HUMAN GENES PASSED DOWN FROM NEANDERTHALS

CURRENTS CARRY LESS HEAT POLEWARD

HOW GOOD ARE EARTHQUAKE FORECAST MAPS?

EARTH

SAVING MONGOLIA'S DINOSAURS ONE KID AT A TIME

March 2017
www.earthmagazine.org
american geosciences institute
connecting earth, science, and people

The American Geosciences Institute

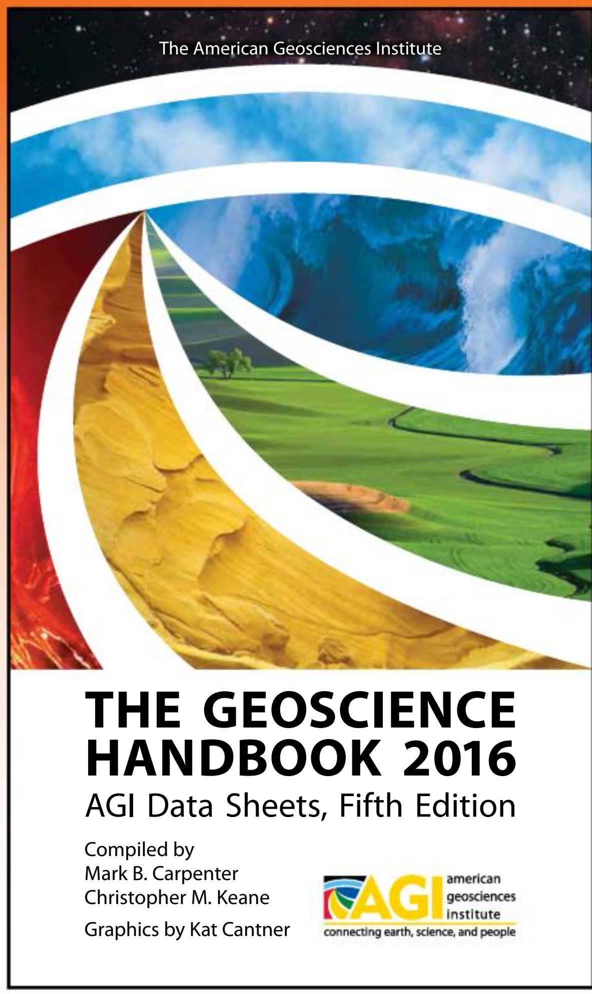
GEOSCIENCE HANDBOOK

AGI Data Sheets Fifth Edition

Mark B. Carpenter,
Christopher M. Keane

For more than 40 years, AGI's Data Sheets have been a critical tool for the geoscientist in the field, the lab, and the classroom. For decades its bright orange cover and three-ring binding were distinctive in the geoscience community. The book evolved into its current, full-color and spiral bound format with the 2005 debut of the fourth edition.

Now AGI has tapped some of the best minds in the geosciences to produce this fifth edition. Featuring the contributions of over 240 experts worldwide in their respective fields, this new, expanded edition is over 470 full-color pages. Three years of work went into the *Handbook* to broaden its scope across the disciplines. With more than 170 complete new data sheets, and full revisions of prior data sheets, over 85% of the content is either new or revised for the fifth edition. The *Geoscience Handbook* is the quick reference tool for key metrics and concepts, a guide to cornerstone papers and recent developments, as well as short tutorials on topics that may not be familiar to all geoscientists.



The Geoscience Handbook 2016: AGI Data Sheets, Fifth Edition
Edited by Mark B. Carpenter and Christopher M. Keane
$59.99
492 pages
ISBN: 978-0-913312-47-6
www.americangeosciences.org/handbook

american geosciences institute
connecting earth, science, and people

2017 3rd NASL

3rd North American Symposium on Landslides

June 4-8 2017, Roanoke, Virginia, USA

Landslides: Putting Experience, Knowledge and Emerging Technologies into Practice
June 4-8, 2017 • Roanoke, VA

For more information and to register:

www.aegweb.org/landslideroanoke2017

The main objective of the symposium is to provide a stimulating forum for geoscientists, engineers, planners, economists, program managers, and other decision makers concerned with landslide hazards and their impact on society. Papers related to investigation, classification, monitoring, analysis and mitigation of landslides, as well as case studies on innovative analysis techniques and solutions will be presented.

2017 AEG Annual Meeting

in partnership with the
53rd Forum on the Geology of Industrial Minerals

Colorado Springs, CO
September 10-16, 2017

www.aegannualmeeting.org

PEAK OF THE PRACTICE

AEG | COLORADO SPRINGS 2017

ENVIRONMENTAL AND ENGINEERING GEOLOGY

The planned symposia and technical sessions include induced seismicity, slope stability and debris flows, rock mechanics, drone technology, industrial minerals and mining, geophysics, groundwater, and flood hazards. Short course topics will include drone technology, debris flows, rock coring, and professional ethics.

2017 Coastal Hazards Professional Forum

Save the Date!

November 14-16, 2017

ENVIRONMENTAL ENGINEERING AEG GEOLOGISTS

www.aegweb.org

1100 Brandywine Blvd., Suite H, Zanesville, OH 43701 • 844-331-7867 • contact@aegweb.org

March 2017 | vol. 62 no. 3 | www.earthmagazine.org

EARTH

FEATURES

VOICES

ON THE COVER: Since 2009, paleontologist Bolortsetseg Minjin has held workshops to bring dinosaurs to kids throughout rural Mongolia. Read more on page 24. Credit: Thea Boodhoo

NEWS

DEPARTMENTS

From the Editor

Credit: Thea Boodhoo

One of the most profound developments for public awareness of geoscience was the creation of national parks. By not only preserving, but publicly identifying, areas with unique natural history — and usually geology — national parks made geologic features into destinations. For the full value of the learning opportunity afforded by such sites to be realized, however, accurate scientific information and context must be presented to the public as well. The parks should not exist merely for "photographic opportunities" — as a member of a prior administration suggested to me as I pushed for more support of geoscientists in the national parks.

Sometimes, the disconnect between the availability of nature on display and the availability of learning opportunities can be even more subtle: I have been to two national monuments that were explicitly designated based on their geologic features, but at which the visitor centers made mention only of the local flora and fauna while presenting nothing about the geology. These sites did not even allow hiking to the parts of the property that contained the fossils of interest. But compared to the challenges in other countries, these definitely qualify as "first world problems."

In "Saving Mongolia's Dinosaurs and Inspiring the Next Generation of Paleontologists," contributor Thea Boodhoo explores the challenges of harnessing the natural resources of one of the world's richest dinosaur locales — Mongolia's Flaming Cliffs — to build a nearby center for learning about paleontology. Boodhoo also discusses attempts to bolster the development of future Mongolian scientists and, even more importantly, to cultivate interest and pride in the country's natural history among its population for the sake of preserving sources of national heritage.

Mongolia is known worldwide for its incredible assemblage of dinosaur fossils, including specimens of *Velociraptor* and *Tarbosaurus*, yet most kids there can't name a single Mongolian dinosaur. Paleontologist Bolortsetseg Minjin aims to change that, as Boodhoo, who joined Bolortsetseg's Institute for the Study of Mongolian Dinosaurs last year, explains. From protecting fossils at the Flaming Cliffs, to repatriating illegally exported dinosaurs, to bringing educational experiences to children throughout Mongolia, Bolortsetseg's passion is creating a profound impact, and it makes for an interesting read.

Of course, if Mongolia is a bit far away, or if plutons and arêtes are more to your liking, then make sure you read this month's Travels in Geology. Former EARTH intern Bethany Augliere writes about her adventures in "Exploring Maine's Magnificent Mount Katahdin." Regardless of your preferred destinations, enjoy this month's issue.

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

EARTH is published monthly in digital formats (ISSN 2373-1559) for a base subscription rate of $20.00 a year. EARTH is also published in print bi-monthly (ISSN 1943-345X) for $45.00 a year by the American Geosciences Institute. To purchase single issues, please inquire at earth@earthmagazine.org. Standard mail, nonprofit postage paid at Denver, Colo., and at other mailing offices. Claims for missing issues will be honored only up to six months. Issues undelivered through failure to notify EARTH of address change will not be replaced.

Canadian Post Publications Mail Agreement Number 40065056; Canadian return address: DP Global Mail, 4960-2 Walker Road, Windsor, ON N9A 6J3.

EARTH

4220 King Street
Alexandria, VA 22302-1507, USA
Phone: (703)379-2480 Fax: (703)379-7563
www.earthmagazine.org
earth@earthmagazine.org

EARTH is printed by American Web, based in Denver, Colo. EARTH is printed on 20% recycled (10% post-consumer waste) paper. All inks used contain a percentage of soy base. Our printer meets or exceeds all federal Resource Conservation Recovery Act (RCRA) Standards.

American Geosciences Institute

american geosciences institute
connecting earth, science, and people

The American Geosciences Institute is a nonprofit federation of geoscientific and professional associations that represents more than 250,000 geologists, geophysicists, and other earth scientists. Founded in 1948, AGI provides information services to geoscientists, serves as a voice of shared interests in our profession, plays a major role in strengthening geoscience education, and strives to increase public awareness of the vital role the geosciences play in society's use of resources, resilience to natural hazards, and the health of the environment.

Member Societies

AASP-The Palynological Society (AASP)
American Association of Geographers (AAG)
American Association of Petroleum Geologists (AAPG)
American Geophysical Union (AGU)
American Institute of Hydrology (AIH)
American Institute of Professional Geologists (AIPG)
American Rock Mechanics Association (ARMA)
Association for the Sciences of Limnology and Oceanography (ASLO)
Association for Women Geoscientists (AWG)
Association of American State Geologists (AASG)
Association of Earth Science Editors (AESE)
Association of Environmental & Engineering Geologists (AEG)
Clay Minerals Society (CMS)
Council on Undergraduate Research, Geosciences Division (CUR)
Environmental and Engineering Geophysical Society (EEGS)
Friends of Mineralogy (FOM)
The Geochemical Society (GS)
Geo-Institute of the American Society of Civil Engineers (GI)
Geological Association of Canada (GAC)
Geological Society of America (GSA)
The Geological Society of London (GSL)
Geoscience Information Society (GSIS)
History of Earth Sciences Society (HESS)
International Association of Hydrogeologists/U.S. National Chapter (IAH)
International Medical Geology Association (IMGA)
Karst Waters Institute (KWI)
Mineralogical Society of America (MSA)
Mineralogical Society of Great Britain and Ireland (MSGBI)
National Association of Black Geoscientists (NABG)
National Association of Geoscience Teachers (NAGT)
National Association of State Boards of Geology (ASBOG)
National Cave and Karst Research Institute (NCKRI)
National Earth Science Teachers Association (NESTA)
National Ground Water Association (NGWA)
National Speleological Society (NSS)
North American Commission on Stratigraphic Nomenclature (NACSN)
Paleobotanical Section of the Botanical Society of America (PSBSA)
Paleontological Research Institution (PRI)
Paleontological Society (PS)
Petroleum History Institute (PHI)
Seismological Society of America (SSA)
SEPM (Society for Sedimentary Geology) (SEPM)
Society for Mining, Metallurgy, and Exploration, Inc. (SME)
The Society for Organic Petrology (TSOP)
Society of Economic Geologists (SEG)
Society of Exploration Geophysicists (SEG)
Society of Independent Professional Earth Scientists (SIPES)
Society of Mineral Museum Professionals (SMMP)
Society of Vertebrate Paleontology (SVP)
Soil Science Society of America (SSSA)
United States Permafrost Association (USPA)

International Associate Societies

Canadian Federation of Earth Sciences (CFES)
Geological Society of Africa (GSAf)
International Association for Promoting Geoethics (IAPG)
YES Network (YES)

Executive Committee

President	Jean M. Bahr, University of Wisconsin - Madison
President-Elect	Eve S. Sprunt, Eve Sprunt & Associates
Secretary	Keri A. Nutter, DOWL
Treasurer	Charlene Sundermann, Freshwater Society
Member at Large	Paul M. Bertsch, CSIRO
Member at Large	Carolyn G. Olson USDA-OCE-Climate Change Program Office
Member at Large	Diane R. Smith, Trinity University
Past President	Scott W. Tinker, Bureau of Economic Geology The University of Texas at Austin
Chair of AGI Foundation	Daniel D. Domeracki, Schlumberger
Executive Director	Allyson K. Anderson Book American Geosciences Institute

www.americangeosciences.org

Credit: Background: ©Semisatch/ shutterstock_78010345; AGI logo shape images: lava: USGS, ESW Image Bank; Aztec sandstone: ©Michael Collier, ESW Image Bank; farm: Digital Vision; waves: Digital Vision; clouds: Digital Stock; space: Digital Vision.

A MORE INCLUSIVE AMERICA

I am greatly enjoying the January 2017 issue of EARTH after a year's hiatus from the magazine. However, I'm reminded of why I took a hiatus: the often American-centric reporting. I completely understand, your primary clientele are Americans, so why wouldn't you be Americentric? Except, science dictates a less prescribed, and less biased, viewpoint.

Case in point: in the article, "The First Americans: How and When Were the Americas Populated?" the map of "Early Evidence of Human Sites in the Americas" leaves out the finds from the Bluefish Caves and Old Crow Flats of the Yukon. I realize you can't put everything on the map, but given how few sites there are in the Americas outside of the Lower 48, one would expect a science-based magazine to do a better job of educating Americans about what's going on outside their borders.

Another example: Why are the Pedra Furada sites in Brazil not mapped? I understand they may not be conclusive but, again, some mention should be made. Cartographically, a different symbol could have been chosen to indicate sites that are still inconclusive, but likely.

Anyway, thought you might find the feedback helpful. Love the magazine!

Terry McDonald
Publisher, GeoKnow.net
Guelph, Ontario, Canada

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: SEISMIC RETROFITTING

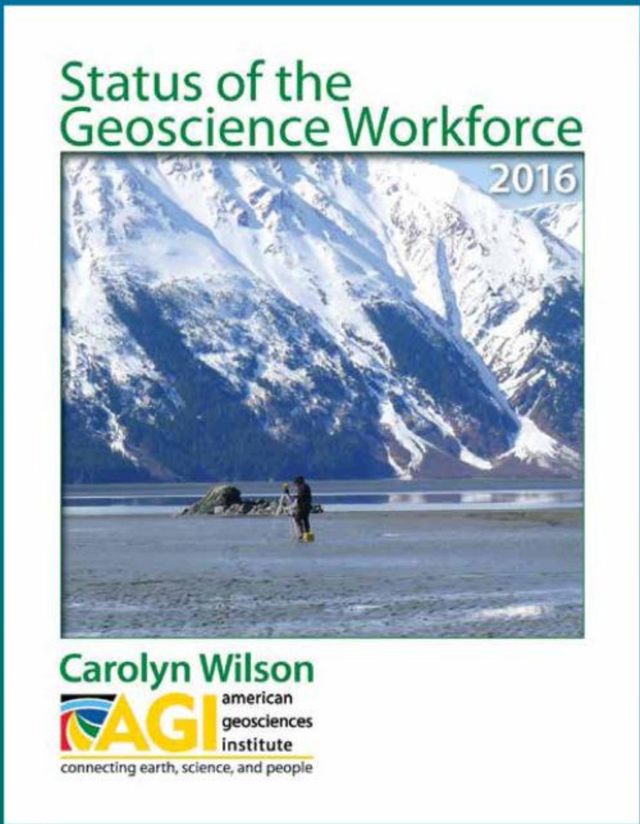
In December, we asked our readers: Should municipalities in earthquake-prone areas require seismic retrofitting of existing homes and buildings to ensure more structures are earthquake resistant? Here are the results:*

Yes, and cities should help home/building owners pay for retrofits	59%
No, it's too costly for too many people	28%
Yes, and cities should pay for retrofits	10%
No, earthquakes are too unlikely to make it cost effective	3%
Yes, and home/building owners should pay for retrofits	0%
Don't know	0%

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

The 2016 AGI Status of the Geoscience Workforce Report

Positive Trends in a Hard Time

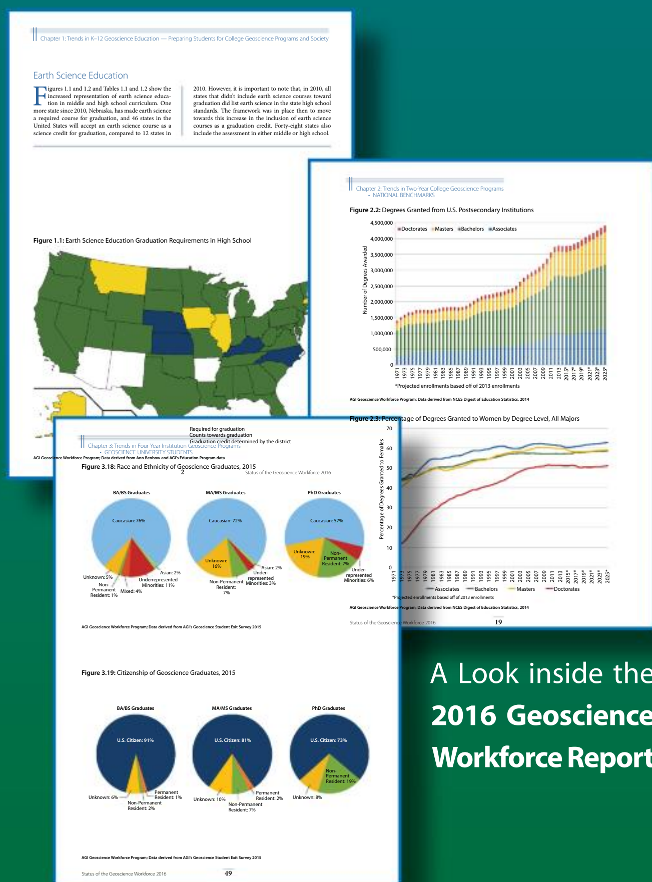


The 2016 Report (ISBN-13: 978-0-913312-54-4) is available for sale either digitally as a PDF for $10.00 or in print for $30.00.

Authored by Carolyn Wilson

The Status of the Geoscience Workforce 2016 report is based on original data collected by AGI as well as from federal data sources, professional membership organizations, and industry. The report integrates all of these various data sources into a comprehensive view of the human and economic parameters of the geosciences, including supply and training of new students, workforce demographics and employment projections, to trends in geosciences research funding and economic indicators. This edition highlights the issues facing institutions of higher education as they prepare future geoscientists as well as the current economic and personnel issues facing the geoscience workforce.

For more information and ordering information, please visit http://www.americangeosciences.org/workforce/reports.



A Look inside the **2016 Geoscience Workforce Report**

american geosciences institute
connecting earth, science, and people

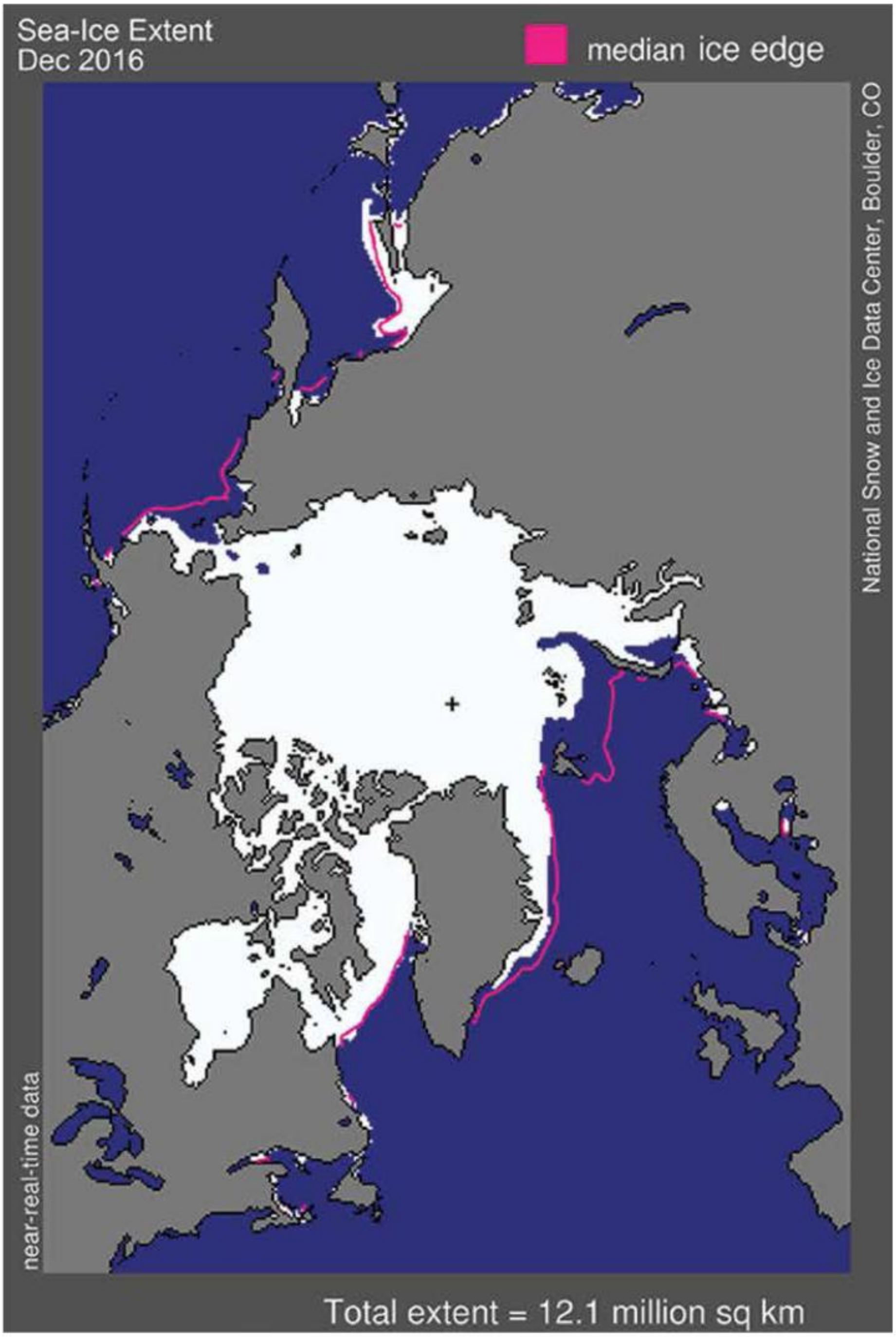
Crazy Times in the Arctic

Mark C. Serreze

I have studied the climate of the Arctic since the early 1980s. In that time, I've had a front row seat from which to observe the radical transformation of the region as I've been involved in research on the Arctic's atmosphere, sea ice, ocean circulation, snow cover, permafrost and hydrologic cycle. For more than a century, it has been recognized that, as atmospheric greenhouse gases increase globally, the resulting warming and its effects would be most pronounced in the Arctic. These predictions have been realized: Over the past several decades, the Arctic has warmed at roughly twice the rate as the rest of the planet. And the Arctic Ocean's sea-ice cover, which waxes and wanes with the seasons, growing through autumn and winter and shrinking through spring and summer, has gradually shrunk.

Sea-ice extents are declining for all months, but as assessed over the period of satellite observations (1979 to present), the extent at the end of the melt season in September is dropping at the remarkable rate of 13 percent per decade (relative to the average September extent from 1981 to 2010). Permafrost is also warming and, in some areas, thawing. Areas of treeless, windswept tundra are being taken over by shrubs. And the Greenland Ice Sheet is melting at an accelerating rate, contributing to rising sea levels. But through all of my time studying the Arctic, never have I seen anything like the events of the last year.

To start, in the winter of 2015–2016, an unprecedented heat wave occurred over the Arctic Ocean. At the end of December 2015, there was a brief period when the surface air temperature at the North Pole appears to have actually risen to above freezing. Late December temperatures at the North Pole at or above zero degrees Celsius are unheard of in the climate record. The heat wave persisted, slowing the wintertime growth of sea ice and, on March 24, when Arctic sea ice reached its seasonal maximum extent, it was the lowest maximum ever recorded,



The Arctic sea-ice extent for December 2016 was 12.10 million square kilometers — a record low for this time of year. The magenta line shows the 1981 to 2010 median extent for December. The black cross indicates the geographic North Pole. On Dec. 22, weather models showed temperatures near the North Pole about 17 to 22 degrees Celsius above average.

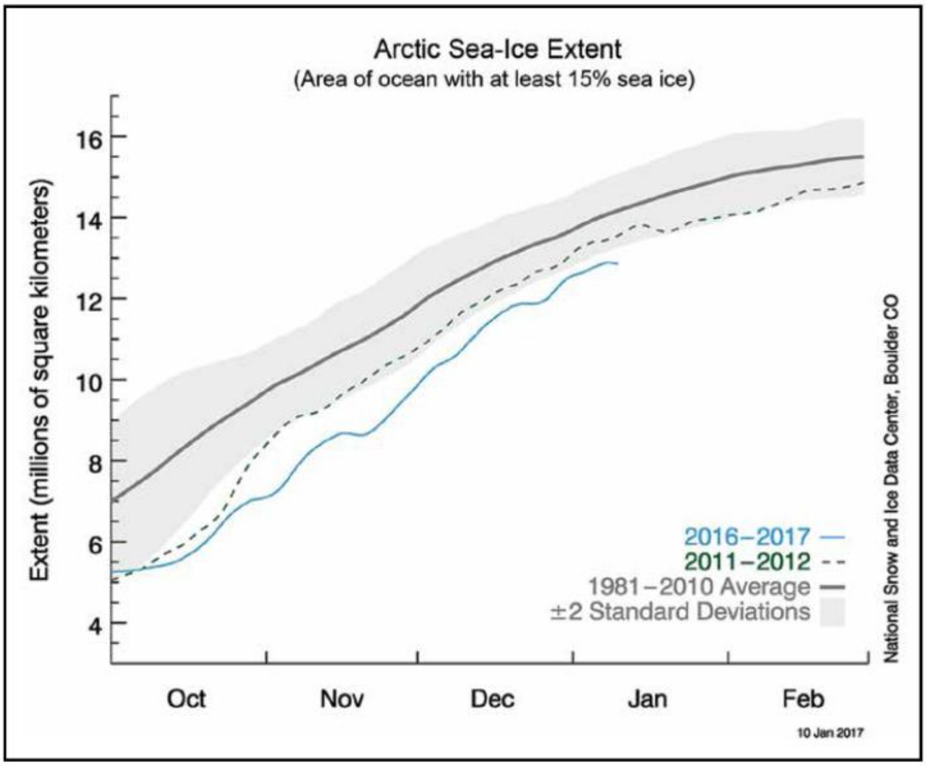
Credit: NSIDC

breaking the previous record set just a year earlier in 2015.

With much less ice than normal at winter's end, the melt season started out on a bad foot, leading to speculation that the following September would also see a new record low. As it turned out, the seasonal minimum extent, which occurred on Sept. 10, ended up as only the second lowest on record, largely because of the remarkably stormy conditions that occurred during the summer, including a pair of tremendously strong and deep low-pressure systems in August. Strong low-pressure systems have a tendency to chew up the ice cover, but they also tend to spread sea ice out over a larger area and bring cloudy and relatively cool conditions with them that inhibit melting. The summer of 2016 was the stormiest summer over the central Arctic Ocean in my experience.

After the Sept. 10 seasonal minimum, the sea ice started its annual pattern of growth, but then another heat wave — even more impressive than the one seen the previous winter — moved in over the Arctic Ocean. In autumn, the Arctic is usually cooling rapidly and sea ice is growing quickly, but both October and November saw record lows in ice extent for those months. There was even a brief period in the middle of November when ice extent actually declined. As I wrote the first draft of this column on Dec. 22, a day after the winter solstice, the Arctic Ocean heat wave was continuing, with the weather models showing temperatures near the North Pole about 17 to 22 degrees Celsius above average. Sea-ice extent continues to track at record low levels for this time of year.

What the heck is happening? By any measure, the heat wave of the winter of 2015–2016, as well as what we've seen this past fall and early winter, represent extreme events. I'd argue that last summer's excessive storminess also represents an extreme, albeit one that probably prevented yet another record-low September sea-ice extent. As any climate scientist will be quick to point out, it is never wise to read too much into individual extreme events — they happen. And there are identifiable causes for the events. Stormy summers tend to bring cool conditions over the Arctic Ocean, and both of the recent autumn/winter heat waves could be related to unusual patterns of atmospheric circulation drawing tremendous amounts of heat into the Arctic Ocean. There has also been a recent shift in ocean circulation, with more warm water from the Atlantic being brought into the Arctic; these warm ocean waters prevent sea-ice formation and warm the overlying air.



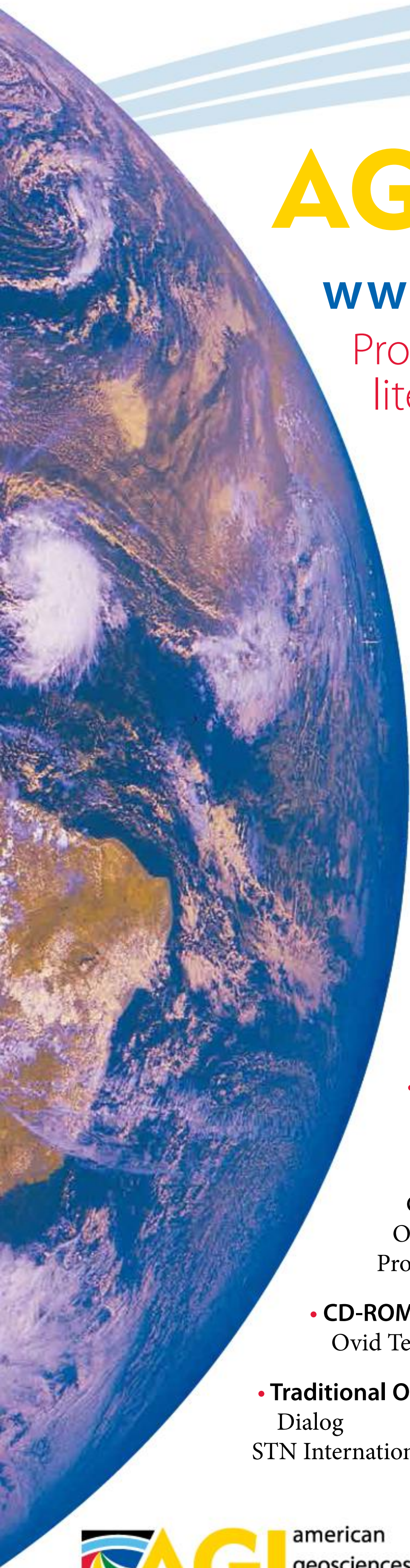
Measurements of sea-ice extent are collected daily. The gray curve in this time series indicates the average sea-ice extent for October through February from 1981 to 2010, with the two-standard-deviation uncertainty represented by the shaded area. The blue curve indicates measurements for the current season through Jan. 10, while the dashed green curve representing 2011–2012 is shown for comparison.

Credit: NSIDC

One could argue that these events are just expressions of natural variability in Arctic climate superimposed upon the overall pattern of warming and sea-ice loss. But changes in extreme weather and climatic events in recent years have been well documented around the world. Heat waves have tended to be hotter, and a warmer atmosphere can hold more water vapor, raising prospects for excessive precipitation. Random extreme events have always been a part of the climate system, but by loading the atmosphere with greenhouse gases, we've also loaded the dice. Are the recent events in the Arctic examples of what we'll be seeing more of in the near future? Time will tell. But after studying the Arctic and its climate for three and a half decades, I have concluded that what has happened over the last year goes beyond even the extreme.

Credit: Matthew Sturm, University of Alaska

Serreze is the director of the National Snow and Ice Data Center in Boulder, Colo., a professor at the University of Colorado Boulder, and a fellow of the Cooperative Institute for Research in Environmental Sciences. He can be reached at serreze@nsidc.org. The views expressed are his own.



GeoRef

GEOREF SERVICES

• GeoRef Preview Database

Want to check on new references even before they're available in GeoRef? Check out the GeoRef Preview Database at no charge at: www.americangeosciences.org/georef/georef-preview-database

This database, updated weekly, contains unedited references that have not yet been completed. Get a sample of the types of publications included in the GeoRef database or keep up with new publications!

• Other GeoRef Databases

Antarctic Bibliography, 1950-2011

The Antarctic Bibliography covers all scientific disciplines related to the region. The Antarctic Bibliography was produced with support from the National Science Foundation with contributions from the Scott Polar Research Institute, University of Cambridge.

Bibliography on Cold Regions Science and Technology, 1951-2011

The Bibliography on Cold Regions Science and Technology includes references to scientific and engineering research related to material and operations in a winter battlefield, the nature and impact of cold on facilities and activities, cold-related environmental problems, and the impact of human activity on cold environments. The Bibliography on Cold Regions Science and Technology was funded in part by the National Science Foundation and the U.S. Army Cold Regions Research and Engineering Laboratory.

For further information on the Antarctic and Cold Regions Bigliographies visit: www.coldregions.org/vufind/resources/about

CanGeoRef

CanGeoRef is a bibliographic geoscience database that covers the Canadian geoscience literature since the early 1800's. It is a product of a cooperative arrangement between the American Geosciences Institute and the Canadian Federation of Earth Sciences. CanGeoRef provides an affordable alternative to the GeoRef database for small organizations, companies and individuals working in the Canadian region.

For a 30-day free trial contact cangeoref@agiweb.org or visit: www.americangeosciences.org/georef/cangeoref-database

AusGeoRef

This bibliographic database, produced in cooperation with Geoscience Australia and drawn from GeoRef, contains information on Australian geoscience publications, both published in Australia or about Australia. AusGeoRef includes over 202,000 bibliographic references on geology in Australia back to 1840, drawn from journal literature, meeting proceedings and abstracts, books, reports and maps.

For further information visit: www.americangeosciences.org/georef/ausgeoref-database

Groundwater and Soil Contamination Database

This highly specialized database provides coverage of literature on the contamination of groundwater and soil. It includes over 157,000 bibliographic references to the worldwide literature on this subject. Documents cited in the database are primarily related to geology, hydrology, and the environment.

For further information visit: www.americangeosciences.org/georef/groundwater-and-soil-contamination-database

WWW.GEOREF.ORG

Early humans dealt with Ethiopian supervolcanoes

About 200,000 years ago, modern humans evolved in East Africa, including in what's now Ethiopia. They — like earlier hominins who had preceded them — likely encountered occasional explosive eruptions spewing ash and lava into the air and onto the landscape, according to a new study in Nature Communications.

Geologists from Ethiopia, the U.K. and the U.S. examined a 200-kilometer-long stretch of the active East African Rift in Ethiopia. There, warm underlying mantle is raising the regional landscape and slowly splitting the African Plate apart, leading to persistent volcanic activity along the rift. But the size and frequency of past explosions are uncertain, and scientists know very little about volcanic activity during the emergence of modern humans. Studying rock samples and geologic structures, the researchers found evidence for a 150,000-year pulse of explosive eruptions large enough to alter landscapes and, therefore, influence early human behavior and evolution.

Currently, more than 10 million people live within this active rift zone, and many of its volcanoes are poorly studied. "We wanted to figure out when the last eruption took place and how frequent explosive volcanism was, so we can make estimates as to the likelihood of future volcanic activity," says William Hutchison, a volcanologist now at the University of St. Andrews in Scotland and lead author of the new study.

To understand the eruptive history of the region, the researchers spent weeks in the field examining ancient lava flows. They also used satellite imagery and airborne laser scanning to map lava flows and other structural features, such as faults and calderas, from above.

To calculate the age of caldera collapse, Hutchison and his team identified the thickest pyroclastic sequence at each volcano. At two volcanoes, Aluto and Corbetti, they analyzed ratios of argon isotopes in crystals of the mineral sanidine, which tell when the crystals — and thus the rock they are in — cooled. To date two other volcanoes, Shala and Gedemsa, they used previously published data.

For post-caldera collapse deposits less than 50,000 years old, burnt vegetation — which was alive before being singed and preserved by flowing lava — from immediately beneath the rocks was dated using radiocarbon dating.

The team found that the volcanoes they studied — four of Ethiopia's largest — had explosive caldera-forming eruptions between 320,000 and 170,000 years ago. Eruption rates along the rift during that period were also five times above the average rate over the last 700,000 years, which came as a surprise, Hutchison says. "We expected that major explosive eruptions would take place at regular intervals, but, instead, found evidence for a burst of explosive activity," he says.

Hutchison and his team provided the first dated history for these volcanic centers, says Christine Lane, a geographer at the University of Cambridge in England who was not involved in the study. "It's an area we have so little data about, so it's really great to see some good chronology and good dating." The eruptions from the study were potentially similar in scale to the deadly 1883 explosion of Krakatoa in Indonesia, which spewed at least 10 cubic kilometers of material. Like Krakatoa, these East African eruptions would have blanketed the ground in ash and ejecta, disrupting habitats and water sources, and they would have left massive craters in the rift floor, Hutchison says.

The caldera walls of Corbetti Volcano, Ethiopia. The caldera was created 200,000 years ago during a colossal volcanic eruption.

Credit: William Hutchison

Modern geochronological techniques were used to calculate the age of volcanic deposits and build an eruptive history for the volcanoes of the Ethiopian Rift.

Credit: William Hutchison

The changes to the landscape raise the question of how the burst of volcanism impacted human evolution, migration and behavior. For example, if explosive volcanism is typical of the East African Rift, it's possible this activity pushed some early hominins out of Africa, Hutchison says. While previous studies have linked climate change and human evolution, little work has focused on the potential effects of volcanic activity, he notes.

"Evidence of this particular phase of volcanism — at this time that was so critical to hominin evolution — opens up the idea that we should be looking into this as well," Lane says. This work will also help scientists date archaeological sites in the region by matching ash found at the sites to ash deposits examined in this study, she says.

Large, explosive eruptions pose little risk to modern inhabitants of the area, Hutchison says. But Aluto and Corbetti, two silicic volcanoes, have both experienced frequent small eruptions over the past 20,000 years. The team also found lava and pyroclastic flows from events in the last 1,000 years, so there might still be hazards to the region, he says.

Bethany Augliere

Ants developed farming millions of years ago

A new study in Nature suggests that ants may have invented agriculture as much as 3 million years before humans.

On the Fijian islands of Viti Levu, Vanua Levu and Taveuni, the ant species *Philidris nagasau* actively cultivates at least six species of *Squamellaria* plants, using the plants for both food and shelter. All of the *Squamellaria* are epiphytes, or plants that grow on other plants, using their hosts for support and nutrients. The ants were observed gathering seeds from the fruits of the *Squamellaria* and inserting them into crevices in host trees. Worker ants constantly patrolled the seeds and, as the seedlings took root in the host, they defecated in the crevices, fertilizing the young plants. As the plants mature, they form hollow chambers at their bases, which the ants were observed using for nests. The ants also harvested the *Squamellaria* fruit, eating the flesh and collecting seeds for planting.

This kind of symbiosis — known as farming mutualism, in which one organism cultivates another for food and/or shelter — has been documented before in ants. The new study, however, offers a new example of obligate farming mutualism: Both the ants and plants are dependent on one another for survival. For example, *Philidris nagasau* ants no longer make their own nests, but rather depend on cultivating plants for shelter.

Guillaume Chomicki and Susanne Renner, both of the University of Munich in Germany, observed ant colonies simultaneously farming dozens of plants linked by a network of ant trails. These ant and plant colonies were sometimes found spanning several adjacent trees. Using DNA sequencing, phylogenetic analyses and molecular clock dating techniques, the team also approximated the start of the relationship between *Philidris nagasau* and *Squamellaria* to about 3 million years ago, when the plants developed a specific adaptation for bark anchoring, and the ants started their planting behavior.

A tree branch with several ant-farmed *Squamellaria* plants.

Credit: Guillaume Chomicki, University of Munich

Mary Caperton Morton

Discovered: One of the last-surviving Asian dinosaurs

Paleontologists have discovered a new species of oviraptorosaur, a group of strange bird-like dinosaurs without teeth. The species, *Tongtianlong limosus*, has been described based on a specimen preserved in mudstone dating to the end of the Cretaceous. The find adds to a growing list of newly unearthed and similarly aged oviraptorosaur species, suggesting the group flourished during the last few million years of the Age of Dinosaurs before all nonavian dinosaurs were killed off in the end-Cretaceous mass extinction.

"It's a type of bizarre, sheep-sized, beaked, feathered omnivorous dinosaur," says Stephen Brusatte, a vertebrate paleontologist at the University of Edinburgh in Scotland and an author of a new study in Scientific Reports announcing the discovery. As it was found, the skeleton of *T. limosus* had outstretched arms, splayed limbs and a raised head — gestures that Brusatte and his colleagues speculate resulted from the animal becoming stuck in mud.

"Amazingly, it is the sixth new species of oviraptorosaur found in the same small area of southern China over the past few years, as construction crews have been blasting through the area laying foundations and building roads," he says. The rapid rate of oviraptorosaur discoveries likely means this group of dinosaurs was "doing very well," Brusatte says. The researchers think that each of the new dinosaurs are unique species — not just different forms of the same species — because each possesses skeletal traits unseen in its relatives. For instance, *T. limosus* has a "highly convex premaxilla [upper jaw bone] that is unique among oviraptorosaurs," they wrote in the study. This diverse group was, Brusatte says, "part of that final wave of dinosaur diversification before the asteroid changed history forever."

An artistic reconstruction of *Tongtianlong limosus*, depicting how the bird-like dinosaur may have perished after getting stuck in the mud.

Credit: Zhao Chuang

Lucas Joel

Broadening ocean current could carry less heat poleward with climate change

Some ocean currents, like the Agulhas Current in the southwestern Indian Ocean, act like giant air conditioners, moderating Earth's climate by shuttling heat from the equator toward the poles. The Agulhas is one of the largest and fastest currents in the world: Flowing southwest along the east coast of Africa, it stretches almost 1,500 kilometers and transports about 70 million cubic meters of water every second toward the South Pole at peak speeds upward of 7 kilometers per hour.

University of Miami technician Mark Graham attaches an acoustic current meter to a mooring line during instrument deployment operations in the Agulhas Current in November 2011.
Credit: James Campbell

Sea-surface temperatures near several currents like the Agulhas, called western boundary currents, have increased more rapidly over the last century compared to temperatures elsewhere in the ocean. This rise in temperature — along with increasing velocities of wind systems across the world — has led researchers to suspect that western boundary currents are gaining strength and transporting more heat poleward.

In a new study in Nature, however, researchers suggest that instead of strengthening, the Agulhas Current is actually broadening and growing more chaotic — thus potentially transporting less heat poleward.

"On a global scale, broadening of the Agulhas Current would mean that the transport of heat towards the poles may decrease, rather than increase, with climate change, leading to warmer tropics and cooler polar regions," says Lisa Beal, an oceanographer at the University of Miami and lead author of the study.

At the local level, Beal says, it could lead to a larger exchange of pollutants and various animal larvae between the South African continental shelf and the open ocean. "This could affect nutrient flow, larvae survival, and ultimately, ocean productivity and fisheries."

To determine whether the current has been growing stronger, Beal and her University of Miami colleague, Shane Elipot, used measurements of sea-surface height gradients as a proxy for current strength.

Many factors, such as winds, tides, currents, and differences in temperature and salinity, can lead to some parts of the ocean surface being higher or lower than others. In general, the larger the difference in sea-surface height, or the steeper the slope of the ocean surface, the stronger the current.

Combining more than two decades' worth of satellite data on sea-surface height with three years of continuous on-site measurements using buoyant sensors moored to the ocean floor, Beal and Elipot found no significant changes in the strength of the Agulhas Current since the early 1990s. They did discover, however, that the offshore boundary of the current had expanded by about 50 kilometers.

It's possible, Beal says, that, rather than strengthening the linear flow of the Agulhas Current, higher wind speeds above the current are causing its flow to become more meandering or turbulent. Turbulent, chaotic areas within ocean currents are called eddies, and "if a current is eddying and meandering more — sometimes over [distances of] 100 kilometers in the case of the Agulhas — then its path is less linear as it flows, and it gets wider when averaged over time," Beal says.

An increase in eddy activity could indeed be causing the Agulhas Current to meander and broaden, says Arne Biastoch, an oceanographer at the Helmholtz Center for Ocean Research in Germany who was not involved in the study. But, he says, it's unclear what exactly is causing these turbulences. "Are these eddies local phenomena or are they drifting in from other regions like the Mozambique Channel?"

The analysis in the new study was confined to a single latitude, 34 degrees south, across the Agulhas Current, but both Beal and Biastoch think that the results can be extrapolated to the rest of this particular current. "The Agulhas Current is relatively narrow at this latitude, so you can measure its entire transport," Biastoch says, "and any change at 34 degrees south should be seen at other latitudes."

Figuring out the origin of increased eddy activity could help researchers determine whether the broadening of the Agulhas Current is an isolated incident, or if other western boundary currents might also be getting wider, which some previous evidence has implied.

However, it's unclear if the results of this study can be extrapolated to the rest of the ocean, Biastoch says, noting that western boundary currents in the Southern Hemisphere are difficult to compare.

Either way, Beal says, "this study will force us to examine some physical assumptions about how the ocean responds to winds, and to consider alternative hypotheses for the warming of currents like the Agulhas."

Adityarup Chakravorty

Early fossils demonstrate dinosaurs' slow rise

The skull of *Buriolestes*, an early saurischian dinosaur.
Credit: Cabreira et al., Current Biology, 2016

Dinosaurs were so dominant through much of the Mesozoic that it's easy to forget that wasn't always the case. The discovery of a specimen of an early small dinosaur alongside a lagerpetid — a precursor to the dinosaurs — is giving scientists a glimpse into the slow-paced early stages of dinosaur evolution.

Found together in the same 230-million-year-old deposit in Brazil, a saurischian dinosaur of the genus *Buriolestes* and a new species of lagerpetid called an *Ixalerpeton* represent some of the earliest-known fossils from the Early Triassic, which began about 250 million years ago. The find, reported in Current Biology, marks the first time that a dinosaur has been found in such close proximity to a dinosaur precursor, indicating the species coexisted.

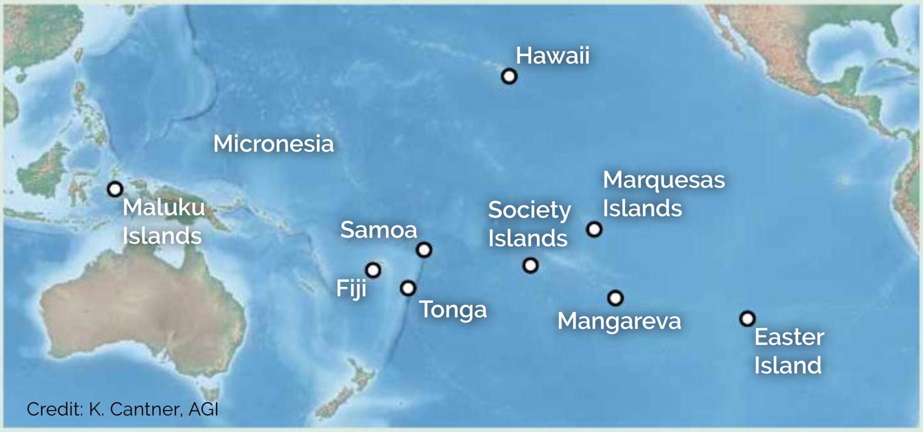
"We now know for sure that dinosaurs and dinosaur precursors lived alongside one another and that the rise of dinosaurs was more gradual, not a fast overtaking of other animals of the time," said lead author Max Langer of Brazil's University of São Paulo, in a statement.

The new discoveries fill some gaps in the dinosaur family tree. The new lagerpetid specimen also provides the first detailed look at the skull, scapula and forelimb of the creature, which is thought to have been a hunter of small mammals. The *Buriolestes* specimen is one of the oldest-known examples of a Sauropodomorpha, the group of long-necked dinosaurs that includes sauropods and their ancestors.

Mary Caperton Morton

Early Pacific seafarers set sail in El Niño years

Even with modern airplanes and ships, the far-flung islands of Tonga, Samoa, Hawaii, Micronesia and Fiji are difficult to reach. Thousands of years ago, the seafarers who first settled the islands had a much more arduous journey, sailing thousands of kilometers and navigating by the stars. According to a new study, these intrepid travelers may have gotten a boost from weather associated with El Niño-Southern Oscillation patterns, which sweep through the Pacific every three to seven years.



During El Niño years, winds and storms in the Pacific shift from primarily westerly to easterly, creating more favorable travel for those heading from already settled islands toward the remote islands of Oceania. "Through time, Pacific Islanders should have developed a great deal of knowledge of different climatic variations, different oscillations of wind and changes in environments that would have influenced their survivability and their abilities to go to certain places," said co-author Scott Fitzpatrick of the University of Oregon in a statement.

Using computer simulations, and climate data describing wind, ocean currents and precipitation patterns, Fitzpatrick's team analyzed potential routes across the Pacific. The simulations, reported in Proceedings of the National Academy of Sciences, identified the most likely points of departure and the paths of least resistance — with favorable winds, currents and island waypoints along the way.

They found that the first inhabitants of western Micronesia probably came from near the Maluku (Spice) Islands and that Samoa was the most likely staging area for colonizing East Polynesia. Their models also indicated that Hawaii and New Zealand may have been settled from the Marquesas or Society Islands, and Easter Island may have been settled from the Marquesas or Mangareva. Some of the team's findings are supported by archaeological evidence, while others challenge current theories of Pacific migration, Fitzpatrick and colleagues wrote.

Still unclear is the ultimate question plaguing Pacific archaeologists: Why would people set sail for unknown islands up to 4,000 kilometers away? "Was it political? Was it a result of population pressure?" Fitzpatrick said. "There were probably multiple reasons why people decided to leave one place and go to another."

Mary Caperton Morton

Improved genetic simulations identify human genes passed down from Neanderthals, Denisovans

You could have your mother to blame for a predisposition to baldness, but you might need to thank a Neanderthal for your ability to fight off disease. In the past decade, researchers have identified a number of genes in the human genome that they believe originated in *Homo sapiens'* close evolutionary kin, Neanderthals and Denisovans. Now, scientists have identified additional traces of such archaic genes in modern human DNA.

Neanderthals lived in Europe and western Asia between about 400,000 and 40,000 years ago; less is known about Denisovans, which have been identified from DNA studies as well as from a few scattered fossils found in Asia that date to about 40,000 years ago. In a new study published in the journal Molecular Biology and Evolution, researchers identified genes that were inserted, or introgressed, into human DNA as a result of interbreeding among Neanderthals and Denisovans and our ancestors. In a process called adaptive introgression, these genes, which likely each conferred some advantageous trait, were then propagated through the genome via positive natural selection.

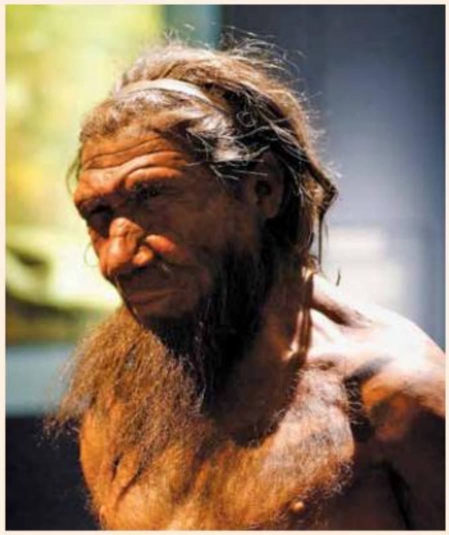
"Previous studies of this nature were rather straightforward, primarily focused on the frequency of archaic genes in modern human DNA," says Joshua Akey, a genomicist at the University of Washington who was not involved in the study. "This study provides a more sophisticated simulation that considers how these genes may have persisted in the genome if they conferred advantages to human ancestors."

Based on genes previously identified as having likely been passed down through adaptive introgression from Neanderthals and Denisovans, Emilia Huerta-Sánchez, a population geneticist at the University of California, Merced, and her colleagues identified genetic signatures — long regions of genome — in humans that are highly similar to the genomes of these archaic hominins. They used these signatures to develop statistical methods and computer simulations to search for genes not previously associated with adaptive introgression in a database of 1,000 modern human genomes.

"While only 2 percent of genes [in modern humans] on average show archaic signatures, the affected genes are concentrated in some very functional regions of the genome," Huerta-Sánchez says. The majority of both new and previously highlighted genes identified in the new study are involved in functions such as lipid metabolism, which could potentially affect body fat distribution; pigmentation, including the ability of skin cells to react to ultraviolet radiation; and innate immunity.

Genetic advantages in these regions of the genome would have helped modern humans migrating out of Africa survive new challenges in Europe and Asia, like bitter cold and novel pathogens, Huerta-Sánchez and her colleagues noted in the study. "Neanderthals and Denisovans had been living in these regions for hundreds of thousands of years, so it makes sense that they had adapted better genetic mechanisms for coping with these challenges," Akey says. "Receiving large portions of DNA from native hominins would have the potential for instilling a number of beneficial mutations into modern humans far faster than natural selection alone."

Improved statistics and simulations are important for identification of adaptive introgression and building a better understanding of its effect on human evolution, Huerta-Sánchez says. She and her colleagues also suggested several topics that need to be considered in future studies, including accounting for multiple gene-mixing events between modern humans and other hominins, more accurately defining genetic subpopulations like Native Americans, and determining whether genes affected by adaptive introgression actually conferred benefits or simply muted deleterious genes that were already present.



A reconstruction of a Neanderthal stands at the Natural History Museum in London. Genetic traces of Neanderthals and Denisovans have been identified in the DNA of modern humans.

Credit: Paul Hudson, CC BY 2.0

Beyond improving our understanding of human evolution, the new research could also impact what we know about the evolutionary histories of other animals. "Adaptive introgression is likely widespread in other species, so making it easier to identify [introgressed genes] may increase our understanding of their evolution," Huerta-Sánchez says.

Dogs might make a logical next target for such work as their evolution is already relatively well understood, Akey suggests. He says he is cautiously optimistic about the prospect: "In terms of species evolution, we know much more about humans, making it easier to map adaptive introgression [in our own lineage] compared to other species. However, this may be a rare case where human genetics helps us understand the evolution of lesser species instead of the other way around."

Josh Knackert

Beneath one volcano, enough water to fill Lake Superior

Beneath a Bolivian volcano called Cerro Uturuncu sits one of Earth's largest-known magma reservoirs, the Altiplano-Puna Magma Body (APMB), which may have a volume as large as 500,000 cubic kilometers. Dissolved in the APMB magma, scientists report in a new study in Earth and Planetary Science Letters, is enough water to fill Lake Superior or Lake Huron — two of the largest lakes in the world.

Water levels in magma bodies can help geologists predict how explosive future volcanic eruptions might be, says Terry Plank, a geochemist at Columbia University's Lamont-Doherty Earth Observatory, who was not involved in the new study. During an eruption, water in magma vaporizes, and "like opening a seltzer bottle, the gas coming out is what drives the eruption," she says. "The more water there is, the more potentially explosive it is."

But measuring exact water levels in magma is difficult. In "rocks that have just erupted, all the water just goes 'Pssshhh!' and it's gone," Plank says. Additionally, the APMB is between 15 and 35 kilometers below the surface, which rules out directly measuring its water content.

To study Cerro Uturuncu, researchers sampled rocks from multiple eruptions along the slopes of the volcano. In the lab, petrologist Mickael Laumonier of the Universities of Orléans in France and Bayreuth in Germany and his colleagues then infused the samples with water as they heated and pressurized the rocks to conditions seen in the actual magma body: up to 1,400 degrees Celsius and up to 30,000 times standard atmospheric pressure. By measuring electrical conductivity in their makeshift APMB magmas during the experiments, the team could tell how much water dissolved in the rock; the more conductive the sample, the more water was dissolved. They found that the APMB ought to be "between 8 and 10 percent weight of water," Laumonier says, which is about twice the amount proposed in previous estimates for similar magmas. "It was so common to find 4 to 5 weight-percent of water … that we didn't expect to find 8 to 10."

What is unclear from the new work, Plank says, is whether the magma might include other substances that, like water, can also increase the magma's conductivity. "They didn't really consider other conductive sources," she says, noting that there could be fluid carbon dioxide, which is very conductive.

If water levels in the APMB are as high as the new study reports, however, it's possible that eruptions from volcanoes that tap the magma body, like Cerro Uturuncu — one of the fastest-growing volcanoes in the world — could be particularly explosive. Cerro Uturuncu last erupted about 271,000 years ago, and volcanologists do not know when the next eruption will be. But the landscape around the volcano "is inflating, so it looks like new magma is arriving every day," Plank says.

On the other hand, if the volcano were to erupt, Plank notes that the water vapor in the magma may not escape quickly enough to increase the eruption's explosiveness. "It's how fast you open the cap of the seltzer bottle that's important," she says. "You could open the cap slowly" and the gas would escape more slowly, causing a relatively gentle eruption. Regardless of exactly how much water the APMB contains, though, it represents a significant hazard, Plank says. "It's huge, it's molten and, in the past, it has had enormous eruptions."

Lucas Joel

The Bolivian volcano Cerro Uturuncu, which last erupted about 271,000 years ago, sits above the Altiplano-Puna Magma Body.
Credit: Jon Blundy

How seafloor oil degraded after Deepwater Horizon

Much of the 4.1 million barrels of oil spilled into the Gulf of Mexico following the explosion of the Deepwater Horizon drilling rig in April 2010 settled on the ocean floor. A new study of the degradation of 125 hydrocarbon compounds in seafloor samples within four years after the spill showed that degradation rates depend on the size of the compound, with heavier-weight molecules taking longer to degrade. The oil was also found to degrade more slowly after deposition on the seafloor compared to when it was in the water column. The results could help researchers predict the fate of seafloor oil in future spills.

Bagby et al., PNAS, November 2016

Pleistocene Greenland was ice-free at times

Analyses of beryllium and aluminum isotopes in the only piece of Greenland bedrock cored from below the ice sheet show that the rock was exposed to cosmic rays (meaning it was ice-free and exposed to the atmosphere) for at least 280,000 years within the last 1.4 million years. The new finding indicates that the Greenland Ice Sheet, which holds enough water to raise global sea level by 7.4 meters, may not be as stable as previously thought.

Schaefer et al., Nature, December 2016

Chinese air pollution clears up mystery of London's 1952 hazardous haze

In December 1952, a fatal fog crept through London for almost five days, smothering the city in a yellow haze that reeked of rotten eggs. The "Great Smog," as it was called, caused up to 12,000 deaths and left more than 150,000 people hospitalized in the worst air pollution event in European history. The calamity sparked the British Parliament to pass the Clean Air Act in 1956, but the exact chemical processes that caused the event have remained a mystery, until now.

Haze results from an accumulation of fine particulate matter — liquid or solid particles with diameters smaller than 2.5 micrometers, which are often produced by coal burning and gasoline combustion, among other processes — in the air. Coal burning produces sulfur dioxide, which can be converted in the atmosphere to sulfate particulates in the form of sulfuric acid. That this conversion occurs is well known, says Renyi Zhang, an atmospheric chemist at Texas A&M University and co-author of a new study in Proceedings of the National Academy of Sciences. "Our objective was to find out the chemical processes leading to sulfate formation."

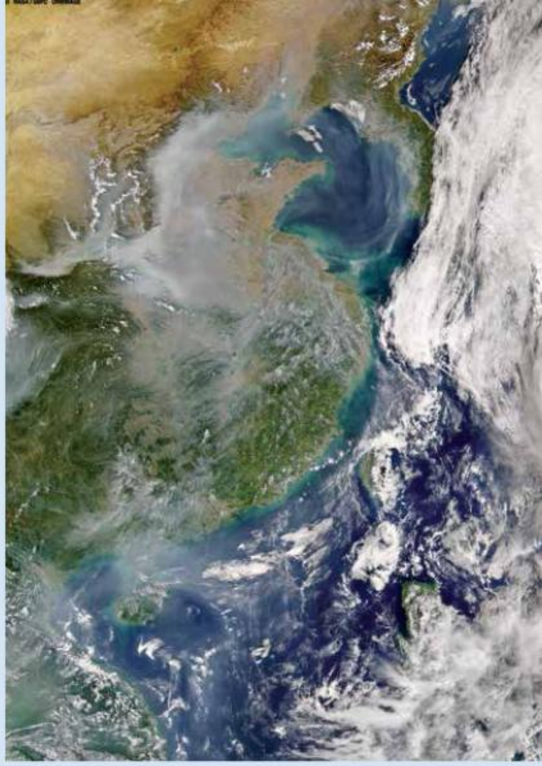
By studying severe haze events in two Chinese cities, Beijing and Xi'an, using a combination of atmospheric and laboratory measurements, Zhang and his colleagues have shed light on pollution problems in both modern China and mid-20th-century London.

"Every winter, the air quality in nearly every major Chinese city reaches horrifying levels, where visibility is sometimes reduced to a few hundred meters," says Russell Dickerson, an atmospheric scientist at the University of Maryland who was not involved in the study. At times, you might not recognize a friend across the street, he says. The World Health Organization recommends 25 micrograms per cubic meter as the maximum safe level of fine particulate matter; in China, it frequently rises above 100 micrograms per cubic meter and has soared to more than 500 micrograms per cubic meter at times. The smog in China's cities is not as acidic, or as acutely toxic, as that which engulfed London; nonetheless, at such high levels it can have severe negative impacts on human health, particularly respiratory health. "It's essential to understand the origin of those pollutants in order to have an effective solution to implement," Dickerson says.

The typical pathway for the conversion of sulfur dioxide to sulfate in the atmosphere involves hydroxyl radicals, Zhang says. This reaction takes about 10 days under normal conditions, but haze in China often forms in just one or two days, so that reaction doesn't explain the phenomenon. This led the team to think of other oxidants that could trigger the sulfur dioxide-to-sulfate conversion, including nitrogen dioxide, which also comes from coal burning and is in vehicle emissions as well.

Indeed, Zhang's team found that nitrogen dioxide contributed to the rapid production of haze in the presence of high humidity: Sulfate formed when nitrogen dioxide and sulfur dioxide mixed with water droplets in the air. Normally, this reaction would cause the resulting haze to acidify, which would then inhibit the reaction from continuing. But a third factor is atmospheric ammonia, which China produces in large amounts through agriculture and insufficient sewage treatment: Ammonia neutralizes sulfuric acid, allowing the haze-producing reaction to continue while simultaneously mitigating the toxicity of the Chinese haze, relative to what happened in 1952 London at least.

The researchers found that sulfate haze at concentrations of more than 100 micrograms per cubic meter was formed when sulfur dioxide and ammonia concentrations were about 50 parts per billion, the nitrogen dioxide concentration was several hundred parts per billion and the relative humidity was greater than 70 percent. Those conditions were reproduced in the laboratory with the same results. "You can only form this severe haze under such conditions," Zhang says.



Thick haze hangs over eastern China in October 2004.

Credit: NASA SeaWIFS Project

"Not only does this study help us understand where the pollution comes from in industrialized China," Dickerson notes, "but it might be predictive of air quality problems in other countries."

It also explains what happened during the Great Smog. Particles in the London fog started out two orders of magnitude bigger than those in China, according to previous meteorological experiments. Initially, these large water droplets diluted the acid that formed. Over time, however, water evaporated from the haze but the acid did not, which created a concentrated acidic fog for multiple days. London did not have the same amount of ammonia in its skies that modern China does; without the ammonia to neutralize the haze, the Londoners were essentially breathing in highly acidic particles. It was likely the acidity that led to so many deaths in December 1952, Zhang and his colleagues wrote.

Bethany Augliere

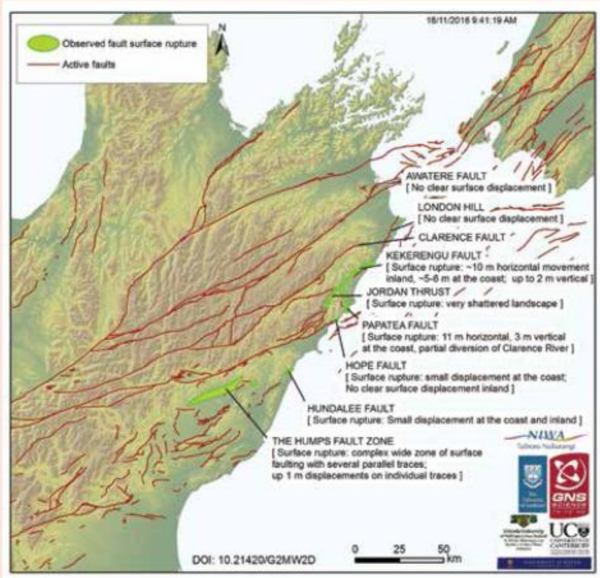
Kaikoura quake jumped from fault to fault in New Zealand

A magnitude-7.8 earthquake struck New Zealand's South Island at about midnight on Nov. 14, 2016, causing two fatalities, triggering a tsunami and multiple landslides, and destroying infrastructure across the region. Known as the Kaikoura earthquake, it is the largest quake to hit New Zealand since 2009, and it appears that the rupture jumped from one fault to another multiple times as it propagated. The event is still being investigated, but at the time EARTH went to press, at least 10 faults are reportedly thought to have been involved.

The rupture began about 15 kilometers underground near the town of Culverden. There was a "domino effect, as the earthquake rupture jumped from fault to fault, essentially 'unzipping' along a 150-kilometer length of the northeast coast of the South Island," wrote Natalie Balfour of New Zealand's earthquake monitoring agency, GeoNet, in a blog post. With several GeoNet seismic monitoring stations nearby, it "is arguably the most complex earthquake rupture ever to be observed in this level of detail with modern instrumentation," she wrote.

Rupture along the Kekerengu Fault displaced a house and road by as much as 10 meters, and the quake raised parts of the South Island's coastline above sea level by as much as 2 meters, according to data released by NASA. In a video posted to YouTube, GNS Science geologist Kelvin Berryman explained that, at Waipapa Bay along the Papatea Fault, one fault wall probably ruptured at a speed of about 3 kilometers per second, exposing what was once shallow seafloor to the air.

Lucas Joel



Map of New Zealand's South Island indicating some of the faults that ruptured during the Nov. 14, 2016, Kaikoura earthquake.

Credit: New Zealand GeoNet, GNS Science, NIWA, University of Auckland, Victoria University of Wellington, University of Canterbury, University of Otago

Tiny fish illuminates tooth fairy mystery

When kids lose their milk teeth, the roots shrivel up and just the outer enamel falls out — a process known as basal resorption. Now, the discovery of a tiny jawbone from a 424-million-year-old fossil fish is shedding light on the origin of our modern mode of tooth replacement.

Using a microscopic imaging technique called synchrotron x-ray tomography, a team led by Donglei Chen of Uppsala University in Sweden created a three-dimensional map of the entire sequence of tooth loss and replacement in the fossil specimen without damaging it. The study marks the first time that fossil dentition has been analyzed in such detail without cutting a specimen into sections.

"We can follow the process of growth and resorption right down to [the] cellular level, almost like in a living animal," said Per Ahlberg, Chen's colleague at Uppsala and a co-author of a new study in Nature reporting the findings, in a statement.

The researchers describe how the ancient fish replaced its teeth through basal resorption, and cite this as the earliest known example of the technique. "Every time a tooth was shed, the resorption process created a hollow where it had been attached," Chen said. The same process is seen in living bony fish, such as gar and bichir, with new replacement teeth developing alongside old teeth rather than underneath them, as in human toddlers.

"As we apply this technique to more early vertebrates, we will come to understand their life processes much better — and no doubt we will be in for some major surprises," Ahlberg said.

Mary Caperton Morton

Record-breaking North Atlantic wave

A wave measuring 19 meters from crest to trough, which was recorded by a buoy in the North Atlantic between Iceland and the U.K. on Feb. 4, 2013, has been designated as a new world record. The wave occurred after a cold front with high winds had passed. The North Atlantic holds both the previous buoy-measured wave-height record of 18.275 meters, which occurred on Dec. 8, 2007, and the ship-measured record, 18.5 meters, observed on Feb. 8, 2000, by a British oceanographic research vessel.

World Meteorological Organization, December 2016

Gravity changes may warn of large earthquakes

Large earthquakes alter the planet's gravitational field by displacing big portions of the crust. In a new study looking at earthquake-induced gravity signals produced by Japan's magnitude-9 Tohoku quake in 2011, researchers conclude that such signals may prove useful in earthquake early warning systems.

"During an earthquake, you have an instantaneous mass redistribution, and when you move mass, you change the way that gravity pulls on that mass," says Jean-Paul Montagner, a geophysicist at the Paris Institute of Earth Physics in France and lead author of the new study, published in Nature Communications. That change creates a transient "gravity signal," which becomes detectable within seconds to minutes after a rupture.

The Tohoku quake provided an ideal opportunity to study the effects of the quake on Earth's gravity, Montagner says. The event struck just 500 kilometers from a specialized superconducting gravimeter housed at the Kamioka Observatory in Gifu Prefecture, Japan. "This instrument was in a good configuration to pick up the [gravity] signal, not too close or too far from the earthquake," he says.

When Montagner and colleagues went back through the data collected by the gravimeter during the Tohoku event, they found a detectable gravitational shift approximately 65 seconds after the initial rupture, and about nine seconds before the first P-waves arrived in the area of the gravimeter. Gravity signals travel very near the speed of light, so the signals can be detected before seismic waves, which travel at closer to the speed of sound at Earth's surface. Such earthquake-induced gravity signals have never been detected before, in part because they are so small that they are usually drowned out amid the seismic noise produced by large earthquakes.

Detecting such signals also runs scientists into a famous conundrum in physics: Distinguishing rapid gravitational changes from subsequent inertial accelerations of the planet is often impossible. When gravity changes suddenly, the resulting unbalanced forces on Earth are countered by accelerations in Earth's mass that are equal and opposite to the gravity changes, so the two forces effectively cancel each other out. And because the changes happen almost instantaneously and nearly simultaneously, telling them apart in gravimetry data is challenging.

"This problem is part of what led Einstein to develop his theory of general relativity," says Thomas Heaton, a geophysicist at Caltech who was not involved with the study. "As long as the gravimeter is on the surface of the Earth, it will be very difficult, if not impossible, to pick out gravitational changes from the motions of the Earth itself."

Montagner says the Tohoku event provided the perfect scenario — a very large earthquake occurring near a gravimeter — to pick out gravity signals, and improvements in instrumentation, especially gravity gradiometers, could improve detection capabilities. Gravity signals start off small and then grow, so a more sensitive instrument may have been able to detect the signal even sooner, he says. "We are at the limit of sensitivity for these [current] instruments," he says. "That's how science often works: We work at the limits of our knowledge and capabilities. Perhaps in the future, we will find a better way of detecting these signals."

If researchers can reproduce the findings of this study for another large earthquake, such as the magnitude-8.2 quake that struck Iquique, Chile, in 2014, it would support the notion that gravity shifts from large quakes could be useful in earthquake early warning systems in the future, Montagner says. Currently, most earthquake early warning systems, like ShakeAlert, used on the U.S. West Coast, rely on the detection of P-waves, which travel faster and arrive seconds before the more destructive S-waves.

The idea of using gravity signals for earthquake early warning systems faces skepticism, however. "When it comes to early warning systems, there are more promising ways to improve our system than looking for gravity changes," Heaton says, such as improving P-wave detection algorithms and the logistics of early warning system networks.

Debris lines a canal in the coastal Japanese town of Ofunato following the March 2011 Tohoku earthquake.

Credit: U.S. Navy photo by Mass Communication Specialist 1st Class Matthew M. Bradley

But if gravity waves could potentially provide even a few more seconds of notice ahead of damaging shaking, it could make a big difference, Montagner says. "If we can save just two or three seconds, it might be enough time to stop trains, nuclear plants, elevators and cars," which could mitigate damage and casualties.

Mary Caperton Morton

USGS announces largest-ever estimate of continuous oil

In a recent assessment, the U.S. Geological Survey (USGS) estimated that the Wolfcamp Shale in the Midland Basin of West Texas holds approximately 20 billion barrels of oil along with 16 trillion cubic feet of natural gas, both as continuous resources dispersed through the shale. It's the largest estimate of a single continuous oil deposit ever by USGS, almost tripling the 2013 assessment of continuous resources in the Bakken-Three Forks Formation in Texas.

U.S. Geological Survey Press Release, November 2016

South Africa's Barberton greenstone belt contains fossil soils that reveal an earlier start for life on land.
Credit: Sami Nabhan

Life on land 300 million years earlier than thought

Life emerged on land about 300 million years earlier than previously thought, according to a new study in Geology by scientists who discovered minerals in 3.22-billion-year-old rocks that they suggest could only have formed with the help of biological processes.

Researchers led by sedimentologist Sami Nabhan, of Friedrich Schiller University Jena in Germany, studied rocks from the Barberton greenstone belt (BGB) in northeastern South Africa, which contains some of Earth's first terrestrial sedimentary rocks. It's "one of two places in the world where you can see rocks of this age in such good preservation," Nabhan says, the other being in Pilbara in Australia.

Nabhan and his colleagues were looking for signs of life in the ancient rocks, which is not easy; in general, the rock and fossil records are sparser and more degraded the further back in time one goes because weathering and tectonics have had more time to destroy and deform the rocks. But the BGB rocks are "beautifully preserved," so much so that they look like they could be 3 billion years younger than they are, Nabhan says.

In the sedimentary structures preserved in the rock, "you see cross-bedding, you see ripples, you see desiccation cracks, you see these channels filled with conglomerates," Nabhan says. All of these features point toward an ancient braided river setting where the team found ancient paleosols, or fossilized soils, that they could date.

The paleosols contain the mineral pyrite, which is made of iron and sulfur. Microbes incorporate sulfur into their biomass, Nabhan explains, and they can also use sulfur compounds like sulfate to gain energy. When they do this, they selectively use sulfate containing light-weight isotopes of sulfur, he says, which leads to sulfur isotope fractionation in minerals that precipitate in the same environment. The pyrite from the BGB paleosols is enriched in "very light sulfur isotopes," Nabhan says, suggesting life played a role its formation.

Life is not absolutely required for the kind of isotopically light pyrite grains found in the paleosols to form, says Paul Mason, a geochemist at the University of Utrecht who was not involved in the new study; similar fractionation can occur abiotically at temperatures above about 150 degrees Celsius. But, "if the temperature of the paleosol never exceeded 150 degrees or so, then microbial pathways are the only pathways to induce [sulfur] isotope fractionations." Another abiotic process that could be responsible is transportation and introduction of the light isotopes by hydrothermal fluids, Mason says. But this is unlikely, Nabhan says, because the paleosols bearing isotopically light pyrite are traceable over a wide area, whereas hydrothermal fluid transport probably would occur through localized networks of cracks or veins in the rock.

Nabhan says he thinks his team has found the oldest-known evidence for life on land. But, he says, it's possible "that within the next two or three years … other scientists will publish something that pushes it back a few more million, or tens of millions of years."

"It's quite a logical idea that we find life on land at that time," Mason says. "It's a natural consequence of microbial evolution … I don't think in itself it's an especially surprising result, but it's exciting to extend the boundaries" of when we know life first appeared on land.

The team has "done a lot of really good geological and sedimentological background work," Mason says, which is essential when studying Archean-aged rocks in which direct evidence for life is often nonexistent. "Every study is an important piece of the jigsaw puzzle to build up a picture of how the early biosphere was developing."

Lucas Joel

Paleolithic Europeans may have started wildfires on purpose

Pollen data suggest that Europe was mostly unforested during the last glacial maximum about 20,000 years ago, but paleoclimate models indicate that much of the continent could have hosted forests despite the harsh climate. Now, researchers reconcile the two ideas by suggesting that wildfires set by hunter-gatherers roaming Europe at the time — perhaps to open up landscapes to aid foraging and hunting — could have dramatically reduced forest cover.

Kaplan et al., PLOS One, November 2016

Ancient super-sized sulfur bacteria found

Fossilized impressions of "exceptionally large" sulfur-oxidizing bacteria have been found in South African chert that formed 2.52 billion years ago in a deep-sea environment. The fossils range in size from 20 to 265 microns (most modern bacteria are about 1 micron), and are the oldest reported sulfur bacteria. They "reveal a diversity of life and ecosystems, previously only interpreted from geochemical proxies, just prior to the Great Oxidation Event," researchers wrote.

Czaja et al., Geology, October 2016

To cool the planet, volcanoes of the future will need more firepower

On June 15, 1991, Mount Pinatubo sent a plume up 40 kilometers into the stratosphere.
Credit: David H. Harlow, USGS

Explosive volcanic eruptions can spew sulfur gas into the stratosphere — the layer of the atmosphere above where most clouds and weather occur — where it forms sulfate aerosols that reflect sunlight back into space and cool the planet. Now, researchers investigating how volcanic plumes could be affected by projected anthropogenic warming have found that, as temperatures rise, it becomes more difficult for volcanic plumes to reach the stratosphere.

"We know that volcanic eruptions can impact climate, but we wanted to know if this can happen in reverse too.… Can climate change impact how efficient volcanic plumes will be at cooling the planet in the future?" says Thomas Aubry, a doctoral student at the University of British Columbia in Vancouver and lead author of a new study in the Journal of Geophysical Research: Atmospheres.

Aubry and his colleagues used a volcanic eruption plume model, based on projected changes in atmospheric temperature and wind profiles as predicted by global climate models, to assess how high plumes are likely to ascend over the next 300 years. Climate model results were obtained by using three different greenhouse gas emissions scenarios characterized by low, medium and high greenhouse gas forcing and its associated impact on atmospheric temperatures over time. The eruption plume model itself was based on conditions — including plume temperatures and velocities, relative humidity, and atmospheric winds — during historical eruptions in 12 volcanically active regions.

"Plume height is a critical factor in how volcanic eruptions impact climate," Aubry says. When plumes reach only into the troposphere, they tend to be quickly washed out by precipitation and thus have relatively little impact on climate. "But if an eruption plume reaches into the stratosphere, sulfate aerosols can circulate around Earth for over a year, scattering shortwave radiation, absorbing longwave radiation and causing a net cooling of the underlying troposphere," he says. The most recent example of this was the global cooling that occurred for a couple of years following the 1991 eruption of Mount Pinatubo.

In the new study, the researchers found that under the medium and high greenhouse gas scenarios, fewer eruption plumes will reach into the stratosphere in the coming centuries. That's because the troposphere is warming, Aubry says, and a warmer troposphere causes plumes to stop rising: Much like hot air balloons, volcanic plumes rise because they are warmer than the surrounding atmosphere. When the plume reaches an elevation where the air is of similar temperature and density, it stops rising and spreads out. A thicker and more stratified troposphere means that "volcanic eruptions will require more firepower" to reach elevations at which they can exert a cooling effect on the planet, Aubry says.

The work suggests a previously unrecognized positive feedback between climate and volcanic aerosol-radiation. As global warming reduces the frequency of stratospheric injections of volcanic plumes, the long-term average concentration of sulfate aerosol particles in the stratosphere will decline. This will reduce the albedo, or reflectivity, of the atmosphere, which, in turn, would enhance subsequent warming, Aubry says. Of further concern is that global carbon dioxide emissions currently exceed the values within the high greenhouse gas forcing scenario — meaning this process may be already underway.

"The results are surprising," says Alan Robock, a climate scientist at Rutgers University who was not involved in the study. "I had never thought of this impact of global warming on the ability of eruptions to get sulfur into the stratosphere… it is an interesting new understanding of how the climate system works."

Changes in volcanic plume behavior related to greenhouse gas concentrations will likely have only a small impact on the overall climate trajectory, Aubry says, but explosive eruptions matter a lot on shorter timescales. "Studies suggest that an increase in volcanic gases in the stratosphere was a driver of the recent climate hiatus," he says, referring to an approximately 15-year period from 1998 to 2013 during which global warming appeared to slow.

Volcanic eruptions are unpredictable; consequently, few climate models incorporate changes in volcanic forcing into their projections, Robock says. But this study challenges assumptions about steady-state volcanic forcing. "Greenhouse gas-driven climate change could result in less cooling from volcanic eruptions," Aubry says. "Our study gives a way to predict a trend in volcanic forcing."

Kate S. Zalzal

Antarctic warming outpaced global average after last glaciation

Antarctica warmed by about 11 degrees Celsius within 5,000 to 10,000 years after the last glacial maximum, according to a new study coupling temperature measurements from a deep borehole drilled into the West Antarctic Ice Sheet with ice core isotopic data. The estimate is two to three times that of the global average temperature rise over the same period, and highlights the heightened sensitivity of polar regions to changing climates.

Cuffey et al., Proceedings of the National Academy of Sciences, November 2016

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.

Large, tabular icebergs float in Pine Island Bay, part of the Amundsen Sea off the coast of West Antarctica.

Credit: James Smith

- Since satellite observations of the West Antarctic Ice Sheet (WAIS) became available in the early 1990s, scientists have documented continuous rapid retreat and thinning of the massive Pine Island Glacier (PIG), which drains roughly 10 percent of the WAIS into the Amundsen Sea. Calving of enormous icebergs in recent years, including one about eight times the size of Manhattan in 2013, has dramatically demonstrated the rapid loss of ice from the PIG. But when this modern episode of glacial retreat began has been unclear. Based on analysis of sediment cores collected from beneath the glacier's floating ice shelf, James Smith of the British Antarctic Survey and colleagues reported in Nature that it likely dates back to about 1945, when the base of the PIG began retreating from a large seafloor ridge on which it had been grounded. A transition in the cores, from sand and gravel to muds containing the remains of open-ocean plankton, suggested that seawater started seeping past the ridge at this time, forming an ocean cavity beneath the ice shelf and facilitating melting of the shelf from below. The timing of the initial retreat from the ridge, which was completed by about 1970, correlated with an El Niño-associated period of warming in West Antarctica.

- In another study of the PIG, researchers found evidence of a glacial calving mechanism not observed before in Antarctica: Rifting in a 2015 calving event that loosed a 588-square-kilometer iceberg "originated from the center of the ice shelf and propagated out to the margins," noted Ian Howat of Ohio State University, co-author of the Geophysical Research Letters study, in a statement. "Rifts usually form at the margins of an ice shelf, where the ice is thin and subject to shearing that rips it apart," he said. Based on analysis of Landsat 8 imagery, Howat and his colleagues found that the rift — first spotted in images taken in 2013 and occurring farther up-glacier than previously observed — had started at the base of the ice shelf before propagating upward and eventually reaching the surface. The most likely explanation for the rifting style, the researchers suggested, is the formation of crevasses in the base of the ice shelf caused by melting by warm ocean water.

- The Greenland Ice Sheet releases roughly 1,000 cubic kilometers of freshwater each year in the form of icebergs and meltwater into fjords and ocean basins that surround the island. But little is known about the proportions of this volume that come directly from glaciers versus from melting icebergs as they float through fjords toward the open ocean. Parsing these contributions is important for understanding how Greenland meltwater affects circulation in fjords — which in turn impacts further melting and breakup of glacial termini, wrote Ellyn Enderlin of the University of Maine and her colleagues in a new study in Geophysical Research Letters. It is also important for refining global ocean and climate models, they noted. Tracking icebergs in Ilulissat and Sermilik fjords for months using satellite imagery, the team calculated ice volumes lost to melting before the icebergs exited the fjords. They found that 10 to 50 percent of iceberg melting occurs in the fjords — more than previously assumed — and that icebergs contribute more meltwater overall to fjords than glaciers do through most of the year. "Iceberg melting is huge, and so if you don't take that into account you're going to come up with some crazy high estimates for glacier melting that might not be representative," Enderlin said in a statement.

- NOAA released its annual Arctic Report Card in mid-December, citing evidence for continued warming across the Arctic in 2016. Among other observations, the report highlighted that average Arctic surface air temperatures for the year ending in September 2016 were "by far the highest since 1900"; that the summer minimum sea-ice extent was the second lowest since 1979, the year satellite record-keeping of the Arctic began (the sea-ice extent in November was the lowest on record for the month); and that the Greenland Ice Sheet saw the second-earliest onset of spring melting in 37 years.

Timothy Oleson

Articulated dinosaur fossils can still be found at the Flaming Cliffs, and frequently are — by tourists, guides, locals and poachers. Mongolian law instructs those who find such specimens to notify the area's single ranger, but no signage or leaflets exist to convey this. Even when a fossil is reported, Bayanzag Park has no resident paleontologist to excavate it, no prep lab to clean it, no collections facility to store it and no museum to display it.

Credit: Thea Boodhoo

SAVING MONGOLIA'S DINOSAURS

And Inspiring the Next Generation of Paleontologists

Thea Boodhoo

The bones were too yellow, too translucent, and the skeleton had no hands. I could tell the skeleton wasn't a dinosaur, but the illusion was enough to bring my brain to a momentary halt.

"He made this out of camel bones," said Aza, my guide at Bayanzag Park in the Mongolian Gobi, home of the Flaming Cliffs where *Velociraptor* was first discovered. The artist behind the camel-bone creation, Munkhbaatar, had a genuine love of dinosaurs but no scientific training.

"There are some fossils in the other room," Aza noted. We stepped into a dusty alcove where most of a vertebral column, complete with ribs and as long as a loveseat, lay across a low shelf, still in its red-orange sandstone matrix. It was likely from the Nemegt Formation, known for dinosaurs. It belonged in a museum collection, but this small, unofficial building was the closest thing the park had to one.

I was there as a representative of the Institute for the Study of Mongolian Dinosaurs (ISMD) to assess the status of fossils in the park and meet with locals to plan informational material. Ever-present in the back of my mind was the need for a museum in the park, with community outreach programs, a lab and collections facilities.

I had met the ISMD's founder, Bolortsetseg Minjin, the previous summer, a world away from the

Replica fossils, including teeth, tail spikes and a *Triceratops* horn, get young Mongolians excited about paleontology. Paleontologist Bolortsetseg Minjin hopes to inspire some of the children to pursue careers in paleontology and all of them to see poaching as an activity that robs their country of its fossil heritage.
Credit: Thea Boodhoo

Flaming Cliffs. I had spent that summer at Dinosaur National Monument in Utah working on an interactive quarry map. One morning, I heard that some Mongolian VIPs were visiting. One of them was Bolortsetseg (who, like most Mongolians, seldom uses her last name), a paleontologist I had read about who played a key role in bringing a poached *Tarbosaurus* skeleton home to Mongolia. She agreed to an interview for the blog I wrote that summer and told me about the challenges facing Mongolian paleontology. We talked about her ongoing science outreach work with Mongolian youth and her dream of a permanent museum at the Flaming Cliffs. Bayanzag Park is one of the most popular tourist spots in Mongolia, and the cliffs are considered by many paleontologists to be paleontological holy ground. Her visit to Dinosaur was, in part, research for a future Bayanzag museum.

The next time we met, six months later, was over noodles at a Korean restaurant in Manhattan. This time, she interviewed me — about creating a website for the Flaming Cliffs. Our discussion continued over weekly cross-country calls (I live in San Francisco; she in New York City) and evolved into a crowdfunding campaign, a suite of outreach materials, a social media presence and a lot of IRS paperwork. I became an officer and director of the ISMD when we registered as a U.S. nonprofit in July, and by September I was in the Gobi Desert, at a place most paleontologists only dream of visiting, standing next to a dead camel mounted to look like a theropod.

Bolortsetseg and I landed in Ulaanbaatar on Aug. 31, 2016, ready and packed for an expedition across rural Mongolia to bring the science of dinosaurs to kids who literally live on top of them. A roving museum, $46,000 in crowdfunded support, a Land Cruiser full of fossil replicas and printed worksheets, two drivers and a translator/educator all came together to make this Bolortsetseg's biggest workshop season yet. My job was to document everything and tell the story. It was a dream project for someone with my mixed background in communication and science, and it was an honor to see Mongolia for the first time with a native. Better yet, a native paleontologist.

Since 2009, Bolortsetseg has brought fossil replicas to workshops like this one in Arvaikheer.
Credit: Thea Boodhoo

Bolortsetseg joined the first American Museum of Natural History (AMNH) expeditions to the Mongolian Gobi after her country emerged from Soviet influence. In this 1997 image, she is jacketing a *Khaan mckennai* specimen at the Ukhaa Tolgod site.
Credit: Bolortsetseg Minjin

The Paleontologist's Daughter

Bolortsetseg was born in Ulaanbaatar, Mongolia's capital city. Her mother taught at a local college and her father, Minjin Chuluun, was a respected invertebrate paleontologist. In 1996, Professor Minjin was invited on an expedition led by paleontologists Mike Novacek and Mark Norell of the American Museum of Natural History (AMNH) in New York. With some effort, Bolortsetseg's father convinced the Mongolian crew to enlist her as a cook. Her master's in paleontology hadn't exactly prepared her for carving mutton and frying dumplings, so she spent her days prospecting, bringing in delicate mammal and lizard fossils for which she had a keen eye. This earned her the wrath of the Mongolian team leaders, who swore she would never be invited back into the field with them. But she also earned the respect and support of Novacek and Norell, who invited her to complete a doctorate through a joint program of City University of New York and AMNH.

She left Mongolia that year for the first time, barely speaking English and not knowing a soul in New York aside from the paleontologists she worked with.

AMNH left a deep impression on Bolortsetseg the first time she entered the building. Mongolia had a handful of museums at the time, but nothing compared to even the entrance hall at AMNH. And behind the scenes were vast fossil collections, labs and highly skilled professionals who deftly handled, prepared, shipped and mounted fossils of all sizes. She says she realized quickly how much work would have to be done before her own country — whose fossils were this museum's bread and butter — would be ready to do its dinosaurs justice. That work became her mission.

The Flaming Cliffs are the first place dinosaur fossils were discovered in Mongolia, by AMNH expeditions during the 1920s. Today, the cliffs and their fossils are legally protected as part of Bayanzag Park, but enforcement of that protection is underfunded and facilities for fossil storage and preparation are nonexistent.
Credit: Thea Boodhoo

Like many fossils from Mongolia, this *Protoceratops* is fully articulated and preserved by sandstone in three dimensions, making it a highly sought-after specimen. Also, like many fossils from Mongolia, it was exported from Mongolia illegally for sale to a private collector in the United States.

Credit: Bolortsetseg Minjin

The Dinosaur Exodus

The history of paleontological science in Mongolia began in 1922, when AMNH sent zoologist Roy Chapman Andrews on the third of the Central Asiatic Expeditions. Andrews led a team of paleontologists, geologists and archaeologists into the Gobi Desert. It was here, at a red sandstone outcrop, that Andrews named the Flaming Cliffs, where they found their first Mongolian dinosaur: *Protoceratops*.

AMNH pulled out of Mongolia in 1925 as Soviet influence took hold, but that didn't mark the end of exploration in the country. In the late 1940s, a Soviet expedition discovered the giant tyrannosaur *Tarbosaurus bataar*. In the 1960s, paleobiologist Zofia Kielan-Jaworowska led the Polish-Mongolian Expeditions, discovering the enigmatic *Deinocheirus* and the famed "fighting dinosaurs" specimen of a *Velociraptor* and *Protoceratops* locked in mortal combat. Once the Cold War ended, AMNH quickly returned, and they've been sending expeditions almost every summer since.

Today, the Flaming Cliffs is known worldwide among fossil enthusiasts. The Cretaceous-aged red sandstone matrix preserves stark white fossils in three dimensions, often fully articulated. The "Jurassic Park" film franchise added to the site's fame in 1994 when it chose the name of a certain small, feathered Flaming Cliffs theropod for its human-sized, scaly antagonists. Today, *Velociraptor mongoliensis* is one of the most well-known dinosaurs, everywhere except Mongolia.

When Bolortsetseg first visited Mongolia after moving to New York, she started talking to kids about dinosaurs. Most had never seen a dinosaur fossil. None could name a species from Mongolia. Some even told her dinosaurs were mythological.

Few Mongolians know that *Velociraptor* was first discovered in their country, in part because each fossil excavated has been taken elsewhere for display.

Credit: illustration by Emily Willoughby, courtesy of the Institute for the Study of Mongolian Dinosaurs

Roy Chapman Andrews may have begun a prestigious tradition of dinosaur paleontology in Mongolia, but his expeditions also heralded a less noble legacy: removing fossils from the country. When Andrews published his riveting tales of scientific discovery, Mongolia's fossil riches caught the attention of collectors from around the world and a black market trade was born. Mongolians desperate under Soviet influence, and later during the aftermath of the Soviet Union's collapse, were more than happy to extract old animal bones for money to feed their families.

Today, Mongolian laws prohibit the export of vertebrate fossils and require excavators to carry permits, but those laws have been hard to enforce without funding or manpower. In the last four years, Bolortsetseg has helped repatriate more than 30 illegally exported Mongolian dinosaurs that have turned up in the U.S. alone.

Preventing Poaching With Education and Infrastructure

The realization that so many fossils had been stolen over the past century inspired Bolortsetseg to take action. "Once a fossil left the country," she says, "knowledge left with it."

This realization spurred her to create the ISMD. Paperwork went through the Mongolian legal system in 2007. In 2009, with support from paleontologist Jack Horner, then of the Museum of the Rockies in Montana, the new organization launched Mongolia's first dinosaur-focused outreach project. It was a workshop to teach 32 rural and nomadic children about the dinosaurs of their homeland.

The workshops have been a hit with kids and teachers almost every summer since, but a box of replicas and a PowerPoint presentation can only go so far. Back in New York, Bolortsetseg focuses much of her time on bringing real dinosaurs back to Mongolia. Seeing the skeletons in person, she says, will have a much bigger impact.

Bolortsetseg says she hopes that bringing dinosaurs back to Mongolia will help future Mongolians summon the names of *Velociraptor*, *Protoceratops* and *Oviraptor* as easily as the average American conjures *Triceratops*, *T. rex* and *Stegosaurus*. A host of benefits should come with the infrastructure envisioned to make this dream real: increased tourism, local science literacy, a conservation mentality and economic opportunities. With locally relevant programs and a conscientious fee structure, fossil parks and museums have the power to improve the well-being of rural communities by serving as gathering places that foster conversation and inspire new ways of thinking. Eventually, by helping Mongolians see dinosaurs as more valuable when they stay in the country, Bolortsetseg hopes to prevent incidents like what happened in 2012.

In one workshop activity, children determine the sequence of events between a dinosaur dying and a paleontologist discovering its remains millions of years later.

Credit: Thea Boodhoo

It may look like a child's toy collection, but these models are a core component of each Institute for the Study of Mongolian Dinosaurs (ISMD) workshop kit. In one activity, the plesiosaurs, smilodons and crocodilians are used to differentiate dinosaurs taxonomically from other animals that are often mistakenly called dinosaurs.

Credit: Thea Boodhoo

A *Tarbosaurus* Comes Home

"A giant short-armed, two-fingered predatory dinosaur from Asia of 70 million years ago," is how University of Maryland paleontologist Thomas Holtz described *Tarbosaurus bataar*. I'd challenged him to do so without mentioning *T. rex*, the standard to which most people compare large theropods. Since 2012, however, *Tarbosaurus* has become the most famous dinosaur in Mongolia.

Tarbosaurus was discovered in the Gobi in 1946, but came to international fame in 2012 when an illegally exported specimen went up for auction in New York. "Luckily I found out about that auction just three days before the auction date," Bolortsetseg says. She then reported the proposed sale to the Mongolian government. The president of Mongolia intervened and, with support from the U.S. government, the fossil narrowly escaped sale to private bidders. It came home a year later. It now resides in the Central Museum of Mongolian Dinosaurs, where anyone in Ulaanbaatar can visit it.

The success of the *Tarbosaurus* repatriation marked a new phase for the ISMD. The story had been followed closely in Mongolia, and suddenly kids in her workshops already knew the name of a dinosaur

Fossil poachers often leave behind a mess. Skulls are prized because they catch the highest price and are easier to ship, while less valuable bones are broken in the rush to complete unpermitted excavation. Scraps like these are left in haphazard piles.

Credit: Bolortsetseg Minjin

In 2012, an illegally exported Mongolian *Tarbosaurus* skeleton went up for auction in New York. Bolortsetseg lives in New York, and rallied authorities to have the skeleton sent back to Mongolia instead of to a private collection. She took this photo (below) of the fossil while it was still on display at the auction house. Today, the same skeleton (right) resides at the new Central Museum of Mongolian Dinosaurs in Ulaanbaatar, Mongolia's capital city.

Credit: below: Bolortsetseg Minjin; right: Thea Boodhoo.

before she got there. Fossils became a hot issue in national politics, and reporters from around the world wanted to know Bolortsetseg's life story. Poaching by native Mongolians, too, was on the rise as word spread even further that dinosaurs were worth money to collectors. Both knowledge and fossils were now in demand, and Bolortsetseg needed more resources. She needed a museum, and the ISMD's vision of a permanent structure at the Flaming Cliffs was no closer to launching than it had been in 2007. There was, however, one museum within reach.

The Moveable Museum

In the 1990s, AMNH owned several Moveable Museums that traveled around New York City, bringing the Mesozoic to public schools; then it ran out of funding. In 2013, AMNH donated one of these museums to the ISMD — a giant blue Winnebago with the image of a near-life-size sauropod on the side, under the English words, "Dinosaurs: Ancient Fossils, New Discoveries."

Gerry Ohrstrom, an investor and philanthropist who has known Bolortsetseg for years, funded transport of the Moveable Museum from New York to Ulaanbaatar. The bus first toured its new home in August 2015, roving all the way to the Flaming Cliffs thanks, in part, to an Indiegogo campaign that raised $4,460 from 61 backers. The crowdfunded resources weren't quite enough to bring the museum down the long dirt road to the Flaming Cliffs and back, but Bolortsetseg made up the difference from her own savings.

To the grade-schoolers in rural Mongolian towns, many of whom live in yurts and know the back of a horse better than the back of a school bus, the arrival of the Moveable Museum brings the same reaction as a spaceship landing. It's huge: too tall for Mongolian garages and too long to maneuver in most parking lots, so it usually stops in the street, blocking traffic

Bolortsetseg and her team drove the Moveable Dinosaur Museum around Mongolia to share dinosaurs with children, who often waited for hours to go inside and came back for second, third and fourth tours of the museum while it was parked outside their school in Mandalgovi, a rural town south of Ulaanbaatar, in September 2016.

Credit: Thea Boodhoo

for added effect. As the hatch opens, mechanized stairs lower themselves to the feet of the first kid in line and conditioned air whooshes out as if from an airlock. Inside, artifacts of strange worlds greet them: *Protoceratops* skulls and *Oviraptor* nests, images of Earth 100 million years ago, and glowing interactive panels in a language most of the kids can't read. The lights inside are halogen — expensive-feeling and serene compared to the flickering fluorescents ubiquitous in Mongolian classrooms. The exhibits are modern, made of acrylic and steel, with no trace of the Soviet-era cinder blocks or exposed electrical wiring common to most Mongolian museums.

Many of the dinosaurs on the Moveable Museum are replicas of specimens of Mongolian dinosaurs that AMNH visitors have enjoyed since Roy Chapman Andrews shipped them out of the Gobi generations ago. The children of Arvaikheer and Bayankhongor who climbed into our old blue Winnebago, however, were the first of their lineage ever to see them.

As part of the dinosaur workshops, children are given an assignment to find the Mongolian dinosaurs on display in the Moveable Museum. The treasure hunt drives home what the Americans who built the museum already know: Mongolians have a lot to be proud of when it comes to paleontology.

Credit: Thea Boodhoo

Most ISMD workshops are held in classrooms, like this one in Bayankhongor.

Credit: Thea Boodhoo

Four Weeks in Mongolia

In summer 2016, ISMD applied for nonprofit status in the U.S. and launched a fundraising campaign to keep the Moveable Museum running, create new outreach and educational materials, and hold four weeks of workshops for kids aged 7 to 14 in Bayankhongor, Arvaikheer, Dalanzadgad, Mandalgovi and Ulaanbaatar. By August 14, the campaign had raised its goal of $45,000, and around midnight on September 1, Bolortsetseg and I landed at Chinggis Khaan International Airport.

We assembled a team and gathered supplies. Mongolia is a big country with few paved roads, so we would spend more days traveling than educating. Workshops were booked in school classrooms, government buildings and libraries. We had to get as much work in as we could by the end of September, when temperatures would drop fast and the Moveable Museum would need to be stored for winter. The ISMD's plan for its most ambitious workshop season was in place.

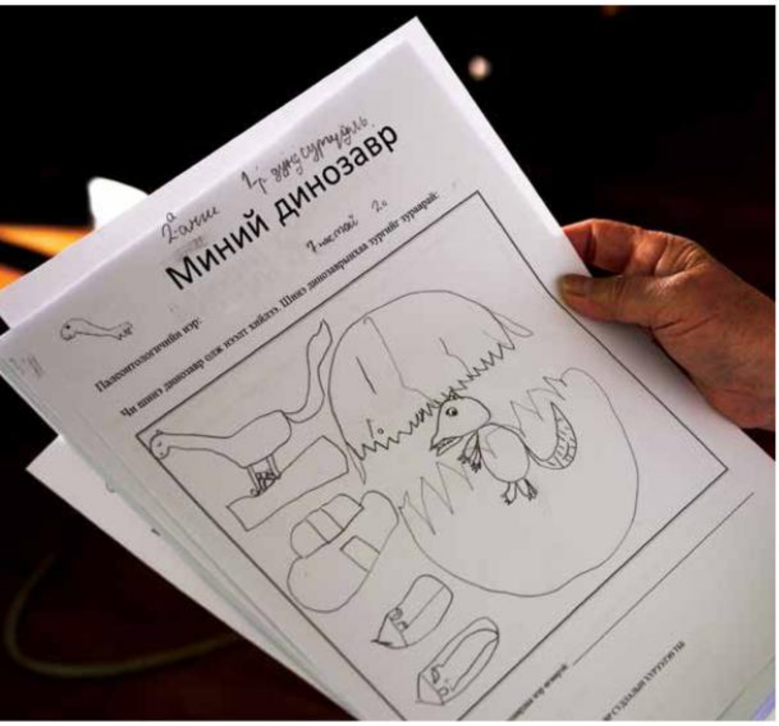
Tarbosaurus quickly became the most famous dinosaur in Mongolia after the repatriation of a poached skeleton made world news in 2012. By 2016, if there was one Mongolian dinosaur that any workshop student already knew of, it was *Tarbosaurus*. The species name, *bataar*, means "hero" in Mongolian.

Credit: Thea Boodhoo

"My Dinosaur"

We started every workshop with an activity called "Minii Dinozavr," meaning "My Dinosaur." While "minii" is a Mongolian word, "Dinozavr" (pronounced dee-no-zow-er) is the Russian interpretation of the Latin word, familiar to Westerners, that means "terrible lizard." Dinozavr is not a common

continued on page 33



When asked to draw a dinosaur, several children in Dalanzadgad had a similar interpretation: a creature popping out of a broken egg, which bears a striking resemblance to an animatronic ceratopsian figure in the town's new dinosaur park.

Credit: Thea Boodhoo

A new dinosaur park in the Gobi Desert city of Dalanzadgad is already inspiring a generation. Scientifically accurate information on the park's dinosaurs is, as yet, nonexistent.

Credit: Thea Boodhoo

THE DINOSAUR GARDEN OF THE GOBI: Motivating Future Paleontologists

In June 2016, the tourism board of Dalanzadgad, a small city in the Mongolian Gobi, opened a new dinosaur theme park on the outskirts of town. It was paid for with a government grant awarded before the 2016 economic downturn. The night we arrived in town, our Gobi team was given a tour by two of the project's biggest advocates.

Upon entering the park, you would be forgiven for thinking you were in any normal amusement park, save for a few details — the two-story-high entrance gate with what appears to be a *Ceratosaurus* perched on top, the hadrosaur statue between the soon-to-be gift shop and the cotton candy vendor, and the animatronic sauropod fountain. There's a merry-go-round, a small waterpark, a row of vendors and one of those giant spinning swings. Once you get past all that, to where the park peters out into the Gobi Desert, you will find yourself in the dinosaur garden.

Roughly a dozen motion-activated, rubber-skinned, roaring beasts are each cordoned off with laminated 8.5 x 11 "Do Not Touch" signs in Mongolian. When I was there, these were the only signs in the park. There was no plaque reading "*Tarbosaurus bataar*: A Cretaceous predator from Mongolia," or even simply "*Tarbosaurus*." In fact, throughout the entire park, there was no written information about dinosaurs at all. Not even a brochure. That's one reason we were brought there.

"He wants to know if the dinosaurs are the right size," said our translator, interpreting for our host, a local parliament member. I took a minute to wrap my head around the question. I was surrounded by unlabeled dinosaurs of varying heights, but since our paleontologist had stayed back in Ulaanbaatar for this leg of our expedition, I was suddenly the resident dinosaur expert.

I panicked briefly, then took a deep breath and looked around before commenting: "This sauropod could be about the right size depending on which one we label it as. Or we could say it's a juvenile. That theropod over there should probably be a *Tarbosaurus* but it's a little small. The *Stegosaurus* is way too small. I'm not really sure what this one is supposed to be so I can't say. The ceratopsian hatchling is obviously way too big but you knew that." (The child-sized hatchling, no doubt based on Roy Chapman Andrews' nearby discovery of the first dinosaur eggs, popped out of its shell and screeched at everyone who walked by.)

A classic *T. rex* and *Triceratops* display dominates the far corner of a new dinosaur park in Dalanzadgad, the closest city to the Flaming Cliffs, where dinosaurs were first discovered in Mongolia. While Westerners immediately recognize these two Cretaceous dinosaurs, many Mongolian park visitors have never heard of them and leave the park knowing little more, as there are no signs conveying information about the dinosaurs on display.

Credit: Thea Boodhoo

An anonymous sauropod, possibly *Saltasaurus*, revels in an abundance of water in a large pool at the Dalanzadgad dinosaur park in the Gobi Desert, one of Earth's driest places.

Credit: Thea Boodhoo

I realized halfway through my descriptions that I was bringing everyone down. They'd put a lot into this and it still, apparently, wasn't up to expectations. As we walked out of the dinosaur garden, I tried to explain that dinosaur displays like this were once common in the U.S. and that they'd inspired a generation of paleontologists despite their inaccuracies. Plus, the dinosaur garden was already inspiring kids. I could see their faces: rapt, lost in wonder. I knew that feeling. I knew the little boy in front of us — staring up at fake blood smeared on the roaring, rubber jaws of an anonymous theropod— would drag his dad around that dinosaur garden until it closed. He would tell his friends about it and ask his teachers. Maybe, with encouragement and learning opportunities, he'd grow up to be a paleontologist.

TB

Visitors can drive to the highest point atop the Flaming Cliffs. There, a small row of vendors sell handcrafted souvenirs to tourists, and a few unmarked trails lead down into the sandstone maze below.

Credit: Thea Boodhoo

continued from page 31

word in Mongolia, but Bolortsetseg prefers it to the Mongolian word for dinosaur, "uleg gurvel."

Although most kids in our workshops weren't familiar with dinosaurs at all — in fact, we even met adults who weren't sure dinosaurs were real — there were exceptions. In Arvaikheer, one boy brought in his favorite comic, starring a *Tarbosaurus*, and an entire class in Mandalgovi already knew that birds were dinosaurs. In another workshop, a group of 11- to 13-year-olds spontaneously started Mongolia's first junior paleontology club, which they named Velociraptor.

Most of the time, the level of existing knowledge in a town depended on whether Bolortsetseg had previously held workshops there. But the kids who were most familiar with dinosaurs were in the city closest to the Flaming Cliffs, Dalanzadgad, where a brand new dinosaur-themed amusement park — yet to be named — had just opened (see sidebar, page 32).

Pressured to open early, the theme park still lacked any information about the dinosaur replicas on display when we visited. There were no plaques and no pamphlets — just animatronic, anonymous animals. The difference the park has made on public awareness, however, was already clear. Our "Minii Dinozavr" sheets in Dalanzadgad came back with renderings of nameless beasts we recognized from the park.

At Dalanzadgad, the team split. Two stayed behind to run workshops while I and three others drove to Bayanzag. This was where we met the artist named Munkhbaatar and his camel-bone dinosaur. Our main destination, however, was the Flaming Cliffs.

The Flaming Cliffs

At the top of the Flaming Cliffs, a dry wind tossed sand in my eyes as I squinted toward the impossibly empty horizon. It was beautiful, but for a state park it was too empty. There were visitors, but just as in the theme park in Dalanzadgad, there was a surprising lack of information for them. No signs, no park maps, no trail markers. As I explored, I visualized the possibilities. A plaque by a small tree-shrub might read, "Zag (*Haloxylon ammodendron*): This small tree only grows in sandy, dry climates." Or on a paper handout, one might see, "Gobi racerunner (*Eremias przewalskii*): Look for this cold-blooded lizard warming itself on the sandstone." At the end of a trail that was unmarked, I imagined a sign describing the vast Gobi landscape below. "Desert of Dinosaurs: Eighty million years ago, this landscape was covered in

Fossils can be found every few steps at the Flaming Cliffs.

Credit: Thea Boodhoo

Scientifically accurate information on dinosaurs, written in Mongolian, is hard to find, but creativity abounds. This dinosaur sculpture was crafted from camel bones by a local artist at Bayanzag Park.
Credit: Thea Boodhoo

red-orange sand dunes. Standing here then, you might spot a *Velociraptor* stalking a *Protoceratops*, or a young *Oviraptor* couple helping their first hatchling out of its shell."

In my imagination, the helpful text was printed in both Mongolian and English, maybe even Russian and Korean. It was accompanied by illustrations and infographics. These signs were one of the many future projects Bolortsetseg and I had discussed, but now that I was there they felt urgent. The local government knew they were needed and wholeheartedly supported a museum in the park, but hadn't secured funding yet. Perhaps we could.

Aza and I climbed down from the cliffs and drove to several other areas within Bayanzag Park. At three stops, Aza showed us unexcavated fossils discovered on prior tours. We had no tools, time or permit to excavate them, but also no way to guarantee they would still be there the following year. Even if we could excavate them, the closest fossil prep lab was more than a day's drive away in Ulaanbaatar. The need for a museum with a lab and collections facility here in the park was undeniable. At our last stop, I spent half an hour casually prospecting and found bone fragments every few steps. How many pieces had left Mongolia in the pockets of tourists who honestly didn't know they were breaking the law because there were no signs, no flyers, not even a notice at the airport to inform them?

Collections and lab facilities are badly needed at important Mongolian fossil sites like the Flaming Cliffs, where camp owners are likely to have a few fossils stashed away for curious customers.
Credit: Thea Boodhoo

Finishing the Workshops, Building Museums

Our last full day in Mongolia was spent at the Central Museum of Mongolian Dinosaurs (CMMD) in Ulaanbaatar, a new museum established as a home for the famous *Tarbosaurus* skeleton and other repatriated fossils. Bolortsetseg and the museum director signed a Memorandum of Understanding regarding future collaboration between the ISMD and CMMD. We discussed sharing funding for fossil preparation and specimen storage, joint fieldwork in the coming year, ongoing educational programs, and a future museum at Bayanzag.

The CMMD is a good start for making dinosaurs accessible in Mongolia, even though much of the facility is still inaccessible to the public, save an entrance hall where attendants in handmade, green felt dinosaur vests sell tickets and remind visitors not to take photos unless they have paid an extra fee. In the entrance hall, a pair of fully assembled giant skeletons greet visitors from atop a rocky platform, ribs and skulls lit from below by color-changing lights. On the left is *Saurolophus*, a Mongolian hadrosaur with a gentle, duck-like face. On the right is the *Tarbosaurus*. Surrounding them along the walls are the remains of *Protoceratops*, *Oviraptor*, and more. All repatriated after illegal export, they were once cloistered away from science and the public. Now they are on display for all, with informational plaques in English and Mongolian.

Bolortsetseg says she's often approached by journalists and documentarians seeking dramatic tales of poacher-thwarting justice. They're always disappointed. Bolortsetseg doesn't see poachers as enemies, no matter how infuriating it can be to find the shattered remains of a dinosaur that has been pried from the rock for profit. Financial desperation, she says, is what drives poaching, and that can be fought by improving the economy. Tourism is already Mongolia's second-biggest industry, and dinosaurs are one thing almost every tourist asks about. That's something that can be capitalized on, but not if fossils keep leaving the country. Poachers, in the long term, are hurting themselves, Bolortsetseg says.

She also says that poaching is best fought with education. Once-a-year workshops and a Moveable Museum are just the beginning. With permanent museums at important fossil sites like the Flaming Cliffs, Bolortsetseg says she hopes to inspire children to become scientists, convert tourists into supporters and show those who would sell a dinosaur for profit that the biggest gains come from keeping dinosaurs at home, next to a gift shop.

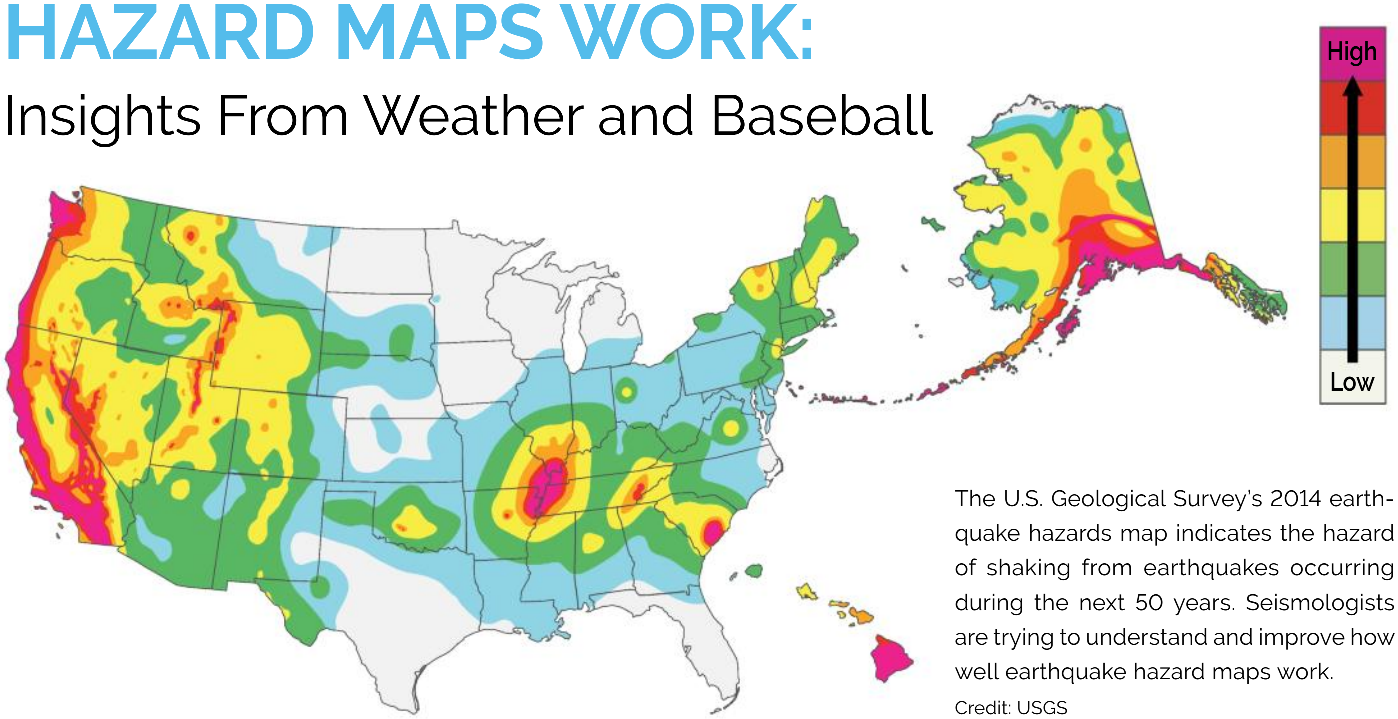
Plans are in the works for a museum at the Flaming Cliffs. In the long term, we hope the museum will serve as a testing ground and a template for facilities serving each of Mongolia's important fossil locales. Thanks to Bolortsetseg's repatriation and poaching prevention work, there will likely be plenty of dinosaur fossils to fill them. And, if the enthusiasm of our young workshop participants is any indication, we may even have enough Mongolian paleontologists to staff them.

Boodhoo (TheaBoodhoo.com) is currently an officer and board member of the Institute for the Study of Mongolian Dinosaurs. She lives in San Francisco.

At the new Central Museum of Mongolian Dinosaurs in Ulaanbaatar, poached dinosaur fossils that have been repatriated are finding a home. Information is provided for visitors in both Mongolian and English.
Credit: Thea Boodhoo

ASSESSING HOW WELL EARTHQUAKE HAZARD MAPS WORK:

Insights From Weather and Baseball



The U.S. Geological Survey's 2014 earthquake hazards map indicates the hazard of shaking from earthquakes occurring during the next 50 years. Seismologists are trying to understand and improve how well earthquake hazard maps work.

Credit: USGS

Seth Stein, Edward Brooks, Bruce Spencer, Kris Vanneste, Thierry Camelbeeck and Bart Vleminckx

Imagine waking up to a cloudy day. The weather forecast predicts rain. Before canceling your hiking plans, it's worth considering how accurate the forecast has been before. If it's been right most of the time, canceling your plans makes sense. If it's often been wrong, you might chance it and go hiking. How you use the forecast depends on how much confidence you have in it, which mostly depends on how accurate it has been to date.

Seismologists now face a similar issue in forecasting earthquake hazards. For about 40 years, they have produced brightly colored probabilistic earthquake hazard maps. Such maps are often used to prepare for earthquakes, notably in developing codes for earthquake-resistant construction. These are not earthquake predictions, but hazard forecasts — an important distinction, because predicting exactly where and when earthquakes will happen is impossible, at least at present. Probabilistic hazard maps use scientifically based statistical estimates of the

Seismologists can gain insights about earthquake hazard maps from other forecasting applications, like weather forecasting. Forecasts, like this spring flood risk forecast map, start with building a conceptual model of the process in question, then implementing it on a computer to produce a forecast and comparing the forecast to what actually happens.

Credit: NOAA

probability of future earthquakes and the resulting shaking to predict the maximum shaking that should occur with a certain probability within a certain period of time. Larger levels of maximum shaking correspond to higher predicted hazards.

However, hazard maps are far from perfect, as revealed by the March 2011 magnitude-9.1 Tohoku earthquake, which forced seismologists and earthquake engineers to face the fact that highly destructive earthquakes often occur in areas that hazard maps predict to be relatively safe. Every few years, the Japanese government produces a national seismic hazard map like that in figure 1. But since 1979, all earthquakes that have caused 10 or more fatalities in that country have occurred in places the map designated as low hazard — Tohoku being one of them. Similar discrepancies between expected and actual shaking have occurred during other quakes, including the 2008 magnitude-7.9 event in Wenchuan, China, and 2010 magnitude-7.1 event in Haiti. In other places, such as the central U.S.'s New Madrid Seismic Zone, hazard maps likely overestimate the hazard.

Surprisingly, although earthquake hazard maps are used worldwide, and affect millions of people and billions of dollars' worth of infrastructure, seismologists know little about how well the maps actually predict the shaking that occurs or why problems with the maps arise. It could be that some aspects of hazard mapping methods are deficient. Alternatively, maybe the methods are fine but the specific inputs used for individual maps are sometimes wrong. A third possibility is bad luck — the maps offer forecasts in terms of probabilities, and unlikely things sometimes happen. As a result, we don't know how good or bad the maps are or how much confidence users should have in them. Fortunately, this situation is starting to change.

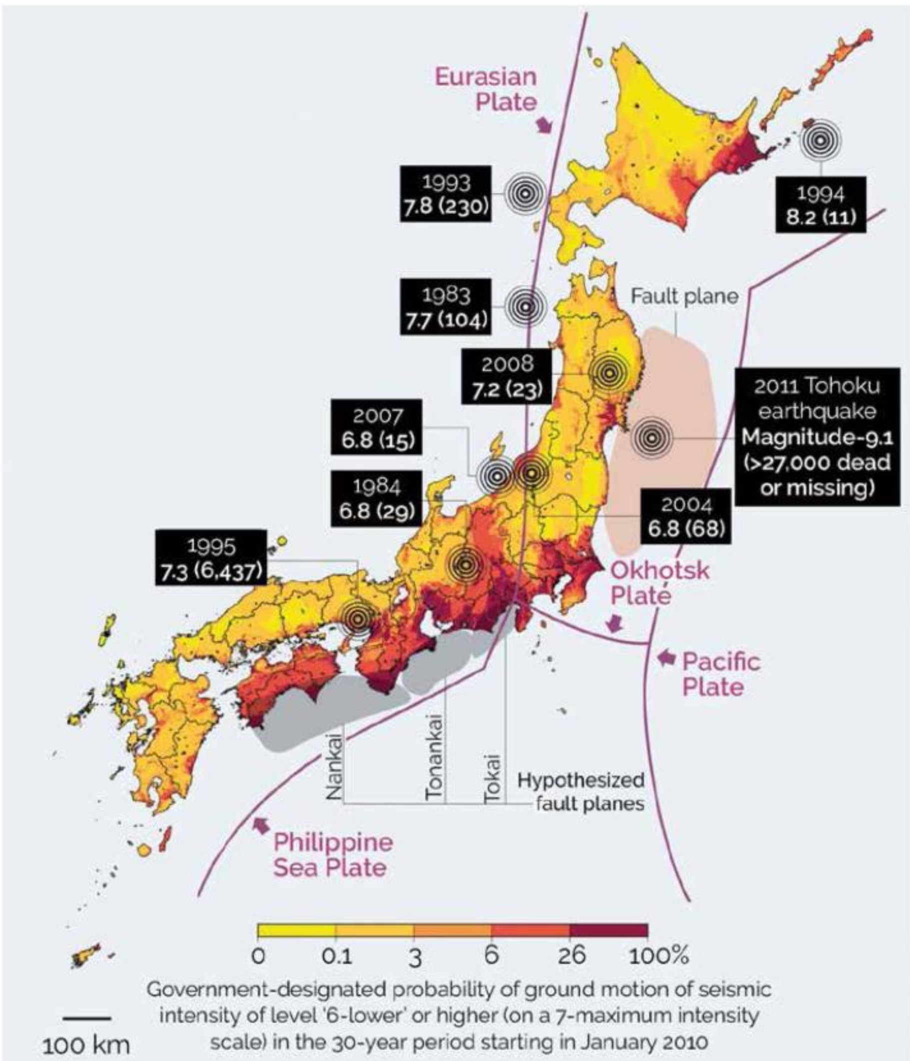


Figure 1: Comparison of Japanese national hazard map to the locations of earthquakes since 1979 that caused 10 or more fatalities. All of these quakes, including the magnitude-9.1 Tohoku quake, occurred in areas designated as low-hazard zones.

Credit: Geller, Robert J., Nature, 2011, reprinted with permission from Macmillan Publishers Ltd.

Mura, Japan, 11 days after the Tohoku quake and subsequent tsunami devastated the area. Hazard maps provide a service, helping regions erect buildings to withstand the strongest shaking expected in an area — but they have to be accurate to provide that service.

Credit: U.S. Navy photo by Mass Communication Specialist 3rd Class Dylan McCord/Released

Assessing Forecasts

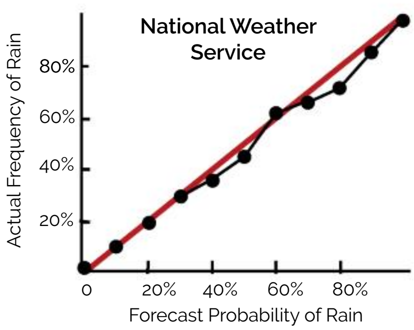
Because earthquake hazard maps offer forecasts, we can gain insights about them from other forecasting applications, like weather forecasting or evaluating a baseball player's performance.

Forecasts start with building a conceptual model of the process in question, implementing it on a computer to produce a forecast, and then comparing the forecast to what actually happens. Weather forecasts are based on models of the atmosphere evolving over time, just as earthquake hazard maps are based on models of how faults behave over time.

Assessing how well this process works involves verification and validation. Verification asks how well the algorithm used by the computer program to produce the forecast implements the conceptual model: Have we built the model right? Validation asks how well the model forecasts what actually occurs: Have we built the right model?

Weather forecasts are routinely evaluated — validated — to assess how well their predictions matched what actually occurred. A key part of this assessment is adopting agreed metrics for "good" forecasts, so forecasters can assess how well their forecasts performed and develop strategies to improve them. Forecasts are also tested against various simpler methods, or "null hypotheses," including checks to see if they fare better than simply averaging weather conditions for a particular place on that date in previous years, or assumptions that a day's weather will be the same as the day before. Over the years, this process has improved forecasting methods and results, and yielded much better assessments of uncertainties.

Weather forecasts can be validated by comparing predictions to observations. For example, we can compare two forecasts of the probability of rain in Kansas City to the fraction of the time it actually rained (figure 2). The National Weather Service forecasts were pretty accurate, whereas a local television station's forecasts were less so; the latter predicted rain more often than it actually occurred. Knowing how a forecast performs is useful: The better it has worked to date, the more we factor it into our daily plans.



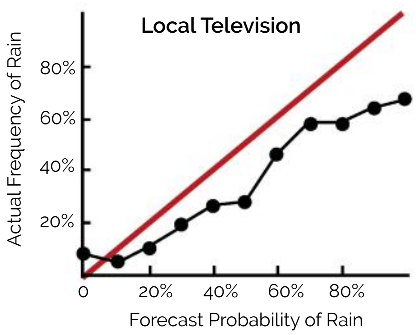


Figure 2: Comparison of the predicted probability of rain to the fraction of the time it actually rained, for National Weather Service and a local television station's forecasts.

Credit: Stein et al., Bulletin of the Seismological Society of America, 2015, after a figure in "The Signal and the Noise" by Nate Silver

Earthquakes in Italy often damage older builidings — such as these in Amatrice, which fell during the 2016 central Italy quakes. For reasons that are unclear, the national hazard maps predict higher levels of shaking than are shown by historical records.

Credit: Terremocentroitalia, CC BY 2.0

Similar analysis can be done for earthquake hazard maps, with a key difference. Rainstorms happen often, so the predicted and observed frequencies of rain at a place can be compared directly and robustly. Large earthquakes, on the other hand, are infrequent, so most places have not experienced major shaking in recent years. To get around this, we can compare the maximum observed shaking over years of observations at many sites on the map to the predicted shaking at those sites. This is similar to what auto insurance companies do when they combine information about past traffic accidents across the country to estimate the chance that you will be involved in an accident in the next six months or whatever the term of your policy.

Using Multiple Metrics

We can use several measures, or metrics, to assess how well a hazard map performed. This is because the predictions of most seismic hazard maps are given in terms of probabilities

Maps are made to reflect probabilities over a designated "return period" — a specific number of years, such as 475 or 2,500 years, denoted as *T*. Maps with longer return periods predict higher hazards, because infrequent larger earthquakes are more likely to occur during the longer period. The value shown on a map reflects levels of shaking that are expected to have a specified probability (p) of being exceeded at least once during a set observation period (t). Figure 3a shows the relationship among these variables, which depends on the ratio t/T. For example, a map with a 475-year return period can show the level of shaking that should be exceeded at 10 percent of the sites in 50 years, because 50/475 is about 0.1, or at 63 percent of the sites in 475 years, because 475/475 equals 1. As the observation time increases, larger earthquakes are expected, so more of the sites should be strongly shaken. The math is the same as that used to figure the probability that a hurricane will hit a town in the next t (perhaps 20) years, if on average one hits every T (perhaps 100) years.

To see how well a hazard map did, we take the sites on a map and plot each as a dot showing the shaking predicted by the map compared to the largest shaking that actually happened (as in figures 3b and 3c). The sites at which shaking exceeded the mapped value fall above the line, which represents points for which the observed and predicted shaking are equal.

The most direct way to assess how well a hazard map worked is to look at the

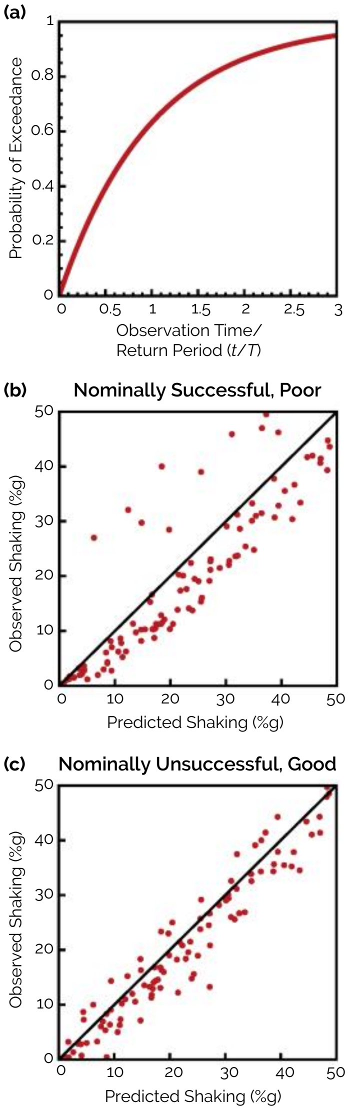


Figure 3: (a) The assumed probability (*p*) that during a *t*-year-long observation period, shaking at a site will exceed the value shown on a map with return period *T*. This probability depends on the ratio *t/T*. Thus if we consider a number of sites, a fraction *p* should have shaking higher than mapped. (b) and (c) Comparison of the results of two hazard maps. The plot in (b) is for a hazard map that is successful by the fractional site exceedance metric, but significantly underpredicts the shaking at many sites and overpredicts the shaking at others. The plot in (c) is for a hazard map that is nominally unsuccessful as measured by the fractional site exceedance metric, but better predicts the shaking at most sites.

Credit: Stein et al., Bulletin of the Seismological Society of America, 2015

difference between the actual and predicted fractions of sites where shaking was higher than the mapped value, which is called the fractional exceedance. If the fraction of sites where shaking was higher than the mapped value is close to the predicted fraction, the fractional exceedance metric is small, and the map did well by this metric.

The fractional exceedance metric measures how well a probabilistic map does what it's supposed to do. However, this measure doesn't consider the size of the differences between the observed and predicted shaking, which are also important. To understand this, consider two different hazard maps.

In figure 3b the predicted and observed fractions are both 10 percent, so the fractional exceedance metric is zero and the map is perfect by this metric. However, many points are far from the line, which is bad. Points far above the line indicate underpredicted shaking: If this map were used in building design, buildings in areas of underpredicted shaking might have experienced major damage. Points far below the line indicate overpredicted shaking: In these areas, structures might have been overdesigned, thus wasting resources. Viewed this way, the map did less well than we would like.

Figure 3c, on the other hand, represents a case where the predicted and observed fractions for exceedance are 10 percent and 20 percent, respectively, so by this metric the map didn't do as well. However, most points are close to the line, so the maximum actual shaking in most locations was close to that predicted — which is good in terms of adequately informing infrastructure design to withstand the maximum shaking without being overdesigned. The shaking wasn't substantially underpredicted or overpredicted, so in this sense the map did well.

Because the fractional exceedance metric doesn't reflect the sizes of the differences between the observed and predicted shaking, we also use another measure of map performance called the squared misfit metric. This measures the difference between the predicted and observed shaking.

The takeaway is that each metric measures different aspects of a map's performance. We could also use other metrics. For example, because underprediction potentially does more harm than overprediction — buildings could suffer major damage, potentially killing or injuring people — we could weight underprediction more heavily. Another option is to weight the misfits more heavily for areas with the largest exposure of people and property, such that the map is judged most on how it does in those places.

Although no single metric fully characterizes map behavior, using several metrics can give useful insight for comparing and improving hazard maps. For example, we can compare the performance of probabilistic hazard maps (which give a range of the expected earthquake size and expected shaking) with another class of maps, called deterministic hazard maps, which seek to specify the largest earthquake, and resulting shaking, that could realistically occur for each location.

The idea of using several metrics to measure hazard map performance makes sense. In general, assessing any system's performance involves looking at multiple aspects. This concept is familiar in sports, where players are evaluated in different ways. For example, a baseball player may be an average hitter, but valuable to a team because he is an outstanding fielder, as measured by a metric called "wins above replacement" that measures both hitting and fielding. In many seasons, Babe Ruth led the league in both home runs and in the number of times he struck out. By one metric he did very well, and by another, very poorly.

Validating Results

Using these approaches, researchers are looking at different aspects of earthquake hazard maps, including validation. One of the challenges of determining how well a hazard map forecasts shaking is that the records of recent shaking are short and/or sparse for many locations. To get long-enough earthquake histories to accurately represent potential shaking in an area, researchers can use shaking records derived by combining historical accounts of shaking with past seismological data. Looking backward in time to validate maps — called "hindcasting" — isn't exactly the same as a forecast of the future, but it is still useful.

Italy offers a good example of the utility of validating hazard maps. Figure 4 shows the maximum intensity of earthquake shaking throughout Italy from 217 B.C. to A.D. 2002. These levels of shaking are generally much lower than those predicted by the national hazard map produced by Italy's National Institute of Geophysics and Volcanology with a return period of 2,500 years, which corresponds to a 2 percent probability in 50 years (50/0.02 = 2,500). The massive discrepancy could result from one or more problems: Some of the assumptions about the locations, timing and level of shaking in future earthquakes that went into the hazard map may have caused overpredictions. Alternatively, and seemingly more likely, much of the misfit may result from the historical catalog of seismicity in Italy having too-low values because of the limitations of the historical record — earthquakes may have been missed or the shaking intensities may have been underestimated from the historical accounts. These results show serious questions about the maps that need to be resolved.

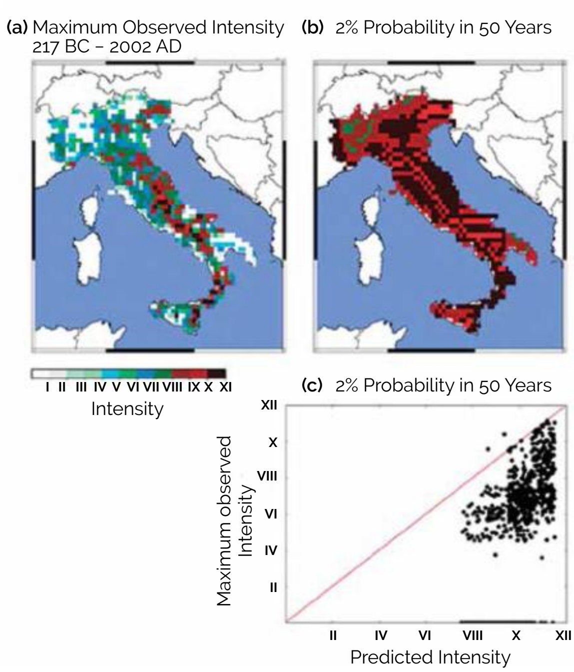


Figure 4: Comparison of (a) historical earthquake shaking intensity data for Italy to (b) a probabilistic hazard map with a return period of 2,500 years. The hazard map overpredicts the observed shaking, as also shown in (c).

Credit: Stein et al., Bulletin of the Seismological Society of America, 2015

Similar analyses for Japan (figure 5) also reveal problems. Based on the problems with the Japan hazard map, Robert Geller, of the University of Tokyo, suggested in a 2011 study in Nature that there is no good way to say that some parts of Japan are more dangerous than others. If this were true, hazard maps less detailed than present ones would be preferable because the additional detail would not be meaningful and could be misleading.

We tested this idea by comparing a 510-year-long record of earthquake shaking to both the Japanese national hazard map and a uniform map, in which the hazard is the same everywhere. Using the squared misfit metric, the national map does better than the uniform map. This is because the squared misfit metric depends mostly on how similar the predicted and observed shaking patterns are in space, which is what we see when we compare the two maps. However, as measured by the fractional exceedance metric, the uniform hazard map does better. This is because the national map somewhat overpredicts the observed shaking. As for Italy, it is unclear what causes these misfits.

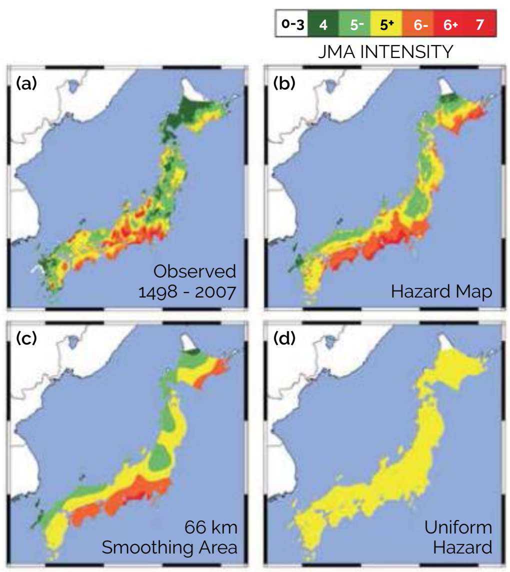
A uniform hazard map amounts to starting with the national hazard map and averaging it over the whole country, so all spatial detail is lost and all places have the same hazard. An intermediate approach is to average, or smooth, the hazard map over different areas, which removes some but not all detail. For Japan, we find that, as measured by the squared misfit metric, an intermediate amount of smoothing works best. Map performance improves when we smooth over distances of up to about 100 kilometers; it then drops off with smoothing over larger areas. This result suggests that the national hazard map may be too detailed.

Verifying Results

Other studies involve verification — how well should the hazard mapping method work? To explore this, we assume an ideal case for an area about

Figure 5: (a) Map of the largest-known shaking on the Japan Meteorological Agency intensity scale in 510 years. (b) Probabilistic seismic hazard map for Japan, generated for 475-year return periods. (c) Hazard map derived by smoothing (b) over 66-kilometer window. (d) Uniform hazard map derived by smoothing (b).

Credit: (5a): Miyazawa and Mori, Bulletin of the Seismological Society of America, 2009; (5b, c, d): Brooks et al., Seismological Research Letters, 2016



the size of Belgium in which we know how often earthquakes will happen on average, how big they will be, and what shaking they will produce. We do two things: First, we generate an earthquake hazard map. Then, we generate a large number of simulated earthquake shaking histories in which earthquakes and shaking occur at random but in accordance with what we know about past earthquake behavior, calculate the largest shaking that occurred over time at each place on the map, and compare these to the hazard map.

For this ideal case, the hazard is uniform, so the hazard map is the same color everywhere (figure 6a). After 50 years of earthquakes, the map of the largest shaking varies from place to place. As shown for one synthetic history, some places (in orange to red) experience greater shaking than shown on the map, while other places (in white to green) experience shaking lower than shown on the map. This matches our real-life experience that when large earthquakes happen, maximum shaking is often higher than shown on hazard maps. The simulation shows that this can happen purely by chance and occurs in about as many places as the probabilistic method would predict. In 50 years, about 10 percent of the sites should have shaking higher than predicted by a map with a 475-year return period. Thus, in this example, the probabilistic method is working as expected.

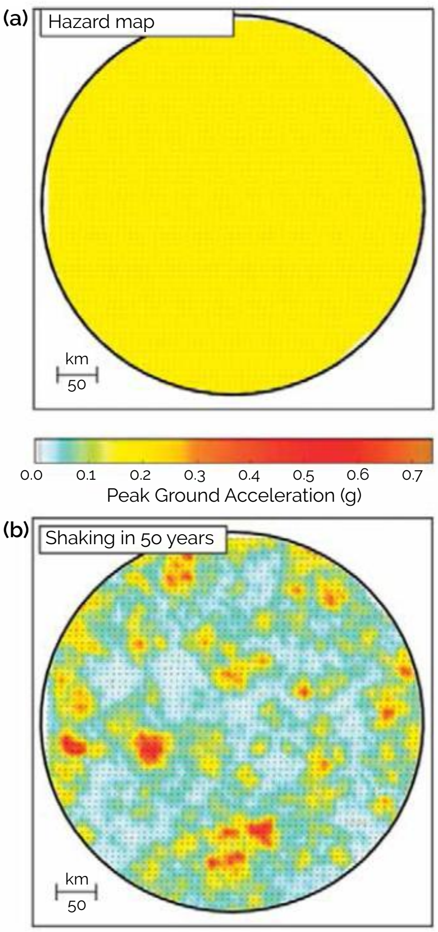


Figure 6: (a) Uniform hazard map for an imaginary area. (b) Map of largest shaking that occurs during 50 years of simulated earthquakes. Some places experience greater shaking than shown by the hazard map, and others experience less shaking.

Credit: Vanneste et al., AGU presentation, 2016

Such simulations point out an interesting problem. When we observe shaking greater than predicted by a hazard map, it is hard to tell whether the misfit is due to a problem with the map, or whether it occurred just by chance, as in the example shown. The longer the period of observations we have, the better our chances of distinguishing between a bad map and bad luck.

To see how this works, imagine trying to decide if a coin is fair — equally likely to come up heads or tails when it is flipped. If the coin is fair, then in the long run, 50 percent of the flips will give heads. However, that's often not true in the short run. In the illustrated example (figure 7), many more heads than tails occur until the coin has been flipped about 70 times. Based on a smaller number of flips, we can't tell whether we're getting an excess of heads because the coin is biased — which would be like having a bad hazard map — or if it's simply due to chance.

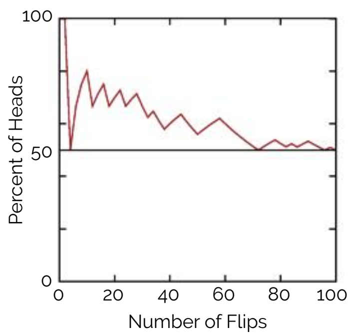


Figure 7: A simple coin flipping experiment in which data initially don't match the expectation that half of the flips should yield heads. Early on, after just 10 flips, seven of the flips were heads, so it appears that reality is not in agreement with expectation; with more flips, reality aligns more closely with expectation. Until we have data from many flips, it's hard to tell whether the model of a fair coin is wrong, or the misfit is just bad luck.

Credit: Seth Stein

Prospects for the Future

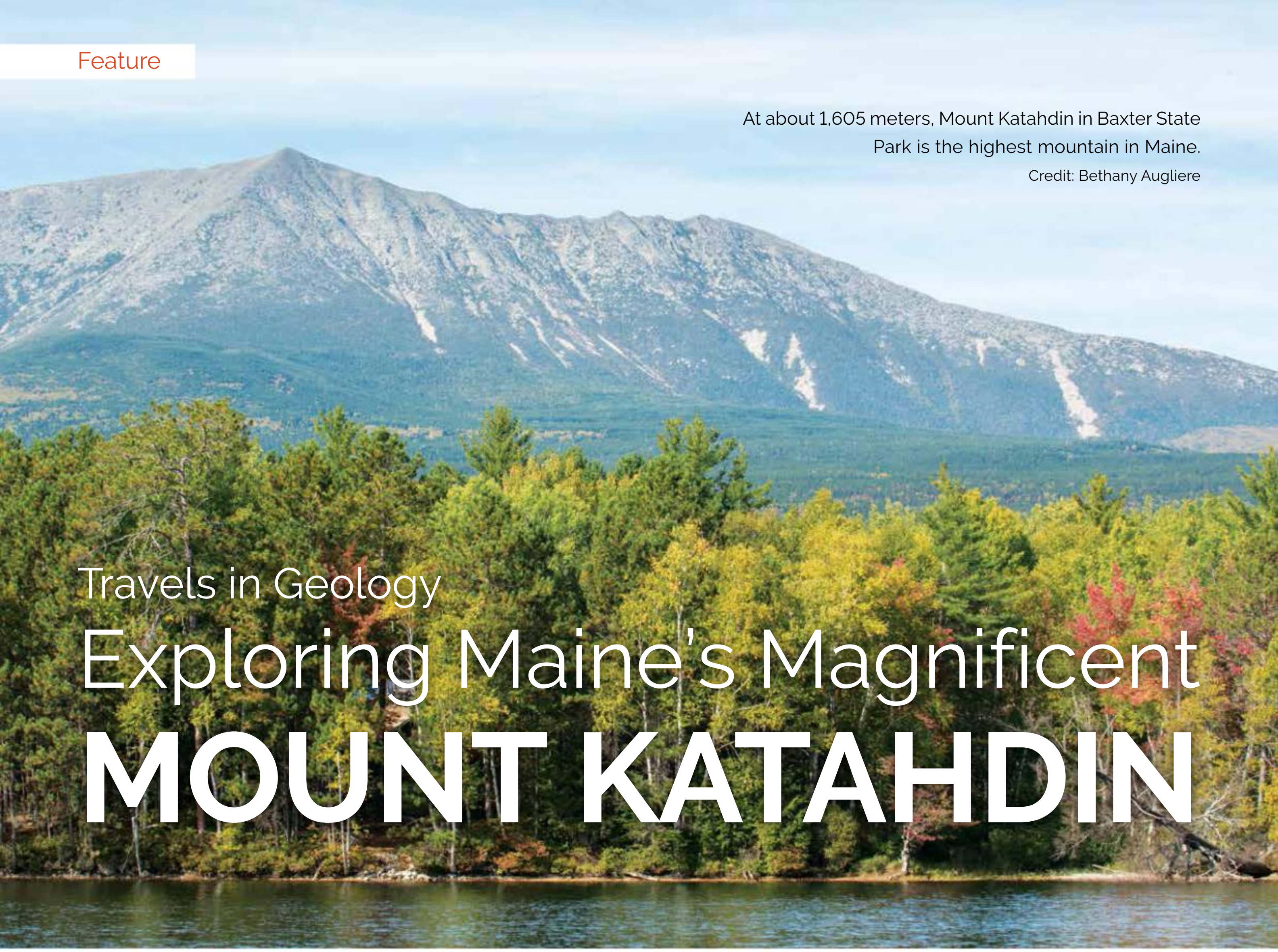
Seismologists are exploring difficult questions in trying to understand and improve how earthquake hazard maps work, and our understanding is growing. There's a long way to go, but it looks as if we're on the right track: We're developing better methods to assess how these maps should work and how they actually do work.

At the same time, it's worth remembering that forecasting the future is always challenging. Studies have shown that experts are often no better than dart-throwing monkeys at predicting human events like sports winners, elections, wars, economic collapses and other events. Forecasting the behavior of natural systems is also tough. The meteorological community, in whose footsteps seismologists are following, recognizes this. For example, the National Weather Service's Climate Prediction Center cautions "potential users of this predictive information that they can expect only modest skill."

Given how complicated earthquakes are, and the limitations of our knowledge about them, seismologists should do their best to improve hazard maps and to understand the maps' uncertainties while accepting and admitting that there are limits to how well we can do.

Stein and Brooks are at the Department of Earth and Planetary Sciences and the Institute for Policy Research at Northwestern University. Spencer is at the Department of Statistics and the Institute for Policy Research at Northwestern University. Vanneste, Camelbeeck and Vleminckx are at the Royal Observatory of Belgium.

Feature



At about 1,605 meters, Mount Katahdin in Baxter State Park is the highest mountain in Maine.
Credit: Bethany Augliere

Travels in Geology
Exploring Maine's Magnificent MOUNT KATAHDIN

Bethany Augliere

After weeks of anticipation and constant checks of weather forecasts to find a day when the skies were likely to be clear, I decided the early fall morning had finally arrived to hike Mount Katahdin — the highest mountain in Maine at 1,605 meters. I woke up at 5 a.m., crawled out of my sleeping bag, got dressed and turned on my headlamp to begin the trek.

Katahdin, pronounced "kuh-TAW-din," was named the "The Greatest Mountain" by the Penobscot Indians — a fitting designation. It's the crown jewel of Baxter State Park, more than 80,000 hectares of wilderness and public forest in north-central Maine, and the northern terminus for the 3,500-kilometer-long Appalachian Trail, which begins on Springer Mountain in Georgia and crosses 14 states. After chatting with locals and park rangers, I got the sense that no matter which of the routes you take up the mountain, it's a long hike and people tend to underestimate it.

In early October, when my hiking companion, Nico, and I were there, temperatures can drop to minus 6 degrees Celsius at night. It's not uncommon for people to get lost, or to start too late and end up hiking in the dark. In rare instances, visitors to Katahdin have tragically succumbed to the elements: Since 1926, 22 deaths have occurred on the mountain. Even as an experienced hiker, I took Katahdin's reputation seriously. My pack included a 3-liter hydration bladder, an extra water bottle, food, an emergency blanket and extra layer of warm clothes, and a small first aid kit.

We registered at the Roaring Brook Campground ranger station with our time of departure and planned route up the mountain. It would be about a 15-kilometer round-trip journey, with a 1,214-meter elevation gain. It was 5:30 a.m., and three other hikers had already started from this location.

Carved From Ice

At first glance, the jagged, treeless mountain resembles a volcano. Its rock, part of a granite pluton, is indeed magmatic in nature, having solidified before it

reached Earth's surface. In fact, it's part of a laccolith — a mushroom-shaped granitic intrusion — that formed about 400 million years ago during the Acadian Orogeny, a major period of mountain building that affected the Appalachian chain from present-day Virginia to Newfoundland and lasted for 150 million years. This happened as the microcontinent Avalonia collided with North America at the leisurely rate of 5 kilometers per million years.

Over time, Katahdin has been shaped by weathering and erosion, especially during glacial periods. Alpine glaciers carved deep bowl-shaped depressions, or cirques, into its flanks. Other glacial features such as kettle ponds, moraines and eskers are scattered throughout Baxter State Park.

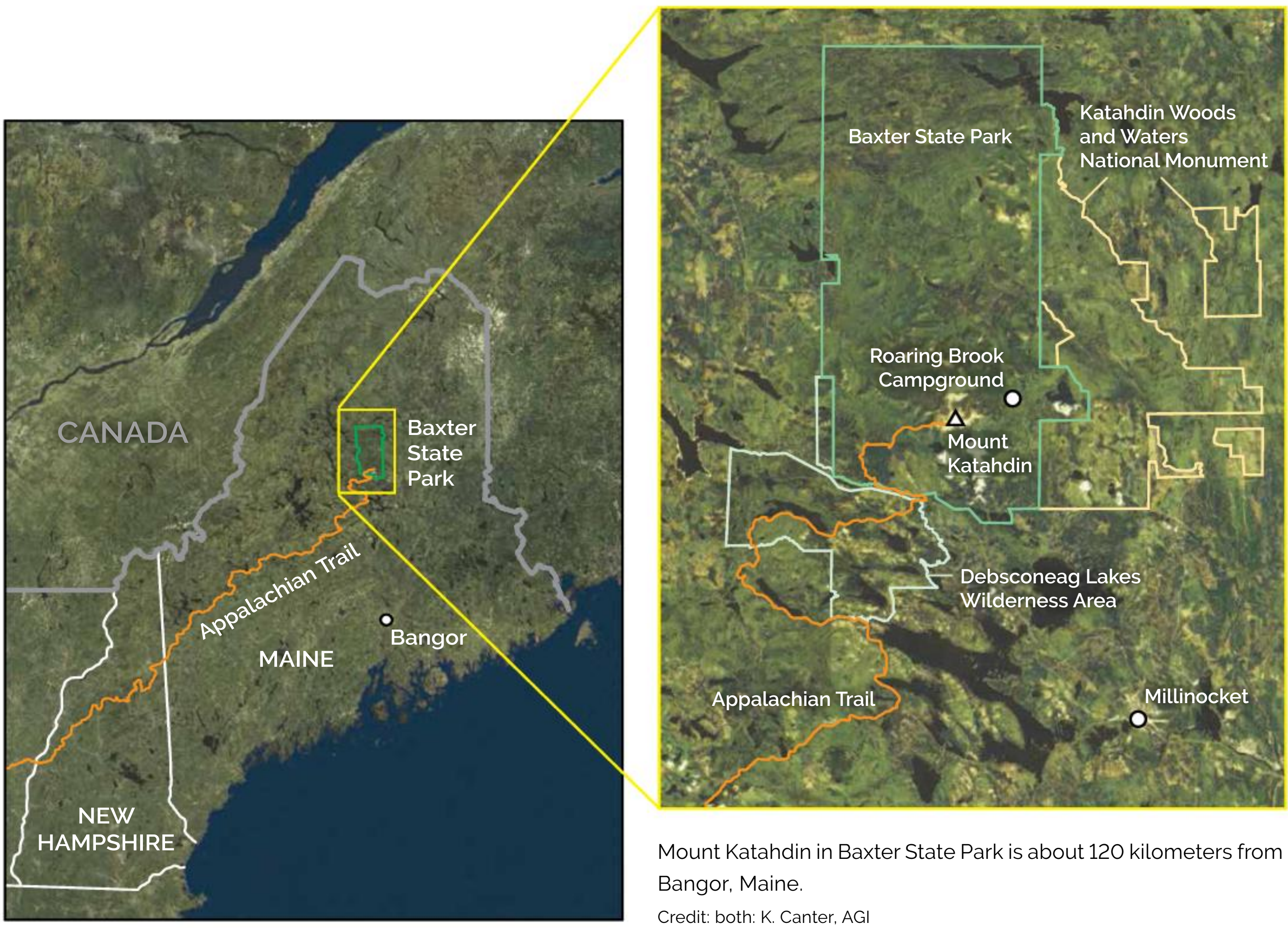
Katahdin has five peaks: Howe, Hamlin, Pamola, South and Baxter, the summit. Between Baxter and Pamola peaks is a narrow 1.7-kilometer-long boulder-scramble along a glacial arête called the Knife Edge, which, at points, is only a meter wide. This adventurous traverse was the primary reason I wanted to hike Katahdin.

Chimney Pond is a small circular lake, called a tarn, found on the east side of Katahdin and a 5.3-kilometer hike from Roaring Brook Campground. From here, hikers can view the steep mountain slopes carved from glacial erosion.

Credit: Bethany Augliere

Discovering the Park

On a trip to Baxter State Park last summer, we explored some of the other 320-plus kilometers of maintained trails in the park, which has no running water, electricity or paved roads.



Mount Katahdin in Baxter State Park is about 120 kilometers from Bangor, Maine.

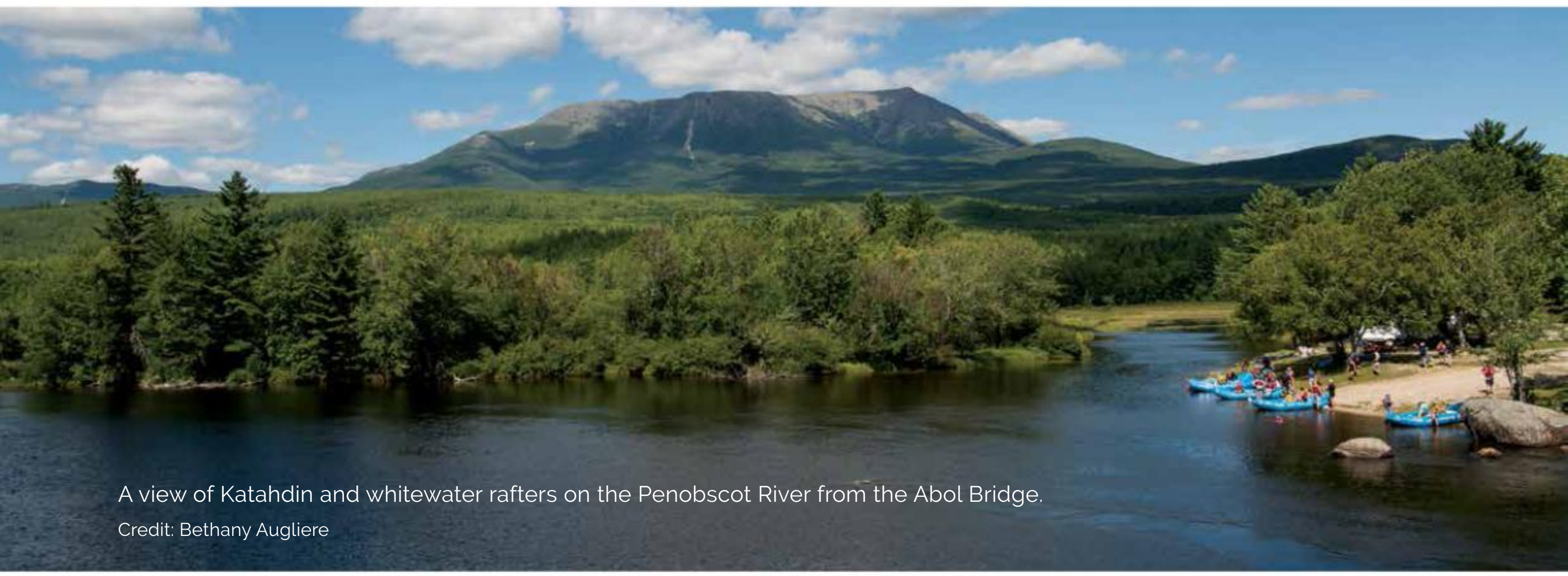
Credit: both: K. Canter, AGI

A view of the rock highway, a large granite slab with cascading water, at Blueberry Ledges, a 6.75-kilometer out-and-back trail in Baxter State Park.
Credit: Bethany Augliere

An easy trek along the Ice Cave Trail ends at a pile of boulders where hikers can climb down into a cool cave with patches of snow and ice left over from the previous winter.
Credit: Bethany Augliere

The rugged nature of the park is maintained "for those who love nature and are willing to walk and make an effort to get close to nature," as park donor and former Maine Governor Percival P. Baxter put it. He purchased the land in 1931 to protect it from logging and deeded it to the state with instructions that it "shall forever be retained and used for state forest, public park, and recreational purposes … shall forever be kept and remain in a natural wild state … [and] shall forever be kept and remain as a sanctuary for beasts and birds."

Being one end of the Appalachian Trail, the state park is known for its



A view of Katahdin and whitewater rafters on the Penobscot River from the Abol Bridge.
Credit: Bethany Augliere

hiking, but it also offers plenty of other options. Visitors can whitewater raft, or canoe, if a more leisurely pace is desired, down the Penobscot River. Berry-picking is a very popular activity in the summer, as is moose-viewing at Sandy Stream Pond and other wildlife watching. Additionally, a short drive away is one of America's newest national park sites — Katahdin Woods and Waters National Monument — designated by President Obama on Aug. 23, 2016.

But we were there to hike, so we found a couple of trails we could follow for a day to take in some great views and potentially spot some moose.

Scrambling over rocks on the Cathedral Trail, a 2.8-kilometer journey to reach the summit at Baxter Peak.

Credit: Nico Ientile

Trails in Baxter

For our first stop, we decided to explore Blueberry Ledges, a 6.75-kilometer round-trip hike. To get there, we turned off the main road into the park for the Golden Road, a logging road that is marked by a giant painted rock. We followed this dirt road for 16 kilometers, scanning the ponds for moose along the way (alas, we didn't see any).

The hike began on the Appalachian Trail. We crossed a small bridge over a section of Abol Stream, with a view of Katahdin towering over the valley.

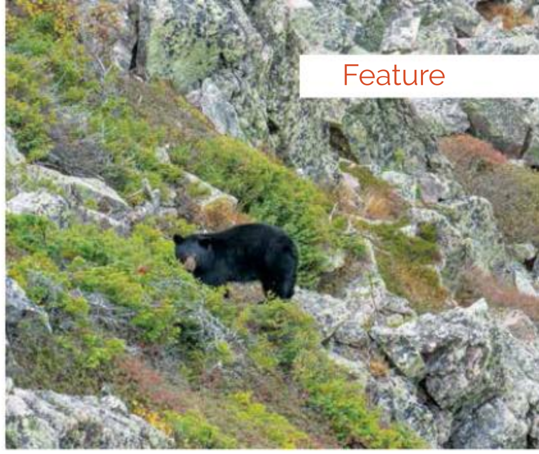
The beginning of Blueberry Ledges was a narrow path through stands of aspen and birch trees. At the end, the trees opened up to flat slabs of granite, forming rock highways flanked by blueberry bushes. We lay in the water to cool off, ate blueberries, and walked around the cascading stream. We had this spot to ourselves — a degree of solitude can be a hard thing to find at other parks, like nearby Acadia National Park.

After drying off in the sun, we packed up to visit our next stop: ice caves. This was a quick and flat 4.8-kilometer round-trip hike in the Debsconeag Lakes Wilderness Area, owned by the Nature Conservancy and adjacent to the state park. This area contains the highest concentration of pristine ponds in New England, and thousands of hectares of mature forest.

The trail to the ice caves meandered through tall pines and moss-coated boulders, with a mild elevation gain.

Eventually we reached the caves' entrance tucked away among a giant boulder garden. The ice caves are actually just open spaces amid the boulders of a talus slope — rocks cleaved off nearby cliffs during the last glaciation — piled together such that they create cave-like features.

We approached the "cave" opening and climbed down steel rungs into the chilly room, quickly realizing how the cave gets its name: It stays so cool that ice and snow from the winter months do not melt. The main room is large enough to stand in, but a recent collapse now prevents even experienced cavers from penetrating farther.



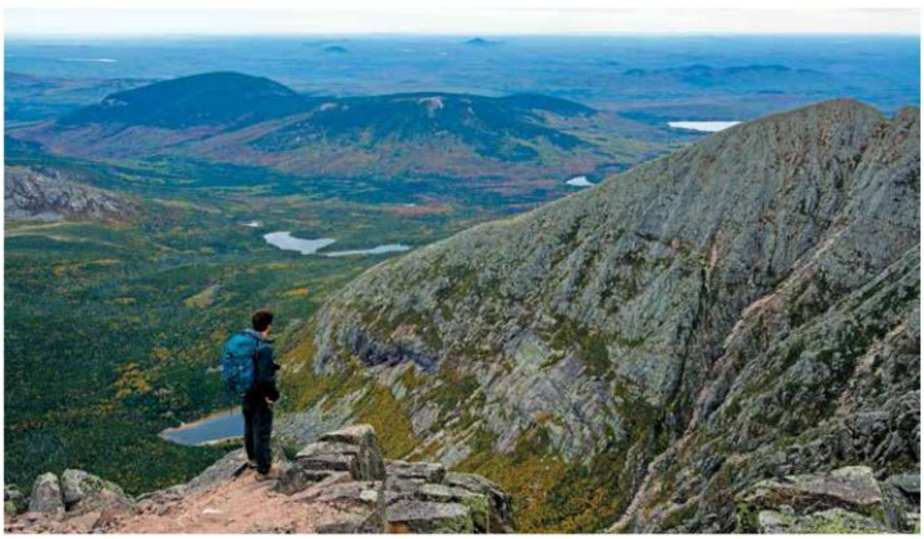
A black bear just below the Knife Edge.

Credit: Bethany Augliere

After two hikes, we were done for the day. Happy with our initial exploration of the park, we decided to return again to summit Katahdin.

The Climb

After that first visit to Baxter State Park, I spent a month poring over maps and trail guides to determine our route up Katahdin and watching the weather forecast for a clear weekend. There are many paths up the mountain, some easier than others. It's not a technical climb, requiring expertise, but it does require endurance and a fair bit of scrambling over rocks. And because we wanted to



Baxter State Park as seen from the summit of Katahdin.

Credit: Bethany Augliere

The Knife Edge Trail traverses between Baxter and Pamola peaks along the apex of a sharp-crested ridge, or arête.
Credit: Bethany Augliere

Hikers descend "The Chimney," a 24-meter scramble down a rock wall crevice, and the most challenging part of the Knife Edge Trail.
Credit: Bethany Augliere

traverse the Knife Edge, we had to go on a day when the weather was cooperating with relatively low winds.

We finally found the right weekend in early October — before the park closed to climbing for the winter — and headed out.

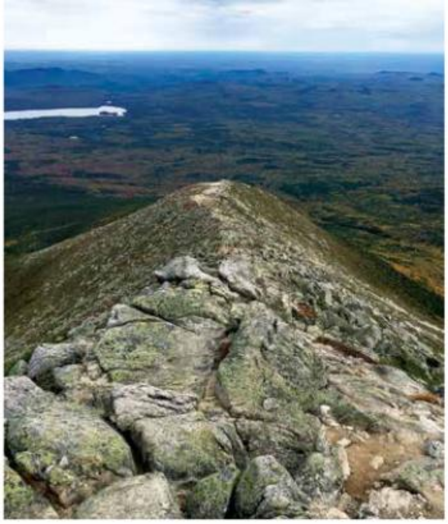
Nico and I camped in the park so we could get an early start and planned a loop trail. We began on the Chimney Pond Trail, a moderate 5.3-kilometer rocky path with a gradual incline through a fir-dominated forest. In the dark of the early morning, the rushing sound of the river to our right was amplified. The sunrise behind us slowly peeked through the clouds and lit up the sky. The rocky terrain required constant attention to maintain our footing. After about two hours, we arrived at Chimney Pond, a small circular lake in the basin of a cirque called a tarn.

Maple trees with yellow leaves mixed among evergreens encircled the clear, glassy water — it was still prime leaf-peeping season in the Maine woods — while Katahdin dominated the background. The gorgeous scene notwithstanding, and with the path ahead in mind, I was anxious to keep going.

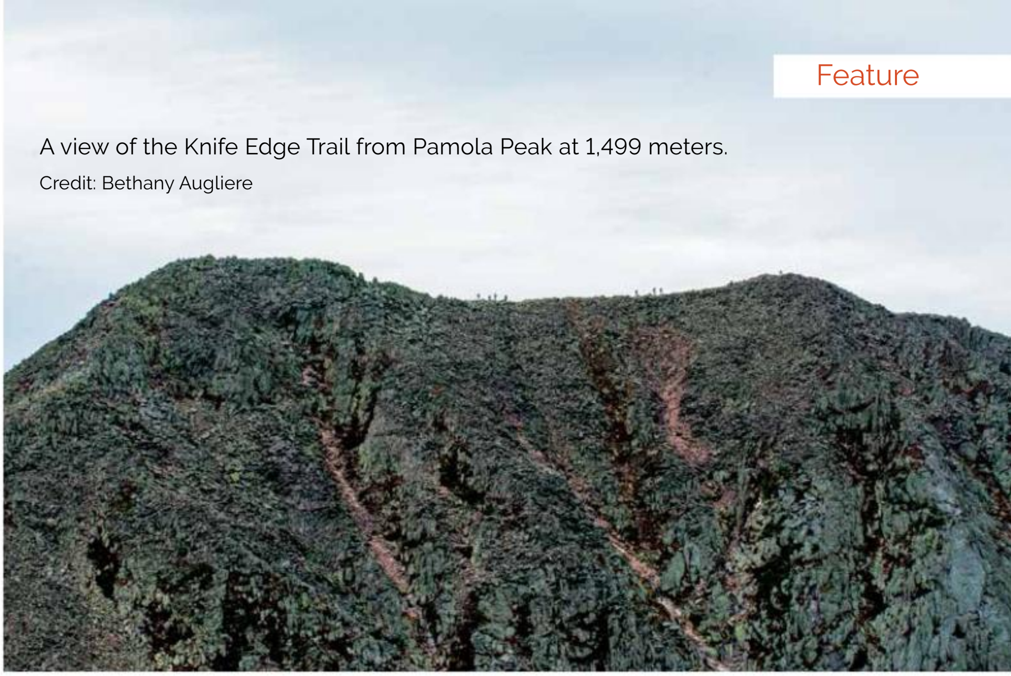
After a short amble through the woods, we reached an opening and saw the Cathedral Trail: a steep climb directly up the side of the mountain, which would quickly bring us above treeline. There are less direct and easier routes to the peak, but this one sounded like the most exciting and challenging to us. The trail wastes no time becoming difficult: The first move over a giant boulder required me to stretch and twist my body to clamber over the rock, and it was more of the same for the next three hours — be forewarned, this isn't a trail for the faint of heart. I occasionally stopped to glimpse the view behind me, which included a steady stream of hikers making their way up the trail. Chimney Pond grew smaller and farther away, additional peaks emerged in the distance, and I saw more lakes and ponds dotting the fiery red, orange and yellow landscape. My legs, meanwhile, grew heavier and heavier.

Three hours from the start of the Cathedral Trail, we reached the summit of Katahdin and arrived at what

A panoramic view at the summit of Mount Katahdin.
Credit: Bethany Augliere



The 5-kilometer Helon Taylor Trail slowly descends below the treeline and brings hikers back to the Roaring Brook Campground.
Credit: Bethany Augliere

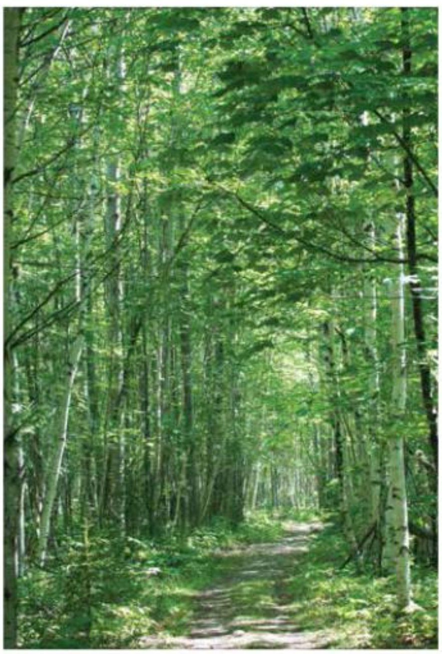


A view of the Knife Edge Trail from Pamola Peak at 1,499 meters.
Credit: Bethany Augliere

felt like a party. Large groups of people were standing by the sign — some even climbing it — that marks the summit to take photos, having arrived by one of six other paths up the mountain. Thru-hikers were celebrating the end of their four- to five-month walk in the woods with beer (which technically isn't allowed in the park), and many people, including us, had stopped to eat lunch and drink in the views. In every direction I saw lakes scattered across the landscape and dozens of surrounding peaks. The red and yellow fall foliage broke up the expansive unchanged deep green of the evergreen forest.

After a respite at Baxter Peak, we packed up for the next leg across the Knife Edge ridge. I was worried that we might not be able to hike the ridge because it's so exposed. This is not a hike you attempt in rain, high wind, fog, or if bad weather of any sort is looming on the horizon. We were told by rangers to make our decision once we reached the top. If you get to the top and cannot attempt the Knife Edge to complete your loop, you just take one of several trail options back down.

Most of the Knife Edge involves hiking over crusty, lichen-covered boulders and fins — rangers and signs remind hikers to stay on the marked path to help preserve the fragile alpine environment. It's not a particularly daunting physical challenge for someone in reasonably good shape and wearing good shoes, though it can be mentally taxing — and perhaps even frightening for hikers with little experience to such exposure. The hardest part for me was staying focused and constantly watching my footing — I could hardly even look up to enjoy the stunning views. A few sections require scrambling over narrow ledges just a few meters wide with steep cliffs that plummet down hundreds of meters on either side of the trail. At one particularly



Hiking around Katahdin is quite varied: it can be a peaceful walk in the woods or a scary traverse across a rocky ledge — sometimes both in the same day.
Credit: both: Bethany Augliere

stomach-churning spot, the trail winds around the side of a granite slab rather than over it.

Physically, the hardest part of the Knife Edge came during a section of the trail known as "The Chimney" toward the end of the ridge (or the beginning for those hikers making the traverse in the opposite direction). One woman coming the other direction stopped to tell us that she'd cried while crossing it. The Chimney is a notch in the ridge, the traverse of which involves a tricky 24-meter climb straight down over boulders without climbing aids, followed by an equally long, though less challenging, climb back up the other side.

Traversing the Knife Edge was exhausting, but the views along the way were spectacular — I was able to steal a few glances along the way — and I felt a huge sense of accomplishment. We even stopped briefly to watch a black bear forage below us on the side of a ledge.

The Descent

The Knife Edge brought us to Pamola Peak, standing 1,494 meters above sea level and named for the legendary bird spirit in Penobscot mythology. Pamola, the god of thunder, lived on, and protected, Katahdin. He's described as having the head of a moose, body of a man, and wings and feet of an eagle. The Penobscot people feared and respected Pamola, so hiking the mountain was taboo.

For the next 5.2 kilometers along the Helon Taylor Trail, we descended from above treeline back into the forest. For this portion of the hike, I wished I had brought trekking poles, as repeatedly stepping down over boulders was a bit hard on the knees. Our path down was long and uneventful, but it was our only option to make the trek a loop after traversing the Knife Edge. With so many trails to explore Katahdin, I think next time we'll pick a different route. Other paths, for instance, offer glimpses of waterfalls and walks along an alpine tableland. Ten hours after we had started that morning, we arrived at the campground, exhausted but exhilarated and ready to relax.

For anyone with hiking experience who enjoys adventure in remote locations, I highly recommend Katahdin. There are multiple paths of varying degrees of difficulty, but whichever path you choose, be prepared for a long, challenging day. The payoff, however, includes incredible views of the Maine woods; the chance to see bears, moose and other wildlife; and ample opportunity to stretch your legs in a wild and rocky landscape. It was even named one of the world's 10 best summit hikes by National Geographic.

Augliere (www.bethanyaugliere.com) is a freelance science writer and photographer. She was an editorial intern for EARTH last summer and wrote from a lakeside cabin in southeastern Maine.

Getting There & Getting Around

Mount Katahdin in Baxter State Park is about 120 kilometers northwest of Bangor, Maine, and its international airport. Once in Maine, you will need a car to get around. You can rent one at the airport or drive in from another large regional city like Boston. Plan to visit in the summer months before Oct. 15, when the campgrounds close. Bear in mind, they can be closed earlier due to weather.

Accommodation options include camping inside the park or at private campgrounds. You could also stay in the nearby town of Millinocket, which has several motels. Roaring Brook Campground is the best option if you want to hike a loop trail at Katahdin and traverse the Knife Edge. Outside the park, in between the town of Millinocket and the park entrance, Wilderness Edge Campground is highly rated.

Gates to the park open at 6 a.m., and parking reservations are required for day-use. Campgrounds fill up quickly, so plan accordingly. Note that dogs are not allowed in Baxter State Park, so if you're traveling with a pooch, drop it off at Katahdin Kritters pet resort in Millinocket.

If you have time to explore the town of Millinocket, visit the Appalachian Trail Café and the local gallery of internationally published moose photographer Mark Picard.

BA

"Sign" marking the logging road to Blueberry Ledges Trail in Baxter State Park. Such signs are common in the region.
Credit: Bethany Augliere

Film: Exploring Florida's Aquifers With Filmmaker Tom Fitz

Bethany Augliere

Filmmaker Tom Fitz describes the first time he found himself sitting, alone, more than 20 meters below Earth's surface and about 300 meters into an underwater cave: He was waiting in position to film a sequence of divers swimming through a narrow passageway as their lights illuminated the chamber for his new, yet to be named, documentary. "I was suddenly in absolute, complete black," Fitz says. "The kind of darkness that we rarely experience."

As he waited in the dark, his mind wandered and a creeping sensation of anxiety began to build. To quell the fear, Fitz flipped on his light, and risked potentially ruining the shot. But after a few seconds of looking around, he realized that all was as it should be, and he was fine. He turned off the light, went back to work and enjoyed the blackness. When the divers emerged from the tunnel "we got a glorious shot," he says.

Fitz is an Emmy-winning natural-history filmmaker who has spent the past 30 years traveling the world, shooting documentaries for the BBC, National Geographic, Discovery and other media outlets. He's filmed spotted dolphins feeding on squid at night in the Bahamas, orcas hunting gray whale calves in Monterey Bay, Calif., and pygmy sloths swimming in Central America.

The Schoolyard Films cave dive team at Ginnie Springs in Florida.
Credit: ©Schoolyard Films

In 2008, he founded Schoolyard Films, a nonprofit dedicated to educating children about the natural world. As the executive director, he produces short films — distributed for free — on various topics that include customized lesson plans for elementary, middle and high schools corresponding to state and national science standards. "An underlying theme throughout all of our work is the importance of stewardship and protecting the planet," Fitz says.

Natural-history filmmaker Tom Fitz.
Credit: ©Schoolyard Films/Kat Brown

The Schoolyard Films dive team (from left to right): Jill Heinerth, Tom Morris, Kat Brown and Tom Fitz.
Credit: ©Schoolyard Films/Glenn Allen

His latest documentary for Schoolyard Films highlights the Floridan aquifer system — which is how he found himself submerged in an underwater cave — and the challenges it faces, such as pollution. "It's a place so few people get a chance to see," he says. "I am really thrilled to join that small group of folks."

The Sunshine State sits on a thick bed of porous Paleogene carbonate rocks that make up the Floridan aquifer system, which spans 260,000 square kilometers of the southeastern United States, including Florida and parts of Alabama, Georgia, Mississippi and South Carolina. This system supplies drinking water for 10 million people, as well as water for irrigation and industrial and agricultural

Tom Fitz filming underwater.
Credit: ©Schoolyard Films/Kat Brown

use, which together account for about 50 percent of the withdrawals from the aquifer system. "It's underneath so many of us as we go about our daily lives," Fitz says, yet "it is largely unknown." He says he hopes the film sheds light on this unknown, but important, system.

Dissolution of the carbonate rock by groundwater has created networks of submerged tunnels and chambers in many locations in the aquifer. In May 2016, he and his crew traveled to Ginnie Springs in Central Florida to shoot inside the watery vaults for a week. But first, he needed a cave diving certification. Despite years of diving, Fitz had never explored caves, which requires specialized training. The hazards range from disturbing the delicate silt on the bottom, which can cloud the water and create a blackout, to getting lost amid the labyrinthine tunnels. And if something goes wrong, you can't quickly rise to the surface, so there is little margin for error. "It's an environment that, sadly, has taken a lot of lives, and so honestly the lesson is, you do it right or don't do it at all," Fitz says.

Before shooting, his team spent a week training with one of the world's foremost underwater cave divers and explorers, Jill Heinerth, who is featured in the film. In previously explored cave systems, tunnels are lined with ropes, which divers follow to find their way. "You never lose sight of your way out; you're always connected," Fitz says. During the week, he and his team crawled around the bottom of a cave with blindfolds on, learning how to navigate back to the cave entrance or work out staged predicaments. That way, if something happened, they would have the knowledge to work through a problem, "rather than just panicking," Fitz says.

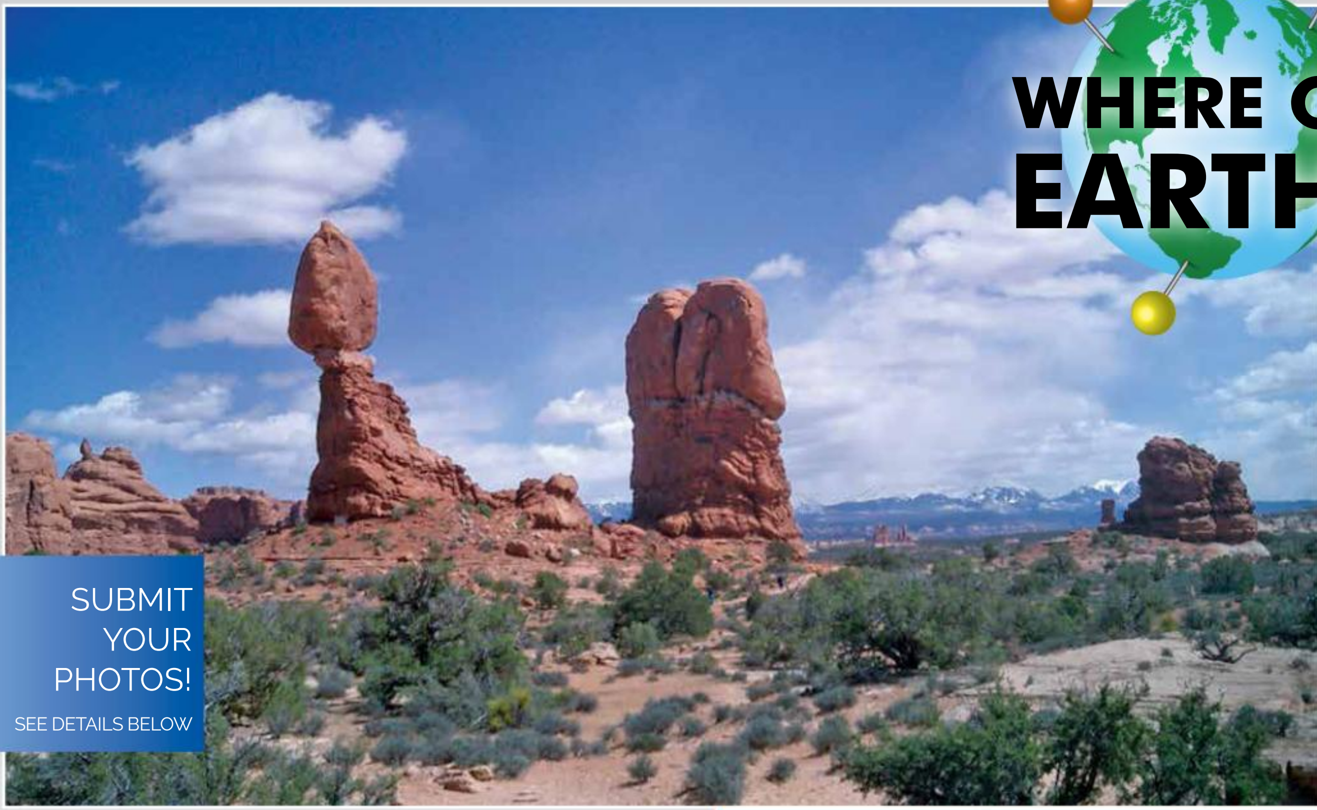
During training, Fitz learned how to swim and kick in a new way, so as not to disturb the bottom sediment. For him, it also made filming smoothly a challenge. "I always aspire to operate the camera in a way that lets the viewer forget that there is actually a camera operator between him or her and the story," Fitz says. But he adapted. Fitz learned he could film moving shots while he was being carried along by the current, and he could get stable shots if he hunkered down on the bottom and held onto the rock. "I was learning how to work in a new environment," he says.

One of his favorite experiences, he says, was finding wildlife in the seemingly stark and lifeless environment. Fitz worked with biologist Tom Morris, a friend and colleague of Heinerth, who helped locate the animals, including catfish and a blind albino crayfish. During the night, the fish leave the cave to feed in the river, but they return during the day and defecate in the cave, providing a source of nutrients for the crayfish. But filming these little crustaceans wasn't easy. "They live in a silty part of the system, and just getting in there safely, and staying in there safely, and keeping the water clear for the camera — believe me, it was full of challenges!" Fitz says.

In the new documentary, viewers will see underwater caves and meet biologists, explorers and a group of young students sampling water quality as part of their school curriculum. To Fitz, the film is appealing because of its adventure and dramatic setting. "You leave the lit world behind you, and there are glorious, big wide open spaces, and very narrow little cracks and passageways to squeeze through," he says. While giving a talk to fourth graders about a year ago, he recalls how, when one student asked him what his next project was, he put up an image of the underwater cave and the kids were awestruck, he says. "The visual aspect of this film will really help engage the students into the story, and that's a good thing for a filmmaker."

Augliere (www.bethanyaugliere.com) is a freelance writer and photographer and a former EARTH editorial intern.

On a field trip organized by the Cambrian Foundation, which conducts environmental educational outreach in schools, these students learned about springs, aquifers, and water quality and accessibility issues.
Credit: ©Schoolyard Films/Cambrian Foundation 2016



WHERE ON EARTH?

SUBMIT YOUR PHOTOS!

SEE DETAILS BELOW

CLUES

- The boulder perched atop this 39-meter-tall rock formation, which may be the most famous of many similarly named rock formations in the United States, is estimated to weigh 3,577 tons.
- The formation is easily visible from the main road through one of America's most popular national parks, founded in 1929, which hosts more than 2,000 documented rock arches ranging from 1 meter to almost 100 meters across.
- The rock formations in the park arose through weathering and erosion of sandstone layers, which were upwarped into anticlines by underlying salt beds hundreds of meters thick, and acted on by water, ice and extreme temperatures over the last 65 million years.

December Answer:

The island of Surtsey was formed by the longest known eruption in Iceland's history, lasting from 1963 to 1967. When it ended, the volcano rose 170 meters above the ocean surface, and 300 meters from the seafloor. Today, only scientists are allowed onshore, as the island continues to be studied to observe how living organisms colonize new land surfaces and how island ecosystems develop. Photo by Grace Sherwood Winer.

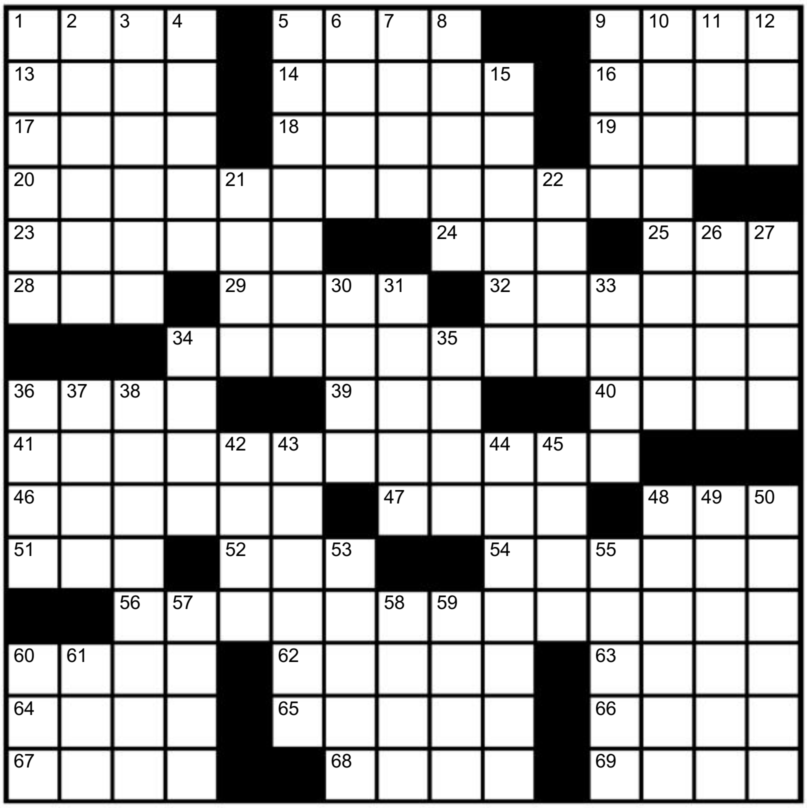
December Winners:

James Acker (Elkridge, Md.)
Paul C. Agnew (Morrisonville, N.Y.)
Jennifer Cugnet (Weyburn, Saskatchewan, Canada)
Rodney A. Sheets (Columbus, Ohio)
Frances Timms (Fareham, Hampshire, England)

HOW TO PLAY

NAME THE ROCK FORMATION & ITS HOST NATIONAL PARK.

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 (March 31). Subscribers can also view contest photos and clues in EARTH's monthly digital editions. From those who answer correctly, EARTH staff will randomly draw the names of five people who will win "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.



Across

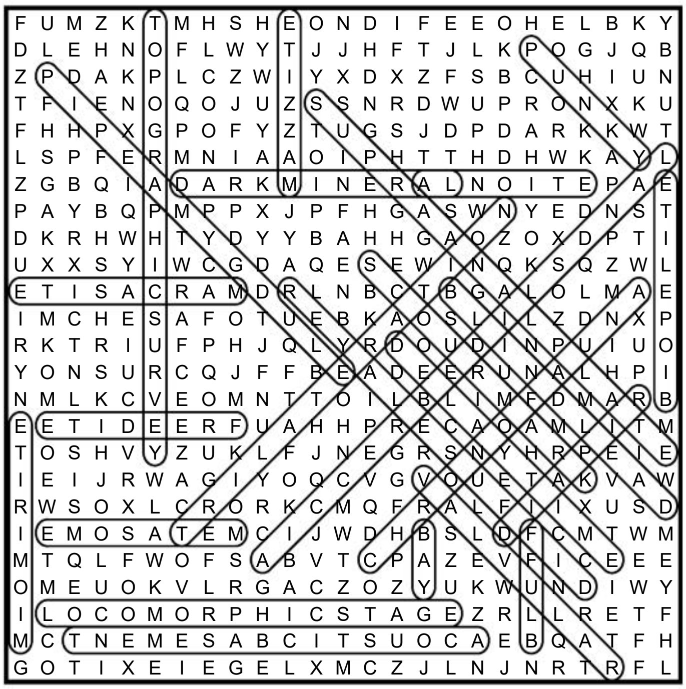
1. Little devils
5. Artist Chagall
9. "Follow me!"
13. Cause for a lawsuit
14. Going to the dogs, e.g.
16. "The ___ Ranger"
17. Islam branch
18. Choker
19. Again
20. Slow music
23. Flexible?
24. "Wheels"
25. "I ___ you one"
28. Swelter
29. Gum type
32. Anthracite hauler
34. Skills
36. "Not to mention ..."
39. Australian runner
40. "___ on Down the Road"
41. Pop culture dino
46. Small eggs
47. Dock
48. Battering device
51. Card
52. Voting "nay"
54. To branch or spread out
56. Gobi dino site
60. Certain surgeon's "patient"
62. Deposed leader's state, perhaps
63. "I, Claudius" role
64. Amerada ___ (former name of Fortune 500 company)
65. Drive away
66. Boris Godunov, for one
67. New newts
68. ___ souci
69. Eye affliction

Down

1. A reflexive
2. Angora product
3. Easily offended
4. Collar inserts
5 Least
6. Bothers
7. Brawl
8. Trig function
9. The Kennedys, e.g.
10. Landlocked land
11. "___ moment"
12. "What's ___?"
15. Threaten
21. Apple's apple, e.g.
22. "Pumping ___"
26. Early hours
27. European language
30. Little, e.g.
31. Chart anew
33. Maple genus
34. "Neato!"
35. South American native
36. Acknowledge
37. Bulgarian money
38. Many homers
42. Lower ab cavities
43. Chemical cousin
44. Male hawks
45. Grad student dread
48. Most abundant
49. Brawl
50. Southern Indian city
53. Vetoes
55. After dinner bits
57. Amount to make do with
58. Sap product
59. Hidden valley
60. Not just "a"
61. Call, as a game

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

Solution to the February 2017 puzzle



With Cave Scientist and Paleoclimatologist Kathleen Johnson

Kate S. Zalzal

Paleoclimatologist Kathleen Johnson has some advice for anyone interested in tropical cave science: befriend experienced cave guides and beware of venomous snakes, ubiquitous bats and Frisbee-sized spiders.

Johnson, a professor since 2007 in the Department of Earth System Science at the University of California, Irvine (UCI), studies cave deposits called speleothems to understand the history of the Asian monsoon system — a critical part of the global climate system impacting billions of people. Her research has taken her to caves in China, Sri Lanka and, most recently, Laos, in an effort to better calibrate and interpret stable-isotope-based paleoclimate records and investigate patterns of past natural climate variability.

Johnson got her first taste of speleothem work as a doctoral student at the University of California, Berkeley, working with sedimentary geochemist Lynn Ingram. Neither of them had worked with speleothems before, but Johnson, intrigued by a project idea mentioned by a colleague in China, quickly began fieldwork at Wanxiang Cave in Gansu Province, China. Over the next seven years, she explored complexities in the relationships among cave geochemistry; trace element and isotope records; and local, regional and global climate.

Johnson's current research is focused on active cave monitoring to improve understanding of the links between climate and speleothem geochemistry and on developing high-resolution paleoclimate reconstructions to capture how the Asian monsoon responded to deglaciations during the Late Pleistocene and Holocene.

Johnson, a member of the Grand Traverse Band of Ottawa and Chippewa Indians in Michigan, has also worked extensively to expose Native American youth to earth system science and to educate them on environmental and natural resource issues affecting native lands. With funding from the National Science Foundation's (NSF) Opportunities for Enhancing Diversity in Geosciences program, Johnson developed the American Indian Summer Institute for Earth System Science at UCI, where it has been run since 2011. The institute is a free, two-week residential summer program for Native American high school students in which they conduct scientific fieldwork and develop and complete research projects related to tribal environmental issues.

Johnson recently spoke with EARTH about what makes a good cave, why it's important to expose Native American youth to earth science, and why the next generation of scientists makes her optimistic about the future.

Kathleen Johnson is an associate professor in the Department of Earth System Science at the University of California, Irvine (UCI), where she studies speleothems to investigate past climates.

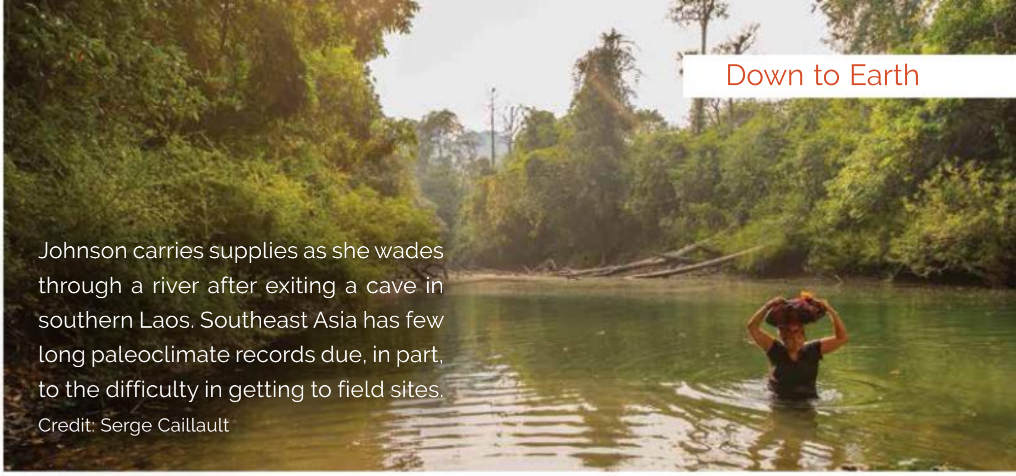
Credit: Kathleen Johnson

Johnson and colleagues from the French-led Explo Laos cave exploration project stand in a large room within Tham Houay Sai Cave in southern Laos. Johnson and her lab at UCI are working to generate carbon and oxygen isotope records from speleothems from caves located in Southeast Asia.

Credit: Serge Caillault

KSZ: What makes a cave good for paleoclimate work?

KJ: The most important thing is that it has to have stalagmites. Stalagmites, which grow up from the cave floor as water drips off the ceiling, are preferable to other types of speleothems like stalactites — which grow down from the ceiling — because stalagmites have a more clear and simple stratigraphy. We also want to select samples from a location, usually deep within a cave rather than at the entrance, that has not been affected significantly by evaporation or by very large swings in temperature that can affect the stable isotope signal. Ideally, the cave is also hydrologically active with speleothems still forming. This allows us to do the monitoring that we would prefer to do, including measuring temperature, humidity, and carbon dioxide in the cave air, and soil sampling around the cave.



Johnson carries supplies as she wades through a river after exiting a cave in southern Laos. Southeast Asia has few long paleoclimate records due, in part, to the difficulty in getting to field sites.
Credit: Serge Caillault

KSZ: How did you start working in caves in Laos?

KJ: Some colleagues are involved in a large archaeology project in Southeast Asia called the Middle Mekong Archaeological Project. They are looking at questions about human and cultural changes along the Mekong River, and they are interested in the role that climate may have played in some of those changes. They invited me to come along for a field season in 2010. We visited about 20 caves and identified one in northern Laos that is particularly promising called Tham Doun Mai. Right now, we are trying to interpret a carbon and oxygen isotope record spanning the last 45,000 years from that cave.

KSZ: What questions do you hope to address with this work?

KJ: There are only a handful of paleoclimate records from all of Southeast Asia. We want to understand how the monsoon system responded to orbital forcing and changes in ocean circulation. We also want to know how abrupt climate changes may have impacted human culture there.

Johnson and her colleagues hold a speleothem just collected from a cave in Laos. Analyses of the speleothem will help characterize how the Southeast Asian Monsoon varied during the Pleistocene and Holocene.
Credit: Kathleen Johnson

I'm also interested in the mechanisms that control the oxygen isotope composition of precipitation — which is essentially what is recorded in the speleothem calcite. There are incredibly strong similarities between variations in oxygen isotope records from sites across Asia that are thousands of kilometers apart. Rather than reflecting local rainfall or summer monsoon intensity at a local site, it's becoming more clear that oxygen isotope variability reflects a much larger signal related to monsoon intensity, and we don't fully understand it yet. We're lucky that speleothems also contain other types of proxies, like trace element ratios and carbon isotopes that do reflect more local water conditions. We're trying to combine all those together to learn about large-scale regional climate change and also more local processes.

KSZ: Have you encountered safety concerns in any of the caves you've studied?

KJ: Many of them are quite easy to get into, but we usually bring experienced cavers with us to make sure we can get through safely, and to explore new regions of the cave. We had a biologist who specializes in cave insects with us on a recent trip to Laos. He showed us some crazy stuff and tried to catch spiders the size of Frisbees. We've also had to be careful of vipers near cave entrances, and we encountered two Burmese pythons inside a cave once. The scariest thing that ever happened to me was when I stepped right over a cobra while hiking to a cave in Sri Lanka.

KSZ: How did you become involved with Native American youth?

KJ: Native Americans are very underrepresented in the geosciences. Yet there is a unique need for qualified geoscientists in tribal communities, given the large amounts of land managed by tribes and all the natural resource and environmental issues that face them. I didn't grow up on a reservation, but I grew up being exposed to native culture and was encouraged to learn about it. Like many students, when I went away to college and graduate school I became a bit separated from that aspect of myself. Later, at UCI, I connected with the American Indian Resource Program, and in 2011 my proposal for the summer institute was funded.

KSZ: What do students learn and do at the institute?

KJ: Native high school students from across the country apply, and we generally select 40 students with a range of academic backgrounds. We start with a basic earth system science orientation and then head off to camp along a river on the La Jolla Indian Reservation in Southern California for about a week. While there, Julie Ferguson, another faculty member at UCI, along with the teaching assistants and I teach about the atmosphere, biosphere, hydrosphere and geosphere. We teach the students field skills and how to identify connections between various components of the earth system. We go on field trips to see the local geology and to relate it back to other earth systems.

During the second week, we come back to UCI and spend most of our time developing research projects based on tribal environmental issues — ranging

Students participating in the American Indian Summer Institute in Earth System Science (AISIESS) work together to make a poster characterizing different components of the earth system.

Credit: Kathleen Johnson

from water quality issues and climate change to renewable energy and waste management. Projects on pipelines and mining come up a lot too. Many Navajo students have grandparents who have, or had, major health problems from working in the uranium mines or drinking contaminated water. We have the students look into the science of these issues, but a lot of them also look at the public health side of the issues and what can be done to improve conditions. At the end of the week, we have a symposium where the students each give a 10- to 15-minute talk.

KSZ: Do you try to incorporate a Native American perspective into teaching earth science?

KJ: We try to integrate native culture into it as much as possible — studies have shown that that's a much more effective way to engage native youth. We try to incorporate discussions about traditional environmental knowledge into our discussions and lessons, and we bring in tribal environmental professionals whenever we can. We also incorporate other cultural aspects like bringing in local natives for storytelling or singing or dancing.

KSZ: What are the students' favorite parts of the program?

KJ: Their favorite day is always the water cycle day, when we get in the river to take discharge measurements. We also spend a whole day on the carbon cycle. They develop hypotheses, design experiments and present their results about what factors most affect soil respiration rates. The students are generally incredibly motivated, smart and excited to be there. They are often a little surprised at how much fun it is in addition to how much they learn.

KSZ: Have students gone on to study earth science further?

KJ: Nearly all of our students who have completed high school have gone on to college, and I know of at least nine or 10 who are majoring in earth system science, geology or environmental science. By the end of the two weeks, the students have bonded and formed a supportive community. Going off to college can be really challenging for native students; they don't usually have the sense of community that they are used to. But after the summer institute, they are part of this whole group of smart, motivated native students who take their education seriously and who want to go on to do big things. As they go into college, that becomes a major support system for them.

KSZ: What's next for the institute?

KJ: The NSF program that originally funded this project has been phased out. The summer of 2017 will be our sixth year, but we don't have enough funding left to do a full-scale program, so we're planning a reunion type of event for former students who have stayed engaged in earth science. We're also going to try for other funding, including private funds. We hope we can continue the program as is, or we may consider developing it into a broader STEM program of which earth system science will be just one component.

KSZ: How do you feel about earth science as a tool to solve environmental problems?

KJ: My research plays a small part in improving our understanding of the natural variability of the monsoon system. Generating these new data will hopefully improve characterizations of these systems in climate models and lead to more accurate projections of future change in those regions. There is going to be a continued need for earth system scientists, so I'm optimistic about the future of the field. Working with students, not only the native students, but also the students at UCI, makes me incredibly optimistic because the next generation is certainly up for the challenge and they have high hopes to effect change.

Zalzal is a freelance science writer in Lyons, Colo., and a former EARTH editorial intern.

AISIESS students on a hike to learn about the geology and ecology of Southern California.

Credit: Kathleen Johnson

March 11–13, 1888:
The Great Blizzard of 1888 Paralyzes New York City

Kate S. Zalzal

On Tuesday, March 13, 1888, the streets of New York City were nearly unrecognizable. What had been well-lit homes and storefronts, bustling with shoppers, families, workers and businessmen just two days before, now looked like a frozen battlefield, pummeled by a blizzard whose force had taken the city by surprise. The streets were clogged with deep snow and debris from signs, broken wires, downed poles, trees, and carts that had been abandoned as people fled to shelter. The few people who were out stumbled through deep snow drifts, fighting against a brutal icy wind; some never made it to safety.

Snow fills the street, sidewalks and doorsteps along a stretch of Park Place in Brooklyn, following the Great Blizzard of 1888.

Credit: NOAA

During the two and a half days that the Great Blizzard of 1888 raged, it dumped heavy snow and brought hurricane-force winds and frigid temperatures to much of the Northeast, paralyzing cities and towns from the Chesapeake Bay to Montreal, Canada, for up to a week. Snow blocked roads, rail lines and elevated trains. It also took down telegraph and telephone wires in cities, bringing nearly all communication to a halt and leaving residents in disbelief that the conveniences of their modern cities could fail so catastrophically.

Approximately 400 people perished in the storm — including at least 200 in New York City — frozen in snow banks, or killed by fires, accidents or a lack of urgent medical care. It took days to dig out from under the snow, and weeks to restore communication lines and remove the piles of waste and garbage that had built up in the city.

The Great Blizzard of 1888 — also called the Great White Hurricane — remains one of the most famous and severe snowstorms in American history. But it wasn't just the storm's meteorological measures that made it so memorable — it brought enormous disruptions to urban life at a time when technology and population growth had surpassed the capacity of city planning to manage it. The storm and its costly aftermath exposed New York City's weaknesses, but also helped galvanize efforts already underway to modernize communication, transportation and sanitation infrastructure.

The Storm

In the days leading up to the blizzard, temperatures were unseasonably mild. On March 10, a low-pressure system that developed over the central U.S., spanning from Canada to Mexico, began moving east. The front contained two storms, one in the north dropping snow, and one in the south dropping rain. By the evening of March 10, the northern storm began to weaken, while the southern storm appeared to be moving out to sea. But the next day, the southern storm turned and moved northward up the Atlantic coast. The warm, moist storm met with cold northern air, spawning the hurricane-like blizzard.

As the storm moved up the coast, the high winds dashed 35 ships together in Lewes Harbor in Delaware. By the time the storm was over, more than 200 ships had been wrecked or grounded along the coast and at least 100 seamen had died.

By Monday evening, March 12, rain had turned to wind-driven snow in New

Children climb on a snow pile on Baxter Street in New York City.

Credit: NOAA

Men stand next to a snow pile after the storm.
Credit: NOAA

York City and the temperature fell into the single digits. The storm raged all day on Tuesday. By the time it ended, parts of New Jersey, New York, Connecticut

A horse-drawn trolley car abandoned on 9th Street in New York City.
Credit: NOAA

Men shovel snow into train cars to be taken out of the city. An "Army of the Shovel" was formed to clear the city of snow.
Credit: NOAA

and Massachusetts were buried by up to a meter and a half of snow, including more than half a meter in New York City. Wind speeds reached 72 kilometers per hour, producing a lethal windchill and pushing the heavy snowfall into massive drifts, some reaching as high as second-story windows. The high winds also blew down signs, lamps and anything else that was loose in the streets and alleyways. People outside got stuck in the deep snow, abandoning their carts, trucks and even horses when they could no longer move them.

Tens of thousands of passengers who had boarded trains on Tuesday morning before realizing the gravity of the storm were caught between railway stations, stuck in freezing, crowded rail cars. Rail lines coated in ice became too slippery, causing commuter trains to derail and collide across New York City. Eventually, passengers abandoned train cars on tracks blocked by deep snow.

A reporter wrote in the New York Sun of his attempts to get to an assignment by elevated train. After nearly six hours of waiting, and only moving a few blocks, he and others on the train climbed down a makeshift ladder to the street. A man who had lashed two ladders together to reach the raised tracks charged each person 25 cents to descend (equivalent to about $6 today).

Perhaps the gravest danger of the storm was posed by the thousands of telegraph, telephone and power poles holding up webs of wires overhead. As the poles and wires crashed down under the force of the wind and the weight of accumulating snow and ice, they took out trees, signs and other poles and lines, leaving twisted, sizzling piles of debris on the snowy streets. Before the storm was over, the city was lit only by gas and candle light.

The falling wires also set off fires around New York City. Firefighters, immobilized like everyone else, could do little to fight the flames in many instances. Property losses were estimated at $25 million (equivalent to about $660 million today).

A Buried City

The storm subsided on March 14, but with transportation halted, many New York City residents now faced the immediate crises of running out of food and heating fuel. They also had to contend with the towering snow drifts left behind.

Rail lines and roadways were impassable in the days after the storm, as those assigned to clear the snow were stranded by it as well. Eventually, horse-drawn snowplows cleared the majority of the main streets, but many side streets remained heaped with snow; some piles persisted into the summer. Groups were organized to load snow into railcars and carts to be taken out of the city, or dumped into the sea. When temperatures warmed, the great volumes of melting snow led to flooding in many parts of the city.

Even in the midst of the blizzard, many New Yorkers were incredulous that a storm could materially affect their daily lives. In a tongue-in-cheek response to the dismay that goods were unable to be delivered daily to homes during the blizzard, a March 13, 1888, New York Times editorial read "… it is the small ills of life that worry the most, and probably thousands of New Yorkers yesterday morning … when they had to get through their breakfasts without their favorite newspaper, their hot buttered roll, and their fragrant coffee enriched with boiling milk, began to seriously question whether life was worth living after all, with all those trials and tribulations to undergo."

A man travels by horse and sleigh during the blizzard. Behind him, telegraph and telephone wires are coated with ice.
Credit: NOAA

Ice- and snow-coated telegraph and telephone wires hang low on a New York City street. The storm exposed weaknesses in city infrastructure and prompted improvements, like the burial of electrical wires and the building of underground subway systems.
Credit: Associated Press

The Storm's Legacy

In 1888, New York City was the commercial and financial capital of the country, eager to continue staking its claim to a place among the world's great cities. An influx of wealth and a growing immigrant population created a diverse and cosmopolitan community. Despite the physical destruction and loss of life wrought by the storm, the most troubling aspect for many residents may have been the loss of communication. A New York Times article written in the days after the storm lamented "the ease with which the elements were able to overcome the boasted triumph of civilization … our superior means of intercommunication."

In the two decades before the storm, New York City's sky had become crowded with communications and power poles, some up to 30 meters tall and carrying up to 20 wires each. The city had already ordered that wires be buried following public outcry after several gruesome accidents occurred during line repairs. However, the high cost and lack of enforcement meant that most businesses ignored the order. The blizzard reignited the debate, providing visible evidence of the dangers of aboveground lines. According to the New York Times, the storm "may accomplish what months, if not years, of argument might have failed to do."

It would be several years before the poles finally came down and the city began building its underground communications and electrical system. Alarmed by the paralysis and economic losses brought about by the storm, cities like Boston and New York also began making plans to move public transportation infrastructure underground. Boston began laying subway tracks in 1895, opening the country's first subway system on Sept. 1, 1897. New York City followed suit in 1904.

The blizzard also exposed the inefficiencies in waste removal in New York City. Piles of garbage, horse manure and sewage filled the streets after the storm. Municipal government officials organized an "Army of the Shovel" to remove snow — only after the snow was gone could the garbage be removed.

Memories of the event remained strong in the years after the Great Blizzard. To the survivors, the storm stood out as an unprecedented natural disaster in the city's history. The experience also became a source of pride for many, as its destruction propelled progress and technological transformation. Ultimately, the disaster was a great equalizer: Everyone was affected in some way in the struggle to cope with nature.

Zalzal, a freelance writer based in Lyons, Colo., was an EARTH editorial intern in 2016.

Please visit our website, www.earthmagazine.org/classifieds, for these and many other current career opportunities.

CAREER OPPORTUNITIES

ASSISTANT PROFESSOR DEPARTMENT OF GEOLOGICAL SCIENCES

The Department of Geological Sciences at Ball State University is inviting applications for a full-time tenure track faculty position available August 1, 2017.

Major Responsibilities: Teach courses in discipline or as required by the interdisciplinary Ph.D. program in Environmental Science; have and maintain an active research program in Quaternary Geosciences with an environmental focus; collaborate and participate with existing environmental science faculty to expand research activities within the college; actively procure external funding; produce refereed research publications; participate in service functions. Successful applicant will be appointed in the Department of Geological Sciences.

Minimum Qualifications: Earned doctorate in geoscience or closely related environmental science field; post-doctoral experience related to the geoscience discipline. Areas of expertise may include some combination of geology, oceanography, paleoclimatology, geochemistry, environmental geoscience, or related field.

Preferred qualifications: A record of extramural proposal submissions; evidence of extramural grant acquisition; strong record of refereed research publications; demonstrated ability to teach graduate and undergraduate students; research interests that complement existing environmental science faculty.

Send electronically in PDF format: cover letter, curriculum vitae, statement of teaching and research interests and goals, copies of transcripts, and contact information for at least three professional references to: Dr. Richard H. Fluegeman, Chair, Department of Geological Sciences, Ball State University, Muncie, IN 47306-0475. rfluegem@bsu.edu.

Review of applications will begin immediately. Applications will be accepted through March 9, 2017. Visit our website at: www.bsu.edu/geology.

Ball State University is located in Muncie, Indiana, on an attractive campus 45 miles northeast of Indianapolis. Approximately 22,000 graduate and undergraduate students enroll in one of eight academic colleges that offer 190 undergraduate programs. We offer more than 140 master's, doctoral, certificate, and specialist degrees, with many of them ranking among the best in the nation.

Ball State aspires to be the model of the most student-centered and community-engaged of the 21st century public research universities, transforming entrepreneurial learners into impactful leaders – committed to improving the quality of life for all. The university offers an excellent benefits package.

EEO/AA Employer/Veterans/Disabled.

TENURE-TRACK FACULTY POSITION IN THE GEOSCIENCES ELLEN AND BILL NOEL DISTINGUISHED PROFESSORSHIP IN ENERGY RESEARCH

The Geology Program in the Department of Physical Sciences of The University of Texas of the Permian Basin seeks a Geoscientist for a tenure-track faculty position (rank open). Information on how to apply can be found at: www.utpb.edu/eo/faculty/geology-geologist.

All interested applicants should download the application forms from http://www.utpb.edu/services/business-affairs/human-resources/employment-opportunities.

STUDENT OPPORTUNITIES

EARTH SCIENCE WRITING EXTERNSHIP

EARTH's externship is an opportunity for select students and inexperienced writers to learn about the process of writing and editing a news story about recent scientific research, and to get professionally edited and published clips. Most of our externs have backgrounds studying science — particularly geoscience-related fields relevant to EARTH's typical content — and are interested in potentially pursuing science writing as a part- or full-time career option. But EARTH welcomes applicants of all backgrounds who are interested in sharing what's new in earth science with a broad audience. We typically work with three or four externs at any given time, but we regularly rotate in new writers as positions come open.

If you are selected as an EARTH extern, the position is essentially an as-you're-available writing opportunity. In any given week or month when you have time to write, you'll email us and say, "Hey, I have time to write." Then, either we can assign you a story or you can pitch stories to us — it's up to you. If you've got a great idea for a story and would like practice pitching your idea to an editor, you're encouraged to do so. On the other hand, if you'd prefer that we provide you with an assignment — as is the case with many first-time externs, for example — that's fine too.

Our extern-written stories typically cover a recent, peer-reviewed scientific study or report, and include quotes about the study from multiple expert sources — obtained via first-person interviews — just as a professional news story would. Before your first assignment, we'll provide guidance about the general style, tone and structure of the news stories we publish in EARTH to help get you started. And then we'll work with you through the writing and editorial process. You're encouraged to ask questions, and you're welcome write as frequently or infrequently as works for you and the magazine's editorial staff.

The externship is a remote position; you can work from any location and at your leisure. Once a story is assigned, you'll generally have one to two weeks to research, report and write it before turning it in. (We do ask that you stick closely to deadlines, so please keep that in mind when determining your availability to write.) Once edited and finalized, extern-written stories are posted on EARTH's website as soon as possible. Select extern-written pieces may also appear in a print issue of the magazine. Publication, either online and/or in print, is subject to the discretion of the editorial staff and is not guaranteed. The externship is unpaid.

If you're interested in the experience, email a cover letter discussing your interest in the geosciences and why you'd make a great extern at EARTH, your resume or CV, and at least one writing sample to earth@earthmagazine.org to apply.

SERVICES AND SUPPLIES

TRANSLATION SERVICE

Translator.com.au – Fast and accurate translations

IGNEOUS AND CONTACT METAMORPHIC ROCK SUITES

from the Gettysburg and Newark Basins of Pennsylvania. Including

Please visit our website, www.earthmagazine.org/classifieds, for these and many other current career opportunities.

Please visit our website, www.earthmagazine.org/classifieds, for these and many other current career opportunities.

newly discovered Olivine Zones rocks and Monocacy Hill Xenoliths. Price is $75 per suite. Please contact RRK_ANISE_PA@yahoo.com

PROSPECTING MAPS
WWW.GOLDMAPS.COM

OnlyGlobes.com offers a huge selection of maps and globes.

WORLD GLOBES
www.1worldglobes.com and globe gifts www.1worldglobalgifts.com - the largest selection in the world. Classroom maps, history map sets, raised relief maps -www.worldmapsonline.com

GEOLOGICAL GLOBE OF THE WORLD
+ Jupiter & its moons, Mars, MOLA, Venus; Focal Mechanism Lab Kits www.realworldglobes.com

EARTH MAGAZINE SCIENCE WRITING SUMMER INTERNSHIP

EARTH www.earthmagazine.org

EARTH Magazine is your source for the science behind the headlines, covering the latest happenings in Earth, energy and environment news. Combine your love of science and passion for writing with a science writing internship at EARTH this summer.

EARTH is currently accepting applications for the summer 2017 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 10, 2017.

AGI is an equal opportunity employer.

AGIF american geosciences institute foundation

The AGI Foundation's (AGIF) programs impact young people, educators, researchers, the public, and policymakers who together comprise the geoscientists and informed citizens of tomorrow. AGIF's most recognized programs focus on geoscience STEM educational excellence, workforce development, public awareness, and government affairs. Widely acclaimed examples include the prestigious endowed Fisher Congressional Fellowship, development of inquiry-based geoscience curricula for elementary and secondary schools, conducting teacher academies to improve instruction of the geosciences, and the collection and analysis of geoscience workforce data.

Currently, AGIF is engaged in a capital campaign to support the AGI Center for Geoscience and Society. The Center's mission is to enhance AGI's existing partnerships and build new relationships across all sectors of society, within and outside of the geosciences.

The Center has two distinct, but coordinated efforts:

1 The **Critical Issues Program (CIP)** provides decision makers, educators, industry professionals, and the general public with scientifically-based information to understand important contemporary issues that involve the geosciences.

2 The **Education Resources Network (ERN)** provides resources that help teachers and informal educators build geoscience awareness across kindergarten through grade 12 (K-12) populations — the people who will make decisions at personal, societal, and global levels in the future.

Specific programs and services of the Center include:

- Information Resource Development
- Collaboration and Consulting Services
- Stakeholder Meetings
- Innovative Starter Projects

If you are interested to learn more about AGIF, or support the Center's campaign, please contact us at: agif@agifoundation.org

AGI Foundation Leadership

Chair: Daniel D. Domeracki, Schlumberger Ltd.

Vice Chair: Mark Shuster, Bureau of Economic Geology

Secretary: Stephen M. Cassiani, ExxonMobil (Ret.)

Treasurer: William A. Van Wie, Devon Energy Corp. (Ret.)

Executive Director: P. Patrick Leahy, American Geosciences Institute Foundation

AGI Foundation

P. Patrick Leahy, AGIF Executive Director
c/o American Geosciences Institute
4220 King Street, Alexandria, VA 22302
agif@agifoundation.org • www.agifoundation.org
Tel: (703) 379-2480

Rebirth on the Vernal Equinox

John Copeland

March is a particularly tempestuous month. The Anglo Saxons called it "Hrethmonath," which translates as "rough month." The name referred to March's blustery winds that often blow with a force unfelt all winter, and which make March a great month for kite flying and a common time for tornadoes to strike.

During the Roman Empire, March's winds often carried the sound of blaring war trumpets, as the Roman Legions went on the offensive at this time of year. In fact, March is named for Mars, the Roman god of war. And, of course, Julius Caesar was killed on the Ides of March.

But wind and war aside, March is really more about rebirth. On March 20, we celebrate the vernal, or spring, equinox in the Northern Hemisphere. Seasonal beginnings are determined by astronomical mechanics. The vernal equinox marks the moment the sun crosses the celestial equator moving from south to north. It happens worldwide at the same instance: This year, it's at 10:28 a.m., Coordinated Universal Time.

However, there are different ideas about how to define seasons. Astronomers count the vernal equinox as the start of spring, which then ends on the summer solstice, when astronomical summer begins. Meteorologists, on the other hand, mark the beginning of spring in the Northern Hemisphere three weeks before the vernal equinox, on March 1, and end it on May 31.

We didn't always understand that the timing of the equinoxes and solstices occurs as a product of Earth's yearly orbit around the sun. Today, we know they relate to Earth's 23.4-degree tilt on its axis and its motion in orbit. Because of the axial tilt, Earth's Northern and Southern hemispheres each take a turn in the sun during the year, variously receiving the sun's most direct light and warmth. Our biannual equinoxes happen when Earth's axial tilt and its orbital location combine in such a way that the planet is tilted neither away from, nor toward, the sun, meaning both hemispheres are illuminated equally.

The word equinox derives from the Latin words "aequus" ("equal") and "nox" ("night"). Hence, on the equinox, the length of day and night are also essentially equal, though the equality is short-lived as the balance tips in favor of more daylight in the Northern Hemisphere in March and more in the Southern Hemisphere in September.

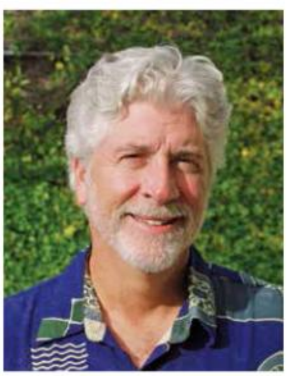
On the first day of spring, we are halfway between the winter solstice and the summer solstice — 89 days from each. However, there are 94 days between the summer solstice and the autumn equinox. This imbalance arises because Earth does not orbit the sun at a constant speed, so the seasons are not equal in length. I don't know about you, but I prefer a longer summer than a longer winter.

Curiously, the equinoxes themselves are not fixed in time. They occur about six hours later every year, equaling one full day every four years, an offset that is reset with each leap year. Our calendar is good, but not perfect.

To our forebears, watching the sunrise or gazing at the moon and stars were sources of mystery, but also continuity as they used celestial movements to mark time. In the millennia before automobiles, electric lights, televisions, computer tablets, smartphones, and clocks, our skywatching ancestors recognized that the sun's path across the sky, the length of daylight, and the location of the sunrise and sunset all shifted throughout the year. The shifts signaled the start of the growing season, or the onset of winter, for example. The ability to predict the seasons was key to survival in ancient times.

Researchers have discovered that many cultures around the world constructed sites that were astronomically aligned on either the equinoxes or the solstices. In Europe, many of the prehistoric Neolithic monuments, standing stones and stone circles, like Stonehenge, are in tune with the equinoxes, aligned with either the rising sun or rising moon. It is probably no coincidence that early Egyptians built the Great Sphinx to directly face the rising sun on the vernal equinox.

On the spring equinox, many ancient cultures celebrated the start of the new year. Just as dawn is the time of new light, our ancestors considered the vernal equinox the time of new life. For many cultures, the spring equinox signaled the return of weather that favored the planting of new crops, and, for this reason, humans have associated the spring equinox with our ability to perpetuate ourselves. It is understandable why we have chosen to celebrate such a momentous occasion, and why it has come to represent "rebirth" in a variety of contexts.



Credit: Fran LoCascio

Copeland is a filmmaker in California who has produced television programs ranging from "Babylon 5" to "Faces of Earth" (produced with the American Geosciences Institute). Copeland also works with MIT's Experimental Study Group to instruct undergraduate science and engineering students in the art of visual communication and storytelling. The views expressed are his own.