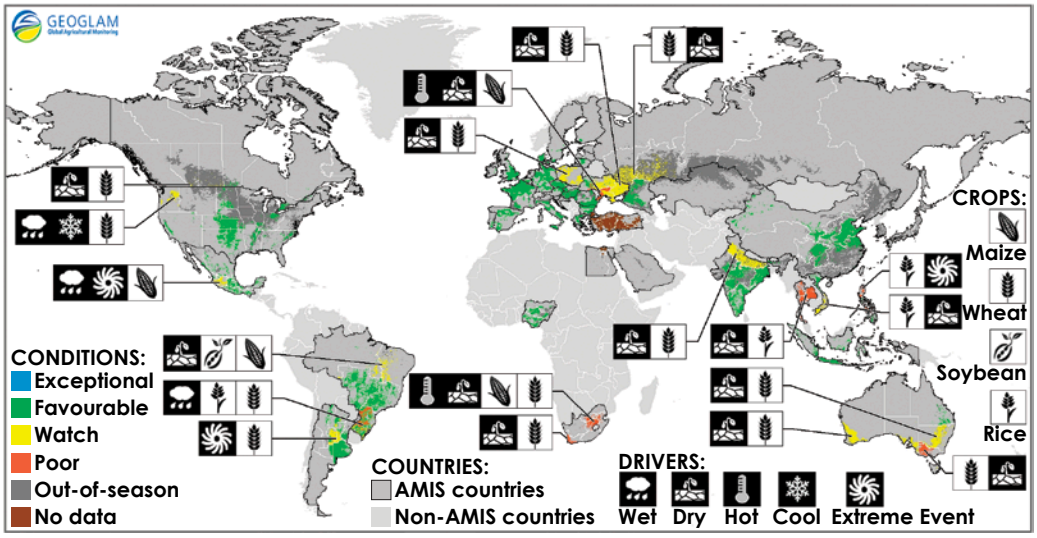
By analyzing a global compilation of agricultural statistics, Ray and Foley uncovered significant differences in the frequency of cropland harvests in countries around the planet. Between 2000 and 2011, 19 countries in Europe, Latin America, Asia and Africa were statistically "unable to harvest their standing cropland even once every two years." In other words, on average, farmers in these 19 nations failed to harvest even half of their crops each year. This was most likely due to crop failure caused by factors such as drought, lack of rainfall at the right times, catastrophic storms and pests. The researchers also identified a larger number of nations that are harvesting their croplands less than once, on average, per year, as well as numerous countries in the tropics which, despite the more favorable climate, are not meeting their potential of two or three harvests per year.

By calculating the maximum potential number of harvests in each country and comparing this with what's actually happening, Ray and Foley identified "harvest gaps." Such gaps "show the potential to grow more food on the same piece of land if conditions become more suitable." Africa has the largest concentration of harvest gaps, followed by Asia and Latin America. Closing these gaps could boost agricultural production by nearly 50 percent above 2010–2011 levels, at least over the short term, although the researchers warned that increasing the frequency of harvests could also lead to the "long-term deterioration of soil, water resources and the agricultural land base." Closing the gaps in a sustainable way may not be easy, Ray says, given that modern industrial-scale agriculture currently relies heavily on the use of chemical fertilizers and pesticides.

Modeling the Future

Scientists aren't just modeling current production, but also how future agricultural production might be affected by the effects of a changing climate — increasing temperatures, variations in precipitation patterns, rising carbon dioxide concentrations, and increasing air pollution.

In 2009, NASA researchers Chris Funk and Molly Brown modeled the convergence of three trends — changes in climate, changes in agricultural production and population increases — and used the results to simulate the impacts on global cereal availability through 2030. The researchers concluded that by that time, global per capita cereal production will be about 327 kilograms, down from a peak of 372 kilograms in 1986. The



This GEOGLAM map from August 2015 shows crop conditions over the main growing areas for wheat, maize, rice and soybeans. Areas with crops that are in less than favorable condition are displayed on the map with the specific crops affected and the key climatic drivers affecting crop conditions.

Credit: GEOGLAM, www.geoglam-crop-monitor.org

projected decrease in per capita production could re-expose millions of people in Asia to chronic undernourishment. Even harder hit, however, would be eastern and central Africa, with their rapidly increasing populations and already low per capita cereal production levels. Without a "concerted effort," the researchers noted, international food security will continue to erode, and much of the planet "will experience significant reductions in food availability as consumption demands increase."

In a warming world, modeling efforts like this provide critical input for formulating new regulations and policies at regional, national and international levels. Germany, for example, implemented a series of climate laws in 2007, one of which was an ordinance that ensures sustainability standards for biofuel production. The United Nations, meanwhile, suggests that changing regulations for mitigating pollution from ozone — whose formation strongly correlates with temperature — is an important strategy for safeguarding food production.

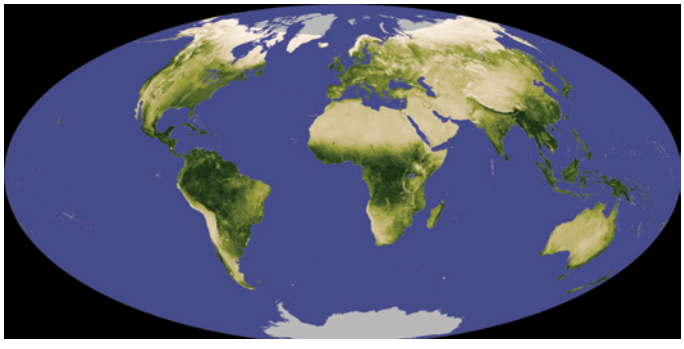
To understand how ozone affects the production of the planet's major crops, a team led by Amos Tai, now an associate professor at the Chinese University of Hong Kong, modeled the individual and combined effects of mean temperature and ozone pollution trends from 2000 to 2050 on the production of the four major crops.

In a 2014 Nature Climate Change study, the researchers estimated that the combined effects could reduce global crop production by more than 10 percent by 2050. They also found that wheat and rice production is generally more sensitive to ozone than maize or soybeans. Depending upon the modeled pollution scenario, the study predicts declines in wheat production of 50 to 60 percent by 2050 in southern Asia, and rice production decreases of up to 5 percent in both southern Asia and China.

Much work also needs to be done to understand the uncertainties inherent in models used to assess environmental and economic impacts, wrote John Ingram and co-authors in their 2010 book, "Food Security and Global Environmental Change." "A major limitation of most models," they wrote, "is that they may address only individual components of the food system and thus are unable to analyze the interactive effects and feedbacks among components."

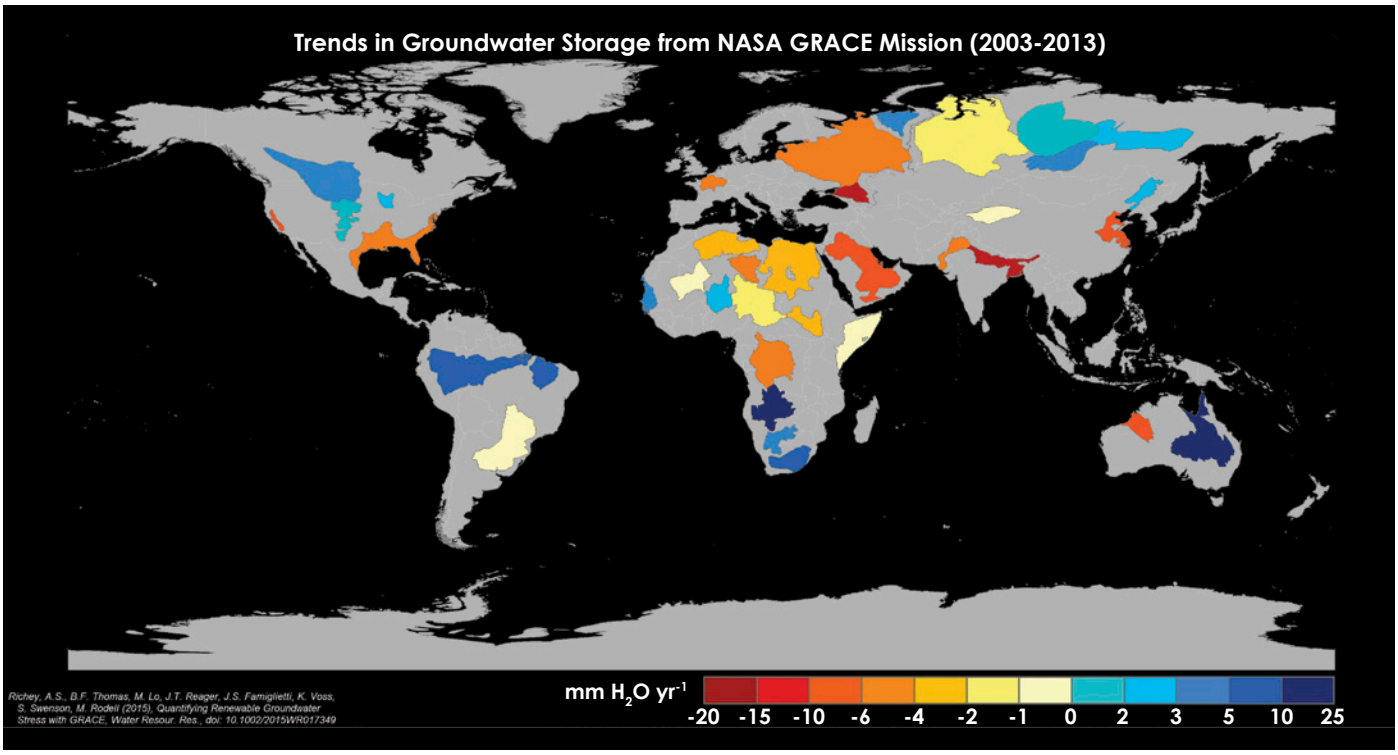
To make modeling assessments more reliable, a major interdisciplinary initiative, Agricultural Model Intercomparison and Improvement Project, led by Cynthia Rosenzweig, a senior research scientist at the NASA Goddard Institute for Space Studies in New York, is working to improve projections of the impacts of climate change on the agricultural sector, with the goal of increasing the ability of all nations to adapt to this change, the researchers say.

The project has organized teams of scientists to improve predictions of agricultural productivity in response to such factors as high temperatures, elevated carbon dioxide concentrations, and limited water resources. Similar teams, organized by model type, crop type and region, are working to improve and integrate environmental and food system models to better understand the relative importance of each of these factors.



Scientists use the Normalized Difference Vegetation Index, shown here from Nov. 1, 2007, to Dec. 1, 2007, to monitor how green different parts of the planet are and to assess how that greenness changes over time due to drought, floods, pests or other influences.

Credit: NASA images produced by Reto Stockli and Jesse Allen, using data provided by the MODIS Land Science Team



Twenty-one of Earth's 37 largest aquifers have exceeded sustainability tipping points and are being depleted, with 13 considered significantly distressed. This situation threatens regional water security and resilience, according to a study using NASA GRACE data from 2003 to 2013.
Credit: UC Irvine/NASA/JPL-Caltech

Amazing GRACE

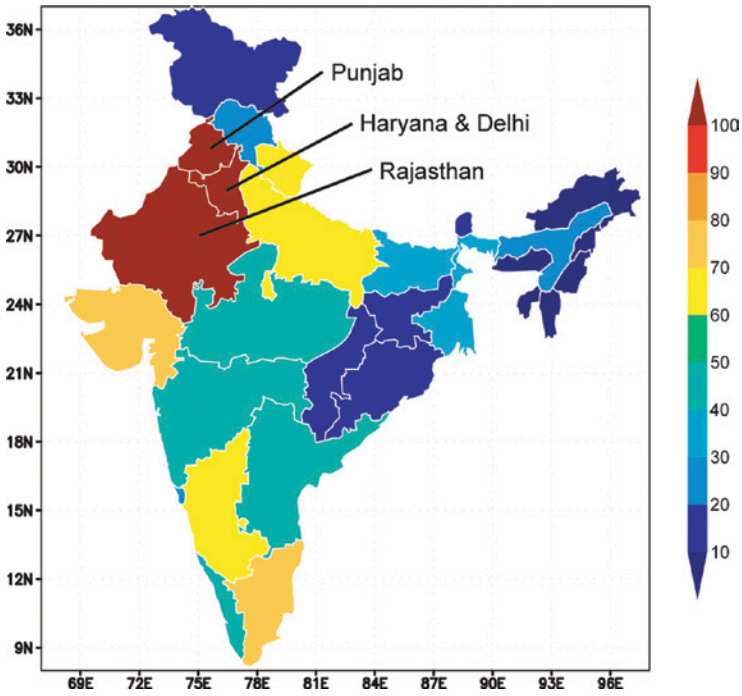
Water is certainly going to be a limiting factor — if not the limiting factor — for feeding 11 billion people. Until recently, agricultural paradigms have focused primarily on improving agricultural production, often to the detriment of the environment, wrote a team led by Foley in a 2011 Nature paper. Unsustainable water withdrawals, particularly in regions with competing water demands, are one of many factors affecting food security, especially given that at least half of the irrigation water used to grow the world's food is supplied by groundwater, wrote Jay Famiglietti, a professor of earth systems science and civil and environmental engineering at the University of California at Irvine, in a 2014 Nature Climate Change commentary.

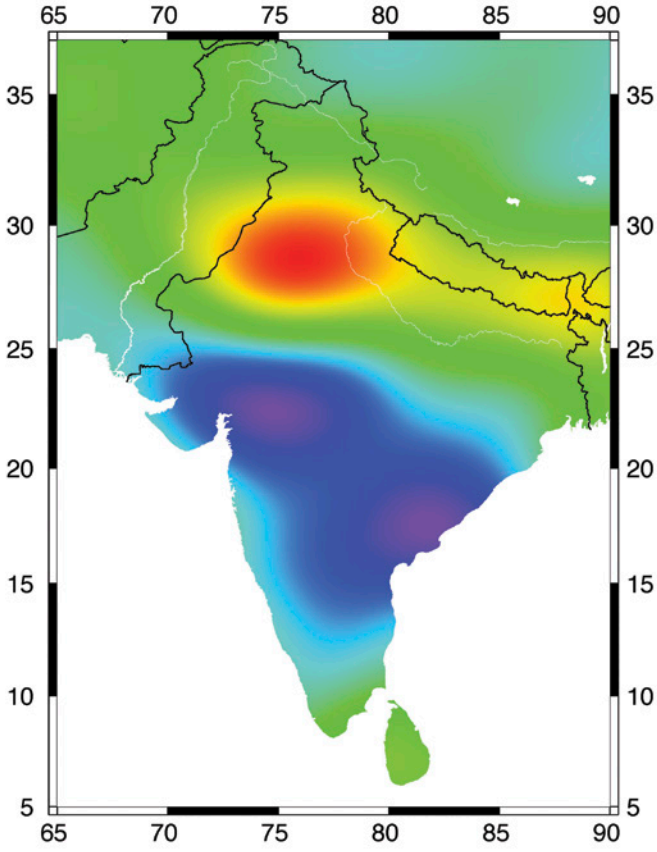
Around the planet, groundwater is being extracted at much greater rates than it's being naturally replenished, and many of the world's largest aquifers — almost all of which underlie and are largely responsible for enormously productive agricultural regions — are being unsustainably pumped. To meet the planet's growing demand for food, groundwater needs to be more carefully managed, especially in crucial agricultural areas, Famiglietti wrote.

In recent years, NASA's Gravity Recovery and Climate Experiment (GRACE) has become a critical tool for monitoring agricultural groundwater withdrawals. The mission's twin satellites make detailed measurements of Earth's gravity field, which allow scientists to calculate changes in the mass of terrestrial water storage, including groundwater, soil moisture and snow, at regional to continental scales. GRACE is providing unprecedented data about groundwater depletion, which are helping scientists anticipate future food security issues around the planet.

In northwestern India, for example, there has been indirect evidence for years of severe groundwater depletion in the "breadbasket" states of Haryana, Punjab and Rajasthan. In 2009, a group of scientists, led by Matthew Rodell, chief of the Hydrological Sciences Laboratory at NASA Goddard Space Flight Center, used GRACE data to confirm that groundwater in the region was being extracted at an average rate of almost 18 cubic kilometers per year from 2002 through 2008. In certain parts of Haryana, local rates of water table decline are as high as 10 meters per year, the researchers reported in Nature.

If measures aren't taken soon to ensure the sustainable use of groundwater in that region, Rodell and his colleagues wrote, the consequences may include shortages of potable water, a reduction of agricultural output and severe socioeconomic stresses. In addition, they noted, competition for limited water resources with neighboring Pakistan, where groundwater is essential for much of the arid nation's agricultural output, is likely to aggravate the already-tense relations between the two countries.





Left: Groundwater withdrawals as a percentage of groundwater recharge, based on state-level estimates of annual withdrawals and recharge reported by India's Ministry of Water Resources. Below: Groundwater volume changes in India from 2002 to 2008, with losses in red and gains in blue, based on NASA GRACE satellite observations. In the "breadbasket" states of northwestern India during this period, groundwater was being extracted at an average rate of almost 18 cubic kilometers per year. Increases in groundwater in southern India are due to above-average rainfall; rainfall in northwestern India was about normal during the study period.

Credit: left: NASA/Matt Rodell; below: I. Velicogna/UC Irvine

Gathering tremendous amounts of global-scale data with advanced agricultural monitoring tools is vital, but farming is still a local endeavor. Somehow, all of that information has to be transferred down to the local farmer, who must be able to use it.

Going Local: Smallscale Changes

Lack of access to information that affects farming practices, such as temperature highs and lows and precipitation records, has historically made it difficult for "smallholder" farmers — family farmers who manage 1 to 10 hectares of land — to make informed decisions regarding how much of which crops they should plant, and when. This is particularly true in sub-Saharan Africa and Asia, where smallholders provide up to 80 percent of local food supplies, according to the FAO. There are an estimated half-billion smallholder farms on the planet.

Farming in India is still primarily done on small family farms, like this one in Tamil Nadu.

Credit: Raj, CC BY 2.0

The recent advent of open data practices, which allow users with Internet access to pull, process and share information from multiple sources, could enable faster and more effective decision-making by on-the-ground smallholders, fostering innovation and offering transparency, according to a 2015 report by the Global Open Data for Agriculture and Nutrition initiative.

About 500 million farms across the world — from Wisconsin to Switzerland to Kenya — are so-called smallholder farms: family farmers managing 1 to 10 hectares of land.

Credit: left to right: Royalbroil, CC BY-SA 2.5; Leiju, CC BY-SA 3.0; McKay Savage, CC BY 2.0

Open data are increasingly being used to underpin mobile phone apps for farmers, who can use them to access critical agricultural information in a timely manner. One example is Plantwise, a program led by the nonprofit Center for Agriculture and Biosciences International that aims to reduce pest- and disease-induced crop losses, which can be as high as 40 percent per year globally. By combining open-access data from a variety of sources into easy-to-search formats, Plantwise has developed a series of tools that help farmers diagnose what is harming their crop, alert them to pest outbreaks and provide access to more than 9,000 fact sheets with information on best practices to prevent crop losses. Within a couple of years, Plantwise has helped more than 2 million smallholder farmers in 33 developing countries.

Plantwise is a program that aims to reduce pest- and disease-induced crop losses by putting technology and big data in the hands of smallholder farmers, such as these in Kenya, to help them diagnose what is harming their crops and prevent crop losses.

Credit: Center for Agriculture and Biosciences International

Another effort using data analysis to help farmers in Colombia pinpointed the reasons for a 17 percent drop in rice yields from 2007 to 2012. After analyzing large datasets from both open and private sources, the nonprofit International Center for Tropical Agriculture (CIAT) helped develop a free agricultural decision-making tool for Colombian rice growers. When their analyses forecast a period of drought, CIAT offered planting advice to any farmer accessing the data, helping the farmers avoid an estimated $3.6 million in potential losses, according to a 2015 report by the Overseas Development Institute. The program is now being expanded to include rice growers in Peru and Nicaragua.

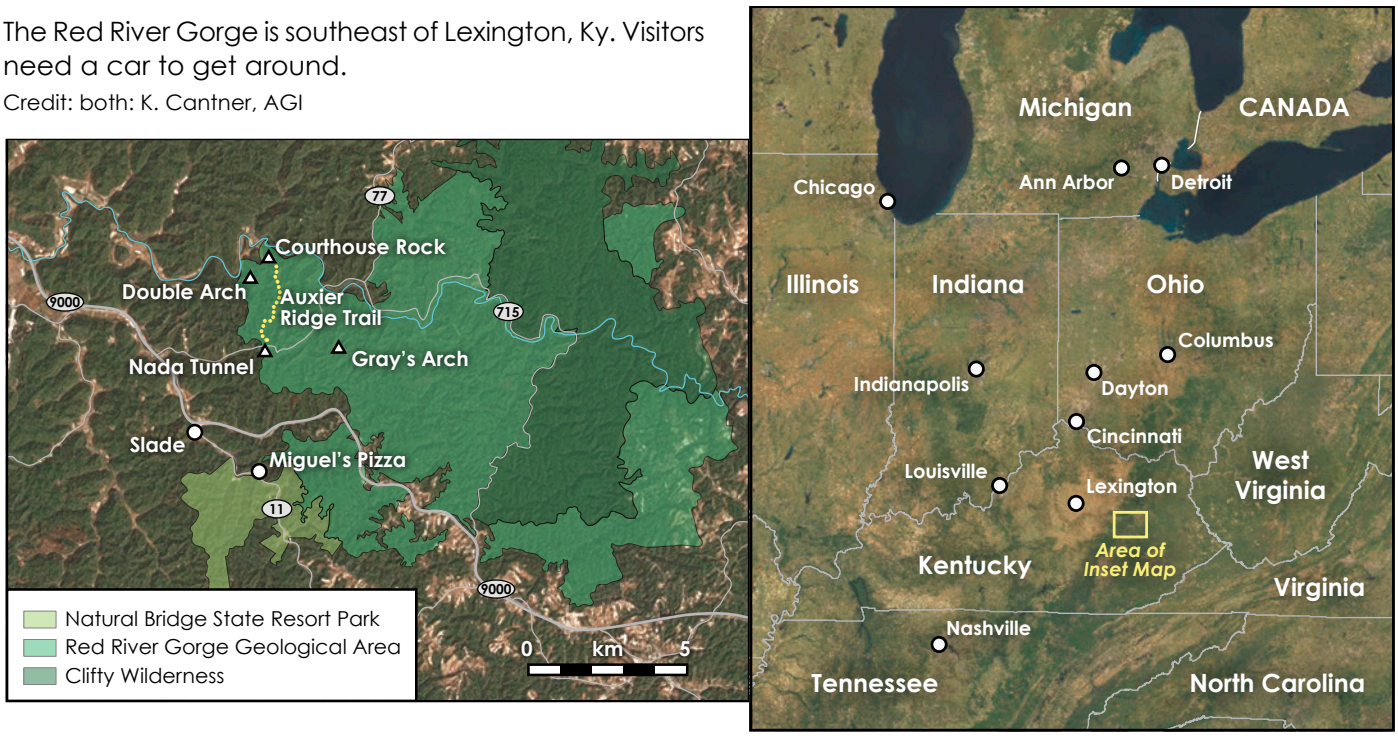
In Central and South America, Africa, India and other regions, billions of people are facing a future of food insecurity and the social unrest that could accompany it. Fortunately, a growing number of tools and technologies have the potential to provide tangible local benefits that will cumulatively allow us to confront these challenges. Increasing crop yields, slight shifts in diet and reductions in food loss and waste can collectively free up enough food to meet most demands, Ray says, although he emphasizes that there are no easy answers. The critical question, he says, is whether we can make these changes faster than the world's hungry population grows.

Based in Boulder, Colo., and trained as a geologist, Cook is a freelance writer whose career has focused on exploring and explaining the history of our amazing planet. She is a roving correspondent for EARTH. Follow her travels at www.down2earthscience.com and @GeoTravelTerri.

A climber hangs from plate-like sandstone protrusions at the Pendergrass-Murray Recreational Preserve.
Credit: Alex Mandrila

Travels in Geology

Rocks and Climbing at Kentucky's RED RIVER GORGE



The Red River Gorge is southeast of Lexington, Ky. Visitors need a car to get around.
Credit: both: K. Cantner, AGI

Lucas Joel

One Friday last June, some friends and I drove five hours from Ann Arbor, Mich., to Kentucky's Red River Gorge, a natural scenic area also called "the Red." By the time we hit Dayton, Ohio, rain clacked against the car windows, and lightning flashed. We continued on, and at about 2 a.m., southeast of Lexington, Ky., we turned onto Highway 11, part of the Red River Gorge Scenic Byway. This 75-kilometer stretch along Highways 11, 715 and 77 loops visitors through the Red River Gorge Geological Area in Daniel Boone National Forest — which features more than 100 natural sandstone arches — as well as Natural Bridge State Resort Park and the Clifty Wilderness.

We continued southeast along the Middle Fork Red River to Miguel's Pizza, housed in a yellow wooden building with fields behind it for camping. There were only a few tents around ours, but in the fall and spring the place can be full. The rain had passed, and thousands of fireflies flickered in the trees.

A view of cliff-forming sandstone strata from Gray's Arch Trail.
Credit: Alex Mandrila

We went to the gorge intending to spend the weekend hiking and rock climbing — the two most popular activities in this natural spectacle — as well as admiring the rocks. The sandstone there is typically coarse, which helps hands grip and shoes stick while climbing. The Early Pennsylvanian sediment (323 million to 315 million years old) that makes up the sandstone eroded from the ancient Appalachian Mountains, which were once maybe as tall as the Himalayas are today.

Thousands of people visit the gorge each year, far less than the number who head to the sandstone arches and red rock gorges of Utah and Arizona. People don't often think of Kentucky as a destination to see these dramatic features. But maybe they should.

Liesegang banding is preserved in the side of a cliff near Gray's Arch.
Credit: Alex Mandrila

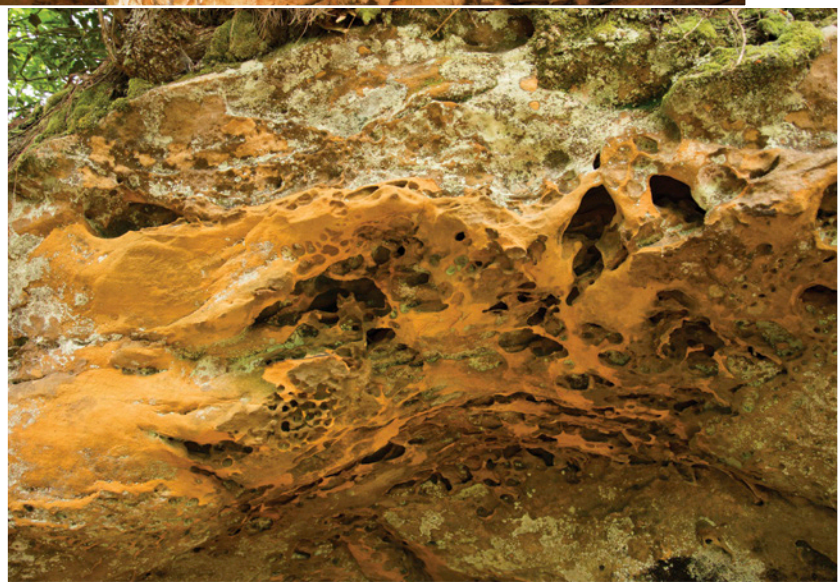
Hiking: Gray's Arch

The Red is heavily forested, and the rocks are often hidden behind trees. The first part of the trail to Gray's Arch, however, follows a ridge from which you can see sandstone cliffs far to the left across a ravine. The strata here, as they are throughout the Red, are horizontal, and the rock is cemented and mostly undeformed. Rock layers are generally massive, and the quartz arenite sandstone can range from fine- to coarse-grained and even conglomeritic. The sandstone is part of the Early Pennsylvanian Corbin Sandstone Member, which, depending on how eroded and incised it is, ranges from 30 to 85 meters thick. The formation often preserves planar and trough crossbedding, and was likely deposited in a braided river system.

Closer to Gray's Arch, more outcrops emerge, some containing pebbles. The rock can be iron-rich and orange to red in places, which is what gives the region's Red River its name. Liesegang banding — swirling bands of iron-rich minerals in rock — is common and can contain hematite and limonite deposits. Before you reach Gray's Arch, you climb down two steep sets of wooden stairs to a gully. Cliffs loom above, and large boulders rest at the bottom amid pink and red dust. One side of one cliff displays extensive, swirling Liesegang bands. The bands are sinuous and protrude from nonbanded portions of the wall.

Far above the boulders is Gray's Arch. As we stood under the arch, we noticed rusty metal bolts hanging on one wall about 6 meters above the ground. These bolts were once used for rock climbing; a climber would clip gear to the bolt, clip a rope to the gear, and climb to the next bolt. Climbing arches is no longer allowed in the Red, though, due to their fragility.

Recent research suggests that sandstone arches, like those in the Red and elsewhere, such as Arches National Park, are stabilized as the surrounding rock erodes. Increased gravitational stress on the remaining sand grains cements and locks them more tightly together. In arches that have collapsed, the sandstone typically disintegrates easily due to the absence of gravity-induced stability.



Iron-oxide-rich sandstone is seen on the way to Gray's Arch.
Credit: Alex Mandrila

Overhung strata cover portions of Gray's Arch Trail.
Credit: Alex Mandrila

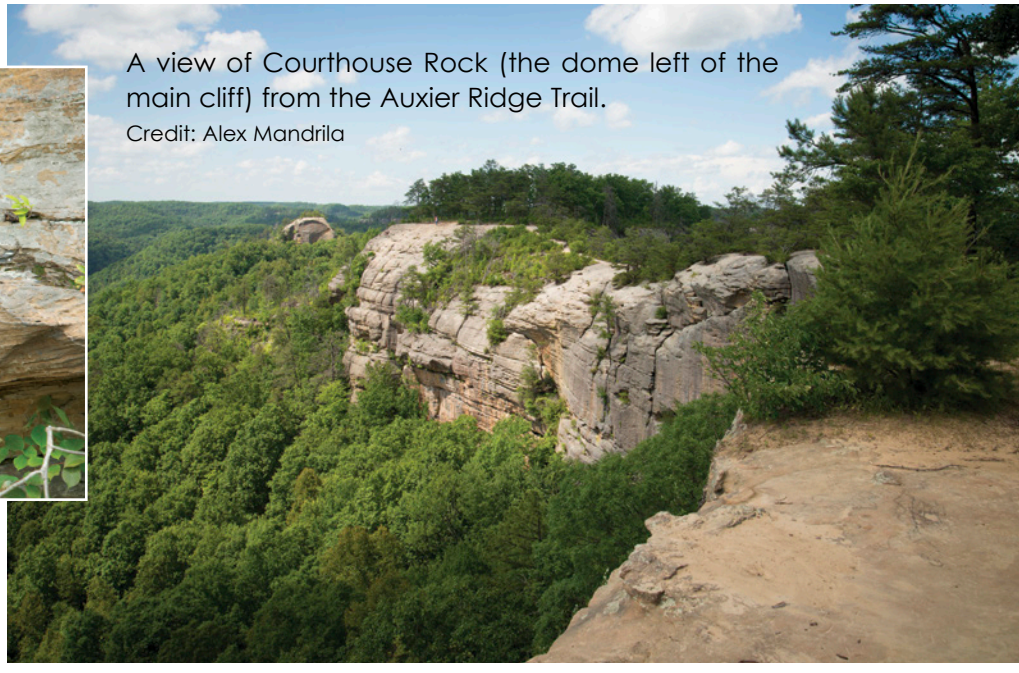
Standing under Gray's Arch.
Credit: Alex Mandrila

Gray's Arch.
Credit: Alex Mandrila

Hiking: Auxier Ridge Trail

The gorges of the Red River Gorge Geological Area began forming after the region uplifted about 600 meters above sea level roughly 285 million years ago during the Permian — a process that formed the Cumberland Plateau from Alabama to western New York — and waterways then cut into preexisting vertical fractures in the Corbin Sandstone.

The Red River continues to incise the local stratigraphy, and today cuts below the Corbin Sandstone and into the Nancy Member, a siltstone and shale layer laid down in the Early and Mid-Mississippian (359 million to 331 million years ago). Its fine-grained character, as well as the presence of the marine trace fossil *Zoophycos*, indicates the Nancy Member was deposited in a low-energy, deep marine setting.



A view of Courthouse Rock (the dome left of the main cliff) from the Auxier Ridge Trail.
Credit: Alex Mandrila

Herringbone cross-stratification is preserved in this outcrop on the Auxier Ridge Trail.
Credit: Alex Mandrila

Erosional features on the cliff face at the Pendergrass-Murray Recreational Preserve make good handholds and anchorages for rock climbers.
Credit: both: Alex Mandrila

The Auxier Ridge Trail, northeast of Gray's Arch, has stunning cliff-top views of a gorge carved by the Auxier Branch of the Red River. The trail has few trees and it can get quite hot in the summer, so be sure to bring water. There are slopes and hills, but the trail is not steep. We passed an outcrop with herringbone cross-stratification, which forms in tidal settings; some researchers suggest part of the top of the Corbin Sandstone was deposited in estuarine settings.

The trail reaches a viewpoint above tall cliffs where visitors can see Double Arch, a squarish two-layer arch, the lower layer of which is formed by a single rock stratum, as well as Courthouse Rock, a tall dome-shaped monolith with flat sides and a round top.

Climbing: Nada Tunnel to Phantasia

We drove through the town of Slade to go rock climbing on a well-known wall called Phantasia, just past Nada Tunnel, a 300-meter-long one-way tunnel that was used by logging trains in the early 1900s. Now on the National Register of Historic Places, it is known as the gateway to the Red. As you drive through it, more than 30 meters of the Corbin Sandstone lie above you.

At Phantasia, we climbed a 25-meter-high route called Pogue Ethics. (The names climbers give walls and routes are sometimes as mysterious as those given to racehorses.) The base of Pogue Ethics is an eroded rock shelter, and the first holds are pockets in the sandstone. Moderate cementation has helped weathering processes form these durable pockets, making them useful for climbing. Halfway up the climb, Liesegang bands protrude from the cliff face, forming additional holds. Here, as well as across much of the Corbin Sandstone, cementation of the sandstone varies vertically; sandstone closer to cliff tops is generally better cemented than rock near the cliff bottoms. This contributes to the cliffs' characteristically overhung shape, with the tops protruding out farther than the bases.

Climbers are often rockhounds; after all, they depend on the rocks for their lives. "Whenever you come across a hold [while climbing] that feels just right, it's like, 'Huh, it took thousands of years for that [hold] to form just like that, just so I could have fun in that moment,'" a fellow climber, Drew Vechell, told me.

Sandstone of the Corbin Sandstone Member is exposed at Nada Tunnel.
Credit: Alex Mandrila

Climbing bolts in sandstone at the top of Party Time route at Fortress Wall.
Credit: Alex Mandrila

The top of the Party Time climbing route offers gorgeous views of the surrounding landscape.
Credit: Alex Mandrila

Climbing: Pendergrass-Murray Recreational Preserve

The next day, we drove south about a half-hour from our campground to the Pendergrass-Murray Recreational Preserve (PMRP), a remote cliff area only accessible via steep dirt roads (an all-wheel drive vehicle is best here) where there is good climbing. The Red River Gorge Climbers' Coalition recently purchased 300 hectares at PMRP to secure access to climbing routes.

The PMRP cliff we visited is called the Gallery, which features opportunities mostly for "sport climbing" (see sidebar). Trees shaded the cliff face, which has plate-like rock protrusions extending outward. The edges of these plates are rounded, making for good holds.

"My favorite [type of hold] is when the rocks are shaped [weathered out] like motorcycle handlebars," said Nathan Webster, a climber from Louisville, Ky., who was at the Gallery that day with his climbing partner, Jesse

Miguel, and Trad Versus Sport Climbing

Miguel Ventura, owner of Miguel's Pizza, has been at the Red River Gorge Geological Area ("the Red") since 1984. He started selling ice cream to tourists, and then started making pizza, which he prepares from scratch in his garage near the main store.

"We were just hanging out [back in 1984], and then the climbers started showing up," Miguel says. "Some guys from the U.K. decided to open a climbing shop at our ice cream store, and they taught me a little bit about how to climb and how to sell the gear, and that's how it started," he says. "At first it was just 'trad climbers,' but then Porter Jarrard came around 1991 and developed sport climbing across the gorge."

"Trad climbing," short for traditional climbing, involves climbers using pieces of gear they carry with them — such as wedges of metal attached to metal wire — which they lodge in cracks in the rock while climbing. They then clip their rope into the installed gear before continuing to climb. If they fall, their gear will, if secure, catch the rope and help stop their fall. Sometimes, if bolts are available on a route, a trad climber may choose to use them, although many trad routes are boltless.

In sport climbing, metal bolts are drilled into a rock wall beforehand, and then a climber clips rope-holding gear into the bolts. If the climber falls, their gear should hold the rope and catch their fall. This typically takes less time than trad climbing because a climber does not have to spend time installing their own gear in the rock.

"At first, in the '90s, there was a lot of conflict between the trad and sport climbers," Miguel says. "Like threats from trad climbers saying 'this is our turf'" to sport climbers. The two groups, though, eventually settled their differences, and now sport climbing is the most popular kind of climbing at the Red thanks to well-weathered footholds and handholds on cliff faces, which do not always have the cracks necessary for trad climbing.

Miguel Ventura of Miguel's Pizza, preparing pizza dough.
Credit: Alex Mandrila

Beyond changes in climbing styles, Miguel has also seen climbers themselves change over time. "You used to see lifer climbers, but not so much anymore," he says. "I've seen five or six generations of college kids come through here, and, even though the place has gotten more popular, most of those kids only last about a year or two."

But, he says, "the gorge is a beautiful place. I'll always be here, and will die here. I love it."

LJ

Amundsen of Cincinnati. "It's like when there's a hole in the rock [around a vertical hand grip in the wall] that you can pass your finger through and put a sling around it if you had to," Amundsen added. "That's a handlebar."

The cliff at the Gallery has pockets and handlebars in the rock to the left, but to the right the rock gets flatter and has more plates. One of my companions climbed pockets on a route called 27 Years of Climbing. Another rappelled down a plate-filled route called A Brief History of Climb. Behind her was meter-tall planar crossbedding in the rock. After PMRP, we drove north back through Nada Tunnel to Fortress Wall and a vertical fracture, or crack, called Party Time. Vertical fractures like Party Time do not occur everywhere at the Red, but they are the zones of weakness that help erosive agents like water carve gorges.

Once you get above the tree line at the Red — whether by hiking or climbing — the views stretch far and wide, and you can get a good sense of how different geologic processes have helped sculpt the landscape. The Red offers seemingly limitless opportunities for enjoying nature, and it is worth the time to visit.

Joel is a freelance writer based in Ann Arbor, Mich.

Getting There & Getting Around

Entry to Daniel Boone National Forest and the Red River Gorge is free. The nearest airports are in Lexington and Louisville, Ky., both about an hour away by car. Cincinnati is two hours away. Having a car is a must for getting to and driving around the Red.

To get there, take the Bert T. Combs Mountain Parkway to exit 33 for Slade, Ky. Turn right onto KY-11S, and drive about 3 kilometers to reach Miguel's Pizza, which has a campground out back.

Camping at Miguel's costs $2 per night, and offers WiFi, cell phone service and warm showers at $1 for every four minutes. Camping is year-round, but the restaurant is only open from March 1 to Thanksgiving. If Miguel's is full, campsites can also be found at Land of the Arches Campground for $5 a night per person. Cabins are available in the area through Red River Gorge Retreats and other agencies. Miguel's allows you to cook your own food on site, but their food is worth a try, especially the pizza. Backcountry camping is allowed, but you must be more than 90 meters from roads and trails, and 30 meters from cliff bases. At Gray's Arch, you must be at least 180 meters from the arch if you want to camp.

You can get to most trailheads by car. All climbing routes entail hiking to the base of the climb; the hikes can range from less than a kilometer and easy to much longer and strenuous. Bring water and food. The best — and thus the most popular and most crowded — time to visit the Red is in fall or spring. In winter, snow is possible. With heat, humidity and insects, summer there can be uncomfortable, but the fireflies might make a trip worth it. Each October, the Red hosts a climbing festival called Rocktoberfest, which can be good for meeting other climbers and for swapping tales, but expect popular walls in the area to be congested.

Fireflies illuminate the evening sky above tents at Miguel's Pizza (right), a great place to camp while exploring the Red River Gorge.
Credit: both: Alex Mandrila

LJ

Apps: Join the Crowd: Introducing a New Generation of Geo-Apps

Julia Rosen

At a time when the technical and computing capabilities of science are evolving at breakneck speeds, it might seem like researchers would always seek out more powerful and sophisticated tools to tackle their scientific questions. But some have chosen the opposite strategy: drawing on the dispersed resource of millions of relatively low-tech devices like smartphones and personal computers — and their users.

Researchers are turning to crowd-sourcing to study a wide range of topics, from cosmic rays to coastal erosion. So, the next time you find your brain — or your smartphone — sitting idle, consider opening up one of these geo-apps and performing a little citizen science.

A new app uses smartphones to detect cosmic rays.
Credit: Crayfis.io

Catching Cosmic Rays

Particles from outer space — mostly protons and alpha particles — rain down on Earth all the time. But astronomers still don't know the source of the most energetic class of these particles, known as ultra-high-energy cosmic rays. Some think they may stream out of active galactic nuclei, while others say that they are produced by colliding galaxies or other cosmic processes. The problem is that researchers haven't spotted enough of these rare particles to determine their origins. And at the moment, building substantially bigger detectors, like the $270-million IceCube neutrino observatory in Antarctica, isn't an option.

However, a group of researchers led by Daniel Whiteson and Michael Mulhearn at the University of California, at Irvine and Davis, respectively, realized that about 1.5 billion small cosmic-ray detectors are already scattered around the world, and one is probably in your pocket right now: smartphones. Although your phone can't detect cosmic rays directly, a chip in the camera can register photons and muons, which are produced when high-energy cosmic rays hit molecules in the atmosphere.

So, the researchers created an app called CRAYFIS (Cosmic Rays Found in Smartphones), which turns your phone into a particle detector whenever it's not in use. The app is still under development, but already users in about two dozen countries have detected more than 23 million possible muon hits. The scientists told NPR that they don't yet know if the app "is the best idea we ever had, or the silliest," but if you want to help them find out, go to crayfis.io and sign up. You could be thanked in the acknowledgments section of an astrophysics paper, or perhaps even be a co-author.

A U.S. Geological Survey app called iCoast enlists users to spot and tag coastline changes after extreme storms, like Hurricane Sandy, which devastated parts of the New Jersey coast in October 2012.
Credit: USGS

Storm Searches

Remember those spot-the-difference games popular in many childhood magazines? The U.S. Geological Survey (USGS) has developed a version for grown-ups that will also help the agency track storm damage and improve its coastal erosion models. The app, called iCoast, simply requires access to the Web, a few minutes of free time and keen attention to detail.

After you log in through the USGS website, the app presents you with

Researchers looking for a way to expand streamflow monitoring in upstate New York installed streamgages and posted signs asking passersby to text them the water height.
Credit: CrowdHydrology/University at Buffalo

photos taken before and after a storm along a section of coast from the eastern seaboard or the Gulf of Mexico. The program guides you through a series of questions to determine, for instance, if the storm washed away structures, destroyed dunes, or deposited new sand. Spotting the differences can be a little tricky — apparently too tricky for computers to do automatically, according to principal investigator Sophia Liu.

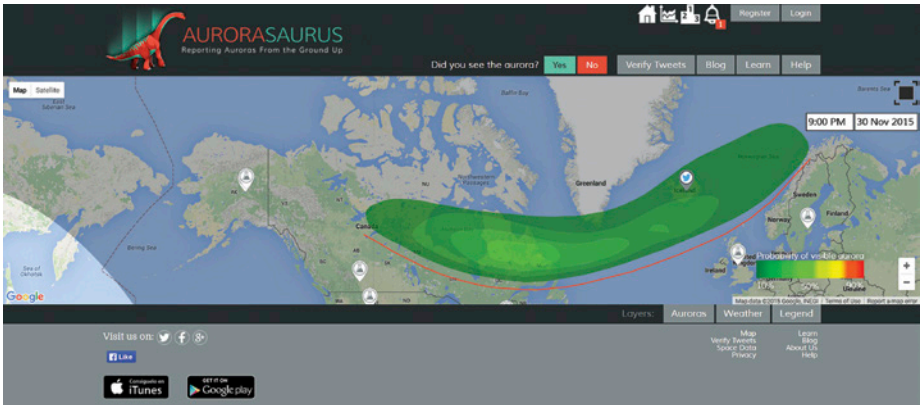
Liu and her partners launched the program in the spring of 2014, and within a year, users had classified nearly 8,000 sets of photos documenting the effects of Hurricane Sandy. However, the researchers still need help; the greater the number of different users who view and classify the photos, the better the results and the models will be.

Aurora-lerts

If you plan to go hunting for the Northern Lights, you'd be well advised to sign up for Aurorasaurus. The app, developed by Elizabeth MacDonald of NASA's Goddard Space Flight Center and her colleagues, provides real-time predictions of auroral activity laid out on an easy-to-navigate map of the world. The app will also alert you when your area is in for aurorae and displays the current cloud cover, so you can decide whether it's worth getting out of bed in the middle of the night.

In addition to the spatial data, the site contains a blog and educational material about aurorae, including what controls their appearance and how to photograph them. The best feature, however, is a real-time graph of the strength of the solar wind, which influences the intensity of the display. It's a little hard to find — click the graph symbol in the upper right-hand corner of the website — but it's extremely useful for those who want to dig into the details.

Aurorasaurus also keeps track of aurora sightings to improve predictions. These sightings are reported by registered users (of which there are already more than 1,500) or pulled from Twitter automatically. Any tweet containing the word "aurora" shows up on the map in the location where it was posted, and Aurorasaurus users nearby are asked to verify whether it's really a sighting (most are not). If you like a little friendly competition, registered users can rack up points by reporting sightings and sifting through unverified tweets.



Aurorasaurus provides real-time predictions of auroral activity laid out on an easy-to-navigate map of the world.
Credit: Aurorasaurus.org

Go With the Flow

CrowdHydrology was launched in 2010 by Chris Lowry of the University at Buffalo and Mike Fienen of USGS with the aim of expanding streamflow monitoring in Upstate New York using text messages. Instead of installing and maintaining a suite of expensive instruments, the team placed tall measuring sticks in stream channels and asked people to text them the water height whenever they passed by.

The initial results based on a few test sites were encouraging, according to a 2012 paper authored by Lowry and Fienen. Crowd-sourced data matched automated measurements fairly well, although — unsurprisingly — there weren't many reports texted during storms, meaning some peak runoff events were missed. And while the researchers tried to place measuring stations in popular recreational spots, different sites saw dramatically different levels of crowd participation, showing that a few dedicated users can make a huge difference.

At the moment, most of CrowdHydrology's sites are in the Great Lakes region. However, the scientists also have one streamgage in Provo, Utah, and another in Corvallis, Ore., and they say they are looking to expand. But no matter where you live, you can use their freely available data. On the CrowdHydrology website, you can choose any monitoring location and access water level data over a given window of time. There's a widget that allows you to graph the data online, or you can download them for future use.

Rosen (http://julia-rosen.com) is a freelance science writer based in Oregon.

Conglomerate: A Geo Word Jumble

1. Aphanite
2. Bandaite
3. Blackjack
4. Bouldery
5. Caking coal
6. Cerioid
7. Channel
8. Corey shape factor
9. Corvusite
10. Crest
11. Drop
12. Dry weathering
13. Endokinetic
14. Fluor
15. Formation-volume factor
16. Gulf
17. Heel
18. Intertonguing
19. Katamorphism
20. Laminar structure
21. Lepidolith
22. Liquid fractionation
23. Meandering valley
24. Parakhinite
25. Polar-orbiting satellite
26. Porticus
27. Real-aperture radar
28. Sand snow
29. Stratophenetics
30. Throat plane
31. Underlapping faults
32. Ustox
33. Wall

L	I	Q	U	I	D	F	R	A	C	T	I	O	N	A	T	I	O	N	Z	P	F	F	Z	L
T	R	J	A	R	O	T	C	A	F	E	M	U	L	O	V	N	O	I	T	A	M	R	O	F
I	O	Y	E	L	L	A	V	G	N	I	R	E	D	N	A	E	M	V	C	P	D	M	C	K
N	T	G	Q	L	T	K	V	N	K	A	X	E	W	G	V	G	D	Y	C	H	F	O	E	U
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O	P	B	S	T	H	E	Z	T	A	P	L	R	A	Y	K	E	O	N	Q	E	H	V	A	I
N	A	V	I	C	B	A	O	A	D	R	Y	W	E	A	T	H	E	R	I	N	G	T	L	X
G	H	S	H	O	T	N	N	I	G	U	E	S	P	I	S	N	M	K	L	K	Y	A	P	C
U	S	U	P	R	Q	S	M	N	N	U	Q	R	N	H	D	L	C	N	R	Z	L	J	T	A
I	Y	C	R	V	L	U	E	W	E	N	L	I	U	O	S	A	N	D	S	N	O	W	A	K
N	E	I	O	U	F	V	J	R	X	L	H	F	K	T	J	S	O	Z	S	C	J	P	O	I
G	R	T	M	S	F	K	K	T	C	K	Z	I	R	K	R	A	R	O	O	X	H	N	R	N
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M	C	O	T	T	H	M	V	R	V	E	T	A	R	Q	E	A	P	V	E	A	U	P	T	C
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B	H	K	K	K	X	P	R	I	D	B	S	S	J	H	P	S	I	D	L	S	S	H	G	A
Y	F	G	K	Q	K	R	C	C	B	O	U	L	D	E	R	Y	T	O	A	A	P	O	D	L
N	M	G	C	F	J	E	N	Z	K	B	F	L	D	W	Y	R	K	O	I	I	E	H	L	A
R	J	W	E	L	L	E	P	I	D	O	L	I	T	H	A	A	L	F	X	D	T	R	D	S
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A	U	U	N	D	E	R	L	A	P	P	I	N	G	F	A	U	L	T	S	S	I	T	P	R
N	P	K	R	F	X	D	W	S	T	S	T	R	A	T	O	P	H	E	N	E	T	I	C	S

This is a word search of terms from the Glossary of Geology. Check out GeoWord of the Day at www.americangeosciences.org/word. Words in the puzzle may be hidden horizontally, vertically or diagonally, and spelled in either forward or reverse order.

Puzzle solution will appear in next month's issue of EARTH.

Solution to the January 2016 crossword

D	U	C	E	■	T	A	B	S	■	■	U	S	E	S
I	R	O	N	■	S	C	R	I	P	■	N	O	T	E
S	E	N	D	■	P	E	A	R	L	■	S	P	U	R
H	A	V	O	C	■	S	C	R	U	N	C	H	I	E
■	■	E	R	O	S	■	T	A	M	E	R	■	■	■
T	O	C	S	I	N	S	■	H	E	R	E	O	F	■
A	P	T	E	R	O	U	S	■	■	O	W	N	E	D
L	E	I	■	■	B	E	A	N	S	■	■	E	M	U
C	R	O	A	T	■	■	Y	O	K	O	H	A	M	A
■	A	N	T	H	E	M	■	B	I	G	O	T	E	D
■	■	■	T	O	N	A	L	■	M	E	T	A	■	■
S	U	G	A	R	S	N	A	P	■	E	S	T	E	R
K	N	O	B	■	U	T	T	E	R	■	P	I	K	E
E	D	D	O	■	E	L	E	G	Y	■	O	M	E	N
P	O	S	Y	■	■	E	R	S	E	■	T	E	S	T

WHERE ON EARTH?

SUBMIT YOUR PHOTOS!

SEE DETAILS BELOW

CLUES

- This man-made lake, when full, is the largest such reservoir by volume in the United States. Over the last 15 years, however, drought has dropped the water level by 37 meters, to its lowest level since impoundment, leaving an infamous "bathtub ring" and exposing a previously submerged "ghost" town.
- The dam that impounds the lake was the largest in the world when it was completed in 1936 and was originally named for the canyon in which it sits. The canyon was carved over the last 5 million years through colorful Paleozoic and Mesozoic strata that were uplifted during the Mesozoic and then faulted and tilted during the Paleogene.
- The dam's iconic facade has been photographed by Ansel Adams and featured in dozens of television shows and films, including the 1949 film-noir classic "The Lady Gambles" starring Barbara Stanwyck.

November Answer:

Straddling the border between Italy and France, Mont Blanc rises to 4,810 meters. The peaks are Mont Blanc granite, which dates to about 300 million years ago, and was uplifted beginning about 22 million years ago. More recently, glaciers have sculpted the peak into its present shape. The nearby town of Chamonix, France, hosted the 1924 Winter Olympics. Photo is by Claudia Schwab.

November Winners:

Arthur Astarita (Portland, Maine)
Claude E. Bolze (Sapulpa, Okla.)
D. Gill (Fountain Inn, S.C.)
Edward S. Grew (Orono, Maine)
Jeff Kirtland (Brisbane, Queensland, Australia)

HOW TO PLAY

NAME THE LAKE & THE DAM.

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 (February 29). 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 "I'm a Geoscientist" T-shirts. 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 and an "I'm a Geoscientist" T-shirt.

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The Jobs & Careers Center provides a central location for job seekers, students, and professionals to interact with one another and to learn more about careers and professional development for geographers.

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Help stuff tote bags, monitor sessions, or process registration check-ins during the conference as a volunteer. Student members are encouraged to apply for this unique opportunity to help offset their meeting registration costs.

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- Globalization
- Climate Change
- Migration and Immigration
- Geography Education
- Human Geography
- GIScience
- Physical Geography
- Urban Geographies
- Social Justice
- Interactive Topical Poster Sessions
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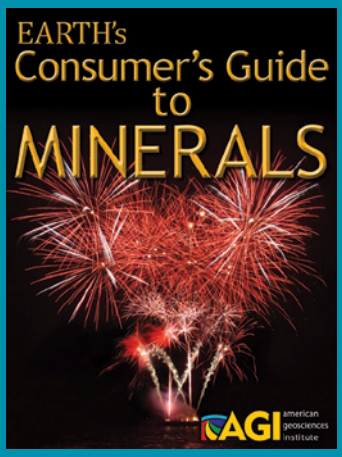

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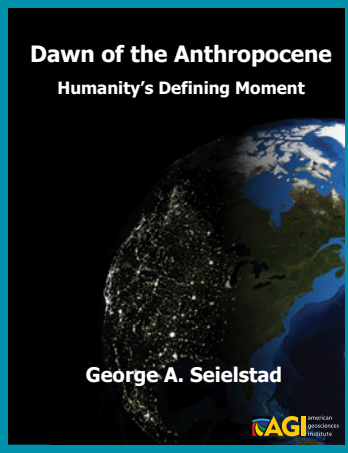

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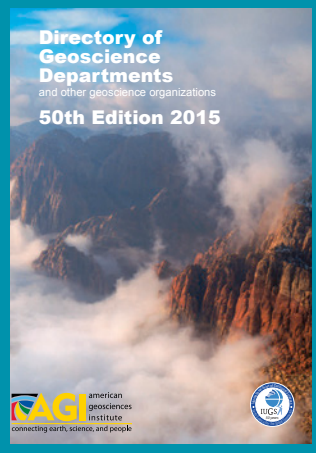

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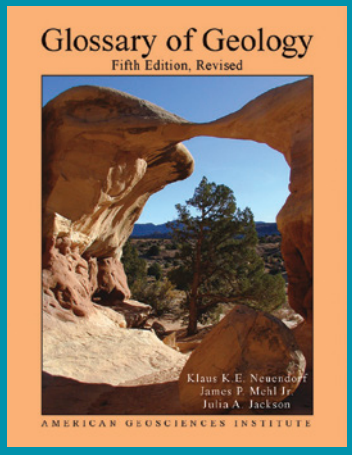

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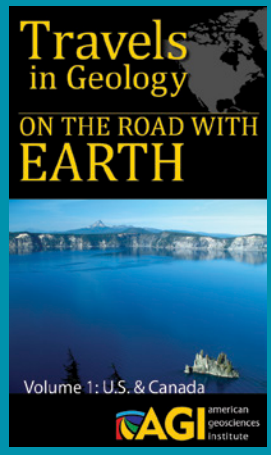

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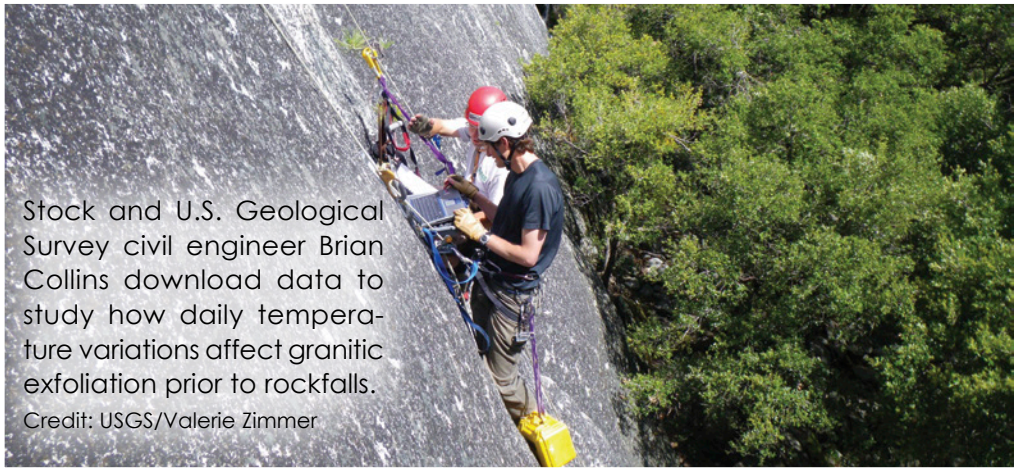
With Yosemite's First Park Geologist Greg Stock

Lucas Joel

As a child growing up in the foothills of California's Sierra Nevada Mountains, Greg Stock and his family took frequent trips to Yosemite National Park. One of his first memories is of hearing and seeing a giant rockfall tumble down the face of El Capitán. Today, Stock studies such rockfalls and how they impact safety in the area as the first park geologist employed at Yosemite.

A love of rock climbing led Yosemite National Park geologist Greg Stock, seen here on a cliff face at Glacier Point in Yosemite, into the field of geomorphology. Credit: Steven Bumgardner



Stock and U.S. Geological Survey civil engineer Brian Collins download data to study how daily temperature variations affect granitic exfoliation prior to rockfalls. Credit: USGS/Valerie Zimmer

In high school, Stock spent much of his free time exploring the many small caves around his hometown of Murphys, Calif. He went on to study these caves and how the sediments they hold can help answer questions about how mountains form for his doctoral research at the University of California at Santa Cruz. Stock's love for the geology of the Sierra Nevada, along with his research on the mountains, made him the ideal candidate when Yosemite announced in 2005 that they would be hiring the park's first geologist.

Crediting John Muir — whose 19th-century explorations and writings brought national attention to Yosemite — as a major inspiration, Stock now spends his time traversing and studying Yosemite's rapidly retreating alpine glaciers, as well as trying to understand what, exactly, triggers the park's many rockfalls. Stock has published extensively on Sierra Nevada geology and is co-author of the popular field guide "Geology Underfoot in Yosemite National Park."

EARTH spoke with Stock last fall about what led him to Yosemite, what caves have to tell us about rivers, and the similarities between rock climbing and surfing.

LJ: What kindled your interest in geology?

GS: Caving, climbing and being in the outdoors overall is what steered me toward geology. As a kid, caving led to rock climbing. And I had questions about the cliffs: how they formed, why they had cracks in them, and why they were shaped the way they were.

LJ: What did you do after graduating with an undergraduate geology degree from Humboldt State?

GS: I had a really nice couple of years working for the National Park Service, spending summers in Sequoia & Kings Canyon National Parks and winters in Hawaii Volcanoes National Park. I was mostly mapping caves, and so I was toggling back and forth between the Sierra Nevada and Hawaii, with a couple months off in between to travel around the Western states and see more national parks. It helped me realize that I still had a ton of questions about geology. So I went back to graduate school at UC Santa Cruz, where I mostly studied cave development and how that played into the uplift and erosion history of the Sierra Nevada. When I was working in Sequoia Kings Canyon, I thought that the caves there could be used as indicators of past river position. A cave high in the walls of a deep river gorge can be a marker of ancient river elevation, and if you can find sediment to date in the cave, then you can come up with an incision rate of the canyon. And we were able to do that for a bunch of caves and measure river downcutting rates over a few million years.

LJ: What were some of the major findings of your doctoral work?

GS: The main thing we found is that the cave sediments did provide pretty robust ages for the caves — they made nice stratigraphic sense — and the river incision rates were also very reasonable. Unfortunately, river incision can't be tied directly to mountain uplift because changes in climate can also cause the incision rates of rivers to change. But, based on the combination of the spatial and temporal patterns that we saw,

we think the work provides support for a recent pulse of uplift of the Sierra Nevada in maybe the last 3 million to 5 million years.

LJ: How did you become Yosemite's first park geologist?

GS: During a one year post-doc at the University of Michigan in 2005, a colleague from Sequoia Kings Canyon dropped me an email and said, "Hey, there's a position open for the first geologist in Yosemite. You should put in for it." At the time I wasn't thinking of a career with the park service — I was much more focused on an academic career. But I love the Sierra Nevada and Yosemite, and I had spent enough time working for the park service to know that I really liked the agency. I like their mission, and I like the people who work for the park service. So I was intrigued. I applied and I got the job.

LJ: Do you know how or why the position was created?

GS: The park needed to have a geologist based here who was available not just to respond to rockfalls or debris flows, but to help the park try to anticipate those events. That's really the kind of thing that requires somebody in the park on staff to not only be able to do the science effectively, but to be the bridge between the science and the decision-making.

LJ: So you're an on-call geologist?

GS: Yes, in the literal sense. I get phone calls at three in the morning sometimes if there's a big rockfall that requires a response.

LJ: How do you feel about having that sort of uncertainty in your work?

GS: Every day is different, which is part of what I love about this job. There could be a day when I go to the office and I'm prepared to work on a report, but suddenly I get a call from dispatch telling me there's been a big rockfall from Glacier Point, and then I spend the next two weeks working on that rockfall. The main thing I do as park geologist is help the Park [Service] understand and plan for geologic hazards, and, in Yosemite Valley, that primarily means rockfalls. We have rockfalls from cliffs about every week, on average. But just in the past 10 days, we've had about 20 rockfalls, probably associated with the first stormy weather that we've had in months.

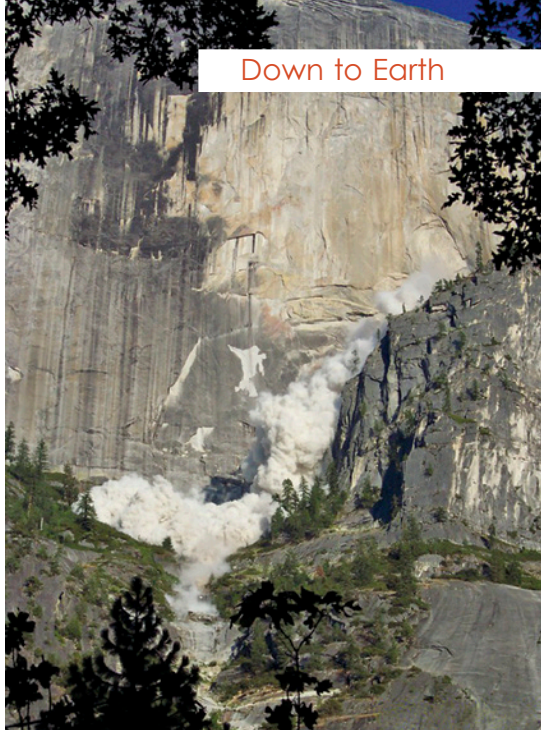
A lot of these rockfalls are not a big deal — they happen in remote areas of the park and they're primarily just of scientific interest. But, occasionally, they will land on roads, they'll land on trails, and in the past they've even landed on buildings, and that's not good.

LJ: What are some of the results of your rockfall hazard work?

GS: I've worked extensively with the U.S. Geological Survey to map out rockfall hazard zones in Yosemite Valley, and to evaluate the risk to people within those zones. We published a report in 2012 that outlined the hazard and risk in Yosemite Valley from rockfalls. By the end of that year, the park had taken steps to reduce the risk to structures from rockfalls by 95 percent, which is a huge risk reduction. That was done primarily by removing or relocating buildings in the rockfall hazard zones, or in some cases repurposing a building to a lower-risk use — for example, converting a dormitory to a storage unit. It was a big effort a couple of years ago, and we're already starting to see the benefits: In February 2014, a rockfall in Curry Village — not a big one, but big enough — landed right in the footprint of a cabin we had removed from the hazard zone a year before, and that rockfall happened at 3 a.m. Most likely there would've been people sleeping in that building if it had still been there.

LJ: Is there a predominant type of rockfall trigger?

GS: There's a huge list of potential triggers. We've seen just about everything occur at one time or another. For example, earthquakes are definitely a rockfall trigger. The 1872 rupture of the Owens Valley Fault triggered many large rockfalls in Yosemite Valley, and John Muir was even in the valley to witness one of those. He wrote quite excitedly about it.



Stock studies rockfalls, like this one in July 2006 on Half Dome, to assess the hazards they present to park visitors.
Credit: Amanda Nolan

If you look at the stats from our rockfall database, the first thing you'll find is that roughly half of the rockfalls have no known trigger, meaning there wasn't enough information about the environmental conditions at the time of the rockfall, or, more interestingly, even when those conditions are known, we don't know what the trigger was — it was apparently a spontaneous event. Those are the most interesting to me because we don't understand them very well.

We're investigating the effects of heat, or thermal expansion and contraction of exfoliation sheets. We're trying to evaluate progressive propagation of cracks that lead to destabilization of flakes [of rock on cliff faces], but which may not record any specific trigger like a freeze-thaw event. But the most common conditions under which rockfalls occur

here are just after rainstorms. The addition of water to cracks just behind these exfoliation sheets is a primary trigger.

LJ: Do you ever think about rockfalls when you're rock climbing?

GS: Oh, of course. I'm probably the most paranoid person in the world when it comes to rockfalls. But I still climb, and I understand that I am assuming the risk. I do it because the rewards are great. But it does factor into what I do — I certainly don't climb during rainstorms or right after them. I'll wait a day or two. I always wear a helmet. I avoid places that have recently been active, because often one rockfall area can be active over several days, weeks or months. I sometimes think that it's similar to surfing an incredible wave in shark-infested waters. The chances of a shark attack are really, really low, and you're going to enjoy an incredible wave, but it is something that is always possible out there, and we need to think about it.

LJ: I saw a video in which you cite John Muir as a major inspiration. Do you feel like you're following in his footsteps?

GS: Yeah, I do feel that way. Part of it is that he was in love with Yosemite, and I feel the same way, so we certainly have that in common. But, more recently, I have literally followed in his footsteps. In 1872, Muir pounded a couple of stakes in the Maclure Glacier, and over a 46-day period he measured the movement of the stakes, measuring the movement of the glacier, which, as far as I know, is the first time anybody did that with any glacier in North America. In 2012, 140 years later, we went up to the Maclure Glacier and reproduced his experiment. We put stakes in the ice; the glacier is less than half the size it was in Muir's time, so it's a very different glacier. The really cool thing is that we got the same result: The glacier was moving at more or less the same speed in 2012 that it was in 1872. So, at those times I do feel a real connection with Muir, because it's like I'm experiencing not just the same landscapes, but the same scientific results.

Stock traversing Yosemite's Maclure Glacier — the same glacier John Muir studied in 1872.
Credit: Jean Redle

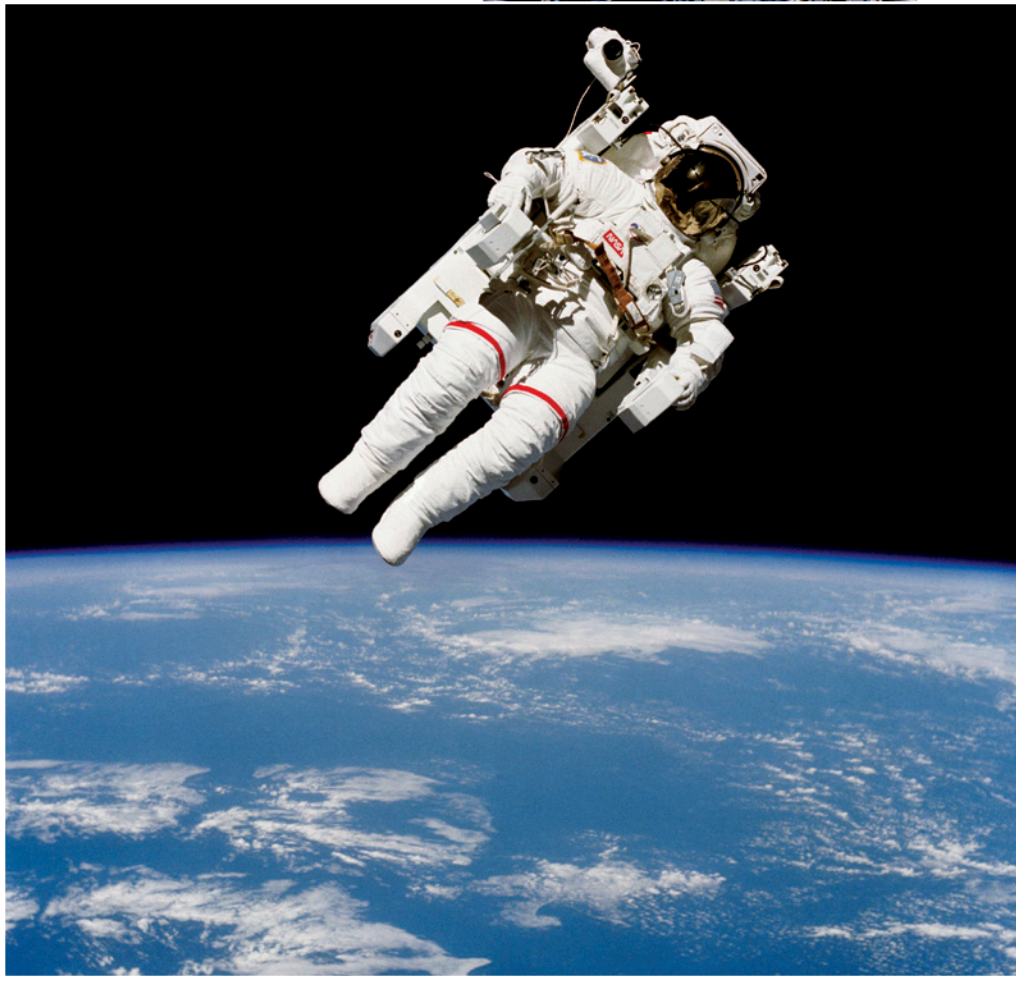
Joel is a freelance science writer based in Ann Arbor, Mich.

February 1962 and 1984: John Glenn and Bruce McCandless Make Space Flight History

Lucas Joel

On the morning of Feb. 20, 1962, John H. Glenn sat inside the Mercury Friendship 7 space capsule, perched atop a rocket that had initially been designed to deliver nuclear warheads to the far ends of the world. That rocket would propel Glenn into space, and into the history books, as the first American to orbit Earth.

Right: Astronaut John H. Glenn Jr. in his Mercury flight suit. Below: Astronaut Bruce McCandless pilots the Manned Maneuvering Unit during the first untethered spacewalk on Feb. 7, 1984.
Credit: both: NASA



A far cry from earlier visions of futuristic space planes that would ferry humans into space, the Atlas intercontinental ballistic missile (ICBM) was the quick and dirty way for a newly formed U.S. government agency called the National Aeronautics and Space Administration (NASA) to get an American into orbit. It was a feat that the Soviet Union — the U.S.'s Cold War and space-race rivals — had achieved the year before in April when Yuri Gagarin became both the first human in space and the first to orbit Earth.

Although not the first American to reach space (that distinction went to Alan B. Shepard on May 5, 1961), Glenn was the first American to match Gagarin's achievement, which immediately lofted him into the national spotlight.

Cold War tensions between the U.S. and the Soviet Union helped spark the space age, which, in the decades after Glenn's orbit, saw many more astronaut achievements. One of those milestones occurred 32 years ago when Bruce McCandless — an astronaut and electrical engineer — was orbiting the planet as part of a mission on the space shuttle Challenger. On Feb. 7, 1984, McCandless exited the shuttle's payload bay strapped to a large backpack-sized vehicle called a Manned Maneuvering Unit (MMU), which propelled him into space completely unconnected to the shuttle. It was the world's first untethered spacewalk.

NASA's Launch

Dreams of human space travel began to materialize in the mid-20th century after key advances in rocket science came about during World War II. With the efforts of Wernher von Braun and other scientists and engineers, Germany developed the V2 rocket, the first long-range ballistic missile.

"Rocketry was pretty amateurish up until the 1930s, but thanks to defense developments during the war, traveling into space began to seem less and less nutty over time," says Michael Neufeld, senior curator in the Division of Space History at the Smithsonian's National Air and Space Museum. "And with the end of World War II, the V2 opened the door to the launch of the ICBM and, in that way, the space launch vehicle." It was not until the early 1960s, though, that rockets large enough to carry a warhead anywhere on the planet — or launch a spacecraft into space — were developed.

Prior to Glenn's 1962 launch, the Soviet Union had outpaced the U.S. in the space race. After the 1957 launch of the Soviet satellite Sputnik, U.S. President Dwight D. Eisenhower committed government funds to accelerate the nation's fledgling space program. At first, the responsibility of reaching space fell to two branches of the military: the Army and the Air Force, both of which were, for defense purposes, interested in developing a presence in the upper reaches of the atmosphere. "It would've been a perfectly reasonable outcome of the Cold War situation that the U.S. space program would have been military-based," Neufeld says. However, conflicts between military branches — and the fact that each wanted to have the strongest foothold in space — helped drive Eisenhower to establish a separate, civilian space agency: NASA. The creation of a civilian-run space program was also meant as a statement, Neufeld says, in the Cold War propaganda battle: "NASA was a good image for the United States because it represented a supposedly peaceful space program, rather than it being some kind of military-run missile initiative as with the USSR's space program."

After NASA came into being in 1958, it soon created Project Mercury, the goal of which was to put an American into orbit. Seven military test pilots were chosen to be part of NASA's first astronaut corps. One of these pilots was John Glenn, who had flown combat missions in World War II and the Korean War. Glenn, before his flight, named his space capsule Friendship 7: Like Alan Shepard's Freedom 7 capsule, the name was a nod to his fellow Mercury astronauts.

Glenn poses for a photo with the Mercury Friendship 7 spacecraft during preflight preparations.
Credit: NASA

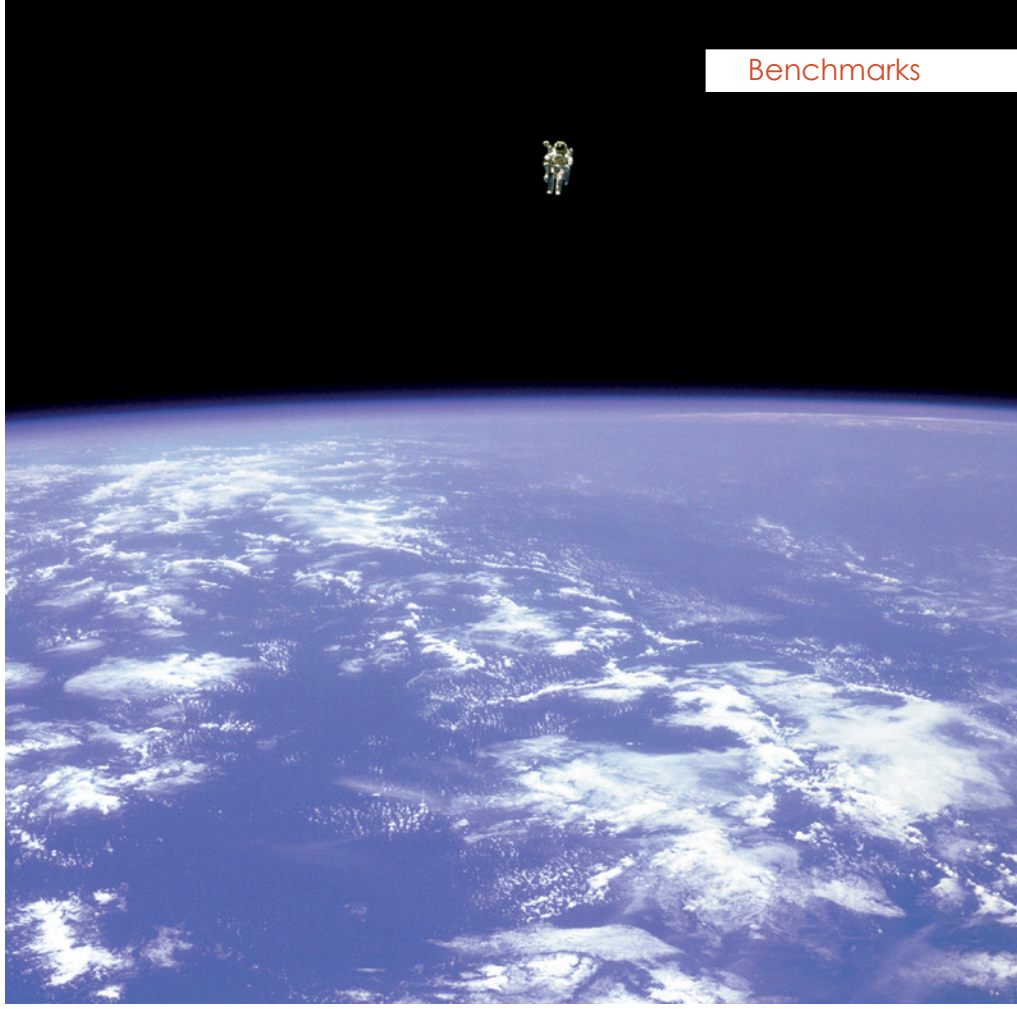
Orbiting Earth

Glenn's launch day — Feb. 20 — arrived, and by 6 a.m. Eastern time he had donned his spacesuit and climbed inside the cramped quarters of Friendship 7, about which he joked: "You don't get into [it], you put [it] on." At 9:47 a.m., the engines were lit, and five minutes later Glenn rocketed into orbit.

Outside his window, Glenn passed over the coast of West Africa, and then over the Indian Ocean, which is where he saw his first sunset from orbit: "A beautiful display of vivid colors ... As the sun gets lower and lower, a black shadow moves across the Earth until the entire surface that you can see is dark except for the bright band of light on the horizon. At the beginning, this band

is almost white in color. But as the sun sinks deeper the bottom layer of light turns to bright orange. The next layers are red, then purple, then light blue, then darker blue and finally the blackness of space. They are all brilliant colors, more brilliant than in a rainbow."

After three orbits over 4 hours and 55 minutes, Glenn returned to Earth and splashed down in the Atlantic Ocean. Shepard may have been the first American in space, but he had not orbited the planet like Gagarin had. "The Soviets orbited Gagarin on the first try, while Shepard made a 15-minute flight up into and then immediately back down from space," Neufeld says. To Americans at the time, this "seemed like an inferior accomplishment." Glenn's orbit thus eclipsed Shepard's flight and for that, New York City and Washington, D.C., held parades in his honor. The flight came to signify the country's first major step into the space age.



McCandless floats about 100 meters from the space shuttle Challenger during the first untethered spacewalk in 1984.
Credit: NASA

Untethered Spacewalk

In the years following Glenn's flight, American space exploration expanded: Astronauts first orbited and then landed on the moon in 1968 and 1969, respectively, and, from 1981 to 2011, NASA's space shuttles ferried astronauts into space on numerous exploratory and scientific missions. In 1984, on one of these shuttle missions — STS-41B — astronaut Bruce McCandless performed the first untethered spacewalk from the space shuttle Challenger. (During a subsequent mission on Jan. 28, 1986, Challenger exploded just after launch, killing all seven astronauts aboard.)

For the spacewalk, McCandless used an MMU that was designed to enable him to roam free of the space shuttle. Departing from the payload bay, McCandless ranged about 100 meters from the shuttle, becoming the "first human satellite," says Valerie Neal, curator and chair of the Smithsonian's Space History Department. While adrift, fellow astronaut Robert Gibson, from inside Challenger, snapped a photo that went on to become an iconic image of human space travel. In the photo, a solitary McCandless, visor down to protect his eyes from the sun, appears suspended in space far above Earth's horizon.

The MMU that McCandless flew, which is now on display at the National Air and Space Museum, was designed so that astronauts could perform tasks at a distance from the spacecraft, such as retrieving a damaged satellite. This would keep the shuttle itself from having to get close to other bodies floating in space. "McCandless himself invested a great deal of his career into developing the MMU capacity," Neal says. "He, more than any other astronaut, is associated with the MMU, both for the fact that he flew it first and because he had put in years of effort developing it and perfecting it to be an astronaut aid."

Including McCandless' flight, the MMU was used on just three shuttle missions. Following the 1986 Challenger explosion, NASA "became a lot more conservative regarding astronaut safety," Neal says. It was decided that most of the tasks the MMU was designed to help accomplish could be done just as well with the space shuttle's robotic arm.

"Had the Challenger tragedy not happened, I think it's likely that the MMU would have continued to be used," Neal says. "It probably would've evolved into a smaller, more compact version [of the] one McCandless used," and perhaps would have been used to help build the International Space Station, she says. Unfortunately, its "potential for making astronauts even more capable workers in space" was never realized.

Joel is a freelance science writer based in Ann Arbor, Mich.

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EARTH is currently accepting applications for the summer 2016 internship.

The intern will work as a full member of the EARTH staff for the summer. Tasks include: pitching and writing news, trends, profiles and feature articles for print; copyediting and proofreading; art research; writing news articles for EARTH online; and keeping up our social media presence. There is also the potential for illustration and multimedia work for the right candidate.

This internship is intended for young writers seeking careers in science writing. Preference is given to candidates pursuing or holding an advanced degree in journalism and with a background in science, especially earth science, or with an advanced degree in science and a strong background in journalism. Upperclassmen with strong science and writing backgrounds, as well as experienced writers transitioning to science writing are also welcome to apply. The successful candidate will have a proven record of being self-motivated and entrepreneurial.

AGI american geosciences institute
connecting earth, science, and people

The internship is 12 weeks long and includes a $4,000 stipend. Starting date is flexible.

The successful candidate has the choice to complete the internship at EARTH's headquarters at the American Geosciences Institute in Alexandria, Va., or remotely from his or her location of choice — anywhere in the U.S.

Send a résumé, three writing samples and a letter describing what you hope to gain from the internship and how your previous experience makes you most suitable for this position via email to: earth@earthmagazine.org

All applications must be received by March 11, 2016.

AGI is an equal opportunity employer.

AGIF american geosciences institute foundation

The AGI Foundation's programs impact young people, educators, researchers, the public and policymakers, all who comprise the geoscientists and informed citizens of tomorrow. AGI Foundation's most recognized programs focus on geoscience STEM educational excellence and workforce development, and public awareness and government affairs. Widely acclaimed examples include the most prestigious endowed Fisher Congressional Fellowship, development of inquiry-based geoscience curricula for elementary and secondary school, conducting teacher academies to improve instruction of the geosciences, collection and analysis of geoscience workforce status and trends, and award winning publications and training materials to increase awareness and geoscience literacy by students, the public and professionals.

A major new initiative that the AGI Foundation is working to fund is the implementation of the new AGI Center for Geoscience Education and Public Understanding. The Center builds upon the foundation of the AGI and capitalizes on its strength as a federation of 50 scientific and professional geoscience societies representing a quarter of a million practicing geoscientists in the United States.

Critical new initiatives of the center require new funding from the AGI Foundation, include the following focus areas:

- Understanding the Status of U.S. Earth Science Education with the 2013 "roll-out" of the Nation's new science standards in which 26 States have signed on and 40 states are expected to fully adopt;
- Supporting innovative Energy Education;
- Conducting and distributing outcomes from Geoscience Critical Issue Forums;
- Expanding the scope and distribution of geoscience career materials and workforce information;
- More outreach to students positioned earlier in the "geoscience education flow".

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A Jurassic Romance

Ward Chesworth

For me there were two notable events in 1847. One was literary, the other scientific. The literary event was the publication of the first Harlequin Romance, more than a century before Harlequin Romances actually existed. It followed the usual formula in which a shy, self-effacing girl goes to work for a domineering, untamed hunk of a man, falls in love with him and, after a convenient house fire rids him of the mad wife he kept stashed in the attic, he surrenders. In the final chapter of Charlotte Bronte's "Jane Eyre" the heroine announces, "Reader, I married him."

The notable scientific event was the death of Mary Anning, the first great female "fossilist" — the term used before "paleontologist" became common. Mary's life of 47 years was spent in and around Lyme Regis, at the foot of the cliffs of Jurassic rock on the coast of the English Channel there. Being female, poor and a religious dissenter, she was denied a formal education, although she and her brother learned a little at least from their father, a carpenter who supplemented the family income by collecting and selling fossils. Mary was academically inclined and went on to teach herself enough geology and anatomy to become a paleontologist in all but name. She was 12 years old when she painstakingly excavated a "crocodile" that her brother had found, and which was later named the world's first ichthyosaur (that's "fish-lizard" in paleo-speak).

Just out of her teens, she discovered the partial skeleton of a second world's-first — another marine reptile, though one more reptilian than the ichthyosaur. Plesiosaur (or "near-lizard") became its name. Later, she excavated other plesiosaurs, including the one that defines the genus. Louis Agassiz of Harvard's Museum of Comparative Zoology named two fossil fishes after Mary — a rare contemporary recognition of her contributions to science. She was finally called a geologist in a biography published 78 years after her death from breast cancer. In 2010, a panel of the Royal Society of London named her one of the 10 most influential women in British science. Largely because of her and the dinosaurs she discovered, her part of England is now called the Jurassic Coast as a kind of "come hither" to tourists. It helps of course that Michael Crichton made the Jurassic the sexiest period in the stratigraphic column.

The cliffs around Lyme Regis where Mary collected are at the southern end of a band of Jurassic rocks that can be followed diagonally across England for almost 500 kilometers, forming the Cotswold Hills along the way to its final destination on a second Jurassic Coast where the North Sea confronts Yorkshire. For my generation of alumni of Manchester University's Department of Geology, this second Jurassic Coast is associated with a charismatic teacher of paleontology named Fred Broadhurst. Fred was a "Bevin Boy," who chose as a teenager to do his national service working in a coal mine. When he went on to become a paleontologist he wrote his doctoral thesis on the nonmarine lamellibranchs he found in the mine. I was arguably Fred's least-attentive student, being more interested in a female botanist in the class, but his enthusiastic, colorful lecturing style carried me through to a passing grade. When I became an academic myself, I discovered that I had learned a great deal from Fred's example, and consciously adapted his teaching technique as my own.

In 1960, Fred took his undergrad class to the second Jurassic Coast. Below the beetling cliffs of Robin Hood's Bay near Whitby, one of the students hammered off a knob of rock and brought it to be identified. Fred and his assistant Jas Potts agreed that it was vertebrate bone and later confirmed that a large Jurassic reptile lay buried in the tidal zone. Fred obtained funding to return to the coast to excavate the fossil and bring it to his lab. I was a geochemistry graduate student by then, but managed to insinuate myself into his party of six volunteer laborers. For two days, from dawn to dusk, we worked between tides to excavate blocks of the Jurassic. We then dragged the blocks up ladders to the cliff top and headed back to Manchester.

After cleaning and trimming away unwanted rock, the 4.3-meter-long fossil was reassembled like a jigsaw puzzle. What emerged was one of the most complete plesiosaurs ever discovered, and a new species, *Hauffiosaurus tomistomimus*, was born. In 2012, after decades in a glass case in the geology department, "Percy the Plesiosaur" was moved across the road and placed in a new display at the University of Manchester Museum.

You may be wondering what happened to the botanist who diverted my attention from Fred's fossils in his paleontology class. Reader, I married her.

Credit: Antonio Martinez Cortizas

Chesworth is a Fellow of the Geological Society of America and Professor Emeritus at the University of Guelph, Canada. He thanks Rosemary Broadhurst for her help. Email: wcheswor@uoguelph.ca. The views expressed are his own.

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