

VOLUME 250

JULY 2026

NUMBER 01

MUMMY SLEUTHS | PIT VIPERS | THE USA AT 250

NATIONAL GEOGRAPHIC BEYOND EARTH



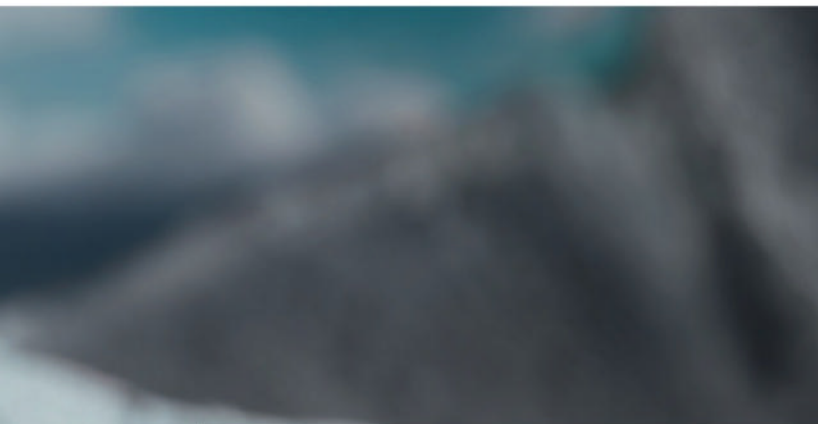
HOW WE'RE PREPARING
TO LIVE AND WORK ON THE
MOON AND MARS



OVERSEAS DUAL TIME CARDINAL POINTS – NORTH

Reference 7930V

41mm, titanium



VACHERON CONSTANTIN
GENÈVE

ONE OF
NOT MANY.

FROM *the* EDITOR

NATHAN LUMP

EARLIER THIS YEAR, NASA's Artemis II mission to the moon captivated the world, a lunar flyby that took four astronauts farther from the Earth than anyone has ever been. Through a partnership with NASA, *National Geographic* had been working with and interviewing those involved for many months before launch, including the astronauts, to whom we provided special cameras and training to capture photos and video for us in space. So we were thrilled to see the mission's success—and the incredible moments the astronauts documented along the way. If you missed our coverage, I encourage you to visit nationalgeographic.com/artemis for some terrific stories, photographs, and footage.

The Artemis program reawakened many people's interest in space exploration, and since its ultimate aim is to put astronauts on the moon once again, I find it a fitting prelude to this month's story that takes a closer look at novel experiments conducted here

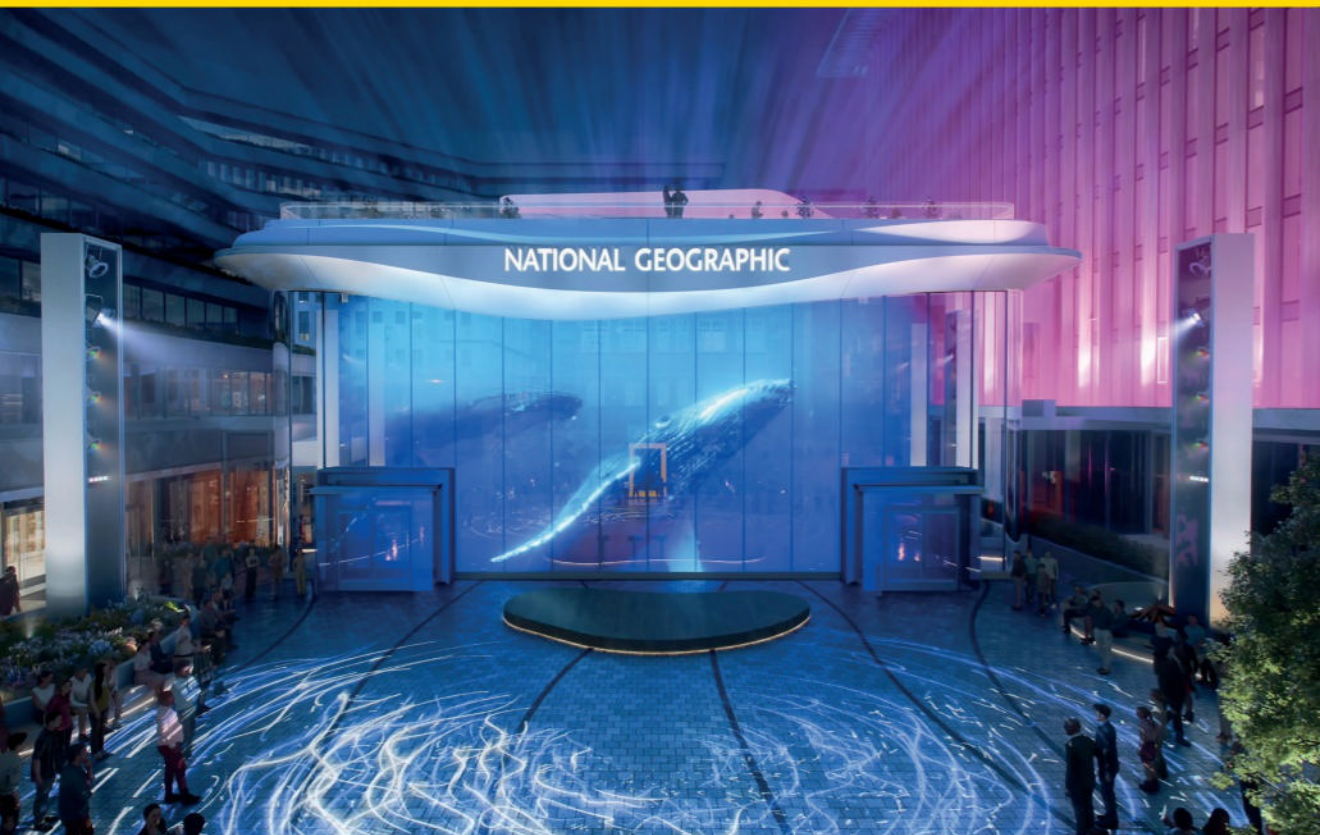
on Earth to simulate what it will be like for humans to work and even live long-term on the moon or Mars. The real challenge, it turns out, may not be getting there but figuring out how to thrive once we do.

We also have a fascinating feature about the work of researchers at the Institute for Mummy Studies, who are using advanced technology to unlock the knowledge contained in preserved human remains. And because July marks the 250th anniversary of the experiment known as the United States, we bring you a celebration of the nation's wonders. It's a big country, incredibly diverse in its landscapes and wildlife, its people and cultures, its traditions and celebrations—and after two and a half centuries, that remains its enduring strength.

I hope you enjoy the issue.

A handwritten signature in black ink, likely of Nathan Lump, the Editor.

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THE SECRETS THAT
MUMMIES KEEP**

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Conservationists in western Honduras have rallied around a seemingly unlikely species: the venomous jade palm pit viper. Now they're leveraging sentiment for the serpent to launch creative protections for its cloud forest habitat.

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Along Spain's southern coast, a peninsula packed with greenhouses is a critical laboratory for feeding an expanding population.

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A promising vaccine might just stamp out one of the gravest threats to the much loved marsupials.

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**WHAT IT
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As plans take shape to travel to the moon and Mars, a growing number of scientists and enthusiasts are staging ever more elaborate simulated missions. Here's what the dress rehearsals are teaching us about the next era of space travel.

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ON THE COVER In a stretch of Utah desert meant to simulate the Martian surface, practice-run "astronauts" Rym Y. Chaïd, Ricardo J. Gonzalez, and Shriya Musuku conduct a nighttime pre-mission exercise outside the Mars Desert Research Station.

Photograph by MACKENZIE CALLE



EARTH MOODS:

FREQUENCIES VOL. 1

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WHEREVER YOU LISTEN TO MUSIC

OUR WORLD

BEHIND THE SCENES WITH NATIONAL GEOGRAPHIC

Nicola Twilley followed scientists from the world's only mummy research institute deep into an Austrian mine.



ON AN UNDERGROUND SEARCH FOR ANCIENT DNA

→ For her story on the cutting-edge work being done by scientists at the Institute for Mummy Studies in Bolzano, Italy (“The Secrets That Mummies Keep,” p. 16), writer **Nicola Twilley**, a longtime *New Yorker* contributor and cohost of the science and food podcast *Gastropod*, spent a week with a team of researchers in a millennia-old Austrian salt mine. The scientists, who are finding new ways to study human remains, were particularly interested in deposits of feces—left by miners as far back as the Bronze Age. Twilley and her hosts spent their evenings grilling sausages over an old blacksmith forge. By day, the researchers used DNA analysis to examine the fecal relics to reconstruct the miners’ diets, which included fava beans, stew, and beer. “Everyone was blown away by the results,” Twilley says.

FIELD DATA

The hunt for an endangered snake



Nights that **Jack Devlin** spent roaming a Honduran cloud forest while searching

for the elusive jade palm pit viper (“The Snake That Saves Mountains,” p. 84)

12.79

Inches of rain that fell on Santa Rita during the month that Devlin stayed in the town. He believes even more dropped in the forest: “probably the most incredible [one] I’ve ever seen,” he says.

5

Bags of rice Devlin used to store his camera gear to ward off moisture—preserving

his lenses and helping him score some astonishing close-ups of the venomous serpent.

PHOTO: ANDREA DE GIOVANNI, EURAC RESEARCH

HOW ANTONI POROWSKI FINDS THE SOUL OF A CITY

→ Every October, we curate our much anticipated Best of the World list on *nationalgeographic.com*, a roundup of the most awe-inspiring destinations for travelers. Now it's a four-part docuseries, ***Best of the World with Antoni Porowski***. The show follows *Queer Eye* alum Porowski, who last trotted the globe with Nat Geo on his series *No Taste Like Home*, as he searches for what he calls the “soul and spirit” of some of the world's great cities, dishing on the food, places to stay, wellness experiences, and singular characters who bring each one to life. At right, Porowski shares tips for traveling like a pro.

Best of the World with Antoni Porowski is streaming on Disney+. Check local listings.



While filming around London for *Best of the World*, host Antoni Porowski helped fertilize a giant water lily at the Royal Botanic Gardens, Kew.

“I always make sure that I have a few hours to just get lost.”

Aimless wandering, Porowski says, is key to finding that oddball specialty shop or authentic restaurant with grandma in the kitchen.

“Discomfort is great.”

Not in your hotel bed but in your experiences. Porowski has a fear of heights, but he always finds an aerial view overlooking each city he visits.

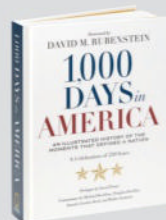
“I just ask a million questions.”

Considerate curiosity, the host insists, is almost always rewarded.

Plan your next trip with the 2026 Best of the World list at natgeo.com/bestoftheworld.

NEW FROM NATIONAL GEOGRAPHIC BOOKS

→ How did 13 scrappy colonies grow to become a global superpower? One day at a time. As the United States celebrates 250 years of independence, *1,000 Days in America* offers new perspectives on the country's pivotal moments—from Paul Revere's ride to Facebook's launch—with insights from celebrated historians Annette Gordon-Reed, Douglas Brinkley, Walter Isaacson, and Michael Beschloss.



NATIONAL GEOGRAPHIC EXPLORERS

These contributors have received funding from the National Geographic Society, which is committed to illuminating and protecting the wonder of our world. Learn more about the Society's support of Explorers at natgeo.com/impact.

Mackenzie Calle (at left) takes a selfie with fellow crew-member Shriya Musuku in Utah.



Why Mackenzie Calle Donned a Space Suit for a Photo Assignment

→ Brooklyn-based photographer **Mackenzie Calle**'s latest project for the magazine ("This Isn't Outer Space. Yet." p. 108) took her to rural Utah, where she participated in a simulated space mission—one of 16 concurrent events staged around the world last fall. Over two weeks at the Mars Desert Research Station, Calle wore space suits, practiced emergency drills, and traveled in rovers across sandy expanses as part of a test run for a future mission to the red planet. Normally an observer, Calle turned the lens on herself, using a drone and camera timers to record her trailblazing adventures. "I felt really out of my element," Calle admits. But she soon embraced the thrill of being "part of the story for the first time."

Davide Monteleone

"The Secrets That Mummies Keep," p. 16

The photographer, based in Milan and Zurich, visited Austria, Italy, and Bolivia as he followed a team of scientists pioneering new ways of studying the long dead. In Bolivia he used ultraviolet and infrared light to reveal details of mummies that were otherwise undetectable. The experience, he says, offered an "almost intimate encounter with the past."

Chris Gunn

"Wonders of America," p. 46

For this issue, Gunn traveled from Washington, D.C., to photograph two places with quite different claims to fame: Crystal Cave in Put-in-Bay, Ohio, site of an enormous walk-in geode, and Missouri's Cathedral Basilica of St. Louis, home to the country's largest mosaic installation. "No amount of research prepared me for the scale and brilliance of the mosaics," says Gunn.

1M

What are pangolins? If you've never heard of the pangolin, you're not alone. Despite being little known, pangolins are the world's most trafficked mammal, with more than **one million** pangolins poached in the past decade.



PHOTOARK
JOEL SARTORE

For many of us, creating or updating our will is one of those tasks that always fall to the bottom of the pile. In fact the average person takes more time to plan a vacation than to plan for the future. You owe it to yourself to be prepared. When you leave a gift to the **National Geographic Society** in your will or trust, or by beneficiary designation, you can protect critical animal species for generations to come.

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IN FOCUS

JUST IN FROM OUR PHOTOGRAPHERS



LIVELIHOODS

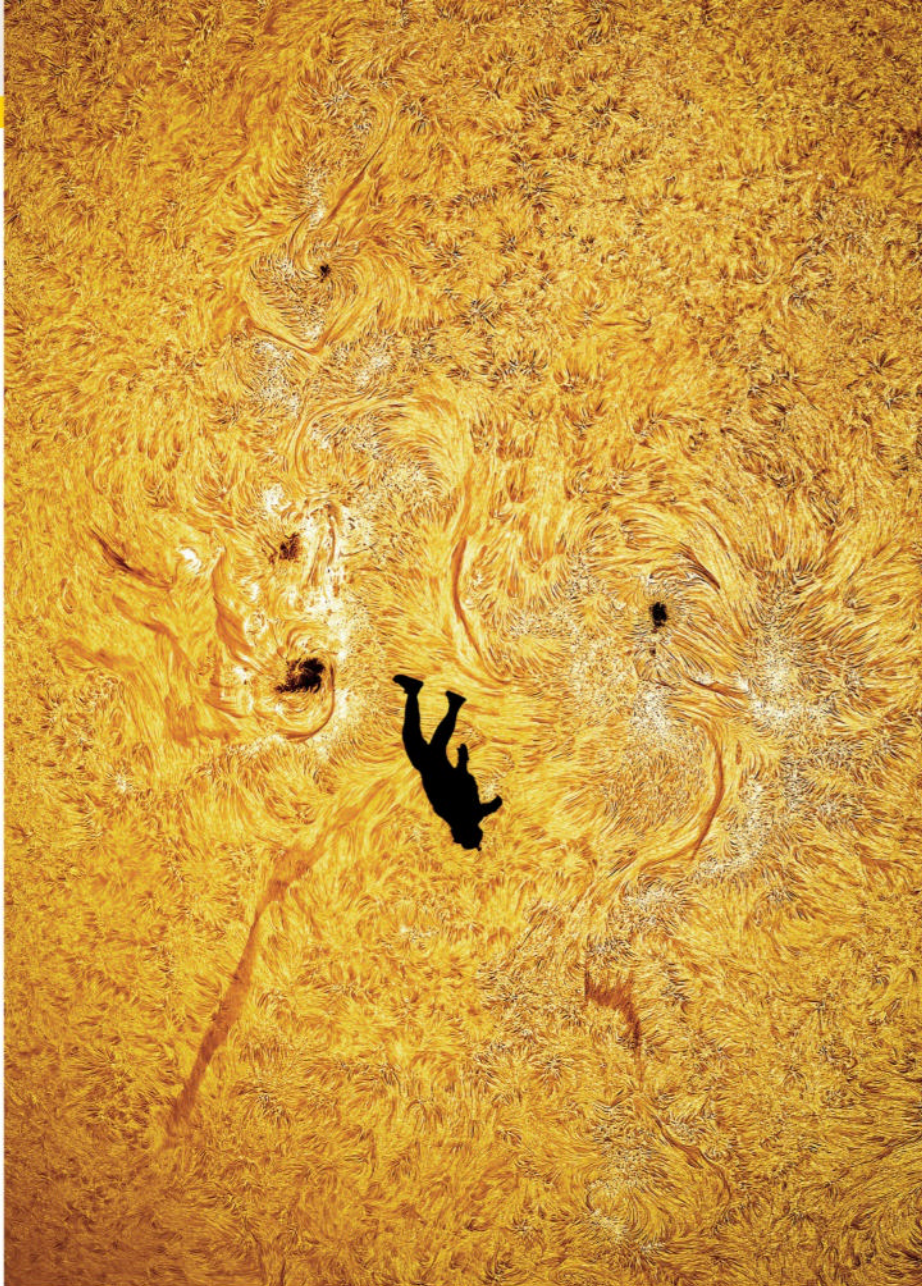
Each morning, the lifeguards on Haeundae Beach in Busan, one of South Korea's most popular summer destinations, perform an elaborate series of stretches, group runs, and rescue drills. Photographer **Forrest Walker** encountered this crew as they finished a swim workout. "The beach felt more like a training ground," Walker says, "with a quiet discipline." That is, until the lifeguards assumed their posts—and the sunbathing masses began to gather.



OCEAN LIFE

Living in a fishing village on Mexico's Baja California peninsula, photographer **Nicolas Hahn** noticed that the midday winds pushed all kinds of sea creatures close to shore. During one snorkeling session, he discovered this remarkable scene: a collection of mauve stingers, a type of small bioluminescent jellyfish.

Hahn got stung a few times around his mask, but the pain was worth it. His underwater lens captured every last tentacle in astonishing detail.



ASTRONOMY

Photographer **Andrew McCarthy** took this image of skydiver Gabriel Brown silhouetted against the sun after Brown leaped from a motorized paraglider over Arizona's Sonoran Desert. To create the surreal backdrop, McCarthy connected his camera to a modified telescope that can reveal the chromosphere—a layer of gases and plasma that surrounds the sun. He then stacked multiple exposures to enhance the effect.



WILDLIFE

When **Lukas Andree Andersen** visited Lake Kerkini in Greece, a famous wintering ground for the Dalmatian pelican, he figured he'd get close to these imposing creatures. He didn't anticipate how close. After a pelican landed on the roof of his boat, it grabbed the photographer's wide-angle lens with its pointy bill. "I just started shooting," says Andersen, who somehow managed to frame the perfect angle of a pelican staring down at its prey.

THE
SECRETS
THAT
MUMMIES
KEEP

A one-of-a-kind research
institute is transforming our
understanding of how
our ancient ancestors lived.

WORDS BY
NICOLA TWILLEY

PHOTOGRAPHS BY
DAVIDE MONTELEONE



Unlike their more famous Egyptian counterparts, mummies from the transitional period between the Tiwanaku and the Inca in Bolivia's Andean highlands were often placed in the fetal position.

Some of Bolivia's
oldest mummified
remains are located in
high-altitude caves,
where they are revered
by local communities
with whom *National
Geographic* consulted
before making
these photographs.







AS HEAD OF THE WORLD'S ONLY INSTITUTE FOR MUMMY STUDIES,

German microbiologist Frank Maixner has sampled a lot of ancient soft tissue. There were the thin, jerky-like strips of internal organs found stored in terra-cotta jars in a secret crypt beneath the main altar of the Medici family chapels in Florence, Italy. Those were discovered to contain evidence of malarial infection in a preserved blood vessel. In Switzerland, the mercury-laden mummified wife of a pastor turned out to be distantly related to former British prime minister Boris Johnson. Her stomach yielded the historic genome of the bug that's still responsible for most gastric cancers and ulcers today. A Bolivian child mummy from around 700 years ago was so well preserved that her braided hair, pulled into pigtails, was soft to the touch. And, of course, there were dozens of ancient Egyptians, not to mention Ötzi, the fabulously well preserved Copper Age Iceman found on the border between Austria and Italy.

Still, it came as something of a surprise last fall to find Maixner deep in the world's oldest operating salt mine, in Hallstatt, Austria. With Daniel Brandner, who works for the Natural History Museum Vienna, he had descended into a freshly excavated section. Looped along the narrow tunnel wall, a plastic hose carrying fresh air from the surface rustled gently. Their headlamps illuminated

the salt-laden rock pressing in from all sides, transforming it into glittering pink-gray crystals. Then they found what they were looking for: an ancient human turd, embedded in the salt at about waist height. Many of Maixner's most exciting findings have come from sampling the contents of his mummy subjects' stomachs and guts—but researchers have found that same richness of human, plant, animal, microbial, and viral DNA once the material exits the body.

"This is quite loaded," said Maixner, who, dressed in a white Tyvek jumpsuit, resembled an astronaut. He knelt next to Brandner to consider the sample from all angles. It had been laid down by an Iron Age miner more than 2,000 years ago, sometime between 570 and 552 B.C., yet it seemed disturbingly fresh, down to the brownie-like texture and faint—but distinctive—aroma.

Over the course of the next half hour, wielding tools that ranged from a pneumatic chisel to a paintbrush and tweezers, Brandner gradually extracted a sizable chunk of this priceless prehistoric poop. The atmosphere was tense—the pair froze each time a piece of the surrounding salt was dislodged—but thrilling, especially once Mohamed Sabry Sarhan, a colleague of Maixner's at the Institute for Mummy Studies, exposed the interior of the excrement inside a portable UV-sterilized box, designed to reduce any chance of modern contamination. Deep inside the fibrous brown mass, shielded from the world for thousands of years, were hairs: two superfine and light, and two more that were thicker and darker. "We'll see if we can get some DNA from the

Mohamed Sabry Sarhan of the Institute for Mummy Studies, in Bolzano, Italy, holds a sample of yeast that he cultivated from the stomach of the 5,300-year-old mummy Ötzi.



Frank Maixner, head of the Institute for Mummy Studies, and other members of a team who work to reconstruct prehistoric dietary profiles examine paleofeces deep inside the world's oldest operating salt mine, in Hallstatt, Austria.





hairs,” Sarhan said, popping each one into its own airtight vial.

The next night, back at the institute’s headquarters in the Italian city of Bolzano, Sarhan stayed up late, plating the most promising samples on petri dishes filled with nutrient-rich jelly. When we returned the next morning, it appeared these millennia-old microbes had awoken from their extended hibernation and begun to reproduce. “I was expecting one or two species, but we see a lot of stuff, even bacteria with spores,” he said.

Later, Maixner speculated that this could be a world first: Pending replication and review, it seemed as though Sarhan had successfully cultivated at least one living microbe from an ancient human’s gut. “So if this was true, then this will be a really big story,” said Maixner. The discovery could offer a time machine of sorts, a way of glimpsing the ancient human microbiome in all its ancestral glory before it was decimated by the ravages of today’s ultra-processed diets.

The potential for scientific discoveries that led Maixner deep into the bowels of an Austrian mountainside emerged only recently, thanks to a combination of

technological breakthroughs that have revolutionized the tiny world of mummy studies and the growing medical understanding that the contents of our guts can reveal more about us than pretty much any other part of our anatomy.

For most of human history, mummies have been thought to be fascinating, spooky, and scientifically irrelevant; skeletons were (and still are) where all the good DNA is for studying population migration and human evolution. Researchers generally favored hard evidence—bones and teeth—over softer remains, no matter how well preserved. But the past decade has seen a paradigm shift in our ability to detect and analyze all kinds of organic traces from much squishier parts of the body. The so-called “-omics” revolution—next-generation genetic sequencing combined with the computational power necessary to make sense of the resulting big datasets—has already transformed human health research. Now it’s giving archaeologists the tools to go beyond simply figuring out the age, sex, and ancestry of an ancient human to instead painting a holistic picture of his or her lifestyle, diet, and health, to get much closer to what it was actually like to be that person.

The Institute for Mummy Studies has, since its founding in 2007, become known as a leader in the field of extracting and decoding information from ancient remains—including still legible DNA for all kinds of human parasites, diseases, and microbes. This success has opened what Maixner calls “a new window back in time.” And, as it turns out, just like the preserved soft tissue of mummies, preserved soft feces are full of ancient biomolecules.

Unfortunately, like mummies themselves, well-preserved ancient feces are rare. Under normal conditions, excrement decomposes even faster than human bodies, and, in the rare cases it does survive, it has either hardened into a fossil, known as a coprolite, or is jumbled together in an ancient latrine, loosened from its ties to a specific individual and date. Forget pottery and pyramids: Today a



Maximilian Piniel is an archaeobotanist with the Austrian Archaeological Institute, where he inspects the Hallstatt samples for visible plant parts.

well-preserved ancient turd is a treasure. That's why, safe in their individual salty tombs, the dozens of Hallstatt paleofeces—along with the mine's ancient wood infrastructure, datable down to the year—represent the archaeological equivalent of a winning lottery ticket.

LIKE MOST OF HIS colleagues in the sparsely populated field of mummy studies, Maixner became an expert on organic human remains somewhat by accident. Careful, soft-voiced, and with a penchant for Hawaiian shirts, he was finishing his Ph.D. in microbial ecology in

Vienna when he saw a job listing. The description was intriguing—the Institute for Mummy Studies was looking for someone to set up a laboratory purely for the analysis of ancient DNA. But Maixner was skeptical such a thing even existed. “It took me some time to believe that there are still biomolecules actually present in these ancient artifacts,” he admitted.

In the early 1980s, when Michael Crichton took the idea for *Jurassic Park* from an entomologist studying extinct DNA at the University of California, Berkeley, the proposition that the chemically unstable double helix could survive for thousands, let alone

MEDICAL IMAGING AND MOLECULAR ANALYSIS

This naturally mummified pre-Columbian male was found on the outskirts of La Paz, Bolivia. He was photographed with a full spectrum camera that captures radiation beyond the range of human vision. Each exposure highlights a unique layer of otherwise hidden information.

A

Infrared light is invaluable for revealing the structural integrity of the skeleton beneath the layers of mummified tissue.

B

Under ultraviolet light, collagen in skin and connective tissue appears to radiate a bluish hue, while some lipids and burial compounds produce green or orange fluorescence.

C

These amber images were shot under standard visible light and show the true color of the preserved tissue and bone.

A



B



C



millions, of years was pure speculation. Then, in the 1990s, following the invention of a process that allows specific genetic sequences to be extracted from vanishingly tiny traces of DNA and amplified until they are identifiable, researchers claimed to find ancient genes in a 120 million-year-old weevil preserved in amber, in a 16 million-year-old fossilized magnolia leaf, and more.

“It appeared we were on a fast track to a new dawn in paleobiology,” writes biochemist Dale Greenwalt, a researcher at the Smithsonian National Museum of Natural History and author of a recent book that chronicles the study of ancient biomolecules. Unfortunately, many of these early claims turned out to be false: The DNA that had been multiplied came from tiny fragments of modern contamination, rather than the ancient past.

The next 20 years saw “a long controversy about whether ancient DNA was authentic,” said Albert Zink, a National Geographic Explorer and former Institute for Mummy Studies director. Sometimes it clearly wasn’t, but he and other mummy experts believed that sometimes DNA that was many thousands of years old really could be found in ancient remains. This heated debate was only put to bed in 2011 with the publication of a paper that found DNA in a mummified crocodile. “It sounds funny, but it was really a game

changer,” Zink told me. “It was clear that it cannot be contamination because there were no crocodiles in the lab.”

Next-generation sequencing, which began making its way into laboratories in the 2000s, avoids the bias inherent in earlier methods. It reads all the DNA, rather than targeting particular snippets for amplification. Rigorous anti-contamination protocols conducted in special labs with equipment used only for the analysis of ancient biomolecules also helped restore credibility to the field. Nonetheless, mummies were still suspect. Zink, who first became hooked on mummies by way of a fascination with ancient Egypt, believes Tutankhamun and his kin might be to blame for the fact that mummies historically have been overlooked by serious researchers. “I worked a lot in Egypt, and the preservation is not the best,” he told me. “That’s why people said there’s no DNA in mummies.”

Despite the fact that they’re neither the oldest nor the most intact, these carefully bandaged pharaohs are the first association most of us have with the term “mummy,” and, indeed, they were the first preserved human remains to be called mummies. Curiously, this was based on a misunderstanding: The Persian word *mūmiyā*, or *mumia*, originally referred to a black tarry substance sourced from a handful of asphalt seeps in the Dead Sea region and highly regarded as a medical treatment by medieval Arab physicians. A translation mistake led apothecaries in Europe to use the visually similar and more easily available resinous secretions from ancient Egyptian corpses, selling it under the same name—which came to refer to all preserved soft tissue.

For centuries, Europeans saw mummies as only ground-up medicine. But after Napoleon’s failed invasion of Egypt at the turn of the 19th century inspired a fashion for all things Egyptian, mummy mania took hold, and “unwrapping” parties—where wealthy people unveiled ancient remains more in the spirit of P. T. Barnum than scientific inquiry—were the hottest ticket in

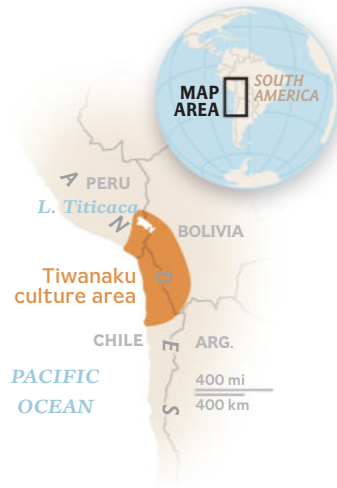
**MUMMIES
WERE WIDELY
PERCEIVED
AS, AT BEST, A
CURIOSITY AND,
AT WORST, AN
EMBARRASSMENT.**

Europe and North America.

The end result was that mummies were widely perceived as, at best, a curiosity and, at worst—once Western museums woke up to the fact that displaying other people’s ancestors as some kind of freak show was not a good look—an embarrassment. When journalist Heather Pringle attended the Third World Congress on Mummy Studies in 1998, she reported that “nearly everyone was gainfully employed doing something other than studying mummies.” Despite the perennial hold these eerily immortal bodies exert on the popular imagination, she discovered “there are few salaried jobs and very few full-time mummy experts.” Arthur Aufderheide, a Minnesotan pathologist who is often regarded as the father of modern mummy research—he co-founded the World Congress on Mummy Studies and authored the field’s definitive guide, *The Scientific Study of Mummies*, in 2003—complained in the book’s preface that it was “still an orphan discipline.”

Into this void stepped the Institute for Mummy Studies. It was launched nearly two decades ago as part of Eurac, a private research center established to study issues of interest to South Tyrol. Ötzi the Iceman was originally found on a glacial ridge above the Tyrolean Schnalstal Valley, and, after undergoing years of examination at Innsbruck University in Austria, he was finally repatriated to the South Tyrolean provincial capital in Bolzano. Eurac’s leadership determined that Ötzi merited an entirely new research division. “The Institute for Ötzi was the first name,” said Zink. “I convinced the director and the president that we should rename it, because my idea was to study all kinds of mummies.”

Zink and his team have indeed studied all kinds of mummies ever since; still, it was Ötzi that finally convinced Maixner that mummies were his future—especially after researchers rediscovered the Iceman’s long-lost stomach. Based on initial investigations, scientists thought the 5,300-year-old Iceman’s stomach had decomposed, but in 2009, the year Maixner joined the institute,



a radiologist discovered it was not only intact but full, and had simply migrated upward during the process of mummification. In 2010, in a sampling campaign partially supported by the National Geographic Society, Ötzi was defrosted long enough to retrieve some of the stomach and intestinal tissue and contents, and Maixner began his analysis.

“When I identified ibex in the Iceman’s stomach content, that was the biggest surprise. That told me, OK, this cannot be contamination,” Maixner said. “It was a very special moment, for sure, looking at these samples and realizing what we can do.”

SOME OF THE OLDEST mummies in the world can be found in South America, where the Chinchorro people of what’s now northern Chile began preserving their dead almost three millennia before Egyptian embalmers developed the process that eventually gave preserved ancient soft tissues their name. Yet most present-day South Americans don’t know that many of their ancestors were mummified—thanks largely to the Catholic zeal of the invading Spanish, who thoroughly extirpated what they saw as a heathen practice.

Bolivian biochemist Guido Valverde was an undergraduate studying hematology in



Human feces retrieved from the Hallstatt mine have already been found to contain fava beans, millet, and barley, as well as DNA evidence of more exotic foods such as walnuts and fermented products like blue cheese and beer.

La Paz, when he stumbled across a book from the 1960s describing techniques used to determine the blood types of mummies stored in the National Museum of Archaeology of Bolivia. When he asked the museum staff about the mummies, they had no idea how many they had in the collection or even where they were. “No one had access to these individuals,” said Valverde. “They were just left behind in the storage room at the museum.” (This is a surprisingly common fate: Tulane University, in New Orleans, once rediscovered two Egyptian mummies under

the bleachers of its old stadium, from where they’d inadvertently attended three early Super Bowl games.)

“It took the museum two or three years of cleaning, recovering, and recataloging the individuals to at least have a preliminary understanding of what they had,” Valverde said. “They ended up with 50 mummies and more than 500 human skulls—it’s the largest collection of human remains in Bolivia.” His interest thoroughly piqued, Valverde wanted to use his biochemical training to unlock these mummies’ secrets. But there was an issue: “It’s

very difficult to develop these projects in my country, because there are no laboratories with these kinds of standards,” he explained.

In 2017, Valverde reached out to Maixner. Having established themselves with the success of their multiyear analyses of Ötzi, Maixner and his colleagues have become go-to experts for anyone with mummies they want to learn more about. After analyzing a preliminary sample, Maixner confirmed that the DNA in the Bolivian mummies was sufficiently preserved to study. Then he suggested expanding the project’s ambition by including colleagues from the Institute of Mummy Studies who work on facial reconstruction and conservation, as well as the Horus mummy research team, an international group co-led by American cardiologists Gregory Thomas and Randall Thompson that began studying atherosclerosis in ancient remains in 2009. (They have yet to find a single culture that did not suffer from hardened arteries.)

Finally, with all the necessary permits in place, the entire team descended on La Paz to spend two weeks working with the mummies, carrying out CT scans and taking more than 400 samples for molecular analysis. Among their most intriguing early findings was the DNA of *Streptococcus pyogenes*. “It’s one of the most impressive bacteria: It can give you a cold, or it can eat your flesh,” Valverde told me. This is the first time the pathogen has ever been found in an ancient individual in the region—no one even knew it was present in the pre-Columbian Americas—and it seems to be a more ancestral strain than the version that circulates today, which means it could help explain the evolution of this exclusively human-associated bacteria. What’s more, the sample also contained genetic material from ancient viruses that attack this bacteria. Maixner told me that biomedical researchers think these could hold the key to developing a treatment that is effective against a broad spectrum of *Streptococci*, including the ones that are responsible for millions of cases of

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pneumonia, meningitis, and inflammatory heart disease every year.

Meanwhile, though it was not part of their original plan, Maixner and Valverde discovered that some of the ancient Bolivians had existing openings in their abdominal cavities through which the scientists could extract feces without causing any additional damage. “It turns out these are the most precious samples,” said Valverde. The full analysis, which Valverde expects will shed new light on the otherwise virtually unknown pre-Columbian gut microbiome, is still underway. The preliminary findings are groundbreaking. But for Maixner, they’re also frustrating. “Even though mummies are beautiful and I like them a lot, they have a limitation,” he told me. The thing that makes them so special—their exceptional, even unique preservation—constrains their relevance. “It’s only one, it’s an example, it’s a case study,” Maixner said, quoting typical responses to mummy research. “Those are our most hated words.”

Modern scientific studies pin the validity of their insights on replication, statistical

This mummified Bolivian child, just seven or eight when she died, is so well preserved that one can still see her thick black braids. Researchers at the Institute for Mummy Studies are analyzing her DNA and CT scans to help tell the story of her short life.





significance, and representative sampling: The discovery of DNA in a single mummy can never conclusively make the case that ancient South Americans regularly ate quinoa or suffered from strep. Which is why Maixner was so excited when he heard that a salt mine in Austria contained dozens, maybe even hundreds, of perfectly preserved paleofeces.

THE TOWN OF HALLSTATT, set on a deep blue lake surrounded by Alpine peaks, is so breathtakingly picturesque that in 2012 Chinese developers constructed a near replica as a luxury community in Guangdong Province. Selfie stick-wielding tourists overflow the original, but most of them remain unaware of the real reason for the town's existence: a salt deposit that has been mined for 7,000 years, creating a site so important within archaeological circles that it has given its name to the entire Proto-Celtic Hallstatt culture of Late Bronze Age to early Iron Age Europe.

"For prehistoric societies and all of the thousands of years before that, we need to remember that salt is vital," said Daniel Brandner, from the Natural History Museum Vienna. "Without salt, you can't survive." Not only do we need to consume about a quarter of a teaspoon a day to prevent metabolic malfunction and death, but without refrigeration, salt was essential for food preservation. During the Late Bronze Age and for much of the Iron Age, Hallstatt was the main supplier of salt for central and eastern Europe. The mine is still operational today: Every year, Salinen Austria AG extracts 400 Olympic swimming pools' worth of brine from the subterranean deposit to produce 320,000 tons of salt.

Brandner led us into the mine via a tunnel dug in the 1700s. We walked single file, stepping on the ties of the narrow-gauge railway the miners used to transport their gear. The smooth, whitewashed walls at the entrance soon gave way to dark, roughly chiseled rock, streaked with veins of the pink-gray salt. The air was cool and humid,

Kerstin Kowarik, who studies prehistoric diets at the Austrian Academy of Sciences, knows that Iron Age miners ate fava beans but hopes to discover what else was on the menu in order to learn what it was like to live some 3,000 years ago.

with the sound of water slowly dripping in the background.

The prehistoric sites inside the mountain have all been discovered by accident, when early modern miners stumbled upon what came to be known as *Heidengebirge*, a German term used to refer to heathen areas. Researchers can't just probe the mountain for empty voids, because they've been filled up—either slowly, by salt creep (under pressure, rock salt flows like a liquid, closing up tunnels at a rate of about half an inch a year), or quickly, during landslides that still threaten the area. One of those cave-ins, in 660 B.C., resulted in Hallstatt's only recorded human mummy: an Iron Age miner trapped underground. The so-called "man in the salt" was found in 1734, with his leather shoes and some clothing intact, according to contemporary descriptions. "Unfortunately, it was too early for science," said Brandner. "They brought him down to the priest and decided to bury him"—without noting where. He's never been seen since, though Brandner suspects there may be more mummies concealed in the mountain. Only around 2 percent of the mine's ancient workings have been excavated.

We followed Brandner up, down, and along the tight passages, crouching and slithering our way through a series of twisty, under-illuminated wormholes for 20 minutes, until he came to a stop in a small room, more than 300 feet beneath the Earth's surface. "We are standing in the old Bronze Age cavity," he said. "The catastrophe is all around us." The landslides were a stroke of luck for future archaeologists: Because the mined voids were stuffed full of debris from the surface, their original dimensions were maintained.



By drilling boreholes through the fill at different angles, Brandner has established that the original chamber was vast—at least four stories tall and the size of nearly five tennis courts laid side by side. All around us lay big limestone boulders, rubble, smashed wooden timbers, and an entire maple tree, dirt still clinging to its web of roots. Nearby beech trunks were used to precisely date its final year in the sunshine to 1063 B.C. Beneath us was the negative imprint of a staircase, cast like a shadow into the fill. The original—an intact 3,100-year-old wooden structure that is the world's oldest known staircase—was safely stored in a climate-controlled room closer to the mine's entrance.

All around us, jutting out of the walls, were spectacular organic remains that looked as though they'd been left there yesterday—a fragment from a fur cap, half a pickax, and a thick rope made of braided fibers from the inner bark of lime trees—but no feces. This excremental absence was pointed out with typical frankness by Kerstin Kowarik, a specialist in prehistoric archaeology at the Austrian Academy of Sciences. “The Iron Age is full of shit,” she said. “In the Bronze Age, it's much more rare.”

There are just six known Bronze Age poops at Hallstatt, and they are the only confirmed human remains from that era in the mine. Brandner assumes that this disparity in deposits is the outcome of the eras' different mining styles. In the Bronze Age, salt was mined downward, whereas in the Iron Age, miners worked in horizontal chambers. “It makes no sense to shit on the floor when you're mining downward,” he said. “But in the Iron Age, they don't care; they can just leave it where it fell.”

The Hallstatt feces have been studied since the 1930s. An earlier generation of archaeologists dissected them under the microscope to find parasite eggs and botanical remains. But no one had performed a molecular analysis until 2019, when Maixner and his colleagues conducted preliminary tests on three feces from an Iron Age chamber and one from the

Bronze Age, just to see whether there were enough intact ancient biomolecules to merit further study. To Maixner's surprise, the DNA was astonishingly undamaged despite its age. From the lining of the gut wall came enough human genetic material to establish that each lump of excrement was the unmixed product of a separate individual, and all four were male.

The microbial DNA was even more plentiful, yielding sufficient data to allow Maixner and Sarhan to compare the guts of these miners with present-day Indigenous populations, which they resembled much more closely than they did modern Westerners. In particular, the team examined the diversity of a common gut microbe, *Prevotella copri*, which is associated with plant-based, unprocessed diets. All four feces contained the full repertoire of the microbe's complex carbohydrate-processing capabilities, whereas Westernized guts typically lack some of that functionality. “This is something we've lost,” said Maixner. Curiously, one of the feces looked different from the others: less fibrous and more finely textured. Radiocarbon analysis revealed it actually dated back only to the 1700s—but, despite lacking the seed husks and straw of the older poop, it still looked more like the Indigenous microbiome than the Western one. “Somewhere after the Baroque period is where it all went wrong,” said Maixner.

The feces also contained enough DNA and proteins from food to allow the team to reconstruct the miners' diet. Based on microscopic plant and bone remains, Hallstatt miners had been thought to rely heavily on a fava bean, millet, barley, and meat stew similar to a dish named *Ritschert* that's still eaten in the region today. Traces of those ingredients were found in the samples, but one of the two Iron Age feces also contained walnut DNA—a luxury product that would have been imported from hundreds of miles away—as well as the tell-tale signal of the microbes involved in making blue cheese and beer, in what was also the first molecular evidence

‘THIS IS TRULY A NEW WAY TO TRAVEL BACK IN TIME.’

— FRANK MAIXNER
HEAD, INSTITUTE
FOR MUMMY STUDIES

for their consumption in Iron Age Europe.

Sarhan studied these microbes in detail to establish whether they showed signs of being domesticated or wild—in other words, whether the miners were intentionally cultivating microbes to produce particular flavors in their fermented foods. By comparing the penicillin genome in the Iron Age poop to the mold used to make modern blue cheeses, such as Roquefort, as well as to its wild, food spoilage-related relatives, he showed that it was more than halfway along the evolutionary path to being a purely cheese-focused microbe. Similarly, the yeast appeared to be closest to those used to make today’s pale ales. “They were actively looking for specific tastes,” concluded Kowarik. “It’s evidence of an actual cuisine”—lost flavors that, thanks to their microbial traces, we can now not only identify but perhaps also even taste ourselves one day.

THESE PROOF-OF-CONCEPT samples were retrieved pre-COVID. Thanks to the pandemic, combined with the bureaucracy of scientific grantmaking, the team’s return to the mine to sample dozens more feces had been significantly delayed. “I’ve been to the mine three or four times now, and each time, I’m like, please, Daniel, give me the sample!” Sarhan

said, as we unpacked the scientific equipment. “Now we’re actually doing the samples, it’s like a dream.” The team members set themselves up in a small chamber carved off the main tunnel: Brandner was equipped with a red clipboard listing the feces and their find sites; Sarhan had a box of coffee-filled chocolates to keep his energy levels high.

After a slow start, the group fell into a rhythm. Brandner photographed each specimen; Maixner cleaned and weighed them; then Maximilian Piniel, an archaeobotanist, surveyed the specimens for visible plant parts, which Sarhan, working in a clean suit and sterile glove box, delicately tweezered out as he exposed the untouched interior of each excrement for the first time in thousands of years, to extract his crumb-size samples.

After three days, the team had sampled 30 feces. Sarhan was jubilant. In the entire scientific canon, he told me, there are fewer than 20 published molecular analyses of paleofeces performed using the latest technology, and about half of them have been done by the team at the Institute for Mummy Studies. “We doubled this, and we plan to do 20 more from [the museum storage in] Vienna,” he said, slapping his hands on the table for emphasis. At long last, Maixner told me, he will have assembled enough evidence to transcend the solo case study limitations inherent in mummy research—enough to be able to make authoritative statements about these ancient salt miners, from their taste preferences and their metabolic health to their parasite and disease burden.

The full analysis will take two years and involve partners in labs around the globe, but already it seems clear that the insights these feces will provide are intriguing. Kowarik rattled off a long list of questions she hoped might finally receive answers: Did everyone eat dairy? Did what they eat change over the seasons? How much meat did they eat, from which parts of the animal, and how did they process it? Maybe, she speculated, they will even solve “the case of the missing fish.”

Guido Valverde (at right), from the Institute for Mummy Studies, and Ruben Sergio Mamani Roque, from the National Museum of Archaeology of Bolivia, with a pre-Columbian female, mummified between 1100 and 1450.



Archaeologists have found no fish bones and no fish-related parasites from the first millennium in Hallstatt, yet some of the Iron Age miners were buried with fishhooks.

Sarhan, who has a background in plant pathology, was particularly thrilled to find what he thinks is an intact wheat kernel with signs of smut, a fungal disease that can still wipe out harvests. The information contained in both of those genomes could ultimately help farmers today. Brandner estimates that only a couple dozen people mined the saltworks at a time. Given that many of the

Iron Age samples came from an area mined over the course of just 18 years, it's possible they'll even have more than one sample from the same person and thus be able to build a biochemical portrait of a single individual's diet and health as that person aged.

"The combination of clear dating... and still having all this information in the form of biomolecules—this is something unique," said Maixner, who was so excited and yet so sleep-deprived by the end of the week that he seemed almost delirious. "This is truly a new way to travel back in time."



A COUPLE OF DAYS later, we met in the mountains again, this time on the Italian side of the Alps, at the ArcheoParc Schnalstal, near where Ötzi was found. The sky was still bright blue, but the air was cold and the larch-covered mountainsides glinted gold with the turning of the season. While Kowarik and Brandner excavate artifacts, and Maixner and Sarhan extract biomolecules, the ArcheoParc practices another technique for understanding the past: experimental archaeology. Its

director, Johanna Niederkofler, has frequently collaborated with Maixner and his colleagues to make sense of their findings. While her partner, Stefan Tappeiner, peeled feathery tissues from a big, ridged bracket fungus and then struck two rocks together, again and again, to light them with a spark, she explained that the purpose of experimental archaeology is to learn by doing. If we lit a fire, sliced meat, and dried it in the same way the Iceman might have done, for example, what else would we realize in the process—and would we end up with the same stomach contents, molecularly speaking? To help make sense of Ötzi's last meal, Maixner had asked Niederkofler to dry flint-cut meat in different ways. The results helped guide his ongoing analyses.

As we sat around the fire in the honeyed autumn light, bathing in its warmth and smoke while hungrily watching the meat we'd sliced using a flint knife dry and the flatbreads we'd made from the grain we'd ground puff up and burnish, Maixner explained why he'd brought me here. The new tools he and his colleagues have brought to the study of preserved ancient biomolecules—whether in mummies or feces—are enlarging our understanding of the past by leaps and bounds. “But you can’t explain these results without all the other tools of archaeology,” he insisted. “You have to combine.” By trying to re-create the cheese that miners at Hallstatt ate or the beer they drank, he said, we could see more clearly what we do know and what we do not—what is still interpretation.

We sat, talking and eating, a long way from the lab in Bolzano or even the salt mines of Hallstatt, immersed in an entirely different, more embodied understanding of the past. “This was the world for a long time,” said Niederkofler softly. Mummies, perhaps precisely because they preserve the tender part of humankind—the part that hurts and bleeds, eats and poops—speak to us. Finally, we have the tools to listen. □

INSIDE
National Geographic's
 BRAND-NEW
MUSEUM
of Exploration

**A bold museum in Washington, D.C.,
 lets visitors experience how scientists,
 adventurers, and storytellers reveal
 the world's wonder—one artifact at a time.**

Words by
 JAMES ROSS GARDNER

→ **AN EXPLORER'S TOOLS** remind us that the act of discovery has always been as much about ingenuity as daring. In search of answers to the toughest questions about our world, explorers go to extremes: The bottom of the ocean. The edge of space. The empty spots on the map. And to get there, they innovate, calibrate, and iterate.

That idea is at the heart of the new National Geographic Museum of Exploration, or the MOE, a more than 100,000-square-foot, sustainably built center opening this summer in Washington, D.C. Its mission is to “inspire the explorer in every visitor,” says Emily Dunham, the National Geographic Society’s chief campus and experiences officer. Exhibits and immersive offerings include galleries drawing from a vast photo archive, towering outdoor projection screens, a 400-seat theater, and a collection of artifacts and gear that have helped propel and inspire nearly 140 years of fieldwork by National Geographic Explorers.

The four objects that follow are among the many on display at the museum—each with a story to tell about dauntless, endlessly curious individuals redefining our sense of what’s knowable.

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**A SUIT FOR
 SURVEYING THE
 SEAFLOOR**

In 1979, off the Hawaiian island of O’ahu, oceanographer and Explorer Sylvia Earle plunged 1,250 feet wearing an armored, pressurized suit called a Jim (named for a diver who inspired its design). “It was basically a wearable submarine,” says Society exhibition content developer Hilary Bergen, created for commercial uses like underwater maintenance and salvage. Earle, then working on a book about marine exploration for the National Geographic Society, used one to spend more than two hours walking along the seafloor, still the deepest untethered sea walk ever made. A replica Jim suit at the MOE re-creates the look of Earle’s on the day of her dive, which spurred further use of atmospheric diving suits in aquatic research, advancing our understanding of deep-sea ecosystems. Nearly five decades later, Earle is 90, still diving, and still called by the nickname she earned that day: Her Deepness.

PHOTO: CHUCK NICKLIN



PHOTO: CREDIT NAME TK

Oceanographer Sylvia Earle wore a rigid, pressurized suit to make a record-setting walk along the Pacific Ocean seafloor in 1979. She was lowered and raised by a research submersible.



A rooftop terrace above the new museum's main pavilion overlooks a courtyard, seen here in a rendering. At night, the outdoor space hosts an immersive show that highlights the wonder of Earth's oceans, projected onto the pavilion's glass facade and other surroundings. The Museum of Exploration opens June 26. Visit natgeo.org/moe.

THE CAPSULE THAT REACHED NEW HEIGHTS

A huge helium-filled balloon lifted the nearly 13-foot-tall *Explorer II* gondola into the stratosphere above South Dakota one morning in November 1935. Inside the magnesium alloy orb were U.S. Army Air Corps balloonists and Explorers Albert Stevens and Orvil Anderson, who reached a record altitude of more than 13 miles above the Earth that day. The pair recorded observations about cosmic rays and solar radiation and brought back some of the first photos to show the planet's curvature. Like the original *Explorer II* gondola, today in the

collection of the Smithsonian Institution's National Air and Space Museum, the reproduction at the MOE is encircled by canvas

ballast bags, along with the dangling cases that carried nearly a thousand pounds of batteries to power the Explorers' equipment.



After ascending to the stratosphere in 1935, the *Explorer II* gondola was trucked to National Geographic Society headquarters, now home to the MOE.

PHOTO: RICHARD HEWITT STEWART



In 2003 storm chaser Tim Samaras and his team placed this armored Tinman camera housing in the path of a powerful tornado in South Dakota.

A WINDOW INTO THE STORM ^

To help legendary tornado researcher and Explorer Tim Samaras glimpse the inside of a funnel cloud, National Geographic engineers created this armored, arrowhead-shaped camera housing, nicknamed Tinman and designed to keep a camera on the ground in high winds. It was

just one of the instruments—many designed by Samaras—that the storm chaser and his crew placed in the path of tornadoes in order to capture never before recorded meteorological data. In 2003, in South Dakota, Samaras logged the greatest drop in pressure then ever recorded. A

decade later, he was pursuing a storm in Oklahoma with his adult son and a colleague when a tornado overtook their vehicle. No one survived. Exhibiting Tinman at the MOE, Bergen says, is a tribute, an opportunity to “honor the contributions” of a one-of-a-kind scientist.

PHOTO: CARSTEN PETER





Before it was installed at the MOE, photographer Sandesh Kadur's customized Suzuki helped him track animals in the wild, as here in India's Nagarhole Tiger Reserve.



AN OFF-ROAD VEHICLE AS INTREPID AS ITS OWNER

To seek out some of the planet's most elusive animals—Bengal tigers, lion-tailed macaques, king cobras—wildlife photographer and filmmaker Sandesh Kadur long relied on his heavily customized 1997 Maruti Suzuki Gypsy, a kind of mobile photo studio he dubbed Gypsu. Kadur removed the vehicle's back roof so he could stand and shoot from a higher vantage point. He installed a sliding rail for his camera to glide along and a stabilizer mount up front for filming while he drove behind swift-moving creatures—"keeping up with the action," Kadur says. All that tinkering, says the Explorer, allowed him to "push the envelope... of the visual storytelling in the field." Installing the storied ride at the MOE meant lifting and lowering it into the building with a crane—one more act of ingenuity for Gypsu's final journey.

PHOTO: FELIS IMAGES



First Sunrise

MAINE

MORNING LIGHT

falls softly on the Atlantic coastline, grazing the rocks and the spruce boughs, waking wild headlands and harbor towns. Maine is the first place in the continental United States to see the day break, although just where the light first lands depends on the time of year and thus the sun's place on the horizon. Near the spring and autumn equinoxes, when the sun rises due east, the earliest rays hit the cliffs of the peninsula called Quoddy Head, the easternmost point on the U.S. mainland.

—BRIAN KEVIN

Wonders OF America

To mark the 250th anniversary of the United States' independence, we present a celebration of some of the country's most distinctive and superlative places and experiences: the grandest, wildest, strangest bits of geography and culture across all 50 states and five major territories. From natural marvels that shape the nation's dynamic character to cherished traditions and quirky landmarks that bring communities together, it's a lineup as extraordinary and diverse as the country that inspires it.



Maine's rugged Quoddy Head peninsula is the easternmost spot in the continental United States.

CAIT BOURGAULT

Smallest Post Office

OCHOPEE, FLORIDA

THE OCHOPEE Post Office is a 60-square-foot shack along a bend in the road in the heart of the Florida Everglades, a box of corrugated aluminum with a shingled roof and a hurricane shutter for an awning. Inside, Postmaster Don Walters can extend his arms, rotate in place, and very nearly touch all four walls. On one of them, a collection of photos stretches back to 1953, when a fire destroyed the original post office, located inside a general store. After the fire, a tomato farmer's storage shed was repurposed as a substitute. On the opposite

wall is a medley of postcards sent by fans from around the world.

Hundreds stop by each day, many of them locals, including Seminole and Miccosukee tribal members—the Ochopee postal route covers both tribes' lands. But most are tourists sliding through the cathedrals of cypress along the Tamiami Trail, hopping gleefully out of their cars to glimpse America's smallest post office. Some buy postcards, scratching out notes to their families, while others just ask for a selfie with Walters, who's often clad in aloha shirts because, as he says, "they're expecting Jimmy Buffett."

In the decade that he's held the job, Walters has watched bears, alligators, and even a rare Florida panther passing through the tableau framed by his service window. Fewer birds and raccoons these days, he says. More pythons and, inevitably, more traffic. Of course, he's also noticed fewer letters and more parcels as the internet has solidified its central role in American life. Still, he loves—truly loves—seeing people glow as they approach his window asking to buy a postcard. It is a genuine act in an increasingly perfunctory world; a big gesture from a small place seemingly untouched by time. One morning this spring, a family of four from Indiana sauntered up, bought postcards, then used the side of the shed to write home before continuing on toward Miami. Walters stamped them and added them to a growing pile. "I could do this for the rest of my life," he said. —MICHAEL ADNO

Postmaster Don Walters has a postage-stamp office.



ALFONSO DURAN (POST OFFICE); SUMMER LOGAN (RODEO); BRIAN SKERRY (SHARK)



Cowgirl Emma Parr guides her steed through a barrel race run at last year's Prescott Frontier Days rodeo in Arizona.

Oldest Rodeo

PRESCOTT, ARIZONA

ON JULY 4, 1888, a small crowd gathered in a dusty field to watch ranch hands turn their day jobs into a rambunctious spectator sport. One

wrangler was nearly crushed lassoing a steer. Another mounted a bronc that, one observer wrote, contorted itself "sideways, endwise, perpendicular, horizontal, and in every conceivable shape." Today, 138 years in, the Prescott Frontier Days rodeo bills itself as the world's oldest, and tens of thousands attend to cheer riders, ropers, and racers keeping cowboy culture alive. —ROSE MINUTAGLIO



Sharkiest Waters

CAPE COD, MASSACHUSETTS

Jaws turned the great white shark into an American icon, but only recently has the movie's coastal New England setting become a great white hot spot. During a recent four-year study, scientists estimated some 800 of the sharks visited the waters off Cape Cod, their numbers peaking during the summer, giving the stretch of Massachusetts coastline one of the world's densest concentrations. That's because gray seals, their once dwindling prey, have rebounded after decades of protection. Don't let Spielberg scare you, though: Only two fatal Cape Cod shark attacks have been documented since 1936. —ALEXA MCMAHON

Loopiest Wooden Roller Coaster

BRANSON, MISSOURI

450,000

Board feet of lumber used to build Outlaw Run, at the Ozarks' Silver Dollar City theme park, one of only two wooden coasters in the world (the other's in Sweden) that flip their riders upside down three times.

81

Degrees of the coaster's first death-defying drop—162 feet—speeding the cars enough to power them through those three inversions. Woodies, as wooden coasters are known, lack the strength and rigidity of steel coasters, so building in each twist or spiral requires clever engineering and steel plates.

10,605

Rides that superfan Derk Garmon, of Homer, Illinois, has taken on Outlaw Run since its 2013 opening. "I rode it one day from 9:30 in the morning until midnight," says the retired insurance appraiser. "Of course, I had to take some breaks in there." —BK

MARK THIESSEN, NGM STAFF





At Missouri's Silver Dollar City theme park, Tiffany Gripka (at left) and daughter Marley Gripka ride the Outlaw Run roller coaster, which flips riders upside down more than any other wooden coaster in the country.

Biggest Megafauna Comeback

BLACKFEET INDIAN RESERVATION, MONTANA,
AND BEYOND

THIS SUMMER, wildlife managers from the Blackfeet Nation intend to release several dozen bison in the shadow of a mountain called Ninaiistako, or Chief Mountain, on the border between the tribe's 1.5 million-acre reservation and Glacier National Park, in northwest Montana. The release is part of an ongoing campaign to establish something close to a free-roaming herd, the first such attempt by a tribal nation and a pivotal moment in the country's oldest wildlife reintroduction effort—one that's seen America's national mammal rebound from a few hundred to half a million animals.

Plains bison once numbered in the tens of millions across North America but were driven nearly to extinction by the end of the 19th century, their slaughter part of a deliberate strategy to erode Indigenous ways of life. Their resurgence stems from more than a century of conservation work, starting with the American Bison Society lobbying for protected herds on public lands, then continued by federal agencies and conservation groups.

More recently, tribes in the U.S., along with First Nations in Canada, have taken a leading role in restoring what Indigenous communities often call buffalo, expanding the conservation mission to stress cultural

renewal and sovereignty. Most bison today are livestock in commercial herds, but among those primarily managed for conservation, some 30,000 are stewarded by roughly 45 tribes, says Michael Bo Vocu, executive director of the InterTribal Buffalo Council. That's more than twice the number on all federal lands.

To the Blackfeet people, or Niitsitapi, bison are known as *iinnii*, a word that suggests more than just wildlife—also relatives, teachers, providers. The tribe's first *iinnii* were transferred from a Canadian national park a decade



LOUISE JOHNS

A wide-angle photograph showing a large herd of bison running across a lush green field. The bison are in various stages of motion, with some kicking up dust. In the background, there are rolling green hills and a prominent, flat-topped mountain under a sky filled with white and grey clouds.

Nearly 50 bison briefly ran free in northwest Montana after Blackfoot Nation wildlife managers released them near Chief Mountain, also called Ninaiistako, in 2023. The animals were rounded up after wandering onto private ranchlands, but the tribe plans another release.

ago, descendants of a wild herd once captured in Blackfoot territory. The vision was not only to maintain a herd as a sacred resource, for meat and hides, but also to release a small number, helping restore a wild population.

It's a plan few other tribes have the land to support, says Ervin Carlson, director of the Blackfoot Buffalo Program. The tribe also negotiated agreements permitting bison to range beyond reservation boundaries and into Glacier and Canada's neighboring Waterton Lakes National Park. But upon

their initial release in 2023, several animals quickly wandered onto private ranchlands, sparking ranchers' concerns about competition with grazing cattle, so the free-roaming iinnii were rounded up and re-penned.

The next release will follow the completion of a years-long project to fence off private lands—all in the name of restoring a relationship that shaped the land before fences ever divided it. The setback doesn't diminish the commitment of tribal leaders like Blackfoot Nation Fish and Wildlife director Brandon Kittson. "It would be so amazing to see large numbers of these animals running or moving across the landscape in a natural way," he says. "They belong here." —LAILANI UPHAM

Floatiest Festival

ALBUQUERQUE,
NEW MEXICO

A MASS ascension at the annual Albuquerque International Balloon Fiesta is one of the great American spectacles: a kaleidoscopic flotilla of some 550 hot-air balloons. The world's largest balloon fest draws pilots from around the world, thanks in part to a unique wind pattern called the Albuquerque Box. In the mornings, cooler northerly winds blow beneath a temperature inversion, with warmer southerly winds above. It's "the perfect storm of goodness," says longtime event meteorologist Randy Lefevre, allowing balloonists to simply rise, fall, and drift on the currents.

—JENNIFER LEMAN

WIRESTOCK, INC./ALAMY STOCK PHOTO

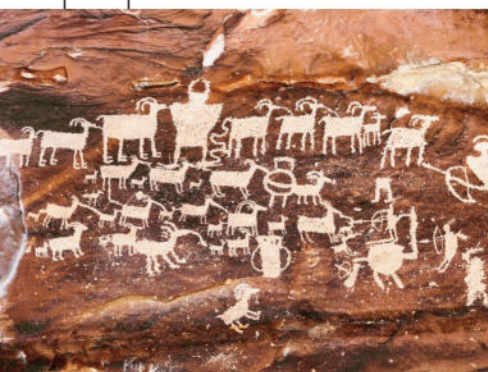




The annual Albuquerque International Balloon Fiesta attracts hundreds of balloonists and hundreds of thousands of spectators.



Supporters line Canton Avenue in Pittsburgh during last year's Dirty Dozen bike race, in which cyclists tackle 13 of the city's steepest hills.



Vastest Outdoor Art Gallery

NINE-MILE CANYON, UTAH

THE COUNTRY'S longest expanse of petroglyphs and pictographs is in this red-rock canyon, where the marvels extend far beyond the nine miles the site is named for. Forty-six miles of cliff walls host some 100,000 images carved and painted by the Fremont and Ute peoples. Highlights include the Great Hunt Panel, where a cryptic horned figure observes a bighorn sheep hunt. —RM

KOJIHRANO, ADOBE STOCK (ART); DAVID ALLEE (STREET)

Steepest Street

PITTSBURGH, PENNSYLVANIA

THE SIGN AT the base of Canton Avenue, in the Pittsburgh neighborhood of Beechview, declares the partially cobblestoned lane “the steepest street in the continental United States.” The title has its challengers—it depends a bit on where and how you measure—but with a maximum grade of 37 percent, Canton earns the marker’s admonition that you don’t simply stroll up the single-block street: “You have to conquer it.”

The improbable incline brings out good old-fashioned American neighborliness. Some residents prefer to park at the bottom, even in good weather, and they occasionally help one another up with groceries. Michael Hartman, a certified first responder who’s lived on Canton for five years, has been known to administer first aid to the cyclists who regularly test their mettle on the street, sometimes toppling over, including during an annual race up and down the city’s steepest hills. The neighbors look out for delivery drivers too, warning them against stopping on the hill, as transmissions have been known to get stuck in park. Alas, says longtime resident Sheila Edwards, no one on Canton even bothers buying Halloween candy—the hair-raising slope seems to scare off trick-or-treaters. —AMY SCHAARSMITH



JAMES WEST, AIR FORCE



Longest Runway

MOJAVE DESERT, CALIFORNIA

The big dreamers who came up with the first reusable spacecraft needed big, safe places to land them—places like a dried-up desert lake bed. At Edwards Air Force Base, Runway 15/33 (named for its magnetic heading) is the world’s longest operational runway at 29,487 feet. Along with two other landing strips on the same dry lake (one, now inactive, was even longer), it was perfect for high-speed, high-stakes space shuttle touchdowns. Today, the stretch of sun-baked clay is a crucial testing ground for everything from supersonic aircraft to military transports. —JL



The huge live oak known as the Village Sentinel likely put down its roots no later than the 16th century.

Shadiest Oak

WAYCROSS, GEORGIA

THE MAJESTIC live oak at the heart of the Baptist Village retirement community has been known for about 60 years as the Village Sentinel, but the tree is perhaps 500 years old—and enormous. The National Champion Tree Program has certified its crown spread (the canopy's widest point averaged with its narrowest) at 161 feet, the largest of all of the program's 78 champion oaks. Every day, Baptist Village CEO Eric Mathison looks out his window at the residents who sit beneath the Sentinel's massive branches. Imagining the aged tree emerging from invisible roots, he says, puts him in mind of "the circle of life." —BK

CAROLINE ALLISON



At the annual Frank's Super Hop contest in Las Vegas, hydraulics-boosted lowriders, like Anthony Maldonado's customized 1987 Oldsmobile Cutlass Supreme, compete for height and style.

Bounciest Car Show

LAS VEGAS, NEVADA

DURING THE DAY, Sandy Avila and 20,000 other attendees of last year's Las Vegas Lowrider Supershow roamed a convention center, admiring more than a thousand impeccably customized, improbably low-slung vehicles. The annual event is the country's biggest single-day gathering of lowrider fans, a chrome-filled carnival of mid-century sedans, convertibles, and more, their chassis inches off the ground, paint jobs luminous, wire-spoke wheels polished to a sheen. And installed in plenty of them is an ingenious bit of engineering designed to elevate—literally—all that detail work in a way that demands attention.

That innovation takes center stage at night, in a parking lot on the Strip, which is where Avila pointed her rose-gold 1966 Chevy Impala. The president of Pasadena, California's Lady Lowrider Car Club, she wanted a front-row spot to watch the biggest of the weekend's "after hops," unsanctioned street parties where lowriders with mighty hydraulics try to out-bounce one another for cash and street cred. The big ticket is Frank's Super Hop (named for its impresario, hydraulics wiz Frank Castillo). From dusk till dawn, some 130 tricked-out "hoppers" took turns

pitting suspensions against gravity—a feat of pistons, springs, and pressurized hydraulic fluid—some lifting their tires nine or 10 feet off the ground. Frank's has all the energy of a Vegas title fight, with crowds whooping as bumpers hit pavement and parts fly. "It's definitely, like, the Super Bowl of hopping," Avila says.

But competition is just one aspect of a tradition rooted in the post-World War II car boom, when the automobile was fast becoming the defining emblem of American culture. The first lowriders rolled out of garages in Chicano neighborhoods in Southern California and the Southwest, where young, working-class men (mostly) transformed secondhand cars into declarations of style and defiance. By modifying factory cars—complete with candy-colored paint jobs, airbrushed murals, and plush upholstery—customizers announced their resistance to a mid-century American culture of conformity. And unlike prewar hot-rodders, who built their cars for speed, lowrider enthusiasts made theirs for cruising *bajito y suavecito*: low and slow.

Lowriding is still, for many, a celebration of Chicano identity, but the scene in Vegas these days is diverse and global—and has more and more women, says Avila, who comes in part to connect with other all-female clubs. Mostly, though, she comes to bounce with her friends down the Strip, "to get dope pictures" while she's hitting the switches under her dash that hop her Impala's front end or lift a tire so she's three-wheeling. It's an amazing feeling, Avila says, being seen.

—DENISE M. SANDOVAL

JEFF MINTON AND CHRIS MCPHERSON

Longest Highway Tunnel

WHITTIER, ALASKA

BLASTING 2.5 MILES through Maynard Mountain in 1943 was a feat. Maintaining the Anton Anderson Memorial Tunnel, with its single lane for cars and trains, is its own challenge. Jet-turbine-like fans keep it ventilated. A hot-water-circulating system prevents icing. And the control centers on both ends? Bombproof, built to withstand frequent avalanches. —ERIC WILLS

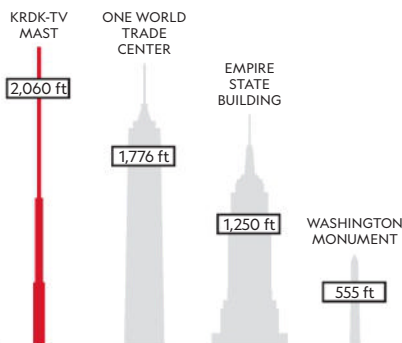


Most Storied Talent Show

HARLEM, NEW YORK CITY, NEW YORK

ELLA FITZGERALD, Sammy Davis, Jr., and James Brown are a few American icons who made their names at Amateur Night at the Apollo Theater. For 92 years, the lively crowd at the country's longest-running talent competition has helped judge aspiring singers, dancers, and other performers by either cheering loudly or booing them off stage. A boo isn't always a career killer: In 1989, heckles ended the set of a 16-year-old comedian named Dave Chappelle. —RM

BRENDAN GEORGE KO (WATERFALL); H. MARK WEIDMAN PHOTOGRAPHY; ALAMY STOCK PHOTO (TUNNEL); SHAHAR A ZRAN, GETTY IMAGES (SHOW)



Tallest Structure

GALESBURG, NORTH DAKOTA

The steel-latticed KRDK-TV mast, rising above a patchwork of cornfields in the midst of the Great Plains, is a testament to the power of lightweight construction. At 2,060 feet, the spire is the most towering edifice on U.S. soil, taller than any American skyscraper, broadcasting high-on-the-dial cable channels across some 15,000 square miles. —BK



Rainiest Place

MOUNT WAI'ALE'ALE,
HAWAII

IN ANY GIVEN year, 350 to 450 inches of rain are likely to drench the dormant volcano at Kaua'i's center. Other Hawaiian spots can contend for the title of rainiest—annual totals fluctuate, and data collection can be spotty—but Wai'ale'ale has set eye-popping records, topping a hundred inches in a month as recently as 2021. The nearly mile-high peak snags moist trade winds, which cool and condense around its summit, enrobing the mountain in waterfalls. —BK

After one of the frequent heavy rains on Hawai'i's Mount Wai'ale'ale, hundreds of thin cascades cover the cliff face known as the Weeping Wall.

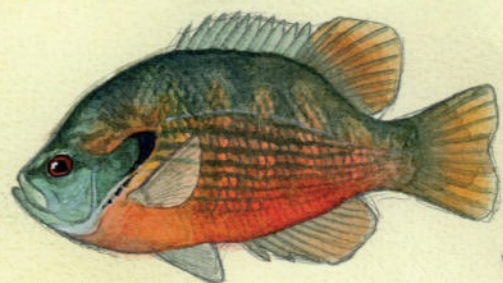
Fishest River

CAHABA RIVER, ALABAMA

AT THE HEART of the watershed that conservationists call America's Amazon, a wild stream snakes for nearly 200 miles through some of Alabama's most scenic countryside. What makes it miraculous is below the surface. The Cahaba holds more native fish species per mile than any other North American river over a hundred miles long: 130 of them, roughly the same as the entirety of California. Its rocky shoals create oxygen-rich riffles for saddleback darters, skygazer shiners, and bullhead minnows. Its swift-moving portions host Alabama hog suckers, Coosa chubs, and frecklebelly madtoms. And its deep pools are home to longnose gars, highfin carpsuckers, and prehistoric-looking paddlefish. That breadth of species, in turn, supports an exceptional variety of turtles and snakes, along with freshwater mussels, which rely on fish to disperse their larvae.

The bounty results from a nearly alchemical convergence of complex Appalachian geology, a dense network of feeder streams, and hefty rainfall from Gulf storms (the most species-dense short river, the Conasauga, is in the same basin). Tributaries carve through diverse, tightly packed rock strata, giving each creek distinct microhabitats where different species thrive. Unlike most big rivers in the South, the Cahaba has no significant dams. The result, says Brian Keener, director of the University of West Alabama's Cahaba Biodiversity Center, is "an absolute global biodiversity hot spot." —ASHER ELBEIN

ILLUSTRATION: MADISON MAYFIELD



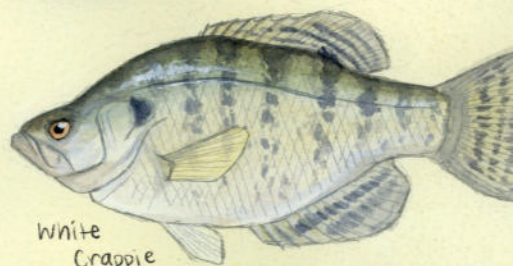
Redspotted Sunfish



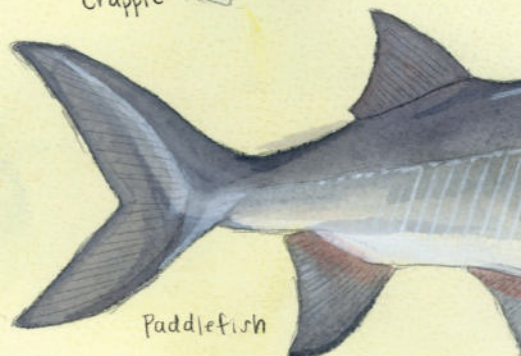
Highfin Carpsucker



Alabama Hog Sucker



White Crappie



Paddlefish



Longnose Gar



Skipjack
Herring



Naked
Sand Darter



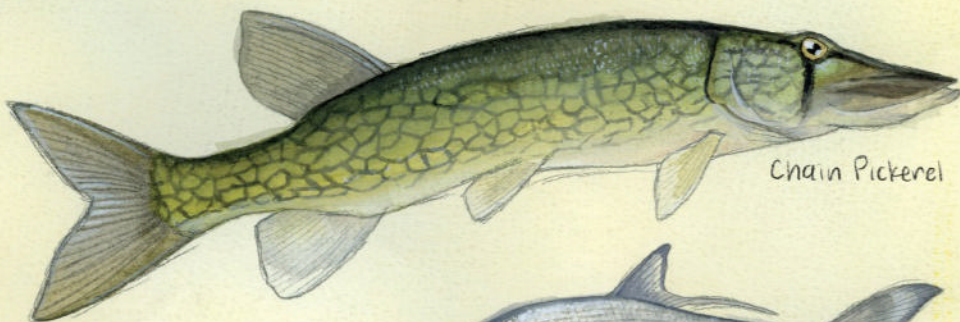
Mobile
Logperch



Shadow Bass



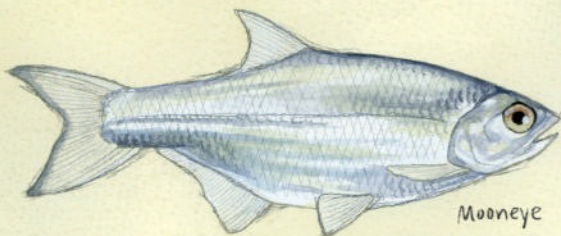
American Eel



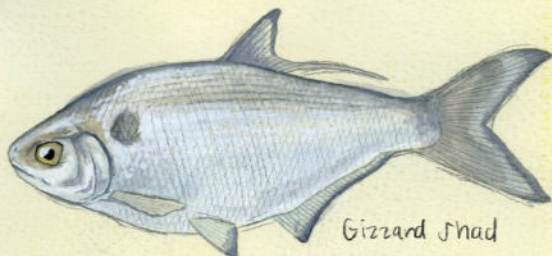
Chain Pickerel



Coora
Chub



Mooneye



Gizzard Shad



Skygazer
Shiner



Frecklebelly Madtom



Warmouth



British surfer Andrew Cotton rides a giant at Cortes Bank, the California offshore seamount that produces some of the world's most towering waves.

Gnarliest Wave

CORTES BANK, CALIFORNIA

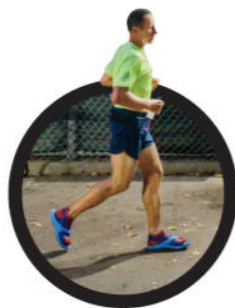
OFFICIALLY, THE BIGGEST wave ever surfed in the U.S. was a 77-foot leviathan ridden in January 2008 by then 42-year-old big-wave ace Mike Parsons. The spot was one few surfers in the world have ever laid eyes on: Cortes Bank, an open-ocean break about 100 miles southwest of San Diego, where some extraordinary underwater topography creates a volatile, legendary wave factory.

Cortes Bank is *almost* an island, a barely submerged seamount that rises abruptly from depths of thousands of feet. Since it's surrounded by deep water, the long-traveled and unobstructed swells that reach it can be remarkably powerful—and in just the right conditions, they climb the underwater ridge and surge upward to become colossal, cathedral-like waves.

And while rising seas have some surfers worried about the erosion of coastal surf breaks, deepwater ones like Cortes are little affected by a few feet of sea-level rise. In fact, climate change could make waves at Cortes even burlier, since warming waters fuel more energetic storms.

Even now, though, riding Cortes is a pros-only affair. Veteran surfer Greg Long, who survived a near drowning there in 2012, calls it “as extreme and dangerous as anything that I would ever want to do in the ocean.” But despite blacking out beneath three waves and being resuscitated by his safety team, he’s kept on surfing Cortes since. Such is the magic, he says, of “the bathymetric miracle that exists there.” —CHRIS DIXON

FRANK QUIRANTE (SURFER); ED JONES, GETTY IMAGES (RUNNER)



Longest Footrace

QUEENS, NEW YORK
CITY, NEW YORK

5,649

Times that runners circle a single block to complete the annual Sri Chinmoy Self-Transcendence 3,100-Mile Race, the world's longest certified footrace, founded in 1996 by the late Indian spiritual guru (and Queens resident) Sri Chinmoy.

40

Days (plus nine hours, six minutes, and 21 seconds) it took Finnish newspaper deliveryman Ashprihanal Aalto to set the course record in 2015, sleeping just a few hours a night.

26

Vertical feet a Sri Chinmoy runner gains (and loses) during one loop of the block. Sounds meager, but a finisher will have ascended the equivalent of five Everests. —BK



Earliest Recorded Powwow

CHARLESTOWN, RHODE ISLAND

LAST YEAR, the Narragansett Indian Tribe observed what it called its 350th annual August Meeting with traditional drumming, dancing, and song. The gathering, rooted in honoring the harvest of green corn, is believed by the tribe to be North America's oldest recorded powwow—a word that likely comes from the Narragansett *pau wau*, although this originally referred not to a meetup but a spiritual leader. The event welcomes the public, and it's been impressing

outsiders since the 17th century: One colonial account describes the Narragansett holding “a great dance... a sort of invocation.” Of course, there is no U.S. history without Indigenous history. “We were here for thousands of years before,” says Lorén Spears, a Narragansett tribal citizen and executive director of the Indigenous-led Tomaquag Museum. “When you think like that, the time on record is only a short period of time in the ongoing celebration.” —R.M.

Dinalyn Spears, a citizen of the Narragansett Indian Tribe, dances during last year's August Meeting.



DANNY NOWLIN, NASA (ENGINE TEST); ALLISON CHENARD (DANCER)



Largest Rocket Test Site

HANCOCK COUNTY,
MISSISSIPPI

APOLLO PROGRAM

scientists liked to say that the path to the moon leads through Mississippi. The rocket engine testing stands at the Stennis Space Center, christened in 1961 on 138,800 acres of Gulf Coast flatwoods, are towering testaments to the American impulse to treat the impossible as simply an engineering problem. And the old aphorism still holds true: The engines that launched this year's Artemis moon mission were put through their paces at Stennis. —BK



Norwich Free Academy running back Mhi'Blessin Maddox-Moore charges downfield during last year's Thanksgiving Day game.

Oldest High School Football Rivalry

NORWICH AND NEW LONDON, CONNECTICUT

LAST THANKSGIVING, Temika Moore stood halfway up the bleachers at the New London High football field, right on the 50-yard line, doing what you're not supposed to do when the New London Whalers play the Norwich Free Academy Wildcats. "Go!" she yelled. "Go...GO, GO!" During the 150th year of America's longest-running high school football rivalry, Moore was cheering for both teams. But she was no ordinary spectator. One of her sons, Mhi'Blessin "Bless" Maddox-Moore, was a senior running back and linebacker for Norwich Free. Another son, Zhi'Mir "Freak" Maddox-Moore, was a

KEVIN HUANG (FOOTBALL); GEORGE GRALL, NATIONAL GEOGRAPHIC IMAGE COLLECTION (SALAMANDER)

sophomore wide receiver, defensive back, and kick returner for New London.

In the history of high school football, no series has been played longer. Since the first New London–Norwich meeting on May 12, 1875, both teams have seen their share of joy and heartbreak. Also acrimony: The game was suspended for two years in 1951 due to a brawl. Controversy: In 1909, the final score was disputed, and a member of the national rules committee stepped in to declare a tie. Peculiar lore: In 1889, a punted ball was lost in a New England snow squall—went up and seems never to have come down.

High school football was once a coming-of-age tradition in every corner of America, but participation in the sport has dwindled. Still, there remain towns where the game feels less like an extracurricular activity and more like a treasured inheritance. “This is a milestone football game, and we’re privileged and blessed to be here,” Wildcats head coach Dylan Schroth told his team before kickoff. “You’re going to make your mark to set up the next 150 years.”

Last year’s meetup added a new twist to the old clash: It was the first game on record with brothers on opposing teams. As the contest rolled on, Norwich Free pulled away, scoring 21 unanswered points, including a rushing touchdown by Bless from four yards out. Final score: Norwich Free 28, New London 12. Series score: 82-70-11, Norwich Free.

After the game both Maddox-Moore boys headed toward their mom. Bless tried to trade jerseys with his brother. Freak looked like he wanted to disappear.

“You’re crying,” Temika said, surprised.

“Yeah,” Freak said.

“Why?”

“I didn’t want to lose.” —SETH WICKERSHAM



Most Biodiverse National Park

GREAT SMOKY MOUNTAINS NATIONAL PARK, TENNESSEE & NORTH CAROLINA

RANK AMERICA'S 63 national parks by size, and Great Smoky Mountains comes in middling. But scientists have identified a stunning range of some 23,000 species there, famously including more salamander varieties than anyplace else on Earth—among them the Blue Ridge two-lined, above. Credit a plethora of habitat types across 6,000-ish feet of elevation, says former park research coordinator Paul Super, who has one of the Smokies' 969 lichen species named after him. And because glaciers stopped short of the park, it's home to northerly species that came fleeing ice and never left. —BK

Deepest Underground Lab

LEAD, SOUTH DAKOTA

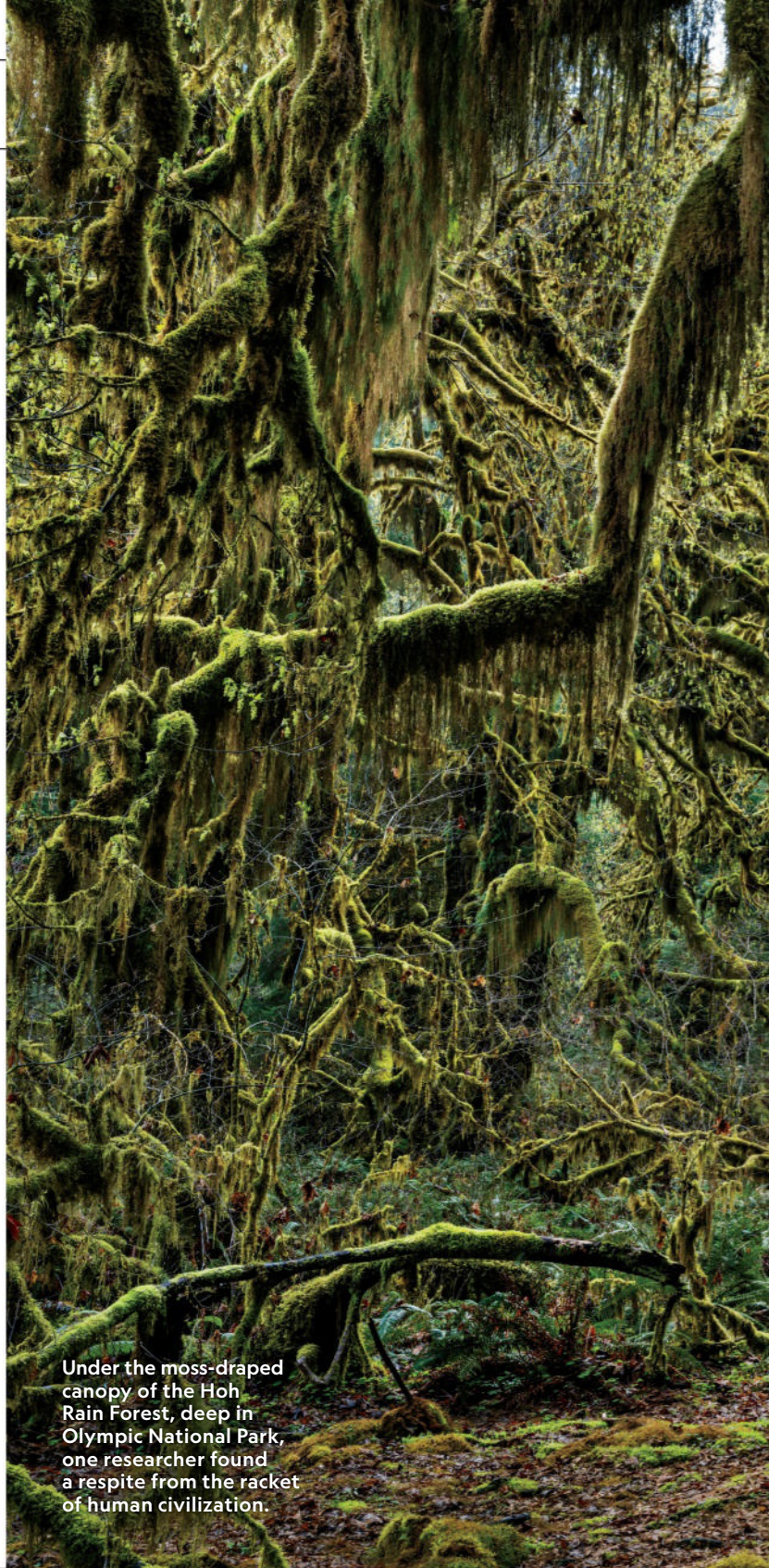
In America, even a tapped-out mine can reinvent itself as something extraordinary. The Sanford Underground Research Facility, some 4,850 feet beneath the craggy Black Hills, attracts the world's leading astrophysicists, many of whom come to study dark matter, an elusive substance thought to be the glue that binds galaxies together. All that surrounding rock shields the former Homestake Gold Mine from background radiation—so if a hypothesized dark matter particle ever hits one of the facility's detectors, scientists will know they've found one of the holy grails of modern physics. —BRIAN RESNICK

Quietest Spot

OLYMPIC NATIONAL PARK, WASHINGTON

IN THE COUNTRY that birthed the concept of wilderness preservation, one of the hardest things to protect is silence. Acoustic ecologist Gordon Hempton co-founded Quiet Parks International to seek outdoor places sheltered from the thrum of humanity: cars and planes, generators and chainsaws, distant sirens. His leading candidate for the lower 48's most hushed hollow is the spot he calls "one square inch of silence," in Olympic's Hoh Rain Forest, where ambient sound registers at the same decibel levels as the softest whisper. That is, Hempton clarifies, when it's not raining. —EVE CONANT

EDWARD BURTYNSKY, COURTESY SUNDARAM TAGORE GALLERY AND HOWARD GREENBERG GALLERY, NEW YORK



Under the moss-draped canopy of the Hoh Rain Forest, deep in Olympic National Park, one researcher found a respite from the racket of human civilization.





Longest Running Hot Dog Stand

FORT WAYNE, INDIANA

MYSTERIES AND DISPUTES swirl around America's de facto national dish. Who invented the hot dog? Why the canine-related name? And is it a sandwich? What's certain is that no establishment has been consistently selling hot dogs longer than Fort Wayne's Famous Coney Island. Since 1914, through wars, recessions, and the ups, downs, and up-again of downtown,



Hugest Organism

MALHEUR NATIONAL FOREST, OREGON

Above ground, *Armillaria mellea* manifests as honey-colored mushroom clusters. But beneath the mossy forest floor, they're all connected by a vast web of mycelium, growing for millennia and feeding on tree roots. The humongous fungus, Earth's largest living thing by biomass, is believed to be 8,650 years old, weigh as much as 35,000 tons, and spread across 2,385 acres. That's older than the Giza Pyramids, three times heavier than the Eiffel Tower, and nearly triple the size of Central Park. —RM



Ethan Gruber oversees the griddle at the venerable Fort Wayne's Famous Coney Island.

Most Meandering Dinosaur Tracks

OURAY, COLORADO

FOR GENERATIONS, the Charles family mined their land in the San Juan Mountains for gold, but five years ago, they realized they'd found something even rarer: 134 fossilized footprints left by a long-necked sauropod 150 million years ago. The West Gold Hill Dinosaur Trackway, now managed by the U.S. Forest Service, is the country's longest continuous stretch of dinosaur prints, as well as a unique example of a track that loops back on itself—a moment of rambling passage made permanent in glacier-scoured sandstone. —AM



the Main Street diner has stayed more or less the same. So have its mild wieners, grilled on a flattop and adorned with yellow mustard, hand-chopped onions, and a secret sauce whose spice mix is known only to owners Jimmy Todoron and Kathy Choka. It's a classic Coney dog, but for more than a century, Fort Wayne has claimed it as its own. "I honestly feel like the restaurant belongs to the city," Todoron says. "I kind of just manage it for them." —BRETT MARTIN

JENN ACKERMAN AND TIM GRUBER (GRIDDLE); MILEHIGHTRAVELER; GETTY IMAGES (TRACKS); NICK FISHER, OREGON PUBLIC BROADCASTING (FUNGUS)



The Cathedral Basilica of St. Louis houses one of the world's most significant mosaic collections. "You can tell the effect that the mosaics have on our visitors," says the Reverend Monsignor Henry J. Breier, "because the images, the sacred art, are windows into the holy."

Largest Mosaic Installation

ST. LOUIS, MISSOURI

41.5 million

Tiles of glass and colored marble that render sacred scenes on 83,000 square feet of walls, arches, and domes at the Cathedral Basilica of St. Louis.

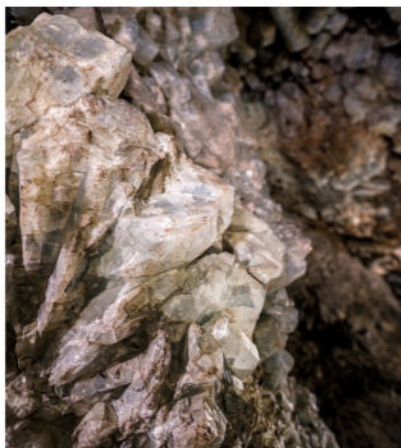
76

Years required to complete the ornate design work, which originally began in 1912. Among the many commissioned artists was famed mid-century art deco designer Hildreth Meière.

160

Hours that volunteer docent Claudia Wright has spent building an immense catalog of all the imagery represented: the number of chalices (16), lambs (4), scepters (9), dragons (36), and so on. "I don't know why," says Wright. "I just thought it was fascinating." —BK

CHRIS GUNN (BOTH)



Sparkliest Cave

PUT-IN-BAY, OHIO

THE INTERIOR of the country's largest geode is roughly the size of a two-car garage, its walls covered in thousands of opaque, whitish-blue celestine crystals, most as big as footballs and some even larger. Researchers call it a fluke: Celestine pockets aren't uncommon in the region, says mineralogist Jamison Brizendine, but none have crystals "even remotely the same size."

Visitors to Heineman's Winery, on Lake Erie's South Bass Island, can walk right inside, some 40 feet underground, down a flight of stone steps. The winery's founder discovered Crystal Cave while drilling a well in 1897, and Heineman family lore says the first person to glimpse it was his five-year-old son, lowered down in a bucket. In the century-plus since, it's lost none of its luster. —JERRY DENNIS



Darkest Sky

BIG BEND NATIONAL
PARK, TEXAS

IT'S HARD TO definitively quantify darkness—
atmospheric factors vary from night to night—but Texas's biggest national park is enveloped by the world's largest certified dark sky spot, the 15,000-square-mile Greater Big Bend International Dark Sky Reserve. With virtually no light pollution, it's one of the best places in the U.S. for Milky Way views, where nighttime visitors can look up and see the star-spangled canopy as they would have 250 years ago. —RM

From March to October, Big Bend's Casa Grande Peak is illuminated at night by the Milky Way.

AMANDA FRIEDMAN

Can These
TINY INSECTS
Stop the Next
WILDLIFE PANDEMIC?

The lowly blowfly is known for feasting on feces and corpses. In Tennessee, one intrepid researcher hopes to use them as a biological warning system for disease.

Words by
JACQUELINE
DETWILER GEORGE

Photographs by
NICHOLAS CONZONE

→ **IN A PANORAMIC APPALACHIAN MEADOW** in Great Smoky Mountains National Park, a pair of scientists hover over a nebula of little black flies. Unlike visitors in town for the early fall elk rut, Charity Owings, a University of Tennessee assistant professor and National Geographic Explorer, and her graduate student Makhali Voss aren't particularly interested in catching a glimpse of the park's charismatic megafauna. Instead, they've set up a small plastic canister stuffed with putrid chicken livers, fumes wafting off of them like vapors from a cartoon pie. The flies love it. Voss slaps a net over the entomological melee, surprising the insects into flight, and before they can escape, she whips her haul in a figure eight pattern to force them into the net's bottom. It's an impressive move, balletic even.

"Who taught you to do that?" Owings quips.

"You did!"

Owings and Voss study blowflies, a family of insects



Forensic entomologist Charity Owings studies captive blowfly colonies like this one at the University of Tennessee, Knoxville, to learn how the insects can be used to track the spread of pathogens in the wild.



that gorge, and lay their eggs, on decaying animal flesh and feces. True crime fans will be familiar with the power of these flies as tools of science. Forensic entomologists log cycles of blowfly egg laying and maggot maturation in a corpse to reveal how much time has passed since a person died. But Owings and her team are using the insects

to solve other types of mysteries—such as, in the case of today’s experiment, whether a tapeworm parasite called *Echinococcus granulosus* is spreading through the Great Smokies’ elk population.

Blowflies carry in their stomach clues about the world around them, including DNA from the animals they touch or

chemicals those animals have encountered. Owings and her team are using a revolutionary method she co-developed in graduate school to test the flies' stomach contents for DNA from bacteria, viruses, and parasites.

"Our whole goal is to try to make surveillance of pathogens really quick and easy," Owings says. Instead of spending time and money trying to locate sick animals and test them, the team can gather nearby flies

and analyze them in the field. "That's a game changer," she says.

Some biologists think *Echinococcus* might have arrived in elk brought down from Canada during a species reintroduction effort, which has since created a local reservoir for the tapeworm. The worry is that the parasite, which can form large cysts in the heart, lungs, and liver, could spread to carriers like coyotes and

When blowflies land, they pick up clues about their environment—including chemicals and DNA from animals they encounter. Researchers in the Great Smoky Mountains capture them with plastic traps and analyze them in the field.



domestic dogs and eventually humans.

A few hours later, at a motel in North Carolina's rural Maggie Valley, Voss carries the desk from her room over to Owings's to construct a makeshift laboratory next to the TV. The scientists cut off the flies' abdomens with scissors and a pair of pointed tweezers, smash them with a few drops of DNA extraction liquid, and place them into a white-and-orange laptop-size console called a Bento Lab before heading out to grab some pizza.

The Bento Lab is a portable DNA analysis machine created by a pair of students at University College London to bring the kind of hard science normally performed in labs out into the field. When Owings read about the device in a paper by a team of scientists who were using it to analyze seawater on a boat, she knew it would be perfect for analyzing fly guts. While Owings and Voss are gone, the Bento Lab runs the abdomens through cycles of PCR (polymerase chain reactions), amplifying the DNA pattern associated with *Echinococcus* until it can be seen as an obvious line on a gel electrophoresis screening tool. It's simple work, if you're a researcher.

The long-term goal is to make the on-location analysis even easier, by creating something akin to a COVID or pregnancy test that an ecologist—or a park ranger without any scientific training—could use. The road to such a test could be a long one: Simpler testing tools would require the help of chemists and product designers, not to mention funding.

In the morning, preliminary results have come back positive for *Echinococcus*. After running more tests for confirmation, Owings and her team will alert the Tennessee Wildlife Resources Agency and work jointly on a plan to mitigate the parasite's spread. They can inform public health officials, local veterinarians, and the public of the risk, but it's not feasible to treat infected elk.



The next day, Owings and Voss head over to collect more flies near the park's Oconaluftee visitors center and meet up with their colleague Richard Gerhold, a veterinary parasitologist who has helped Owings come up with new applications for her research. "We are only limited by funding and our imagination," he says of flies' potential as an ecological tool. Already, Owings and her colleagues have used data from blowflies to track chemicals commonly used in chemical weapons materials—an undertaking supported by the Defense Advanced Research Projects Agency that could eventually be used in conflict zones.

Owings can rattle off a list of other possible uses that range from locating missing hikers through their DNA to identifying new animal species. "There's always a new question," she says. Inevitably, the response is "Well, let's test it." □

 The nonprofit National Geographic Society, committed to illuminating and protecting the wonder of our world, funded the work of National Geographic Explorer Charity Owings featured in this story.



THE SNAKE THAT SAVES MOUNTAINS

High in the cloud forests of western Honduras, the stunning and elusive jade palm pit viper has become a symbol of a vanishing ecosystem—and now a critical part of a new conservation effort.

WORDS BY
LIZZIE WADE

PHOTOGRAPHS BY
JACK DEVLIN



The emerald-colored scales of the jade palm pit viper allow it to blend into the damp foliage of the woodlands where it lives. In recent years, much of its Central American habitat has been destroyed to make way for coffee plantations and pasture for cattle.





ON A CHILLY WINTER NIGHT,

herpetologist Tasman Ezra joined a small group of reptile lovers as they spread out through a misty cloud forest in western Honduras, anxiously searching for the endangered snake that had brought them together. They wore knee-high rubber boots and scanned the mossy trunks and damp leaves around them with high-powered headlamps that cut through the fog. The country was in the midst of a cold front, and for two nights running they hadn't found their prize. But tonight the clouds had broken, and the team spotted, in quick succession, several signs of cold-blooded life: a salamander, a frog, and then another frog.

An hour past dusk, Ezra's shout cut through the forest: "Thalassinus! Thalassinus!" Within the long, dark leaves of a bromeliad attached to a tree trunk, he had glimpsed a few patches of iridescent green scales. They belonged to a particular species: *Bothriechis thalassinus*, colloquially known to some devotees as the jade palm pit viper or thalassinus.

With its electric green body punctuated by lines of black, turquoise, gray, and sometimes pink, thalassinus exerts an irresistible pull on "herpers," the reptile-and-amphibian equivalent of bird-watchers. Part of the snake's allure is that researchers know very little about it. Every observation reveals something new about the species, which can grow to more than two feet long and is thought to prey on frogs, mice, and other small critters that scurry around at night.

That enthusiasm has helped turn this stunning and venomous snake, perfectly adapted to its remote and ethereal habitat, into a symbol of the western Honduran cloud forest and is the spark behind a growing local interest in protecting

the terrain. In fact, several years ago, this very mountain was on its way to being clear-cut for a coffee plantation. Instead, Ezra and a team of herpers raised money in a last-ditch attempt to buy it and turn it into a nature reserve now run by their own conservation group called HonduHerp. But that was only the beginning. As the surrounding communities have come to

Herpetologist Tasman Ezra scans the forest canopy for jade palm pit vipers in Tierra del Tamagás Reserve, near the town of Santa Rita in Honduras. Ezra co-founded the organization HonduHerp in 2023, and it's been managing the reserve since then to protect snake habitat.





Since Tierra del Tamagás Reserve was established, HondurHerp's staff and volunteers have been studying the jade palm pit viper's adaptations and behavior. Little is known about the mysterious snake, so every observation contributes to our understanding of the species.



recognize the snake's value to the ecosystem, they've begun to devise other creative ways to safeguard the forests that this extraordinary animal calls home.

The jade palm pit viper is thought to live only in the tropical cloud forests of western Honduras and eastern Guatemala, which are increasingly threatened by deforestation. "Coffee is the cancer," says Alexander Alvarado, a local bird-watching guide who has become a passionate herper and now serves on HonduHerp's board of directors. The cash crop grows well at the same elevations where the vipers thrive, leading to the replacement of cloud forests with coffee farms. "These mountains"—thalassinuses' mountains—"are just disappearing," says Ezra. Honduras lost a quarter of its humid primary forests between 2002 and 2024, according to estimates by Global Forest Watch.

For Ezra and his longtime friend and fellow reptile enthusiast CJ Baker, the turning point came in 2023, when Alvarado alerted them that yet another mountain near the town of Santa Rita was about to be sold and clear-cut for coffee. Ezra and Baker, both of whom live in the United States but had fallen in love with herping in biodiverse Honduras, jumped into action.

Jade palm pit viper sightings are rare, but this ancient sculpture featuring a mythological double-headed serpent at a Maya archaeological site in western Honduras hints at a long-standing connection between snakes and humans.

They started desperately posting on social media and asking everyone they could think of—"friends, family, friends of family, family of friends," Ezra says—for donations. They raised \$50,000 to buy the mountaintop and founded HonduHerp to run it. They've since turned the land into a locally managed and legally protected reserve called Tierra del Tamagás.

But fundraising alone wouldn't be sustainable. While some environmental scientists see crowdfunding as an increasingly important financial tool for protecting species and

habitats around the world, a disproportionate amount of the money raised has often gone to protecting mammals and birds. Researchers in Australia recently found that less than 15 percent of crowdfunded conservation projects globally focused on reptiles and amphibians. “It’s an uphill battle with snakes,” Ezra says.

Rallying the community seemed like the best way to make a continued impact. Not everyone may be a natural-born herper, so HonduHerp has been working to change perceptions of the jade palm pit viper by emphasizing the reptile’s rare and delicate beauty. “It’s like a fever,” Gabriel Arita, HonduHerp’s regional conservation coordinator, says of the excitement of spotting a thalassinus. “And we started infecting our friends.”

The group now works closely with Honduras’s National Institute of Forest Conservation to co-manage Cerro Azul Copán National Park and several other protected areas in the region. It has established several thalassinus breeding pairs, each from a different mountain, at Rosy Walther Zoo in the capital city of Tegucigalpa, which may be used to augment struggling populations and help researchers study the species’ needs and behavior.

As thalassinus fever spread in and around Santa Rita, more Hondurans learned how to herp in order to catch a glimpse of the town’s elusive emblem, including Francisco Cueva, a local coffee farmer and former hunter. After joining the herping fold, Cueva began to think more carefully about his impact on the ecosystem. He’s now manager of Tierra del Tamagás Reserve, protecting the forest and the animals in it from poachers and loggers, and regularly monitoring its number of



SHRINKING TERRITORY

To protect the endangered jade palm pit viper, the conservation group HonduHerp is partnering with local communities to preserve the snake’s threatened habitat, cloud forests above 3,200 feet. HonduHerp is working to define this viper’s exact range, which remains a mystery.





In Santa Rita, this mural highlights how the jade palm pit viper has become a community emblem, thanks to HonduHerp, which hosts talks at schools and farms.





thalassinuses and other reptiles and amphibians. “I went from visiting [the forest] to destroy it to visiting to protect it,” he says.

When Arita and Cueva go to local schools for snake safety presentations, they encourage respect for all the region’s snake species while trying to dispel students’ fears of being bitten. (A thalassinus’s venom would probably be painful and cause swelling but isn’t thought to be fatal to humans.) After a recent presentation, rapt students lined up to pose for photos as Arita draped a boa across their shoulders. Their parents may soon be among the many people who call the HonduHerp team to rescue snakes they find in their homes, rather than reaching for a machete. Opinions are slowly shifting: A thalassinus mural decorates a wall along Santa Rita’s main road; another guards a nearby swimming pool.

One of the newly converted thalassinus fans is coffee farmer Enrique Guerra. He’d received offers to

“chainsaw” his forest and plant more coffee, but he knew that would be a mistake. “The mountain,” he says, “is the lung of the community,” supplying clean air and fresh water to the towns below. HonduHerp is now helping him turn his own mountaintop land into a second reserve. Protecting the jade palm pit viper means protecting the entire cloud forest, including dozens of other endangered species, from rare tree frogs to remarkable birds such as the resplendent quetzal.

Between the two reserves, the group has helped conserve nearly 300 acres of threatened land so far. The community continues to find



Left

While many forests in western Honduras have already been cleared for agriculture, there is a new alternative for landowners worried about farming's environmental impact: Work with HonduHerp to preserve the land.

Below

Under a dense blanket of clouds, Tierra del Tamagás Reserve manager Francisco Cueva (at left) and HonduHerp's regional conservation coordinator, Gabriel Arita, stand near the edge of the reserve.

its own way to take the mission even further. After Cueva's neighbors saw his work in Tierra del Tamagás, they approached him about ways to protect the land between that reserve and their village of San Manuel, to safeguard the water that flows down from the mountaintop. Cueva and HonduHerp helped the community establish its own nationally protected area around the forest's creeks, another 170 acres of land saved from the threat of deforestation in the jade palm pit viper's honor. Beyond these reserves, HonduHerp is also building relationships with coffee farmers to encourage the use of shade-grown techniques, with the goal of preserving the forest canopy—or even planting more trees—on their properties.

Back in Tierra del Tamagás Reserve last winter, one of the herpers approached the thalassinus within its bromeliad shelter, extending a long pole with a hook on one end to gently lift the magnificent snake into view. It was a juvenile, measuring about a foot long. Everybody gasped, unable to contain their excitement.





A tree at the border of Tierra del Tamagás Reserve marks the dividing line between protected and unprotected land. To the left, the vipers' habitat remains untouched. To the right, the forest has been razed for coffee production.





“That is such a beauty,” Ezra said.

For as many thalassinuses as the herpers have seen, each encounter with the mysterious snake still feels special. So many questions about the species remain: How many individual jade palm pit vipers live in the reserve? What do they eat, and how often? How far can an individual travel over the course of a night, a month, a season? Can the snakes survive in secondary forests that have regrown over the past few decades, or do they depend exclusively on old-growth primary forests? This expedition, meanwhile, has contributed to an entirely unexpected discovery: Jade palm pit vipers hunker down in plants during cold snaps.

One day soon, HonduHerp hopes to have the resources to implant individual thalassinuses with tags and radio transmitters to track their movements and help find answers, which will guide the group’s conservation strategy and significantly expand scientific knowledge about this increasingly appreciated but still little-known species. Until then, the team is more than happy to do the muddy and exhausting work of searching for more jade palm pit vipers deep into the night. After all, that’s what herpers live for. □

Above

A HonduHerp scientist draws venom from a jade palm pit viper. It will be analyzed and could be used to develop antivenom. While probably not lethal to humans, these vipers’ bites can cause permanent tissue damage.

Right

Arita inspects a jade palm pit viper discovered during an expedition in 2025. He is part of a growing movement of snake enthusiasts in Honduras who are committed to studying and protecting the snake.



HonduHerp helps manage several protected sites in the region. The group also has established a breeding program and hopes to release snakes like this jade palm pit viper, photographed at Tierra del Tamagás Reserve, in places where the population is at risk.







VANTAGE POINT

$36^{\circ} 44' 13'' \text{ N}, 2^{\circ} 43' 3'' \text{ W}$

*Glimpsing
the*
FUTURE
of Fresh
FOOD

Along Spain's southern coast, a peninsula teeming with greenhouses offers a revealing look at how Europeans are getting fed.

Words by SAM KEAN



Satellite map: Matthew W. Chwastyk
SOURCES: PLANET LABS; NASA



→ **THE SPANISH COASTAL** plain called Campo de Dalías was once a scrubland where farmers eked out a living on the dry side of the Sierra Nevada. Then in 1963, state agriculture officials put up a few wood-and-wire frames covered in plastic to protect crops in winter. As plants in the rudimentary greenhouses flourished, the practice spread.

Today the area is known as the *mar de plástico*, a “sea” of 44,000 greenhouses. Together with smaller greenhouse clusters in the surrounding province of Almería, it yields some nine billion pounds of produce a year, mostly for export across Europe. With about 3,000 hours of annual sunshine and low humidity, Almería is ideal for greenhouse agriculture, which has transformed the economy of the once hardscrabble region.

Of course, the boom hasn’t come without costs. Critics have raised alarms about working conditions for the largely migrant laborers, and the year-round growing season puts intense demands on groundwater. But Campo de Dalías is also a lab for innovation, where drones monitor crops and scientists are testing plastic sheeting that can shift wavelengths of sunlight to help plants absorb it.

Perhaps most surprising, researchers from the University of Almería have found that since the 1980s, average temperatures around Campo de Dalías have increased at a fraction of the rate of the broader regional warming trend—presumably because all those reflective roofs reduce solar heating. As more Almería-style complexes spring up worldwide, particularly in China, scientists are looking to these new seas of plastic for insight into how to cool cities on a warming planet. □



Plastic sheeting over the greenhouses of Spain’s Campo de Dalías traps moisture to optimize growing conditions—and might be reflecting enough sunlight to curb warming trends.

PHOTO: ALESSANDRO GANDOLFI. MAP: MATTHEW W. CHWASTYK, NGM STAFF



A NEW SHOT *at* SURVIVAL

Can a critical vaccine save koalas
from a debilitating disease?

Photograph by
JOEL SARTORE

→ **ONE OF THE GRAVEST THREATS** to koalas, alongside habitat loss, dog attacks, and getting hit by cars, is chlamydia. In many populations of the beloved marsupial, around 50 percent are infected; in the hardest hit groups, it's as much as 70 percent. The disease can lead to bladder inflammation, infertility, blindness, and starvation, and causes up to half the koala deaths in the wild. Koalas contract it through bodily discharges, mating, and from an infected mother during birth. Babies, or joeys, are thought to also get it by eating pap, a form of feces their mothers produce that helps them digest toxic eucalyptus leaves.



PHOTOARK
JOEL SARTORE

The National Geographic Society funds Explorer Joel Sartore's Photo Ark project, which aims to document every species living in the world's zoos, aquariums, and wildlife sanctuaries.



Antibiotics alleviate symptoms, but they can also fatally disrupt koalas' digestion and don't prevent future infection. Now help is on the way: After 10 years of research trials led by Peter Timms, a microbiologist at the University of the Sunshine Coast, Australia's veterinary medicine regulator has just approved a vaccine. The shot reduces the likelihood of infection and developing symptoms, preventing death in almost two-thirds of recipients. Timms believes the vaccine, once it's rolled out in the coming years, will be "the single thing that could turn a population around." —HICKS WOGAN

MAP: MATTHEW W. CHWASTYK; NGW STAFF. SOURCE: IUCN. PHOTOGRAPHED AT THE AUSTRALIA ZOO WILDLIFE HOSPITAL IN QUEENSLAND

**SCIENTIFIC
NAME**
*Phascolarctos
cinereus*

COMMON NAME
Koala

**AVERAGE
LIFESPAN**
10 to 15 years

**SLEEP
SCHEDULE**
18 to 20 hours a day

DIET
One to two pounds
of leaves daily,
mostly eucalyptus

**CONSERVATION
STATUS**
Vulnerable





In preparation for the World's Biggest Analog, an audacious experiment that placed earthbound space advocates in the roles of tomorrow's astronauts, crewmembers of the Mars Desert Research Station (MDRS) run a pre-mission exercise in the desert outside Hanksville, Utah.

THIS ISN'T OUTER SPACE.

YET.

Before humans can venture to other worlds—or set up colonies on the moon—there's a lot to be rehearsed. Inside the increasingly realistic and dramatically complex experience of simulated space travel.

WORDS BY
ERIN BERGER

PHOTOGRAPHS BY
MACKENZIE CALLE AND
CASSANDRA KLOS



For two weeks, 76 people lived in 16 habitats designed to simulate prolonged space expeditions on, or travel to, the moon and Mars. At MDRS, crew scientist Shriya Musuku (at left) prepares to exit the base while crew engineer Ricardo J. Gonzalez and commander Rym Y. Chaïd take a space walk (at right).







No major national space programs were involved in running the World's Biggest Analog, making it the most complex independent simulation of its kind. The crews had a sense of autonomy as they chose some of their research exercises across multiple sites. In Utah, MDRS participants including Chaid, shown here, conducted soil sampling.



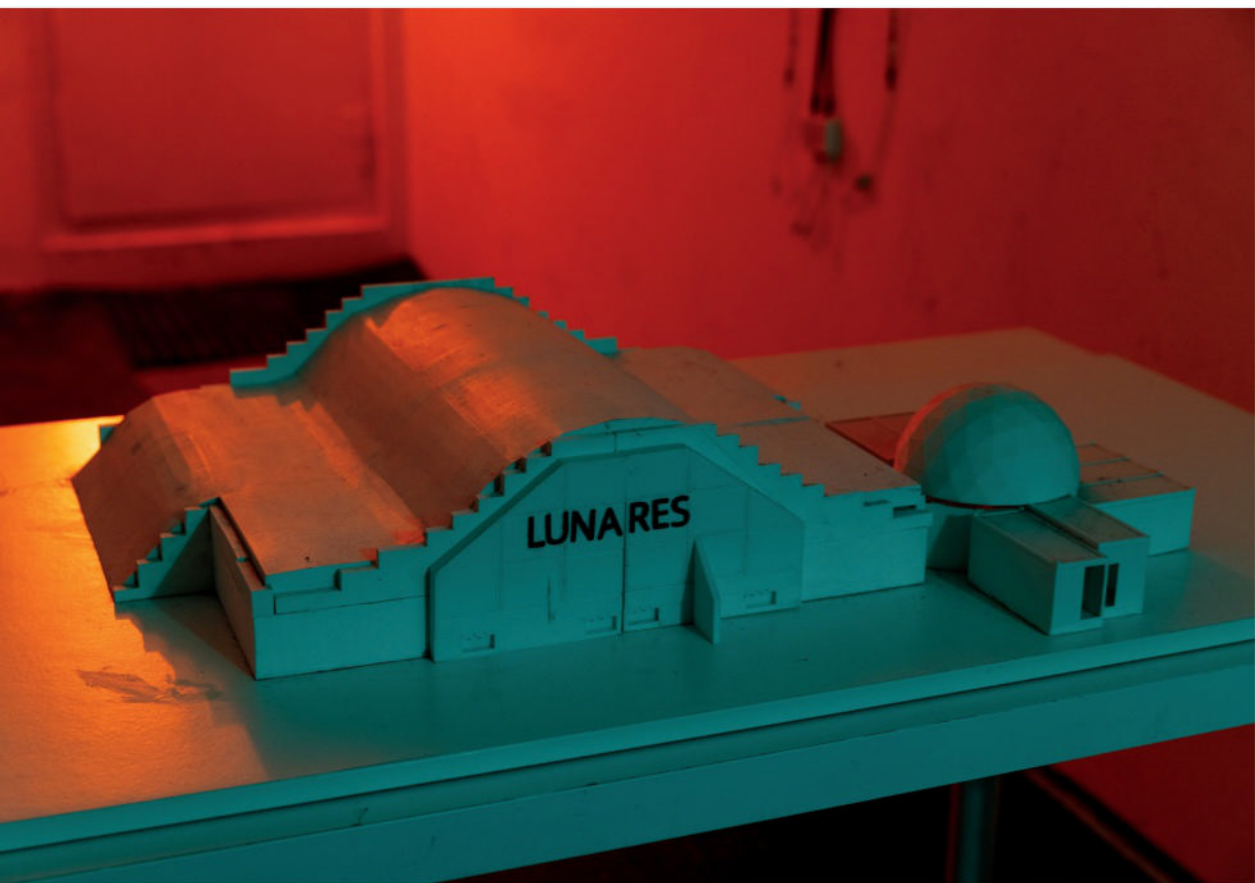
n space, death is always an inch away. An unsecured airlock, a crack in a helmet, a single loose screw. In the face of an emergency, there is no time for a mistake and even less time to panic. It's why astronauts are trained to be creatures of regimen and protocol—even when those astronauts are participating in a simulated space mission at a massive airport hangar in Piła, Poland.

One day last fall, three members of a six-person team sealed their space suits and exited the hatch of their cramped artificial moon base, a bunkerlike habitat adjoining the 3,000-square-foot, completely fabricated lunar landscape at LunAres Research Station. The Polish scientific facility was sealed shut and pitch-black, designed for this crew specifically to replicate the experience of living at the south pole of the moon.

This particular test site is just one of many places around the globe now dedicated to modeling what astronauts may encounter within extraterrestrial environments, a format that researchers often refer to as a “space analog.” In this case, the crew was heading out on an extravehicular activity, or EVA, to take samples of the terrain—a mix of rocks and gravel to replicate mineral-rich regolith. They were also taking part in an experiment of even grander scale.

The LunAres crew had joined with participants from a total of 16 different space analogs running trials simultaneously at scientific sites worldwide as part of an ambitious, international initiative called the World's Biggest Analog. The goal: To test not only many kinds

At LunAres Research Station in Piła, Poland, one crew of astronauts took part in a simulation replicating the total darkness of a crater at the moon's southern pole. To achieve that effect, their artificial moon environment was in a sealed 3,000-square-foot aircraft hangar. A 3D-printed model of LunAres (above) sits inside the station's airlock (below).





Crew science officer Nicole Bolado worked on growing microgreens during her time at LunAres. Without access to direct sunlight, the team tested new ways to extend their food supply beyond the rations they'd packed for the experiment.

of future space missions but also how such operations might stay connected while happening in multiple places across the solar system—specifically, humanity's next two destinations, the moon and Mars.

Earlier this year, NASA's Artemis program sent a team of astronauts around the moon and farther than any crewed mission before, kicking off a new era of space exploration. In 2028 Artemis is expected to lead the first moonwalking expedition in over 50 years. Crewed missions to Mars may begin within the next decade, whether by space agencies or private space companies, which could redefine what the future of extraterrestrial habitation, scientific research, and mining off-planet resources looks like. But all of it depends on making sure that a new vanguard of astronauts will be prepared for the challenges of extended space navigation.

"A miscommunication or a failure to coordinate effectively is going to have not just potential to harm the crew or to have implications for research," says Marissa Shuffler, an organizational psychologist at Clemson University who has worked with NASA on its own earthbound space trials. "A failure could set back programs by quite a bit."

That's where the World's Biggest Analog comes in. The idea originated several years ago with a U.K.-based physics researcher named Jas Purewal, who knew that while many national space programs run their own analogs to prepare future astronauts

for some rigors and challenges of space travel, there's simply no way to test everything an astronaut might encounter. (In fact, NASA refers to such experiments exclusively as "analog," not simulations, because they don't re-create all the variables of space.) At the same time, she noticed that a growing universe of publicly accessible space analogs have been established, creating a shared place for space agencies, private companies, and academic researchers to safely test different scenarios ahead of an actual launch. Through closely coordinated testing, Purewal reasoned, her group might begin to "actually address some of these research gaps."

To do that, Purewal and a small team of volunteers solicited public donations and held an open call for anyone interested in becoming an Earth-based astronaut. If chosen, many analog astronauts agreed to pay a couple thousand dollars to help fund facility costs. The response was overwhelming: Around 500 people applied and underwent a thorough prequalification process aimed in part at gaining insights into how people think and perform under pressure, another skill that's inevitably tested in space.

Case in point: An hour into the LunAres team's moon walk, they received an alert over their helmet radios. One of the crewmembers monitoring their progress had registered that someone's vitals were tanking. Medical officer Domina Stamas and science officer Nicole Bolado discovered that their third crewmember—a space suit-clad test dummy named Emma—was lying prone on the surface.

The nature of her injury was unclear, so they needed to work quickly to drag her back inside the airlock for evaluation. Stamas and Bolado knew what to do; they'd drilled for this scenario. Bolado reached into her backpack and retrieved a collapsible, lightweight gurney. Together, the astronauts tried to assemble the stretcher

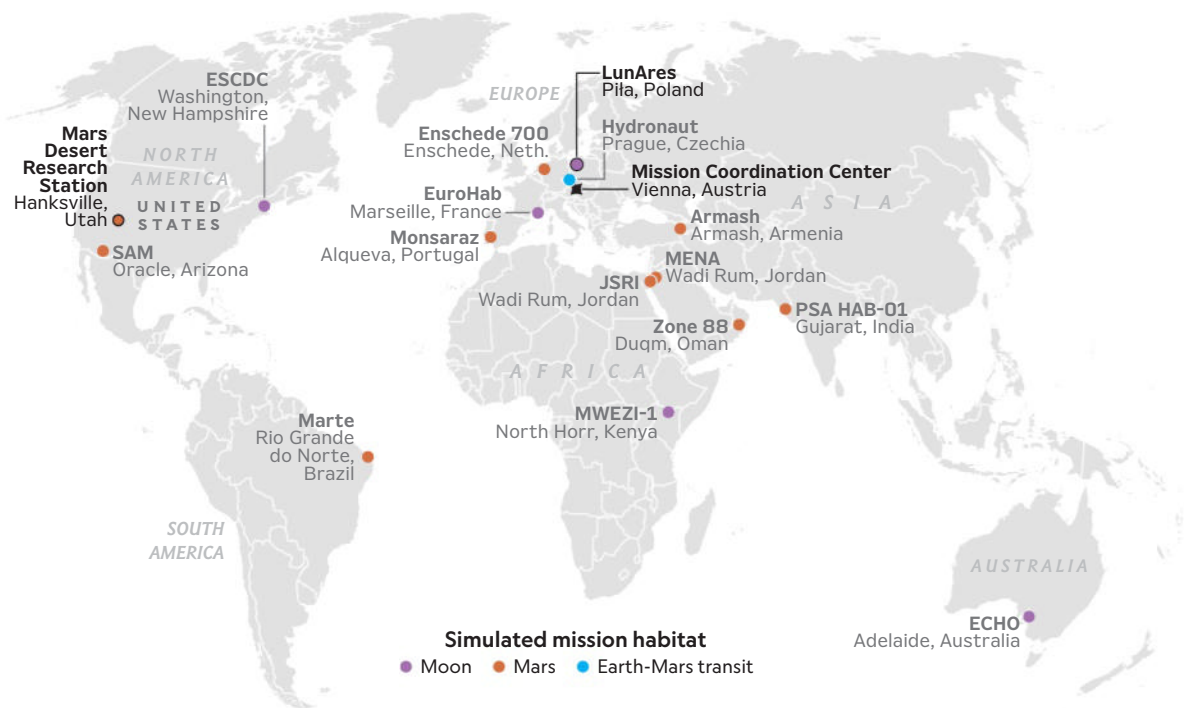


Inside the MDRS base, Gonzalez takes time to stretch as part of a regular exercise regimen. Finding ways to maintain mental and physical health while coping with isolation and confinement was another focus of the simulated missions.



MAKING SPACE

To prepare for the future of space travel, researchers launched the World's Biggest Analog: a global experiment with 16 simulations, exploring challenges we may soon face on the moon and Mars.



by lacing together a series of cords. As precious seconds ticked away, though, they seemed to be struggling.

“HabCom, this is EVA 1—we have misidentified some of the loops,” Stamas radioed back to base. “Can you talk us through how to correctly loop this gurney?”

THE MODERN ERA of simulated space missions started with a few small steps in the Southern California desert. In 1997, not long before the landing of the first ever successful Mars rover, Sojourner, NASA sent a crew of four, including members of the Johnson Space Center Advanced EVA team, to Death Valley to prepare for

unplanned, complex missions that might one day take its astronauts across the solar system. The agency had concluded that the arid, sandy environment was a prime location to conduct speculative fieldwork.

Over the past three decades, proactive space planning has experienced something of a Cambrian explosion. Today NASA’s Human Research Program is involved with about 10 analog test facilities that intersect with how we might better cope with concerns like low-gravity environments, motion sickness, and space radiation exposure. Across the globe, space agencies and private companies have also run simulations in extreme environments that range from the ocean to underground lava tubes and Antarctica. These simulations serve

another essential purpose: spotting new ways to avoid potential disasters caused by tiny, cascading human errors.

In 2013, for example, Italian astronaut Luca Parmitano experienced a water leak in his helmet during a space walk from the International Space Station, forcing him to feel his way back to the airlock with blurred vision. NASA's incident report found, among other miscommunications, that ground controllers brushed off Parmitano's mention of a sensor failure early in the space walk because it had happened before without consequence.

Ignoring a recurring potential concern is known as normalization of deviance, a thought process that, over the decades, has led to the space agency's most significant tragedies. The 1986 *Challenger* explosion occurred after seals failed in low launch temperatures, and the 2003 *Columbia* shuttle disintegrated during reentry after being struck by foam insulation at liftoff. In both cases, the issues had been flagged and deemed acceptable risks.

The problem with space exploration is that there are always new issues to troubleshoot. "There's just not enough time or missions actually occurring in space ... to do every study," says Brandon Vessey, a scientist in NASA's Human Research Program who provides oversight on projects involving analogs and spaceflight.

Independent analogs can help solve that. In one recent study, for instance, researchers used mobile eye-tracking technology to study changes in visual performance and related cognitive demands for astronauts dealing with prolonged time in an enclosed habitat. In another, aimed at growing our extraterrestrial workforce, researchers

measured the activities of an analog crew that included one person with a below-the-knee prosthetic to determine how they performed the active duties required to operate an analog mission.

When it comes to potentially catastrophic issues being overlooked, NASA's own simulations have helped explain how faulty thinking can happen in stressful environments during prolonged space travel. In an agency-funded study published in 2025, Northwestern University researchers discovered that while crews get better over time at familiar tasks like repairs, they actually become worse at creative thinking and navigating unexpected problems.

Such findings have made the agency even more watchful of what's happening in private simulations as they seek to understand how, among other things, group chemistry might lead to more success during trying times. "I have a lot of interest in the isolation and confinement analogs, just because of the complexity of getting people into a mission mindset that's sufficient to believe that the behaviors you're seeing are similar to what you would've seen on a real mission," Vessey says.

While there are some obvious drawbacks to earthbound research—like gravity, for instance—and still no widely accepted formal set of guidelines to govern all test scenarios, NASA remains supportive. "From our perspective," says Vessey, "the more folks out there contributing to preparing for space exploration, the better."

BACK AT LUNARES, as Stamas struggled with the gurney ropes, the communications team inside the base carefully walked her through the assembly process, explaining how to loop and secure a carabiner to ensure the gurney's stability. Even though the crew

 The nonprofit National Geographic Society, committed to illuminating and protecting the wonder of our world, funded the work of photographer and Explorer Mackenzie Calle featured in this story.



Many habitats used in the World's Biggest Analog are accessible for use year-round, including by other researchers seeking places that mimic off-Earth environments. Here, National Geographic Explorer Mackenzie Calle, Chaïd, and Gonzalez embark into the Martian desert of southeastern Utah.





During an expedition at MDRS, Musuku (at right) drives one of the base's four rovers with Calle riding shotgun. These missions were often focused on exploring the terrain, documenting the landscape, and testing the boundaries of communication signals.



recognized that they were trying to pull an imaginary person back to a makeshift airlock attached to a decommissioned Cold War-era hangar that had been filled with sand and rocks, the stress of the situation still felt real.

Everyone was also beginning to feel the effects of natural light deprivation. Cassandra Klos, a documentary photographer and crewmember, said that as the mission wore on, some things they'd done only hours earlier felt like days before, while events from the week prior seemed like they might have just happened. Still, by working together, the crew sped up the problem-solving process enough that it might have saved a real person's life.

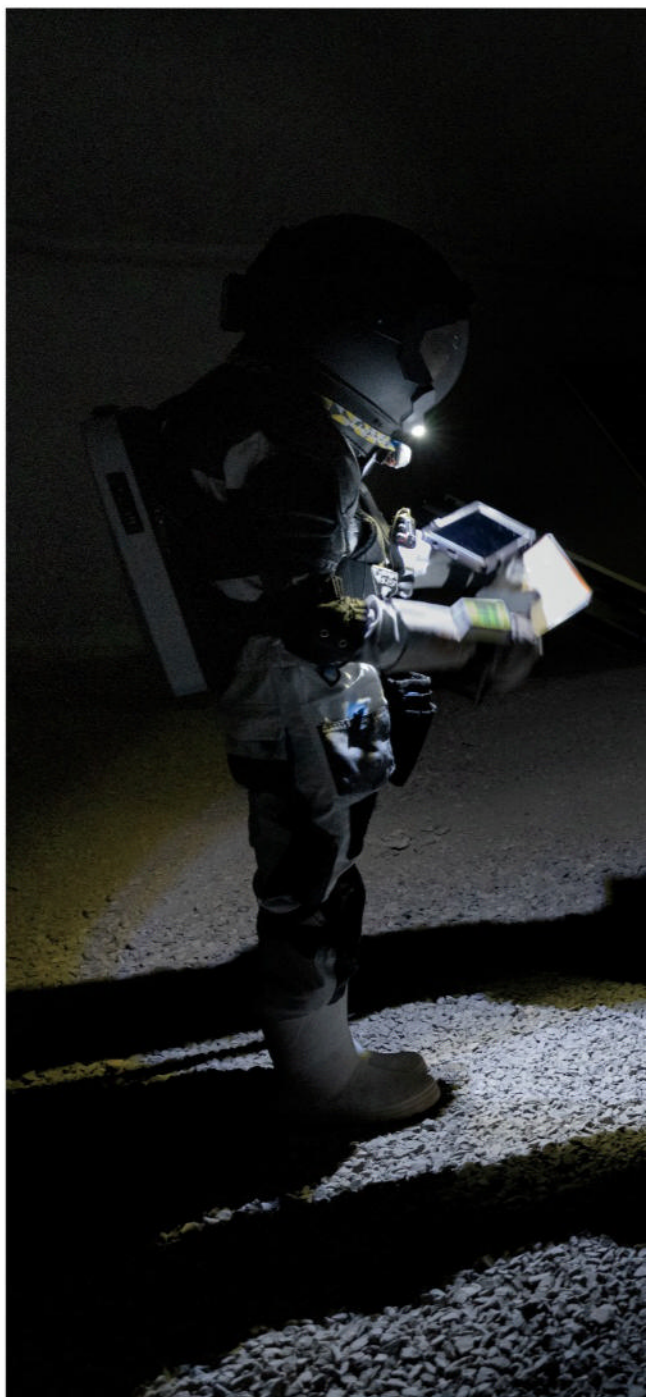
Understanding why the initial confusion occurred is the kind of opportunity that Purewal, who has participated in emergency drills during other analogs, hoped to identify. "You find sort of the holes," she says about seeing what types of problems may arise.

For Emily Apollonio, the founder of Washington, D.C.-based Interstellar Performance Labs, which spearheaded the recruitment of many participants for the World's Biggest Analog, such moments may ultimately help reinforce the question that she finds essential for the next wave of outer space astronauts, regardless of their individual specialties. "Is this person coachable?" is one of her biggest criteria. In order to narrow down the initial pool, her team reviewed written materials from the roughly 500 applicants, selecting 200 candidates to participate in a series of group interviews; from there, about 70 people participated in three months of virtual and in-person team building exercises. To determine their final selections, Apollonio's team looked specifically for crew members who could demonstrate that they were adaptable and capable of collaborative problem-solving.

"It's really a game of trying to figure

out which groups and individuals are going to work best with each other," Apollonio says, adding that the primary thing her team looked for was people's "willingness to learn" and get to know others.

Beyond the teamwork happening at each



habitat, the World's Biggest Analog also tested how an interplanetary mission control might work one day. The entire off-Earth network of bases coordinated with one central command of about 40 operators located at the Austrian Space Forum, a nonprofit public

The hangar at LunAres is filled with dirt and rocks to replicate the moon's surface. During the World's Biggest Analog, a crew of six analog astronauts, including commander Shaziana Kaderali (at left) and crew engineer Makiah Eustice, conducted research with the assistance of a small rover named Leo.





All the crewmembers on LunAres, including Eustice (left), were required to wear space suits while outside their bases. Back inside, a view of Earth through a porthole window (right) was approximated by hanging an homage to the famous 1968 "Earthrise" photograph.



science group headquartered in Vienna, which then relayed critical information to smaller mission control teams at each of the 16 sites.

The team at the Vienna hub checked in on each habitat's scientific experiments, shared daily weather reports, collected mission logs, and connected similar analogs with each other for morale-boosting video chats. They also documented the day's tasks in exhaustive detail, just as a real universal mission control would need to stay running for 24 hours a day to keep people throughout the solar system connected.

"One of the most important takeaways... was the immense depth of trust that had to be established to work together across [six] continents," says Gernot Groemer, the Austrian Space Forum director who led the interplanetary coordination. "Space exploration is a team sport, international, intercultural, interdisciplinary, sometimes even intergenerational."

Altogether, humanity has spent just a collective 12 days on the surface of the moon. And down to the hour, all six Apollo lunar landing missions were intensely regimented, with near-constant communication with earthbound staff. For Groemer and others at the World's Biggest Analog central mission support, the increased autonomy of future deep space crews presented an opportunity to allow participants to explore what will likely be a critical aspect of space exploration: the freedom to chart their own course after touchdown.

THE ASTRONAUTS of tomorrow are going to have a lot more to do once they arrive at their destination, and especially with deep space communication delays, they may have less live support from mission control than ever before. Ambitions might involve living on-planet for weeks at a time, building habitations, growing

crops, and exploring very far afield. These have never been the main responsibilities of astronauts. So, as the LunAres team conducted its work from a dark moon crater and 15 other simulation crews operated from additional interstellar outposts and spacecraft, defining both autonomy and crew protocol became a key part of the collective mission.

This was particularly true at the Mars Desert Research Station (MDRS) in Utah, where a crew of four analog astronauts, including documentary photographer and National Geographic Explorer Mackenzie Calle, carved their own path across the red planet. Some days, two crewmembers would exit their habitat, climb onto a rover, and ramble for up to two or three hours at a time over smooth, sun-drenched red hills near Capitol Reef National Park.

They tested and chose their preferred space suits, gathered geological samples for lab analysis, and practiced emergency drills in the field. For the MDRS team, this was all strategic. Astronauts planning for extended stays on the moon or Mars will have to specialize in more roles like emergency medicine or engineering life-sustaining resources.

"As the number of jobs in space increases, it will be a community," Calle says. "You are going to have personalities, you are going to have differences, and you are going to be close. Those are the only people you're going to have."

All of which makes team chemistry matter even more. That was put to the test one afternoon when Calle and crew scientist Shriya Musuku were in the rover for what had been planned as a standard trip documenting an unexplored region known as the Sea of Shells. Suddenly, they lost contact with their base. Unlike the LunAres medical drill, this was not a simulated emergency. Although they'd been traveling for less than 30 minutes, the sand had deepened, and, with no GPS

or communications link, the way back to base wasn't readily apparent.

"We kind of just realized that we're out here alone, and we have to figure it out," says Musuku. "That probably is one of the worst-case situations if you're out on Mars."

Calle and Musuku decided they must agree completely on each successive step from there on out. They agreed to stop the rover and reset the comms equipment. No luck. With the way back unclear, their next best bet was to find high ground and try to spot North Ridge, a striated domelike section of the desert terrain close to the base. "If you see that, you know where home is," Musuku says.

The pair identified an elevated ledge and slowly navigated the rover up it. At the top, just a few feet from a roughly seven-foot drop-off, they spotted North Ridge. Around the same time, the communications team buzzed over their radio. It had been roughly 15 minutes since their last check-in, and they were "pretty panicked," according to Musuku. After discussing the plan and their route with the comms team, Musuku made what she estimated was a 16-point turn on the narrow ledge, with Calle acting as her spotter, and followed their tire marks back to where they'd lost the main road.

Once safely back at base, the expedition crew and mission control team debriefed. One immediate lesson was that they needed to establish a more concrete protocol for how to dispatch a search party. Another might be that Apollonio's effort to prioritize teamwork had once again proved out.

ONE DAY IN THE not too distant future, humanity may build a real moon base that serves as an off-planet analog for Mars, allowing us to understand the granular details of deep space living while being only a few days' journey back to Earth should something go wrong. But whether the future simulations—on Earth or beyond—are run by NASA-backed specialists or private groups, we will undoubtedly carry our human quirks with us wherever we venture.

For their final night in outer space, the MDRS crew cooked one of their last dehydrated meals together. Meanwhile, at LunAres, the team found ways to stay upbeat, hosting karaoke nights and concocting a set of long-running jokes around Lunar Barbie, based on the popularity of the recent Barbie movie. On their last day, they stood in the fuchsia glow of the biolab's plant lights and counted down from 10 before opening the door and letting out whoops as they emerged into daylight.

The small details might sound trivial, but each communal action kept spirits high as the crew embraced their new reality. One evening, back at the Mars base, Calle found herself looking out at the night sky, imagining a time when someone like her could be stationed among the stars. "It almost felt like ... one of those little dots on the horizon I was looking at was Earth," she says. "There could be any one of a million little pale blue dots I was looking at, but one of them was our whole lives." Simulation or not, the future felt inspiring. □

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NATIONAL GEOGRAPHIC (ISSN 0027-9358) PUBLISHED MONTHLY BY NATIONAL GEOGRAPHIC PARTNERS, LLC, 1145 17TH ST. NW, WASHINGTON, DC 20036. \$89.00 PER YEAR FOR U.S. DELIVERY; \$119.00 TO CANADA; \$119.00 TO INTERNATIONAL ADDRESSES. SINGLE ISSUE: \$15.00 U.S. DELIVERY; \$30.00 CANADA; \$35.00 INTERNATIONAL. (ALL PRICES IN U.S. FUNDS; INCLUDES SHIPPING AND HANDLING.) PERIODICALS POSTAGE PAID AT WASHINGTON, DC, AND ADDITIONAL MAILING OFFICES. POSTMASTER: SEND ADDRESS CHANGES TO NATIONAL GEOGRAPHIC, PO BOX 37545, BOONE, IA 50037. IN CANADA: AGREEMENT NUMBER 1000010298, RETURN UNDELIVERABLE ADDRESSES TO NATIONAL GEOGRAPHIC, PO BOX 879 STN MAIN, MARKHAM, ONTARIO L3P 9Z9. EDETEUR RESP. POUR LA BELGIQUE: MARCO PROVASI-EMD BELGIUM SA, RUE DE GRAND BIGARD 14 - 1082 BRUXELLES - BERCHEM SAINTE AGATHE. REPR. IN FRANCE & ITALY MR. TASSINARI DIR. RESP. ITALY: RAPP IMD SRL, VIA G. DA VELATE 11, 20162 MILANO; AUT. TRIB. MI 258 26/5/84 POSTE ITALIANE SPA; SPED. ABB. POST. DL 353/2003 (CONV. L. 27/02/2004 N.46) ART 1 C. 1 DCB MILANO. STAMPA, QUAD, MARTINSBURG, WV 25401. SUBSCRIBERS: IF THE POSTAL SERVICE ALERTS US THAT YOUR MAGAZINE IS UNDELIVERABLE, WE HAVE NO FURTHER OBLIGATION UNLESS WE RECEIVE A CORRECTED ADDRESS WITHIN TWO YEARS.



GELATIN SILVER PRINT ON LINEN BOARD, 1963
FROM AN 1893 GLASS PLATE ORIGINAL

How a MAVERICK PHOTOGRAPHER EMBRACED *the* DARK

➔ **GEORGE SHIRAS III**, arguably *National Geographic*'s first famous photographer, earned his renown by taking photos at night. And to make those pioneering pictures more than a century ago, he pushed the boundaries of his era's technology. This image shows Shiras, at right, on a lake in Michigan's Upper Peninsula. Using a lantern, he spotted wildlife on shore, then lit magnesium powder for a flash, exposing a glass plate inside his box camera. The resulting shots of deer, lynx, beavers, and more all but single-handedly established wildlife photography as an art form. In 1906, *National Geographic*—which then ran few photos—devoted a whole issue to his work. The edition marked such a turning point that Shiras was honored decades later, in the 75th anniversary issue, when editors marked up this proof. "Before his time," a caption read, "no one dreamed such photographs could be made." —RACHEL SLADE

See this photo and others from our archives at the new National Geographic Museum of Exploration, opening June 26. Visit natgeo.org/moe.



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