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INCA

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TALLEST
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INDIA'S
LAST LIONS

EXPLORING
AFRICA'S
LIVING EDEN



REACH FOR THE CROWN



CELEBRATING THE 2026 ROLEX NATIONAL GEOGRAPHIC EXPLORER
OF THE YEAR. SCIENTIST AND CONSERVATIONIST KRITHI KARANTH WORKS
TO REDUCE WILDLIFE-HUMAN CONFLICT IN INDIA.



THE EXPLORER



COMMITTED TO A PERPETUAL PLANET

FROM *the* EDITOR

NATHAN LUMP

AT NATIONAL GEOGRAPHIC, my colleagues and I are lucky to be part of a global community of scientists, researchers, journalists, and adventurers who are committed to the ongoing work of discovery, always seeking to learn more about our world. To me, one of the most welcome consequences of this perpetual inquiry is how *alive* everything becomes in your mind, how nothing seems static—not the natural world, of course, which we know is always evolving, but also not our ideas about the past.

Consider this month's cover story, about an ancient settlement in Peru called T'aqrachullo. It was home to the Inca—and to the Qolla and Wari before them—and it has been known to archaeologists for more than 30 years. For much of that time it was thought to be a remote outpost of Inca civilization. But thanks to the painstaking work of Peruvian researchers, new

finds at the site are painting a picture that has many scholars reinterpreting its significance, possibly solving an age-old mystery and reminding us that history is far from settled.

This issue shines a light on other places in flux: Antoni Gaudí's basilica in Barcelona, Sagrada Família, which is nearing completion after 144 years of construction; the wilds of Gir National Park, India's last stronghold of lions; and mountain communities in Alaska, where a changing climate is causing more frequent landslides. We also check in with the Okavango Wilderness Project team in Africa, who for more than a decade have been searching for a better understanding of one of the world's most important and enigmatic ecosystems.

I hope you enjoy the issue.

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For more than a decade, researchers have been honing new techniques to explore and study one of Africa's greatest river systems. The full scope of what they've found is only now coming into view.

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A spate of big discoveries led archaeologists to look closer at a once neglected set of Andean ruins. Now their work is revealing intriguing details about Inca religious practices—and may solve a centuries-old mystery.

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CROP CIRCLES
EVERYWHERE?**

How a deceptively simple innovation transformed much of the world's farmland into a dot matrix.

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LIONS OF GIR**

The protection of the world's only remaining Asiatic lions, in western India, is a conservation success story. But what happens when big cats outgrow a small sanctuary?

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The facelike markings on some butterfly wings have evolved in ways we're only starting to understand.

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A LANDSLIDE
DETECTIVE**

Climate change is causing more frequent landslides worldwide. In Alaska, where the risk looms large, one iconoclastic geologist is on a mission to learn how to predict them.

134 **FROM THE VAULT**

ON THE COVER Atop a mesa in Andean Peru, the formerly overlooked archaeological site known as T'aqrachullo is now thought to have been a jewel of the Inca Empire.

Photograph by ARTURO RODRÍGUEZ

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PHOTOGRAPH BY MICHAEL NICHOLS

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OUR WORLD

BEHIND THE SCENES WITH NATIONAL GEOGRAPHIC



Why a world-famous church deserves another look

→ Even though **Nuria Puentes** lives only a few minutes' drive from one of Barcelona's most celebrated landmarks, the Sagrada Família basilica, she had never ventured inside until photographing its newly completed central tower for this issue's feature "How Sagrada Família Reached for Heaven," (p. 38). Her reaction? A "genuine sense of awe and wonder," says Puentes, a longtime contributor to our Spanish sister publication *Viajes National Geographic*. The most powerful moment came when workers installed the final section of a cross atop what is now, after more than 140 years of construction, the world's tallest church. As she piloted a drone around the spire, Puentes says, watching the scene unfold on her monitor was "deeply emotional."

Getting an unexpected close-up in India's lion country

→ While setting up camera traps to capture images of India's remnant Asiatic lions ("The Last Lions of Gir," p. 90), Mumbai-based field producer **Nimit Pandya** got a more intimate view than he bargained for. Working alongside photographer and National Geographic Explorer **Steve Winter**, Pandya was crouching near a water hole in Gir National Park when he saw an approaching lioness—which then sauntered within feet of him. "We made direct eye contact," Pandya says, before the cat bounded off. In 15 years of guiding trips and assisting photo and film productions in Gir, it was among his closest encounters with the reserve's most famous residents.



Field producer Nimit Pandya (center) in Gir, with photographers Steve Winter (left) and Mike McGovern

PHOTOS: ISA BARRIO (PUENTES); ELIZABETH MCGOVERN



IN AN ITALIAN KITCHEN WITH STANLEY TUCCI

→ For the second season of his Emmy-nominated National Geographic docuseries ***Tucci in Italy***, actor and best-selling food memoirist Stanley Tucci eats his way across his ancestral homeland, showing us why culture and cuisine there are inseparable. We asked Tucci how everyday eating across Italy reflects history, geography, and identity.

—ELENA GIARDINA

This season brings you to Sicily and Sardinia. What distinguishes Italy's largest islands?

They're interesting because they're really only united [with Italy]

since 1861. They are Italian but only on paper, in a way. You have so many different dialects... You have one place in Sardinia where they speak a version of Catalan. You have places in Sicily where they speak Greek, places in other parts of it where they speak Albanian... Sardinia almost feels like another country. Or it feels like Italy, maybe 50 years ago.

Across every region, the show's themes seem to be simplicity and seasonality. Why?

All of Italian cuisine is "poor cuisine." There are only five to 10 ingredients

In an episode of *Tucci in Italy*, Stanley Tucci learns a recipe from Giuseppe Bertoleoni (left), who runs the kitchen at Ristorante da Tonino, on the Sardinian island of Tavolara.

in any Italian dish, for the most part... You used what was there. The original Bolognese? The sauce doesn't have any tomato. It's made with a little pancetta, carrot, onion, celery. No garlic, no olive oil. Butter, veal broth, a touch of nutmeg. That's it. One of the most delicious things, and you cook it in 10 minutes. Those were things that were available to everyone.

These days, with basically any ingredient available to us on demand, why stick with that style of cooking?

Why would you want anything else? It's the best food in the world. It's easy to make. It's inexpensive to make. It's good for you.

Any particular meal from these travels that sticks with you?

The [Sicilian] blood oranges. My God, so delicious with wild fennel. It's the simplest dish in the world. Olive oil, salt: Eat it. Have a glass of wine, some bread. Delicious. You'll live forever.

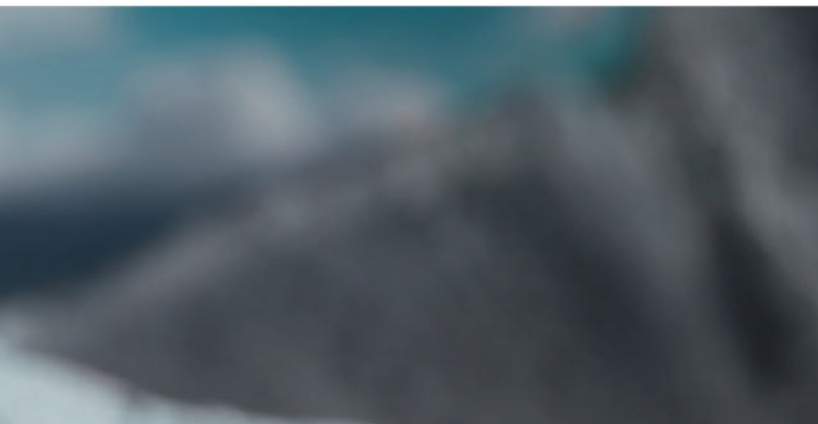
The second season of Tucci in Italy is now streaming on Disney+. Check local listings.



OVERSEAS DUAL TIME CARDINAL POINTS – NORTH

Reference 7930V

41mm, titanium



VACHERON CONSTANTIN
GENÈVE

ONE OF
NOT MANY.

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.



How Corey Arnold went looking for slippery slopes in the last frontier

→ An assignment to shadow a geologist studying bedrock landslides in Alaska ("Lessons of a Landslide Detective," p. 112) covered familiar territory for photographer and Explorer **Corey Arnold**, who lives in Washington but works seasonally on fishing boats in Alaska. "I've always liked to be in hard places where people are doing hard things," he says. In this case, that meant pack-rafting across a back-country lake with his subject, then bushwhacking up nearly 2,000 feet. The payoff, Arnold says, was seeing spots "where, literally, the earth is pulling away, opening up these huge cracks that descended into darkness." His work has also appeared in the *New York Times*, *Wired*, and *Outside*.

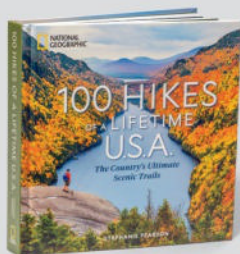
Sharon Guynup,
"The Last Lions of Gir,"
p. 90

An Explorer since 2017, Guynup reported from Gujarat, India, on the future of Asiatic lions. She and photographer Steve Winter received the National Geographic Society's 2024 Eliza Scidmore Award for Outstanding Storytelling for their coverage of captive tigers in the United States.

Steve Winter,
"The Last Lions of Gir,"
p. 90

In 35 years of photographing for the magazine, Winter has memorably covered wild cats around the world. This fall, National Geographic Books publishes *The Big Cats*, a career-spanning retrospective.

PHOTO: JOSHUA CORBETT



NEW FROM NATIONAL GEOGRAPHIC BOOKS

→ Writer and Explorer **Stephanie Pearson** logged some serious miles while cataloging America's most incredible trails—from day hikes to epic treks—for *100 Hikes of a Lifetime USA*. Her top three recommendations:

Kalalau Trail, Hawaii (11 miles) "The beauty is unsurpassed. And it's a difficult trail, so it keeps your mind occupied."

Continental Divide Trail (3,100 miles) "You get so much. Ancient pathways, 14,000-foot summits."

Superior Hiking Trail, Minnesota (300 miles) "If you hit it in the fall? Just a premier experience."

Meet the conservationist helping people live with wild animals

Krithi Karanth, the **2026 Rolex National Geographic Explorer of the Year**, is reimagining wildlife conservation as community engagement.

→ In India, when an elephant tramples crops or a leopard attacks livestock—or worse, a person—the fallout can be devastating for families. It can also destroy the bonds between humans and nature that are crucial for protecting wildlife. That’s why conservation biologist Krithi Karanth has spent years developing novel strategies to help people live alongside some of the world’s most dangerous animals. For that work, she’s been named the 2026 Rolex National Geographic Explorer of the Year, an award recognizing significant contributions to research and conservation among National Geographic Explorers.

As CEO of the Bengaluru-based Centre for Wildlife Studies, Karanth confronts a paradox: that India, crowded with 1.4 billion people, is also a stronghold for wildlife, home to approximately half of Asia’s elephants and roughly three-quarters of the planet’s wild tigers. Conserving those and other species,



she says, requires not just habitat but also hearts and minds. To win them, she launched a platform for users to request government compensation when wildlife damages crops, livestock, or property. It’s helped earn remittance for some 17,000 families. She’s also created a curriculum for schoolkids living near wildlife reserves, now in

1,600 schools, designed to inspire curiosity about and respect for animals.

“Krithi has sparked a movement of hope across India,” says National Geographic Society CEO Jill Tiefenthaler. “By combining science, education, and community partnership, she is redefining how people coexist with nature.”

Next, Karanth wants to apply her ideas outside India, cultivating an international crop of environmental stewards—or even just empathetic neighbors. “Having a set of people who at least tolerate the occurrence and presence of a large animal,” she says, “is a massive victory.”

—RENE EBERSOLE



Karanth and Centre for Wildlife Studies staff use a drone to survey plots for planting trees in Karnataka, India.





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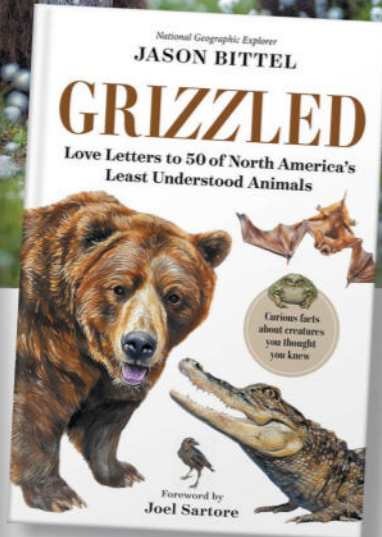
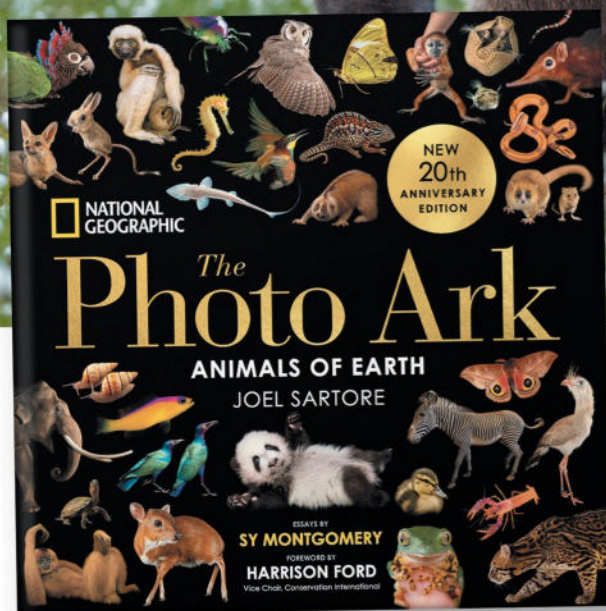
After Brazilian authorities confiscated a pair of shipments of illegally harvested shark fins, photographer and National Geographic Explorer **Fernando Faciole** visited the São Paulo incinerator where the contraband was destroyed. Some 10,000 sharks were killed for the fins, which are black-market delicacies in parts of Asia. Faciole used the longest zoom lens he had to shoot into the inferno. "I did want to get a little bit closer," he says, "but the heat was just so intense."

LEISURE



National Geographic Explorer **Diana Takacsova** has spent nearly a decade photographing Belgium's much touristed 41-mile coastline, along the North Sea, where towering apartment buildings and hotels separate resort towns from fragile dunes and beaches. "For some people, it's a place of nice summer memories," she says, "but for others, it's more of a caricature of [permissive] building policies." In Blankenberge, she found parkgoers playing "snookergolf," a quirky combo of billiards and miniature golf, with a wall of high-rises looming behind.



DISCOVER THE WILD SIDE OF SCIENCE



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 NATIONAL
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ANIMALS

Off Pebbles Beach in Barbados, photographer **Ana Elisa Sotelo** joined Glenfield Clarke on a morning swim with a four-year-old racehorse named Zorah. Handlers, or grooms, like Clarke tend to the care of horses from the island's racetrack, and they're known for leading their steeds to the beach to cool off. Bobbing in Carlisle Bay, Sotelo was mesmerized, she says, by the way horse and groom seemed to "become kind of like one creature."

THE OKAVANGO GIVES UP

An aerial photograph of a winding river, likely the Cubango River, flowing through a vast, dry, and hilly landscape. The river is a light greenish-brown color, contrasting with the surrounding brown and yellowish-green vegetation. The river's path is highly irregular, with several sharp turns and loops. The surrounding land is covered in dense, low-lying shrubs and grasses, with some areas appearing more barren than others. The overall scene depicts a natural, undisturbed environment.

The Okavango Wilderness Project team pilots several flat-bottom canoes called *mokoros* along the Cubango River, which winds through the western part of the Angolan highlands.

KOSTADIN LUCHANSKY

An aerial photograph showing a complex, winding river system in a lush, green landscape. The river is a light green color, contrasting with the surrounding dense vegetation. The river flows through a series of interconnected loops and meanders, creating a maze-like pattern. The vegetation is a mix of dark green and lighter, yellowish-green patches, suggesting different types of trees and plants. The overall scene is a dense, natural environment.

ITS SECRETS

For more than a decade, a team of intrepid researchers have been exploring the river systems of southern Africa, one paddle stroke at a time. Only now is the full picture of what they're discovering coming into view.

WORDS BY BRENDAN BORRELL



Team members use sled harnesses to haul a mokoro loaded with nearly 500 pounds of scientific equipment and supplies across burned pastureland in Botswana. "Every expedition comes with a new set of challenges," says research manager Götz Neef.

KOSTADIN LUCHANSKY



W

WHEN THE RAINS sweep across southern Africa each year in October, rivers feeding the Okavango Delta flood their banks and wash over a roughly 11,000-square-mile area. This vast, swirling labyrinth of islands, marshes, and waterways in the Kalahari Desert links three countries—Botswana, Namibia, and

Angola—supporting thousands of plant and animal species, along with the Indigenous communities who have depended on it for millennia.

Much about life within the Okavango has remained a mystery because of the sheer difficulty of navigating this ever-changing waterscape. Many areas are off-limits owing to local taboos and unexploded land mines left behind from Angola's nearly 30-year civil war. Even the source of the delta's rivers, reputedly in the remote highlands of Angola, eluded European explorers and mapmakers for centuries.



Biologist and National Geographic Explorer Adjany Costa (center) joins other biodiversity experts collecting water and plant samples along a western tributary of the Cubango River. The team has learned that the source of the Okavango Basin in Angola supports at least nine distinct forest habitats.




There are no glaciers there. No snowcapped peaks or ice caves. That absence presented a puzzle that's only grown in ecological importance as temperatures across the continent have continued rising: How was it possible that the delta flowed freely year-round, even through the long dry season?

Over a decade ago, an international group of conservationists, government officials, and scientists came together to seek some answers. With support from the National Geographic Society, they founded what would become the Okavango Wilderness Project. Their goal was twofold: to understand and protect the true source of one of Africa's largest freshwater ecosystems and to document the life it supports. Along the way, they improved their techniques by constantly innovating how they traveled and conducted research, creating an expansive tool kit that could inspire more breakthroughs.


For conservation biologist and National Geographic Explorer Steve Boyes, the team's leader, one key was adopting the right mode of transport: Boyes had already been conducting bird surveys in the delta for years, so he knew to insist on flat-bottom canoes known as *mokoros*, the time-tested means by which local people navigate those shallow, reed-choked channels to fish and hunt wild game.

Though mokoros are traditionally hewed from tree trunks, the team's standard fiberglass models allowed them to carry hundreds of pounds of food and scientific gear while skimming across the water. But during their first launch, on a lake in the Angolan highlands in May 2015, an unexpected challenge emerged. Almost immediately, they hit peat. "We realized, well, there's no water for us to paddle on," recalls Götz Neef, a research manager on the team. "We carried on basically pulling our mokoros for the first 10 to 15 days."

It was the first of many hard lessons. By the time they dragged their boats off the water in Botswana after 121 days in the field, they'd covered 1,500 river miles and added a new item to their equipment list: several sled harnesses to help them haul their boats across the unpredictable terrain.

 The National Geographic Society, which is committed to illuminating and protecting the wonder of our world, supports the Okavango Wilderness Project's efforts to identify the source of one of southern Africa's most vital river systems and document the region's biodiversity. In 2021, the Society joined with De Beers to expand that work through Okavango Eternal, a partnership that aims to support communities and protect nearly 21,000 square miles of wetlands in the Angolan highlands, a newly designated wetland of international importance.



A dense, chaotic flock of red-billed queleas fills the entire frame. The birds are captured in various stages of flight, with wings spread wide, creating a complex pattern of brown, grey, and white. Their bright red bills are a striking contrast against their bodies. The background is a soft, out-of-focus mix of earthy tones, emphasizing the sheer number and movement of the birds.

The Okavango Delta is a refuge for a wide range of animal species in this arid region. These red-billed queleas can number in the millions as they migrate in search of food.

JAMES KYDD



They also added a new fish species to the global inventory. The first net that the team dipped into the lake brought up a climbing perch with a striking checkerboard pattern, a nocturnal species that was unknown to modern science. (In 2021, scientists named it *Microctenopoma steveboyesi* in honor of the expedition leader.)

Since that first trip, the scientific investigators have returned to the Angolan highlands more than a dozen times, completing six other months-long megatranssects of several thousand miles, along with more focused surveys

and environmental and biological sampling efforts. With each expedition, they have not only refined their preparation and equipment but also updated their research methods.

Some water-quality measurements that once required a laboratory can now be made in real time in the field, while a 360-degree camera mounted on the bow of a mokoro captures panoramic images every 60 seconds to produce maps. The team still uses binoculars out in the field and nets to sample fish and aquatic insects, but they've also trialed more sensitive tools, such as 3D-printed spheres



From left

The team navigates a flooded section of Botswana's Boteti River, which is part of a network of waterways spanning more than 120,000 square miles.

Neef (at left) sifts for fish through a fyke net, one of many tools the group has used to discover hundreds of potentially new plants and animals.



that are placed in water to collect genetic traces of organisms, mainly from their tissue and waste, offering a hint at what might lie below the surface. So far, they have identified more than 70 species in water and on land that are new to science, including a bizarre tarantula with what looks like a deflated horn on its back, and hundreds of potentially new species, among them an antelope that needs further research.

Everyone on the team has brought a different set of talents. For instance, boatmen from Botswana were accustomed to slapping their paddles against the water's surface to scare hippos away. In Angola, that tactic only made the dangerous animals more aggressive. "They attacked us three times in two days," says Kerllen Costa, the project's Angola country director and a National Geographic Explorer, of one early trip. Finally, an Angolan team member spoke up, explaining that local hippos responded better to silence. From that point on, the attacks stopped. The team won't even say the word "hippo" out loud now, Costa explains, in accordance with local customs.

As the baseline snapshot of the region's biodiversity has come into focus, the project has started tracking how the system is changing under climate pressure and human use. Fish have grown scarce in some areas due to overharvesting, and team members have been working to create protected reserves to help rebuild their populations.

In southern Africa, 11 major rivers trace their headwaters to Angola, providing a consistent source of water for communities and wildlife throughout the region. After years of exploration, scientists with the Okavango Wilderness Project have mapped their origin: The Angolan highlands hold more than 100 trillion gallons of water in spongelike marshes called peatlands, a discovery that's prompted further protection.

In southern Africa, 11 major rivers trace their headwaters to Angola, providing a consistent source of water for communities and wildlife throughout the region. After years of exploration, scientists with the Okavango Wilderness Project have mapped their origin: The Angolan highlands hold more than 100 trillion gallons of water in spongelike marshes called peatlands, a discovery that's prompted further protection.

A preservation milestone
In January, the team's research and advocacy led to a 20,500-square-mile swath of extensive peatlands receiving recognition as a Ramsar Wetland of International Importance, a major step toward more protections.

ANGOLAN HIGHLANDS WATER TOWER

Newly evaluated source
of the Zambezi River

LISIMA LYA MWONON
RAMSAR SITE

Defining the water tower

In 2015, the team set out to determine how much water the region's wetlands could hold. By studying 40 years of rainfall records, they determined the region stores about 170 million Olympic-size swimming pools' worth.

Lower elevation
limit of natural
water tower
4,180 ft (1,274 m)

NEW SPECIES REVEALED ALONG THE WAY

Over the past decade, the project team has formally identified 70-plus species that are new to science. Nearly 300 more are awaiting further taxonomic study.



Horned baboon spider
Ceratogyrus attontifer
This tarantula has a never-before-seen horn on its back that's soft and elongated.



Climbing perch
Microctenopoma steveboyesi
A new species, named after team leader Steve Boyes, has evolved to move short distances over land.



Angolan rain frog
Breviceps ombelanonga
The pale, wide-eyed amphibian was found in the wetlands of the Angolan water tower.



Lilliput pricklyleg
Porpax sp. nov.
At a little over half an inch long, the species is Africa's smallest dragonfly.



Sand-cotton tree
Cochlospermum adjanyae
While it doesn't have a common name, this new type of underground tree honors biologist Adjany Costa.

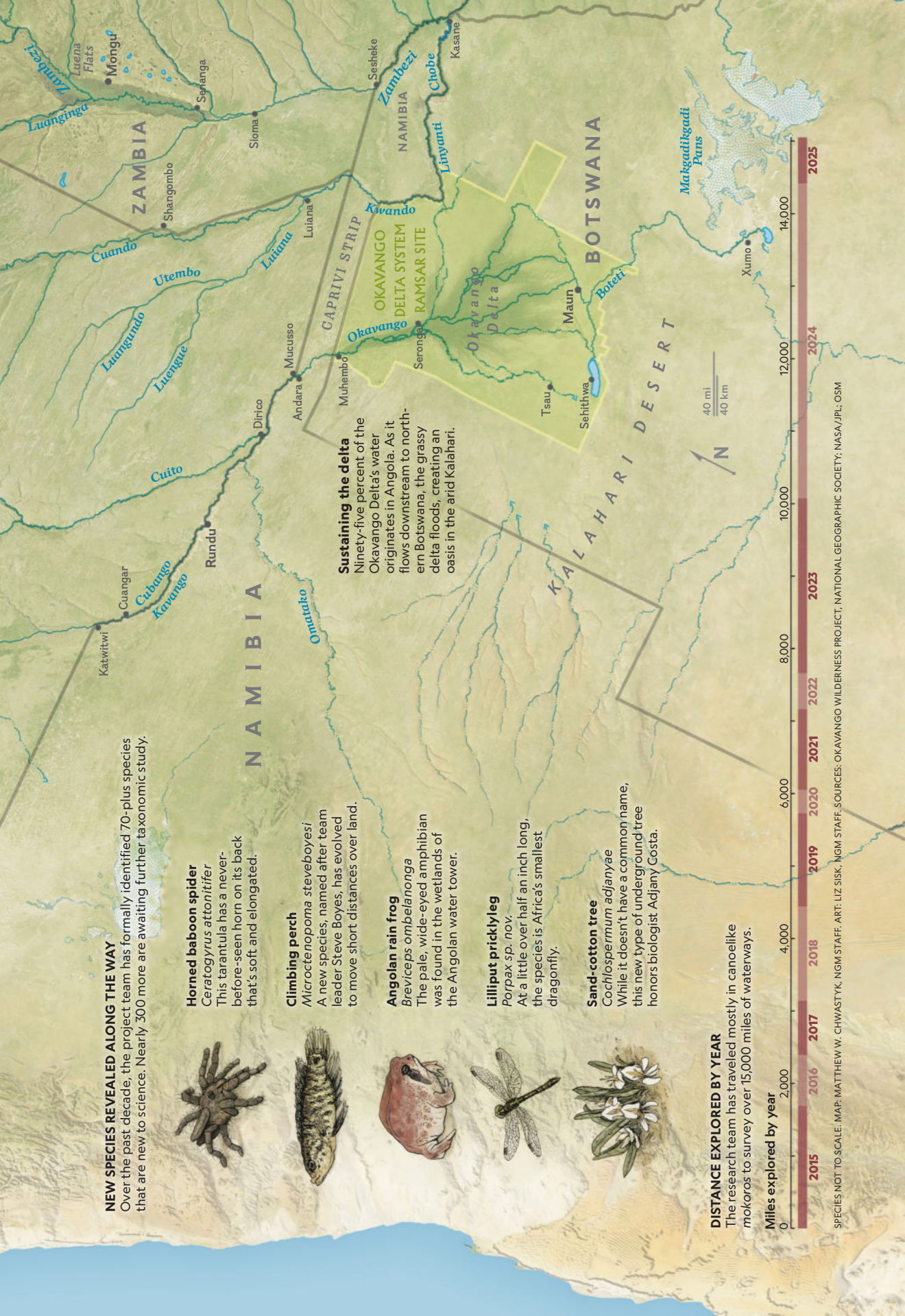
DISTANCE EXPLORED BY YEAR

The research team has traveled mostly in canoe-like mokoros to survey over 15,000 miles of waterways.

Miles explored by year



SPECIES NOT TO SCALE. MAP: MATTHEW W. CHWASTYK, NGM STAFF. ART: LIZ SISK, NGM STAFF. SOURCES: OKAVANGO WILDERNESS PROJECT, NATIONAL GEOGRAPHIC SOCIETY; NASA/JPL, OSM



Sustaining the delta

Ninety-five percent of the Okavango Delta's water originates in Angola. As it flows downstream to northern Botswana, the grassy delta floods, creating an oasis in the arid Kalahari.

THE STRATEGIC WAY TO PACK

To survey one of the largest freshwater ecosystems in Africa, the Okavango Wilderness Project team first had to figure out how to carry up to 500 pounds of scientific and camping gear in one small boat. Here's how they stow it all in a 20-foot mokoro.




The expedition crew's mokoros are loaded to allow access to what is needed on the water while keeping the boats carefully balanced to avoid capsizing.

JOSE BUNDA (@BTH)





-
- 1** Sleeping mat
2 Sleeping bag
3 Tent
4 Dry bag
5, 13 Camp kitchen, including mugs, plates, kettle, and French press coffee maker
6, 14 Wash basins
7, 8 Portable battery banks and power strips for off-grid electricity
9, 10 First aid kits containing such supplies as painkillers, antibiotics, bandages, and IV fluids with comprehensive trauma treatments
11 Mokoro chair
12 Production tent for scientific and documentary work
15 Solar panel to charge batteries and devices
16 Laptop and data collection devices, including acoustic recorders (green boxes), 360-degree camera (above laptop), and water-sampling tool
17 Water-testing kit for monitoring pollution
18, 19 Aerial drones. The larger maps land-scape in 3D; the smaller one conducts surveys and scouts ahead.
20, 23, 28 Stove burner grates and grilling tool
21, 22, 24 Food supplies, specifically rice and beans
25 Hand tools: including machete, axe, shovel, and saw, plus two collapsible stools
26 Sled harness for boat towing
27 Portable Starlink router for internet connectivity
29 Boat patch and repair kit
30 "Kitchen box," including dish detergent, solar lamps, detergent, and hand soap
31 Water filter
32, 35, 37 Aquatic nets and traps
33, 34 Buckets for water collection and specimen examination
36 Boat towing

A man wearing a light-colored shirt, dark shorts, a tan hat, and sunglasses is wading through a river. He is holding a long pole or stick. In the background, there is a large, complex barrier made of many logs and branches across the river. Other people are visible in the background near the barrier. The river has white water rapids. The sky is blue with some clouds.

National Geographic
Explorer Steve Boyes,
leader of the Okavango
Wilderness Project,
guides his mokoro
through a weir that
locals use to collect fish
along a narrow section
of the Cubango River.

POSTCARD LUC HANSEN

The team's measurements have uncovered other long-term concerns as well. When the vegetation turns to a brown color during the longer dry seasons, herders move their cattle right up to the riverbanks to reach fresh greenery. Over the years, the Kunene River in Namibia, which feeds the delta, has grown murkier from erosion and the destruction of the papyrus beds.

Once the water moves downstream, however, it flows through almost 40 miles of papyrus that acts as a natural filter, purifying it before it fans out across the heart of the delta. How much can these papyrus beds take before they break down and stop working?" Neef asks. It's a question the researchers are still trying to figure out, though they have come to realize that the future of the delta will ultimately be decided far upstream.

As for the central mystery that brought them to the delta lands in the first place, Boyes recalls discovering an important clue during their initial expedition. On satellite imagery, the team had spotted depressions in the high valleys that appeared to be little more than grassy patches of land, perhaps seasonal wetlands. Once they arrived in person, the team members realized they had found a mosaic of previously undocumented peatlands—giant subterranean sponges of ancient plant matter—that swell each rainy season and then slowly release water into these scattered depressions and on to the lowlands.

In Scotland, such peat bogs would be unremarkable, but no one expected such an extensive network in a mountainous valley in Africa. A few years later, in April 2017, Boyes brought along scuba gear to explore life underwater in these eerily clear and-green source lakes. "It's like diving in a lake on a moon or Saturn," he says. "It's not on this Earth."

But it would take time for researchers to truly understand the magnitude of the peatland discovery. In 2019, Boyes led across a study that described mountains as "the water towers of the world" because of all the water stored in their snow. He liked that description but was dumbfounded to find that a global map of those towers left Africa entirely blank, representing a yawning gap in our understanding of the continent's watersheds.

Three years later, the team invited Mauro Lourenço, a Ph.D. student at the University of the Witwatersrand in Johannesburg, South Africa, to take a core sample of the mountain. Driving a six-foot steel soil sampler into the ground, Lourenço was startled to find that it didn't go deep enough. The column was pure peat. When he returned with a long core, he discovered that the peat extended more than 12 feet in some areas. Lourenço now estimates that the highlands capture over 100 trillion gallons of water, the equivalent of 10 million Olympic-size swimming pools.

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Boyes (center) waves off a large bull elephant that approached the group on an expedition in 2018 that traversed the heart of the Okavango Delta.

SANDESH KADUR

With the help of remote sensing, field sampling, and repeated expeditions, Lourenço and his colleagues have mapped out the boundaries of what they have dubbed the Angolan Highlands Water Tower, which is sustained by peat, not ice. They believe this could be the first of many such systems that exist across the continent.

The Angolan water tower recently became the country's first ever Wetland of International Importance under a global treaty known as the Ramsar Convention on Wetlands, which will help encourage more formal

protection and management. Its official name, in the local language of Luchazi, is now Lisima Lya Mwono, or "Source of Life."

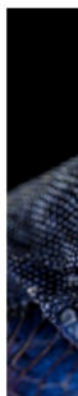
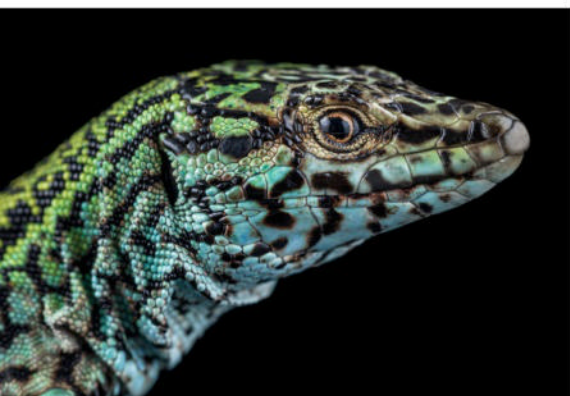
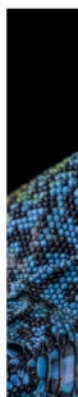
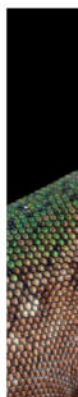
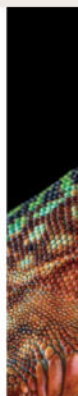
Today the team's mission has evolved from discovering more about that source to gathering information that may inform important ways it can be preserved. At the same time, Boyes and other team members are already exploring new territory. They're working with partners to apply the research techniques they developed in the Okavango throughout Africa to identify and study more water towers supporting the continent's great river basins. □





During a descent of the Cuito River in Angola, the team encountered a waterfall that wasn't apparent on their maps or satellite photos. The water there was clear and drinkable, much like what flows farther downstream within the delta.

CORY RICHARDS





Can These Rainbow
LIZARDS
TEACH US ABOUT
EVOLUTION?

The technicolor reptiles
offer a fresh glimpse into
a biological mystery.

Photographs by
ROBERTO GARCÍA-ROA

→ **FROM SHIMMERY COPPER** to deep indigo, Ibiza wall lizards on Spain's Balearic Islands come in dozens of colors—a natural wonder that has researchers perplexed. For centuries, scientists have attempted to unravel the complex mechanics of evolution. Charles Darwin filled in part of the puzzle with revelations about natural selection, and late 20th-century breakthroughs in DNA sequencing hint at why various physical characteristics might manifest. Still, a lingering question remains: Why do creatures within a single species appear so different? Some answers may lie within the genomes of these vibrant creatures. “We’re trying to understand where that extraordinary capacity for generating diversity and novelty comes from,” says biologist and National Geographic Explorer Tobias Uller, whose team took DNA samples from nearly 2,000 lizards to look for variations that could help explain the kaleidoscopic coloring. He is also considering how environmental factors and the natural history of the island may have given rise to these differences. A collaborator, photographer Roberto García-Roa, is documenting the rainbow reptilians—“a living mosaic,” he calls them—as the team works to solve one of the animal kingdom’s great enigmas. —ELIZABETH LANDAU

Barcelona's long-unfinished Sagrada Família, now 566 feet tall, has become the city's defining landmark—a stunning testament to Antoni Gaudí's technological ingenuity and pioneering creativity.





COMPOSITE OF FOUR IMAGES

HOW SAGRADA FAMÍLIA REACHED

Photographs by
NURIA PUENTES

Words by
CHRISTOPHER HAWTHORNE

FOR HEAVEN

The Barcelona church, already among the world's most famous basilicas, is also now the planet's tallest. As Spain marks a hundred years since the death of Antoni Gaudí, here's how the celebrated architect's magnum opus—144 years in the making—is finally nearing completion.



IN THE FALL OF 1883, a little-known Catalan architect was tapped to take over the construction of a basilica on what was then the outskirts of Barcelona, Spain. The initial plans called for an imposing if traditional design in the Gothic style, much like the other grand cathedrals in Europe. But the young architect, Antoni Gaudí i Cornet, had other ideas.

He had so many other ideas, in fact, that the Sagrada Família, a project Gaudí worked on until his death in 1926, is still famously unfinished. Now, on the hundredth anniversary of the architect's passing, the full sweep of his vision is finally coming into focus. With construction reaching a fever pitch ahead of the centenary, the Sagrada Família has become the tallest church in the world. Towering over an otherwise low-rise section of the city, the basilica resembles a dense, graceful stand of trees: a staggering expression of Gaudí's stubbornness, wild imagination, and technological ingenuity. Last year Pope Francis bestowed on Gaudí the honorific "venerable," fueling speculation that he'll be the first architect ever canonized. His basilica, now the most popular tourist attraction in Spain, is also the preeminent symbol of Barcelona, as emblematic of its host city as the Golden Gate Bridge of San Francisco or the Colosseum of Rome.

Gaudí was a bundle of contradictions. Born in 1852 to a family of coppersmiths, he sympathized with anarchists and atheists in his

youth before embracing hard-line Catholicism. He had an independent and sometimes contentious personality, yet successfully led collaborative teams of bricklayers, sculptors, and engineers as he worked on hundreds of projects. And he was a fierce Catalan nationalist who opposed the Spanish government in Madrid, only to become, alongside Picasso, one of the nation's most celebrated sons. He was also an architect who loved to improvise, often modifying drawings on-site—a habit that was maddening to many clients but allowed him, by trial and error, to develop a style wholly his own, one that looked first and foremost to nature's organic forms for inspiration.

A key breakthrough was Palau Güell, a showy house in an edgy part of Barcelona commissioned by the architect's chief patron, the wealthy industrialist Eusebi Güell. Here, Gaudí explored the potential of the catenary, a parabola-shaped curve commonly used to create tension in suspension bridges. He designed a salon that rises 55 feet through the center of the house. At the top is a dome supported by four catenary arches: the nave of a giant cathedral in miniature.

At the Sagrada Família, catenary arches allowed Gaudí to replace the flying buttresses of Gothic-style cathedrals, heavy and earth-bound despite their name, with an airier and more idiosyncratic vertical architecture. He envisioned a basilica with 18 towers: one each for the four Evangelists, 12 Apostles, Virgin Mary, and Jesus Christ.

Toward the end of his life, as his faith and asceticism deepened, Gaudí moved into his workshop at the Sagrada Família. It was as if he wanted to be closer to his work and to God at the same time. The basilica's budget grew so strained that Gaudí took to badgering friends

Gaudí envisioned the inside of the basilica as a vast forest. He used treelike columns to support the central nave and lit it with a series of recessed skylights in the vault.





In February, workers finished installing the glazed ceramic and glass cross on the top of the basilica. Gaudí intended it to reflect sunlight by day and illuminate at night, serving as a kind of beacon over Barcelona.

and even passersby for donations. (Not that the pace of construction bothered him. As he famously observed of his divine inspiration, “My client is not in a hurry.”) His clothes grew tattered and his beard so long that when he was struck by a city tram one afternoon, he was left lying injured in the street, assumed to be a vagrant. Yet when he died three days later, the news spawned front-page headlines, and spectators packed the sidewalks to watch his funeral procession.

The celebrated architect Louis Sullivan had praised the Sagrada Família as “spirit symbolized in stone.” But when the basilica was ransacked in 1936, during the Spanish Civil

War, it seemed impossible the design would ever be finished. By mid-century, changing architectural tastes also meant its over-the-top decoration began to look out of date. The project languished until Barcelona was awarded the 1992 Summer Olympics, spurring investments in tourist sites across the city.

These days, visitors’ fees more than cover the ongoing building costs, a remarkable reversal of fortune. In February, the basilica reached its final height of 566 feet after workers installed the last section of the cross atop the Jesus tower. The design team, now led by chief architect Jordi Faulí, has for several decades employed sophisticated modeling software, generating complaints that the new towers—Gaudí completed just one in his lifetime—are too streamlined by comparison.

A certain imperfection, after all, lies at the heart of Gaudí’s appeal—his ambition so mammoth that his reach seemed engineered, in ways both stirring and humanizing, to exceed his grasp. □

THE ART *of* DEVOTION

Catalan architect Antoni Gaudí dedicated the final stage of his life to the Sagrada Família, the capstone to his visionary career. In this special section, get an inside look at the design and construction of the Barcelona basilica, and the ingenuity, technology, and projects along the way that enabled its rise.

Graphic by
FERNANDO G. BAPTISTA

and
PATRICIA HEALY



Above

This portrait of Gaudí was taken when he was in his early 30s, around the time he became the lead architect of the Sagrada Família.

Left

His studio within the basilica housed detailed models built to guide construction.

JOURNEY TO THE SAGRADA

Over a 47-year career, Gaudí designed more than 200 projects. Many aspects of his most significant structures can be seen in the famous basilica.

STAGES OF HIS WORK

Gathering influences

Gaudí reinterprets popular historical styles, including Moorish architectural aesthetics.

Transition to the organic

The architect shifts from designing Gothic-inspired buildings to ones influenced by nature.

A singular intention

Gaudí focuses solely on the Sagrada Família, his eclectic vision continuing on after his death.

..... Gaudí works on the Sagrada Família.

- Single-family home
- Apartment building
- Religious building
- Urban space
- Commercial space



Buildings shown at approximate relative scale

Gaudí's first building, a warehouse, features some of his trademark arches.



1 Nau Gaudí 1878-1883

Moorish-style towers



2 Casa Vicens 1883-1885



COLORFUL
Floral motif
light in different
patterns.



3 El Capricho 1883-1885

1883: Gaudí becomes the lead architect of



9 Casa Calvet 1898-1900

VERTICAL SPACE
Curving balconies and symbolic forms accentuate the exterior.

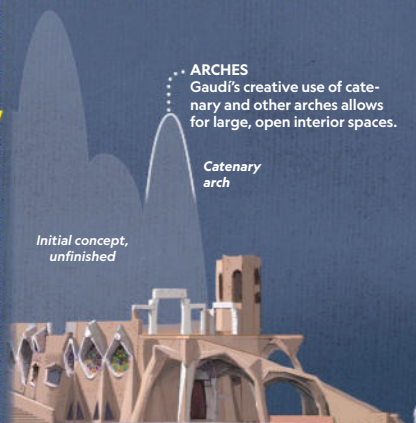


Busts of three patron saints



8 Casa Botines 1891-1892

1893: Work begins

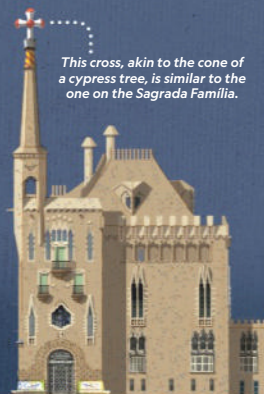


Initial concept, unfinished

ARCHES

Gaudí's creative use of catenary and other arches allows for large, open interior spaces.

Catenary arch



This cross, akin to the cone of a cypress tree, is similar to the one on the Sagrada Família.

10 Cripta de la Colònia Güell 1898-1918

11 Bellesguard 1900-1908

1906: Gaudí

TILES
reflect
erent



METALWORK
A defining feature of Gaudí's style, used here for a decorative gate.

TRENCADÍS
The mosaic technique using recycled ceramics protects and decorates the chimneys.



4 Finca Güell 1884-1887 ▲

5 Palau Güell 1885-1889 ▲

the Sagrada Família.

1885: The chapel in the church's crypt is inaugurated.



Castle-inspired exteriors with towers and turrets conceal airy, light-filled interiors.



Built from local stone



7 Col·legi de les Teresianes 1888-1890 ✝

6 Palácio Episcopal 1887-1893 ✝

ins on the church's first facade.

1892-1893: Gaudí designs a mission in Africa with towers similar to ones at the church.

FORM WITH FUNCTION
Gaudí developed an innovative rainwater collection system.

Rainwater

Cistern



12 Park Güell 1900-1914 🏡



Dragon-shaped roof hides a water tower.

13 Casa Batlló 1904-1906 🏡



Rooftop terrace

14 Casa Milà 1906-1910 🏡

publishes a drawing of the entire church for the first time.

1909: A school for the church workers' children is built on the grounds.

DECONSTRUCTING THE DESIGN

A visitor can't fully appreciate the Sagrada Família without a close look at the details and symbolism that Gaudí embedded in it. Here's a guide to the architect's vision, and the work that remains.

■ Areas to be completed

- Symbolic statues: Winged figures denote angels; the lion is Matthew (angel), the ox is Mark (lion), the eagle is Luke (angel), and the eagle is John (angel).

GLORY FACADE

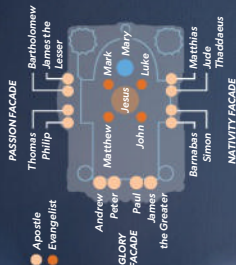
30 ft tall

35 ft

44.5 ft

453 ft

AN EXTERIOR RICH WITH MEANING
All 18 towers are named after biblical figures and adorned with religious iconography.



- Honoring Mary, the Virgin, the tower is topped with the morning star.

Gathering place
A light-filled circular auditorium sits above the facade, allowing the Jesus tower.

PASSION FACADE

- The miter
- The crozier
- The ring

Ornate crowns
Twelve of the towers are topped with crowns and like bishops' regalia, representing apostolic succession.

Organic forms
Many of the towers evoke elements of nature, from plant-topped pinnacles to serpent, lizard, and small gargoyles.

Pinnacle

Gargoyle

Two six-level structures in the sacristy host offices, storage, and multipurpose rooms.

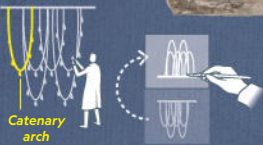
Bell towers will direct sound downward, and into the nave.

Chapel of the Holy Eucharist and the Blessed Sacrament

19TH-CENTURY INGENUITY

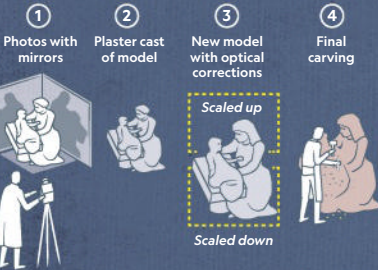
As much an engineer as an artist, Gaudí relied on physical models and a clever approach to perspective that helped him realize his vision.

DESIGNING IN 3D
Weights on ropes simulated structural forces and informed pillar placement for a model. A photo of it was then painted over to complete the design.



Cripta de la Colònia Güell design

NEW SCULPTURAL METHODS
To create sculptures that appear proportional when viewed from the ground, Gaudí employed a combination of innovative techniques.



Wooden scaffolding was used until the mid-20th century.

A base of reinforced concrete sits under the trencadis-decorated pinnacles.

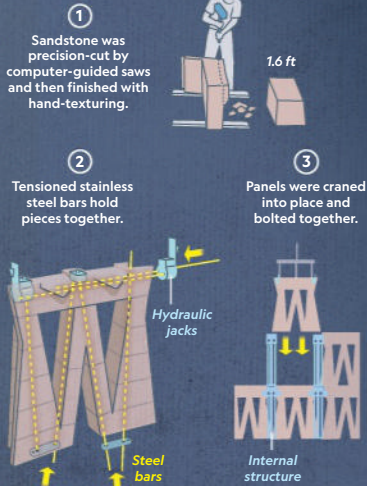
NATIVITY FACADE

MODERN SOLUTIONS

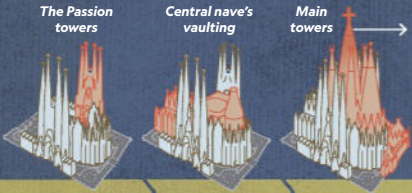
Gaudí knew that the next generation of architects would need to complete his design. Starting in the 1990s, computer software helped them get it done.

THE CONSTRUCTION SYSTEM

Thin panels for the tower walls were prefabricated and installed on-site. They're strong but also flexible enough to withstand forceful winds.



The central structure houses stairs and an elevator.



15 Sagrada Família

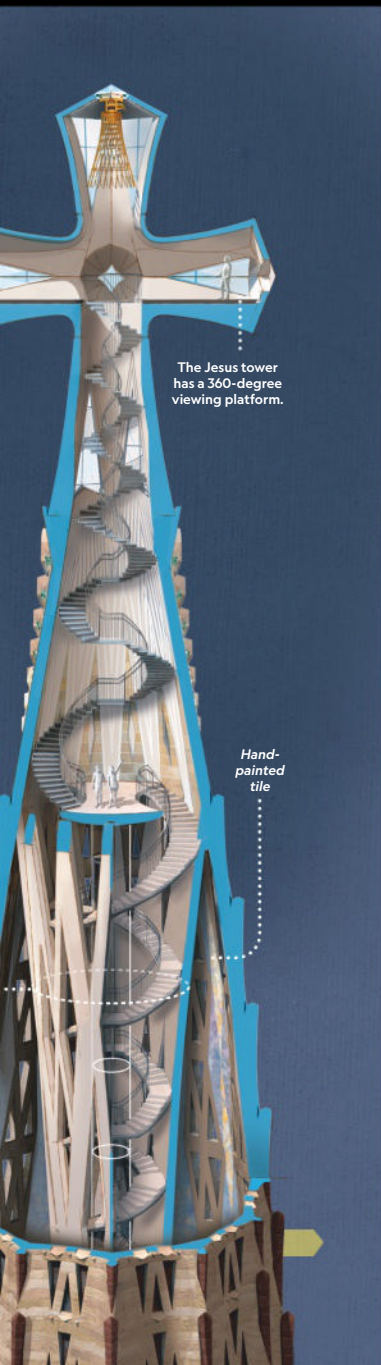
1914: Gaudí begins working exclusively on the Sagrada Família.

1926: Gaudí dies at 73.

1978

2010

2026



The Jesus tower has a 360-degree viewing platform.

Hand-painted tile



Top

The underside of a staircase, which leads to the base of the Jesus tower, reflects Gaudí's fascination with spirals and other motifs found in nature.

Bottom

Toni Cumella (at left) and his son, Guillem, the ceramicists who have manufactured the more than 50,000 pieces of cladding inside the Jesus tower, inspect samples for color accuracy in their workshop near Barcelona.

HOW TO GO

Nearly five million people tour the Sagrada Família each year. In summer, the basilica is open from 9 a.m. to 8 p.m., with reduced hours in the off-season and on weekends. Booking tickets in advance is a must, especially during peak tourist periods. General admission costs 26 euros, and guided tours are available for an extra four euros. Reserve a time slot at sagradafamilia.org. How to make your visit unforgettable? Here are three things not to miss, according to Mònica Santin, a leading Gaudí scholar and Barcelona native.

WITNESS THE LIGHT SHOW

In the mornings, light enters the stained glass windows of the Nativity facade, bathing the interior in shades of blue and green. Another benefit of a morning visit: smaller crowds. In the late afternoon or early evening, the setting sun strikes the Passion facade windows, casting the inside in reddish and orange hues.

EXPLORE THE TOWERS

For an extra 10 euros, visitors can book a tower tour on either the Passion or Nativity facade. Passion boasts better views of the city, but Nativity gives visitors a closer look at the nature-inspired carvings of the architect's original stonework.

GLIMPSE HIS ARTISTRY UP CLOSE

About a 30-minute walk to the northwest, the Gaudí-designed Park Güell showcases his mastery of *trencadis*: the technique of creating mosaics out of broken ceramics and glass. The mosaics adorn sculptures, fountains, and other objects in the park—which also offers a striking view of the Sagrada Família in the distance.



One of Italy's
MOST LEGENDARY
CHEESES
Has a Secret Ingredient:
MAGGOTS

A generation after *casu marzu* was banned across Europe, artisanal cheesemakers in Sardinia still elevate the controversial technique into a culinary art form.

Words by BRETT MARTIN

Photographs by GIANLUCA LANCIAI

→ IN THE SOFT GLOW of a wine-bottle lamp, the larvae were leaping. I was prepared for squirming, having spent weeks researching and contemplating *casu marzu*, Sardinia's maggot-filled cheese. The jumping came as a surprise. Our host, the chef at a restaurant in Dorgali, a small city in the east of the island, had just produced a rough-hewn wheel of *casu marzu*. He carved a circle in the top and pried the thick rind off like a cap. Some of the maggots that had made it their home began abandoning ship, popping off the cheese like bubbles from a glass of ginger ale. The chef took a softened piece of cracker-like *pane carasau*, covered it with a healthy smear of *casu marzu*, and held it out to me. I had been in Sardinia for all of six hours, and frankly, I thought I'd have more time.

Casu marzu, which in Sardinian means "rotten cheese," is the most common name for a cheese in which *Piophilidae casei*, the cheese fly, has been allowed to lay its eggs and those eggs have been allowed to hatch. The resulting larvae eat, digest, and excrete the cheese, leaving it with a distinctive creaminess and the appearance of a well-furrowed field. The result



Sardinia is home to many multigenerational maggot-cheese makers like Domenico Nieddu who produce the local delicacy, which has been labeled the "world's most dangerous" cheese.



All cheese goes through fermentation, but casu marzu is the only Italian variety made with help from maggots that excrete sheep milk fats and proteins.

is an object of both deep pride within Sardinian culture and fascination outside it. Lately TikTok and Instagram are filled with the giggles and shrieks of visitors trying what has been called the “world’s most dangerous” cheese by Guinness World Records. (Theoretically, a maggot could survive the gastrointestinal tract and wreak havoc, though my gastroenterologist gave me his amused blessing before I departed.)

For all of Sardinia’s reputation as a wealthy playground of sparkling seas and mega-yachts, the island remains at its heart a kingdom of shepherds, their ancient work crucial to the island’s economy and identity. There are nearly twice as many sheep as people on Sardinia, and the island produces tens of thousands of tons of cheese a year, including over 90 percent of the world’s Pecorino Romano.

Where there is cheese, there are flies. It has been the Sardinians’ particular genius to turn natural spoilage into a work of culinary art. The general consensus is that the tradition goes back centuries, at least. Today casu marzu remains deeply stitched into the social fabric of Sardinian life. At a summer picnic someone might bring homemade wine, another honey from a beehive, and somebody a wheel of maggot cheese. Some Sardinians will spin you a story that it’s an aphrodisiac, others that it contributes to the so-called blue zones diet credited with the preponderance of long-lived people on the island. But the truth is that many of them just really love it.

In 1962, Italian legislation prohibited commercial sales of the cheese due to safety concerns. Further restrictions in a wider 2002 law banned casu marzu trade



Casu marzu is often made in small batches and brought to gatherings, like this dinner that friends Francesca Urru and Raimonda Mereu attended on a Sorgono farm.

within the European Union. Still, it remains available for Sardinians who know where to look. Between its underground status and the fact that production happens on a microscale, it's difficult to pinpoint the number of shepherds making casu marzu, though one estimate suggests they churn out more than 200,000 pounds yearly.

That casu marzu production relies on a certain amount of randomness—some shepherds will end up with a surplus of wheels in a given season, some none—gives the annual search a certain frantic thrill. One particular enthusiast in Cala Gonone, a seaside town near Dorgali, told me he has the contacts of 10 shepherds that he calls in rotation, the better to ensure a regular supply for his personal use.

Among them is 32-year-old Mario Nieddu, the fourth generation in his family to raise

farm animals in the hills near Cala Gonone. His father, Domenico, taught him how to make casu marzu. It's a fragile time for the cheese, Mario says. Increasingly hot summers because of climate change have affected the life cycle of cheese flies, making their work even less predictable than usual. Last year, out of about 60 wheels, only four or five of theirs ended up as casu marzu. (If the maggots inside a cheese are dead, it is considered inedible.)

That said, there are various ways of encouraging the casu marzu accident. Some cheesemakers will put a fly-ridden wheel in the center of a circle of unoccupied cheeses, the way parents once hosted chickenpox parties. Few are more reliable at producing the cheese than second-generation shepherd Andrea Logias. At his farm in Sorgono, a small commune in the province of Nuoro,

his aging room was blackened with smoke stains and the air thick with flies. Wheels of cheese weighing between six and nine pounds, which he sells to neighbors, were stacked everywhere, and clumps of maggots lay on the floor. These larvae would form cocoons, metamorphose, and then reemerge as flies to begin the process again. They too are multigenerational artisans. Logias compared the process to *farfalle*. Butterflies, the translator interpreted. Imagine the room filled with butterflies.

Broadly speaking, this is how all cheese is made, with various living organisms—bacteria, yeast, mold—transforming simple milk into a kaleidoscopic array of manifestations, some of them among the world’s most sublime foodstuffs. It just happens that the organisms digesting casu marzu are significantly larger and more visibly active.

Outside Sardinia, casu marzu has a place among such other hall-of-fame gastronomic oddities as the Icelandic rotten shark known as *hákarl*, and *kopi luwak*, Indonesian coffee made from beans that have passed through the digestive system of a civet.

These foods are stars of a social media sector you might call YuckTok, but a fervid interest in being grossed out is hardly a new phenomenon. It is, in fact, deeply human, according to psychologist Paul Rozin, who has been dubbed the “king of disgust” for his pioneering work on that emotion. “It’s a feature of humans that we like to overcome aversions,” Rozin says. “We become attached to things that are, for most people, offensive—so we have stinky cheese in Europe and ... insects in many places.”

Laura Mereu, whose family runs Agiturismo Su Connoto, a farm near Sorgono that hosts tastings of local products, likes the fact that Sardinian culture is celebrated by the TikTok cheese-eaters but wonders about the cost. “They give the cheese the right level of importance,” she said. “But they lose the meaning.”





Mario and Francesco Nieddu (top left) learned how to make casu marzu from their father, Domenico Nieddu (top right), who's passing the tradition down to the next generation at their family farm in Cala Gonone. Cheese wheels are aged in small rooms where flies lay eggs that hatch into maggots (bottom left), and presto: a creamy spread with Gorgonzola-like consistency that is traditionally served with a side of *carasau* bread (bottom right).



Mereu showed me something that she thought was an essential part of the casu marzu picture. We drove outside of Sorgono to an edifice of piled stones, like a miniature castle, crumbling and overgrown but still in good enough repair that we could wander through archways and up a stone staircase. This was a *nuraghe*, a remnant of the Nuraghi, the Bronze Age civilization that flourished on Sardinia nearly two millennia before Julius Caesar. There are

thousands of such sites strewn across the island. For Sardinians, they are a powerful reminder both of the depth of their history and of their separateness from the rest of Italy. Mereu sees casu marzu as a similarly important and irreplaceable link: “It is part of a specific food tradition tied to rural life, identity, and memory.”

On my last night in Sardinia, I dined with two professors of microbiology from the University of Sassari: Severino Zara and




Made by and eaten
in the homes of
devoted Sardinians
for generations, casu
marzu has recently
garnered a new follow-
ing of curious foodies
on social media.

Francesco Fancello. A few years ago, Zara began looking for scientific literature on casu marzu and was shocked at how little there was. “There is a lot of folklore around casu marzu, but not a lot of research,” he said. Both men agreed that the lack of study was regrettable—particularly on the cheese fly larva itself. For all we know, they said, it might actually be healthy for humans. “It’s such a robust little biome,” Fancello said.

In 2024, a petition to legalize casu marzu was sent to the European Parliament, proposing rules and safety regulations, “thus safeguarding consumers’ health and safety.” It was summarily rejected on the grounds that the cheese was a “contaminated and decayed product.” In truth, I had the sense that few Sardinians minded. The wink, the handshake, the gleam in the eye—all seemed to be part and parcel of what they loved about casu marzu. For Fancello, it was a bit of a dilemma. As a scientist, he knew a controlled product would be easier to study. As one of seven children of a Dorgali shepherd, he felt that wildness was the very essence of the cheese. “To produce casu marzu, you need freedom,” he said.

Our meal ended with *seadas*, deep-fried pies filled with cheese and honey. We toasted with shots of the sweet Sardinian myrtle liqueur *mirto*. Then we proceeded outside, where a wheel of casu marzu had been opened.

Back on my first day in Sardinia, I had stared at the proffered piece of casu marzu and then, like a skydiver forcing himself to step out of a plane, popped it in my mouth before I could think any more about it. The flavor was strong and goaty, but not as searingly intense as, say, some Spanish cheeses that make you feel as though you’ve climbed inside a goat. It had a bold barnyard tang that simultaneously dried out my tongue and sent my salivary glands into overdrive. There was no identifiable sensation of eating insects. Still, I chewed extra thoroughly, lest any guests make it down the pipe unmasticated. I can’t say casu marzu has become my favorite cheese, but it is peculiarly seductive. Like other spicy foods, it makes you suffer and then, against all logic, you find yourself going back for a little more. By now, at the end of a week crisscrossing the island, I didn’t even hesitate before taking a bite. After all, what’s a few maggots between new friends? □



In southern Peru, archaeologists have unearthed hundreds of structures from an ancient Inca settlement known as T'aqrachullo. Scholars are just beginning to understand how this holy place shaped the story of the Inca.

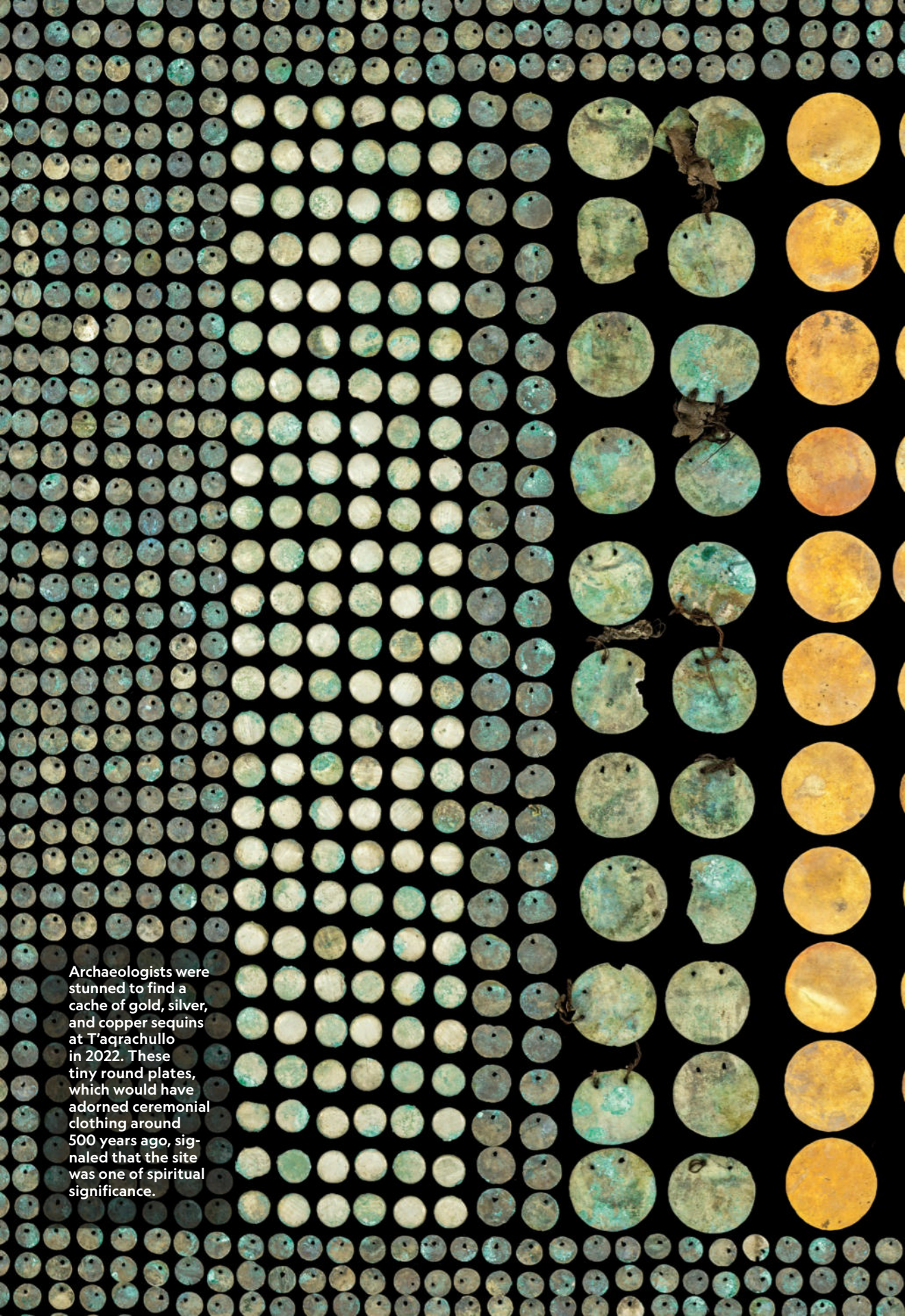


THE SEARCH FOR THE INCA'S LOST CITADEL

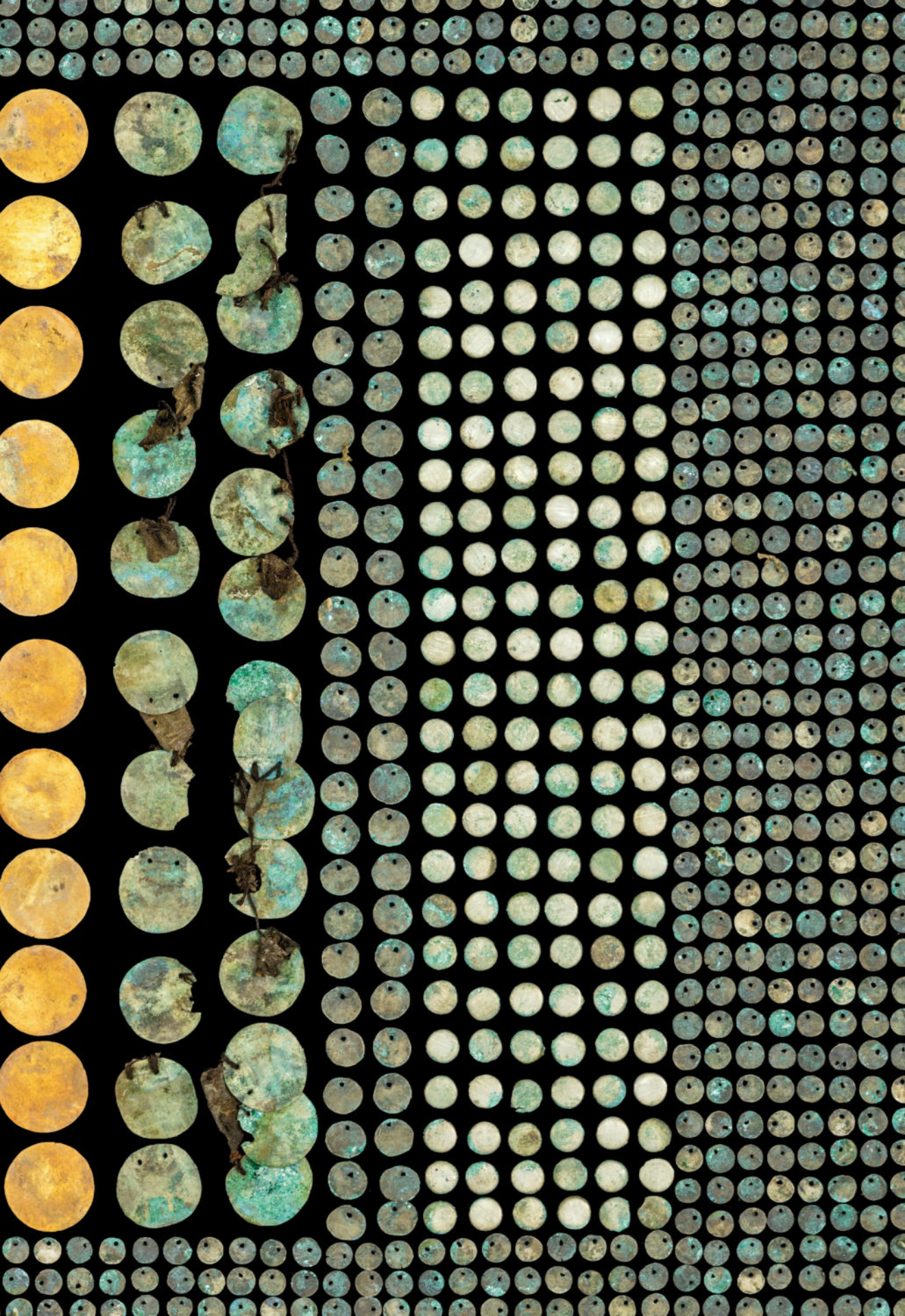
For centuries, a vanished Inca fortress called Ancocagua existed only in lore. Now, at a mountaintop complex in the Peruvian highlands, scientists think they've found the long-lost site—and a trove of treasures that could reshape what we know of the empire's last days.

WORDS BY
ALEJANDRO
MUÑOZ

PHOTOGRAPHS BY
ARTURO
RODRÍGUEZ



Archaeologists were stunned to find a cache of gold, silver, and copper sequins at T'agrachullo in 2022. These tiny round plates, which would have adorned ceremonial clothing around 500 years ago, signaled that the site was one of spiritual significance.



The remains of the Inca settlement

known as T'aqrachullo sit on a windblown mesa in the southern Peruvian Andes, some 300 sheer feet above the Apurímac River—and until recently, the views into the canyon were the most striking thing about the site. The ruins spread out across 43 acres, including an area along the mesa's base, which makes T'aqrachullo roughly four times larger than Machu Picchu, some 140 miles to the northwest. The Peruvian Andes are littered with such sites, stone terraces and foundations overgrown by creeping shrubs. Archaeologists have visited T'aqrachullo for more than 30 years, trekking up the single steep staircase that scratches up the cliff face from the valley floor. But for most of that time, all anyone found there were sherds of pottery and lonely ruins.





John Chauca, an archaeologist with the Peruvian Ministry of Culture, studies a piece of ceramic at T'aqrachullo. Artifacts from the Inca, as well as the Wari and Qolla people who predated them, have been found at the site, which was inhabited for around 700 years before the Inca claimed it in the 1400s.





T'aqrachullo was connected to other cities in the region by the "Inca Road," a network of pathways first established by the Wari people. While many travelers would have passed through the lower settlement at the base of the mesa, seen here, only Inca nobility could access the ceremonial structures at the top.

Anthropologist and National Geographic Explorer Johan Reinhard was the first to propose that T'aqrachullo may be a long-lost settlement and temple called Ancocagua. Now an increasingly large group of scholars believe the mountain fortress, described in conquistadores' chronicles, was the site of a battle between the Spanish and the Inca.



Then one morning in September 2022 archaeologist Dante Huallpayunca was scraping away soil inside a stone enclosure when one of his assistants, working nearby, cried out: “Boss! We found something!” At first, Huallpayunca laughed—his team had recently been joking about discovering treasure. Then he turned and saw the telltale glint of gold.

Huallpayunca had recently joined a robust team that had been digging at the site since 2019, sponsored by Peru’s Ministry of Culture. That day, his crew unearthed an unbelievable trove: nearly 3,000 gold, silver, and copper sequins left buried for hundreds of years. The tables in the team’s small field lab were barely big enough to hold them all. Huallpayunca was blown away. “Many archaeologists never find anything like this in their entire careers,” he says.

The sequins were a breathtaking find,

later determined to have been crafted in the early 16th century as embellishments for the ceremonial garments of the Inca elite. And their presence at T'aqrachullo occasioned a dramatic reassessment of the excavation, which has by now uncovered almost 600 structures—homes, tombs, and shrines to ancient gods—and with them, countless more ceremonial objects made of precious metals. T'aqrachullo, it turns out, was no backwater but seemingly a major political, economic, and religious hub of the Inca Empire.

Now some experts are increasingly endorsing an even more provocative idea: that T'aqrachullo is, in fact, a long-lost Inca city, a near-mythical stronghold once known as Ancocagua (not to be confused with one of the world’s tallest peaks, Aconcagua, in Argentina’s Andes). For centuries, the location of the secluded mountain citadel remained elusive. It was described by colonial-era chroniclers

REALM OF THE INCA

As the Inca conquered territories, they connected existing roads to form a network across 25,000 miles. The “Inca Road” linked some 12 million people and accelerated the exchange of ideas and resources between sites like Machu Picchu and T’aqrachullo.

AN EMPIRE BUILT ON TRADE

- Tawantinsuyu:** Inca territory in the late 15th century formed by four distinct regions
- Region boundary
- Qhapaq Ñan (Andean road system)
- Ruin

PACIFIC OCEAN

A CRITICAL CROSSROADS

Built near the confluence of three rivers, T’aqrachullo served as both a religious center and an important trade stop between the capital, Cusco, and the empire’s southern lands.

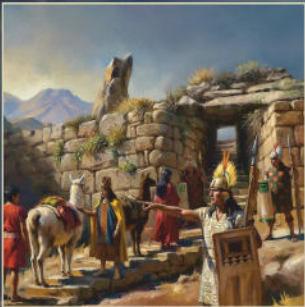


THE MAKING OF A SACRED SITE

T'aqrachullo served as a ceremonial hub where the Inca elite gathered for rituals, as well as where they lived and were buried. Recent excavations have led scholars to believe that these ruins could be the lost fortress of Ancocagua, described by conquistadores in the 1500s as a religious center and the location of a pivotal battle with the Spanish.

The Inca were the settlement's final occupants, at the end of an estimated 2,000 years of human presence in T'aqrachullo.

Civilization				
ca A.D. 650	1000	1450	1532	
Wari		Golla	Inca	Spanish conquest
Middle horizon		Late intermediate	Late horizon	
Historical period				



Restricted access
Not everyone traveling on the Inca Road was allowed to reach the upper section of T'aqrachullo. A narrow entrance and a single, steep path to the plateau are evidence that it was a privilege to live and worship there.

GRAPHIC: DIANA MARQUES AND BRAD SCRIBER, NGM STAFF. ART: ARIA SAFARZADEGAN
SOURCES: CHRISTOPHER HEANEY, PENNSYLVANIA STATE UNIVERSITY; STELLA NAIR, UNIVERSITY OF CALIFORNIA LOS ANGELES; ALAN COVEY, UNIVERSITY OF TEXAS AT AUSTIN; JESSICA CHRISTIE, EAST CAROLINA UNIVERSITY; EMERSON PEREYRA

A ceremonial temple

This gathering space, located at the summit and oriented toward a nearby sacred mountain, was likely where rituals were carried out.



Turn the page
to see inside
the temple

Burying the dead

Archaeologists have unearthed both Wari and Inca graves. Carefully crafted Inca funerary structures called *chullpas*, towerlike tombs for the upper class, were built over the burial sites of earlier civilizations, whose dead were exhumed and moved to communal graves.

Footprints in stone

With no water source and little fertile soil on the mesa, llamas carried water, food, and other supplies along the staircase to the upper site. Over time, the footfalls of the Inca's domesticated animals made indentations in the stone steps, still visible today.


HOW THE INCA WORSHIPPED

Inca nobility, including priests and government officials, traveled to T'aqrachullo's open-air temple, the remnants of which were discovered in 2023. During these religious observances, illustrated on the right, participants sang, danced, and prayed for fertile harvests and good fortune.





Cloaked under a blanket of stars, the ceremonial fountain at the center of the platform was likely constructed by the Wari, about 700 years before the Inca took over the site.



A sacramental pour
Religious leaders assembled on the platform as a priest drank from a cup of chicha, a fermented corn beverage, while pouring the drink from another cup—a gift meant for the gods—into a channel in the stone floor.

High priest

High priestess

Musical offerings
In addition to providing offerings of food, textiles, and jewelry, worshippers played instruments like conch shell trumpets and drums.

Ceremonial dress
Elaborate headdresses and colorful garments made of intricately woven textiles conveyed worshippers' status.

GRAPHIC: DIANA MARQUES AND BRAD SCRIBER, NCM STAFF; ART: ARIA SAFARZADEGAN
SOURCES: CHRISTOPHER HEANEY, PENNSYLVANIA STATE UNIVERSITY; STELLA NAIR, UNIVERSITY OF CALIFORNIA LOS ANGELES;
ALAN COVEY, UNIVERSITY OF TEXAS AT AUSTIN; JESSICA CHRISTIE, EAST CAROLINA UNIVERSITY; EMERSON PEREYRA

as the site of one of the Inca's most sacred temples and of a bloody, dramatic battle that helped hasten Spanish conquest. If they're right—if T'aqrachullo is indeed the fabled fortress of Ancocagua—then the once overlooked outpost not only holds a pivotal place in Peruvian history but also tells a whole new story about the last days of the Inca Empire.

In 1990, T'aqrachullo

was little more than a livestock pasture. Farmers grazed their animals and grew potatoes among the ruins. The stone enclosure where Huallpayunca would eventually find gold was used as an alpaca corral.

"It was a completely abandoned area, overgrown with vegetation," says Alicia Quirita, an archaeology professor at the National University of San Antonio Abad del Cusco. In the following years, she and a colleague, Maritza Candia, were the first scholars to survey T'aqrachullo—known to many in the area by its Spanish name, María Fortaleza—and the first to suspect there was more to the unassuming site than met the eye.

Quirita was raised 70 miles from T'aqrachullo, which is near the confluence of three rivers in a deeply rural district called Suykutambo. Her upbringing was traditional. She wore the woven shawls and wide skirts common among Andean women, chewed coca leaves, and spoke Quechua—the language of the Inca—at home with her family. At school, her teachers barred her from speaking what she calls "my own language"

in favor of Spanish, but Quirita nonetheless grew up fiercely proud of her culture. And her love for the land of her ancestors fueled her desire to pursue archaeology.

She was a university student living in Cusco when she and Candia visited T'aqrachullo for the first time. The pair were surveying undocumented archaeological sites around the region for their thesis, traveling primarily by bicycle from one location to the next and camping amid the ruins. The sites, at one time, had all been outposts along the extraordinary Inca road system, linked by some 25,000 miles of stone and sand pathways to cities and settlements as distant as modern-day Quito, Ecuador, and Santiago, Chile.

At T'aqrachullo, Quirita was surprised to uncover, alongside Inca artifacts, sherds of pottery associated with the Wari (Huari) people—a civilization that predated the Inca and wasn't, at the time, thought to have extended that far south. "The material we found on the surface was fantastic," she recalls.

Then, not long after her visit, she was introduced to an American archaeologist named Johan Reinhard, a National Geographic Explorer and a specialist in Inca religion. Reinhard explained that he had been, for years, gathering clues as to the location of a little-documented ceremonial site called Ancocagua, and he wondered whether Quirita might help him find it.

He knew of Ancocagua from a mention in a 1553 treatise called *Crónica del Perú*, by the conquistador Pedro Cieza de León. The citadel, Cieza de León writes, was one of the five most important temple sites across the entire Inca Empire, home to an ancient

ANCOAGUA, PEDRO CIEZA DE LEÓN WRITES, WAS ONE OF THE FIVE MOST IMPORTANT TEMPLE SITES ACROSS THE ENTIRE INCA EMPIRE.



Archaeologist Emerson Pereyra oversaw a crew of up to 100 people who spent years cataloging T'aqrachullo's discoveries while the ruins were being restored for visitors.

oracle and once rich in gold and silver. Discoveries at other sites that Cieza de León mentions—such as Qorikancha in Cusco, known as the Temple of the Sun—had been foundational to archaeologists' understanding of Inca religious and political life. But the *Crónica* is vague on Ancocagua's whereabouts, and for centuries, historians knew of no other texts that described the sacred place.

That changed with the discovery of the missing part of another conquistador's manuscript, in 1987, in a private collection in Spain. Not only did the Quechua-speaking colonialist Juan de Betanzos describe Ancocagua; he told a haunting tale of a battle that took place there during the last years of the Inca Empire.

Commanded by Francisco Pizarro, Spanish conquistadores subdued the Inca in 1532 after capitalizing on a rift between their leaders. Soon after the Spanish takeover, however, rebellions flared up across the empire. One of the fiercest, according to Betanzos, was at Ancocagua, which he describes as a sacred citadel set high

atop a mesa in a region just south of Cusco.

To quell the uprising, Pizarro's brother led a battalion to storm the fortress, but the Inca rebels blocked the only path that led to it. So the Spanish laid siege, cutting off access to food and water. And when they finally did breach Ancocagua's defenses, many of its desperate residents leaped off its cliffs to their death.

Armed with new clues from the Betanzos text, Reinhard traveled to Peru, where Quirita took him to a number of archaeological sites he'd identified as possibly matching Ancocagua's description. After laying eyes on T'aqrachullo, he was convinced the geography matched the conquistadores' descriptions, and in 1998, he published a paper in the journal *Andean Past* making the case for having identified "one of the most enigmatic Inca sites" in all of colonial literature.

Quirita, for her part, remained skeptical. It would take 31 years and another stunning discovery before she—and many others in the field—began to look at T'aqrachullo in a new light.

After the unearthing

of the sequins, the Ministry of Culture's project to excavate T'aqrachullo took on a new sense of urgency. In charge of the excavation was Emerson Pereyra, an experienced Peruvian archaeologist who has worked digs across the country, including a 12-year stint at Machu Picchu. He'd never heard of T'aqrachullo before the ministry assigned him there, and he was certainly unaware of Reinhard's theory that it might be Ancocagua. Reinhard's paper, published in English during the infancy of the internet, reached very few archaeologists in Peru.

In 2023, Pereyra's team uncovered another of T'aqrachullo's fantastic secrets: the foundations of what they believed to be a grand temple. The structure appears to have been built in stages, the earliest dating back some 2,000 years, meaning that the temple was used not only by the Inca but also by the earlier Qolla and Wari people.

Inside were remnants of a ceremonial fountain, a stone basin into which priests would have poured offerings. Pereyra's crew found gold nuggets tucked into its stonework. A tomb dating to the time of the Wari held exquisitely crafted figurines in the shape of llamas, along with sheets of gold and of the blue-green mineral chrysocolla, crafted to look like pumas. Once again, archaeologists were awestruck by the finds in the former pasture.

"I never saw anything in Machu Picchu compared to what we've found at T'aqrachullo," Pereyra says. "It's astonishing."

Today, Pereyra is aware of T'aqrachullo's association with Ancocagua, and he believes



the discovery of the temple lends credence to the theory. Cieza de León's chronicle notes how the Ancocagua temple was, even during the conquistadores' time, "very ancient and greatly revered," a reference some scholars read as acknowledging its use by the Wari.

What's more, Pereyra's excavation also turned up evidence that the site's later Inca residents might have been preparing for or engaging in conflict: caches of spherical stone projectiles, obsidian spearheads, and even skeletons with signs of violent injuries. He also recalls finding, during the excavation's early days, that the path leading up to the plateau was blocked by six to 10 feet of rock. "At first, we thought the collapse of the stairs was natural," he says. But now he and his



Archaeologists peer into what they believe is a Wari tomb that the Inca opened, emptied, and resealed. A wide range of artifacts (below) have been unearthed at T'aqrachullo, including Inca bowls and flattened metal figurines, likely made by the Wari.



colleagues believe the rockfall was an indication of Inca people deliberately sabotaging the entrances, possibly to prevent the Spanish from gaining access.

What Pereyra hasn't found, however, is evidence of Spanish presence at T'aqrachullo. If the site is indeed Ancocagua, did the conquistadores simply loot it and leave with little trace? Might the Inca themselves have destroyed their own settlement to deny it to the Spaniards?

Time may tell, but probably not soon. Pereyra's excavation ended in 2024, with archaeologists having scrutinized a little more than half of the sprawling site. The rest of T'aqrachullo has been left untouched, reserved for future researchers to someday



The Inca celebrated *apus*, or sacred mountain spirits, with rituals. The shape of this nearly three-inch-tall copper-alloy bell found at T'aqrachullo is inspired by these deities. It's topped by an Andean condor clutching a human face in its talons. The accompanying clapper is carved to resemble a moringa tree seed.

SO MUCH OF THE STORY OF THE INCA HAS BEEN TOLD BY THE COLONIZERS WHO DISPLACED THEM. WITH EVERY NEW DISCOVERY AT T'AQRACHULLO, A PIECE OF THE NARRATIVE IS, IN A SENSE, RECLAIMED.

return with new technologies and improved methods of excavation and analysis. Today the Ministry of Culture is focused on restoring the once woolly site to a state that might welcome tourists. T'aqrachullo hasn't revealed the last of its secrets, but what's next for the site is inviting more people to share in them.

Last November,

Reinhard, now 82, and Quirita, 59, visited T'aqrachullo together for the first time since their trip in 1994. The view from the top of the mesa was as stunning as it had been three decades before, but nearly everything else about the place had changed. These days Reinhard is more convinced than ever that T'aqrachullo is the lost city of Ancocagua. Quirita, for her part, has harbored doubts for years, largely because T'aqrachullo seemed to her to lack the monumental grandeur of other hallowed Inca sites, such as those centered on Cusco and the Sacred Valley.

But as she walked around T'aqrachullo, admiring its hundreds of freshly excavated structures, her opinion started to shift. "The evidence is here," she said, looking around at the terraced ceremonial site. "We are at the temple."

Today the eager student who once bicycled her way from survey to survey is among Peru's top field archaeologists. And to Quirita, the real value of the excavation at T'aqrachullo has little to do with its potential

to solve a 500-year-old riddle. It is instead the fact that—unlike the 19th- and 20th-century "discoveries" of so many other sacred Inca places—the work done at T'aqrachullo was carried out by Peruvian researchers. So much of the story of the Inca, who had no known writing system, has been told by the colonizers who displaced them. But with every new discovery at T'aqrachullo, a piece of the narrative is, in a sense, reclaimed.

That act of reclamation, Pereyra says, is one of the most rewarding parts of his work. He and his colleagues regularly host discussions in the villages that surround T'aqrachullo, sharing their finds with those who live in the mesa's shadow, explaining the significance of their discoveries. "We are helping them recover their culture and identity," he says.

But Pereyra, Quirita, and others hope even more people will come to know T'aqrachullo. Part of the thesis Quirita wrote with Candia back in the '90s was an outline of how the ruins could be both preserved and opened to the public, bringing welcome tourism dollars to her home region, where incomes overwhelmingly rely on farming and mining. Her visions were modest then, but the draw of a long-lost ancient temple might well attract travelers from around the world.

So far, Pereyra says, tourists have only begun to trickle in, mostly locals from around Cusco. There were none on the day that Reinhard and Quirita visited. Still, both archaeologists couldn't help envisioning a stream of people someday soon wending their way up that narrow staircase, marveling at the expanse of stone structures, soaking in an enduring sense of the sacred. □

At the start of each field season, archaeologists and excavators gathered for a day-long ceremony to bless the site and seek permission to work from Pachamama, the Mother Earth deity. Led by an Andean spiritual guide, this group sacrificed an alpaca and poured alcohol around the burned offerings of coca leaves and candy.





An aerial photograph of a Texas panhandle town, showing a dense grid of agricultural fields. Many of these fields are marked with large, circular crop circles, some of which are filled with a solid green color, while others are left in their natural brown and tan hues. The circles are arranged in a somewhat regular pattern, though some are larger than others. A road or railway line runs diagonally across the upper portion of the image. In the lower right, a small cluster of buildings and a parking lot are visible. The overall scene is a mix of natural and human-made patterns.

VANTAGE POINT

36° 02' 46" N, 102° 29' 01" W

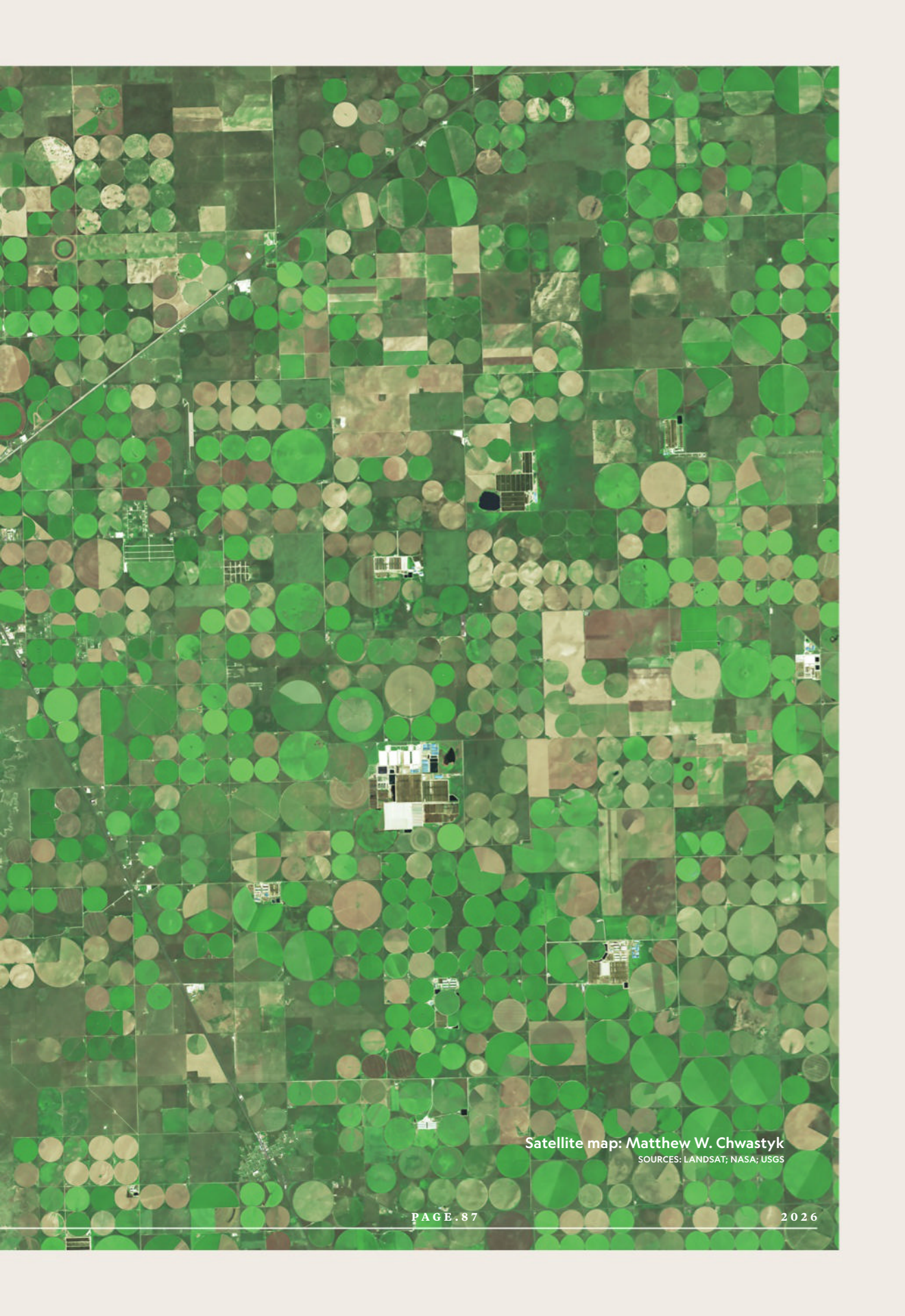
Where Did All These
CROP CIRCLES
COME FROM?

The peculiar geometry surrounding a
Texas panhandle town is the legacy of one
transformative mid-century innovation.

Words by SAM KEAN

1 mi
1 km

JUNE



Satellite map: Matthew W. Chwastyk
SOURCES: LANDSAT; NASA; USGS

→ **FROM ABOVE**, the farmland surrounding Dalhart, Texas, looks like a board game for the gods. Credit that tessellated expanse of green in what was once the heart of the Dust Bowl to center-pivot irrigation, or CPI, a watering system of pipelines studded with spray nozzles, each typically a quarter mile long and swiveling around a fixed point on wheeled, motor-operated towers.

In the roughly 75 years since its invention by a Colorado farmer, CPI has turned agricultural landscapes around the world into vast mosaics of adjacent circles—more than 25 million acres of them in the United States alone—often coaxing huge yields from what had been marginal farmland. The method spreads water more uniformly and with less labor than the ones it replaced, which often involved flooding fields by diverting surface water. CPI, by contrast, relies on wells pumping groundwater, and in the U.S., it's been a particular boon to the rather arid lands above the Ogallala Aquifer, an underground reservoir that stretches from South Dakota to Texas. Nearly a fifth of all American wheat, corn, and cotton is grown in the Ogallala region, supported by more than 100,000 pivot systems, rigs that University of Nebraska irrigation engineer Saleh Taghvaeian describes as “basically making rain.”

Today, Taghvaeian says, CPI is undergoing a spurt of intense innovation aimed at improving efficiencies. Above the Ogallala and elsewhere, producers are extracting water faster than it's being replenished, so engineers have developed pivot-mounted infrared sensors to measure soil moisture and automatically adjust water usage. AI-integrated pivots can analyze crop conditions and deliver targeted amounts of fertilizer, minimizing groundwater pollution. And farmers are increasingly using extendable, GPS-guided arms at the ends of their pipelines to water the corners that traditional CPI doesn't reach—boosting productivity by squaring those iconic circles. □




WHERE WATER BELOW TRANSFORMS THE LAND ABOVE

The Ogallala Aquifer underlies some 175,000 square miles of the central United States, supplying water to the center-pivot irrigation systems that create millions of acres of circular crop fields—but all that irrigation is also leading to the aquifer's depletion.

PHOTO: ZUMA PRESS, INC.; ALAMY STOCK PHOTO; MAP: MATTHEW W. CHWASTYK; NGM STAFF; SOURCE: USGS



On many newer center-pivot systems, like this one outside Dalhart, Texas, spray nozzles dangle on hoses close to the ground to minimize water loss from wind and evaporation.

A lioness is shown in profile, standing on a dirt path in a forest. She is looking upwards towards the dense canopy of trees. The lighting is natural, with sunlight filtering through the leaves. The lioness has a light brown coat and a small, developing mane.

THE LAST LIONS OF GIR

Decades after nearly going extinct, the world's only existing population of Asiatic lions is now overrunning a small reserve in western India, bringing them into closer contact with humans—and each other. Now what?

Words by SHARON GUYNUP
Photographs by STEVE WINTER



Inside Gir National Park, a wildlife preserve located along a peninsula within the Indian state of Gujarat, a young male lion inspects a tree that he and his family often scratch, leaving scents to mark territory.

THE LION

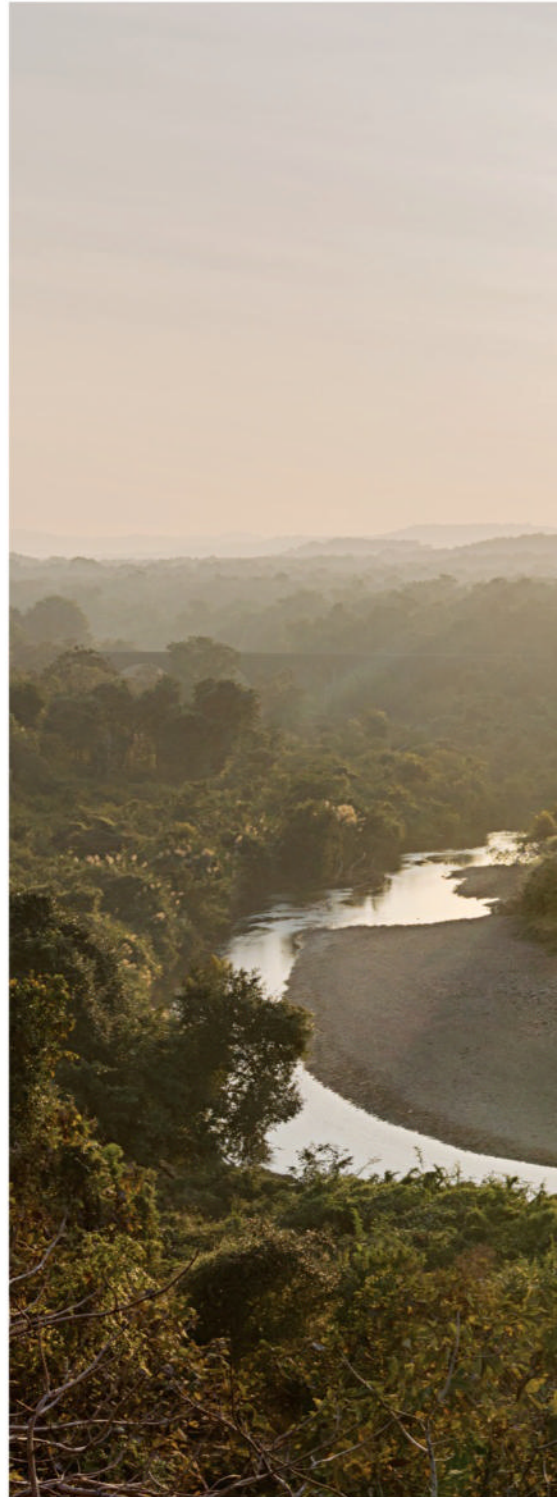
was injured, badly. He looked like a prizefighter, with old scars, new scratches, and fur missing beside his left eye. An open wound gaped along his spine. He'd been rushed by ambulance to the Lion Hospital from India's Gir National Park, where he'd fought with a resident male, probably in a turf war. He was furious, lunging against the bars and roaring at ear-splitting decibels.

The medical team quickly transferred him to a "squeeze cage," cranking the sides inward to immobilize him. He lowered his head, his roars softening. Paresh Vadher, the head veterinarian, donned surgeon's gear and quickly inserted an IV into the lion's tail, injecting pain meds and antibiotics. His team attended to wounds they could reach without being mauled and then wheeled him off to a quieter enclosure, away from other in-patient lions and leopards.

Vadher peeled off his gloves and gave us an update. The cat would remain at the hospital under observation for about a week, then hopefully he'd be released back into the park. There he would rejoin the world's last Asiatic lions, which live only here in Gujarat, a western state of India along the Arabian Sea.

But this isn't another tragic tale of a magnificent animal's demise. A century ago, only a handful of Asiatic lions remained, but extraordinary conservation efforts, with substantial financial support from the Indian government, have brought them back from near extinction. As of the 2025 census, there were 891. Their future, though, is not yet secure.

The deciduous forests that run through Gir provide a crucial refuge for Asiatic lions. They once roamed from North Africa's coastal forests to Greece to Persia, reaching India as early as 15,000 years ago.







A young male lies in the dry grass on a particularly hot summer day. Male cubs stay with their family until they are two to three years old, then strike out on their own.


A SMALL SANCTUARY

Driven to near extinction in the 20th century, India's last remaining Asiatic lions—a subpopulation of *Panthera leo leo*—now live in and around Gir National Park, where they've begun to rebound and roam more widely.



Saving a large carnivore like the Asiatic lion in the world's most populous country, home to 1.5 billion people, is extremely complicated. With more lions, next-level challenges loom. About 44 percent live outside protected areas, with some wandering through villages and cities, preying on livestock and, on rare occasions, attacking people.

Some wildlife experts believe a single cataclysm—cyclone, flood, wildfire, or virus—could derail the lions' miraculous recovery. “We have all the eggs in one basket,” says Yadvendradev Jhala, former dean of the Wildlife Institute of India who's spent 30 years studying Asiatic lions. They need more protected space,

 The nonprofit National Geographic Society, committed to illuminating and protecting the wonder of our world, funded National Geographic Explorer and photographer Steve Winter's work on this story.

and right now the last of their kind are living on a peninsula that juts into the Arabian Sea.

The cats' rebound represents “a great conservation success story,” says Mohan Ram, then deputy conservator of forests for the Gujarat Forest Department, who has worked in Gir since 2018. But along with that success comes a critical question: What will it take to ensure the lions' long-term survival?

FEW PEOPLE REALIZE that the lions in Africa we all know have cousins that reside in India. These “modern lions” diverged into separate lineages some 70,000 years ago. Zoologists had divided the lion kingdom into 11 subspecies, but genetic evidence proves there are just two: *Panthera leo melanochaita*, which lives in eastern and southern Africa, and *Panthera leo leo*, which is found in Central and West Africa, and in a genetically distinct subpopulation in India—the Asiatic lion.

Panthera leo leo once roamed from North Africa's coastal forests through northern Greece, across Mesopotamia and Persia, reaching India at least 15,000 years ago. And everywhere these lions have gone, they've been revered, feared, and persecuted.

The king of beasts has captured the human imagination throughout history, symbolizing strength,





During monsoon season, Gujarat's forests are lush and its rivers are full. But by April, the water dries up, which left this lioness and her cub to seek out one of the few remaining water holes in Gir.

power, valor, and nobility. That's why hunting lions was a glamorous royal pastime for millennia, dating back to the Sumerian period and continuing into modern times with India's princely rulers and the British Raj.

They've adorned cathedrals, city gates, and grand public buildings. Asiatic lions graced Persia's imperial seals. They've been venerated by Hindus for thousands of years. In the ancient Sanskrit Vedic texts, a centaurlike half man, half lion named Narasimha appears as an incarnation of the god Vishnu. One of the Hindu warrior goddess Durga's celestial mounts was a lion. And in 1947, the lion became the new Republic of India's national emblem.

To this day, meeting a lion is considered auspicious, a visit from the divine, and this history is a major factor in the animal's rebound. "The lions in Gir have learned to live with humans, and the humans have learned to live with lions," Jhala says.

Remarkable efforts and innovation over many years averted this cat's near demise. The Indian government established Gir Sanctuary in 1965, and part was declared a national park in 1975. The forest department assembled a massive guard force to eliminate poaching. Starting in 2019, the department adopted high-tech monitoring, built more wildlife hospitals, and increased community programs.

Lions have also benefited from residing in Prime Minister Narendra Modi's home state of Gujarat, where they are a tremendous source of local pride and tourist revenue. The state government allocated over \$40 million for their protection between 2021 and 2024. The combined impact: After more than two decades of critically endangered status, Asiatic lions were downlisted to endangered in 2008. Then new genetic studies recategorized them into the *Panthera leo leo* subspecies; when reassessed in 2025, these lions were still listed as endangered.

Some wildlife experts, like Jhala, feel it will be difficult for the cats to ever truly be safe as long as they live within a single region. A wake-up call came in 2018, when highly contagious canine distemper, likely spread by stray dogs, took down at least 23 lions. It's

Close to 900,000 tourists flocked to Gir National Park in 2024 for the chance to view the Asiatic lions up close. Finding ways to manage the animals as they live in proximity to people remains a top priority for officials.



the same virus that killed about a thousand lions in Africa's Serengeti ecosystem in 1994.

The specter of disease spurred the construction of a dedicated hospital complex for treating Asiatic lions. Whenever possible, Vadher, the lead vet, treats his wild patients—from lions, leopards, and langur monkeys



to spotted deer, pythons, and crocodiles—in the field. But critical cases are rushed to any of 11 hospitals, which double as rescue centers.

The Serengeti outbreak reignited long-standing efforts to find a second home for India's lions. In 2013, the Indian Supreme Court mandated “urgent steps” to relocate a pride.

Officials, following the recommendation of wildlife biologist Ravi Chellam, identified an area in Kuno National Park in the neighboring state of Madhya Pradesh as the ideal spot. To make way for lions, the state government moved 24 villages out of the park.

But a pride was never settled there. Instead, the state government rehabilitated Barda Wildlife Sanctuary, some 90 miles from Gir. Some experts, including Chellam, suggest that may not be far enough away to

mitigate a preventable tragedy like the canine distemper deaths. "Distance provides the required buffer," he says. "Catastrophe can strike."

ON MY FIRST DAY in Gujarat in December 2024, we drove into the park as dawn blanching the sky. The terrain was thick with vines, spiky acacia, and nearly bare teak trees. Sagar Manjariya, one of the park's lead trackers and our guide, scanned for Asiatic lions in the nascent light.

The wind was strung with birdsong. Gir is a biodiverse wonder, home to 338 avian species alone, as well as 41 types of mammals and more than 631 plants and trees. A herd of spotted deer regarded us warily as we passed. Acrobatic langurs bounced through branches above us. One clutched an infant. We spotted flocking plum-headed parakeets, wild



boars, a scampering mongoose, and a tall, antlered sambar, its rump more horse than deer. Peacocks perched and paraded everywhere.

And then I saw them: a lioness, nearly camouflaged in flaxen grass, with her tiny three-month-old cub. We killed the engine. The lioness was vigilant but regal, mostly ignoring us. At first glance, she bore a close

resemblance to her cousins in Africa, but then I noticed differences. She was slightly smaller, with a distinctive belly fold that reminded me of sagging skin following weight loss, and her profile was a bit more elongated.

The baby leaped on her head, gnawed her ears, licked her face, and tugged on her flicking, tufted tail. Finally, she swatted back. She was about 10. She'd lost one of her two cubs, which is not unusual; about 30 percent of cubs do not survive to adulthood, Jhala says.

So she was her offspring's only playmate. They rolled and chased for a delightful half hour. Then the lioness froze, listening. She roared, her blasts reaching a deafening crescendo before quieting to short, guttural grunts. Perhaps she was calling to her pride. She sauntered into the forest and disappeared, her cub trailing close behind.

In the ensuing months, there was a baby boom. When I returned the following March, we encountered a staggeringly large pride: four females and their 10 cubs. Two males were nearby, the only lions in this group that had been given names: Jai, the king, and Veeru. The males slept sprawled in a thicket through the afternoon heat. Even in the dense growth, one could see their tails had bigger tufts, and their manes, though scantier than those of their cousins in Africa, had the Asiatic lion's trademark: a slim Mohawk running from crown to mid-back.

But the most striking difference is how these gregarious cats organize their communities. In Africa, a group of males lives with an extended family of females and cubs. In Gir, the two sexes lead mostly separate lives. Two or more lionesses form a pride, raising and protecting their cubs at times in a communal crèche. They're affectionate families, always greeting each other nose-to-nose or nuzzling faces before plopping down together.

The males buddy up in a coalition of two to six relatives. They protect—and procreate with—a few prides, but one male reigns supreme. The females also mate with males from different coalitions, but for them it's a strategy to protect their cubs. With males confused about who fathered a litter, they're less likely to

A tour group in Gir National Park is treated to a rare sight: an adult male and female Asiatic lion standing together beneath a canopy of trees. The two sexes rarely come into contact, except to share a kill or to mate.





The Gir landscape is also home to a community of roughly 4,300 seminomadic Maldhari herders. Above, three Maldhari children stand with their family's buffalo herd as the first rains of the annual monsoon season pour down.

Lions kill about 2,100 farm animals a year, so the government has established a protocol: Park guards Varsha Rameshchandra Parghi (far right) and Sonal Dhanabhai Jotva meet with Maldhari elder Bharabhai Vejabbhai Ulwa to offer compensation for a mauled buffalo.



kill the young ones, Jhala's research showed. Lions don't tolerate another male's offspring.

These cubs will remain with their family until they're two or three years old. Then the subadult females will merge into a pride, while the subadult males will strike out on their own—researchers tracked one young male that walked about 65 miles over six months.

LIONS NEED SUBSTANTIAL territory, and Gir's four sanctuaries and the national park are clearly filling up. Today an estimated 44 percent of Gir's lions live outside preserves in a human-dominated mosaic of

farmlands, roadways, railways, towns, and cities. Managing them requires a 21st-century conservation paradigm.

Wildlife monitoring strategies in Gir include outfitting park rangers with handheld digital mapping tools that allow them to geotag and share what's happening inside the preserve in real time. They're part of a suite of devices that are invaluable, Ram says, because "ecological complexities and human-wildlife interactions continue to evolve... and technology offers vital tools to better understand, monitor, and preserve this unique ecosystem."

To see this firsthand, National Geographic Explorer and photographer Steve Winter and I spent a day with Gir's Hi-Tech Monitoring Unit at an air-conditioned mother ship of computers, hard drives, and large-screen monitors. Scientific officer Lahar Jhala showed us how they track the six lions they've outfitted with GPS collars around the clock. He clicked through GIS maps overlaid with zigzagging, multicolored lines, showing where the cats go, where they live, and the corridors they travel. It's crucial information needed for conservation and patrolling.

Officials have also had to address a concerning threat: Railway lines cut through the Greater Gir landscape, and lions have been hit by trains. This prompted a mandate from the High Court of Gujarat for trains to slow down in wildlife areas. Now, whenever a lion crosses geofencing near tracks, the tech staff alerts the railway department, stopping trains if necessary. These efforts have significantly reduced the number of accidents in recent years.

Additionally, the tech team members are compiling a "Facebook" of Gir's lions. They're using AI tools to identify individuals from photographs by analyzing their unique vibrissa patterns (whisker spots on their muzzles) and facial scars or other marks. As of December 2025, they'd cataloged 354 lions—some two-fifths of the total known population.

The forest department also monitors a critical stretch of highway near the park. When optical or thermal cameras detect animals nearby, LED displays warn motorists to slow down. Sensors track each vehicle's speed, flashing it—along with the license plate number—on a roadside screen. Live-feed CCTV surveils the park's entry and exit points. A GPS system tracks every tourist safari vehicle in the park.





And in 300 villages, paid informants act as eyes and ears. Everything, it seems, is monitored in Gir.

Officials are formalizing an “eco-sensitive zone” around the national park and three sanctuaries—a shock absorber barring mining, factories, and pollution while allowing for animal movement.

The last serious poaching incident occurred in 2007, when eight lions were killed for their claws, bones, and canine teeth, valuable items on the Asian black

market. That tragedy sparked greater protections. Today more than 600 officers patrol the region. About a third are women, dubbed “the Lion Queens of India” in a 2015 documentary series of the same name.

This is one of the few places on Earth with zero poaching, according to Ram. A report from the IUCN found



that India's lions are 20.5 times safer than their counterparts in Africa.

MORE LIONS ARE NOW living in close proximity to the people of Gujarat, where a hundred villages lie within three miles of Gir National Park, along with some 4,300 semi-nomadic Maldhari herders who live

Two lionesses keep a roughly five-month-old cub between them as they cross a drying streambed in Gir National Park. Compared with their counterparts in Africa, Asiatic lions are smaller, with elongated belly folds.

inside the adjoining sanctuary. But now, lions are broaching new territory where people haven't lived with them in generations and may not have the same tolerance or caution.

On average, Asiatic lions mauled 12 people and killed one person each year from 2020 through 2024, Ram says. But halfway through 2025, the lions had already been linked to at least five deaths. In February, a lion mauled a seven-year-old boy. In March, a lioness killed a farmer working his fields and a man was partially eaten, found surrounded by lion pugmarks. In May, it was a 22-year-old man; in June, a five-year-old boy. Their families will receive around one million rupees from the government, the equivalent of about \$11,000.

We met with a survivor, Tapbhai Makwana, in his tiny village outside the park. A slim man of about 55, he looked decades older. Some 30 years ago, a lioness killed a cow and was chased away from a neighboring village. She then encountered Makwana working in his field and ambushed him from behind, sinking her claws deep into his back and buttocks. He called it "the worst experience of my life, mentally and physically." His neighbors heard his screams and raced him to the hospital, where he spent a week. The medical bills took a huge financial toll on his family. Back then, there was no government help.

Makwana was permanently crippled, and he lives in constant pain. And yet, in our conversation, when asked about the significance of the lions, he said, "I still have immense respect for the big cats." The lions are a fact of life in Gir. Many villagers are far more worried about the leopards that also live here, which can be more dangerous.

Maldharis have lived on this land since the late 1800s, though thousands were relocated when the national park was created in 1975. With fewer cows and buffalo grazing, sambars and other prey rebounded. Within the protected area, the lions' diet is now about 74 percent wild, a dramatic change from the 1970s when the lions mostly survived on livestock—but they still kill about 2,100 farm animals each year. The government now compensates farmers to keep them from retaliating; higher sums for milk-producing females,

less for a young or an old animal. Still not quite at market prices, but better than they once were.

We learned that a lion had killed a Maldhari's buffalo the night before. So we headed to his *ness*—a temporary settlement made of mud and thatch for an extended family of about 60—to observe the compensation process. As we arrived, two female guards dressed in crisp, beige uniforms and jaunty berets dismounted from their motorcycle. A gaggle of children surrounded them as they sat down with the clan's elder, Bharabhai Vejabhai Ulwa, who was wearing an ivory-colored stocking cap and a traditional white cotton kurta that glowed bright in the sunlight.

They spoke in Gujarati, the guards filling out seemingly endless forms. Their mutual respect was palpable. Ulwa pulled out a cell phone, showing evidence that included photos of himself beside his half-eaten buffalo. Finally, he signed papers with an X. He's illiterate but wealthy: The herd's rich milk commands good prices, and the family lives here and grazes its animals cost free.

Some farmers welcome the lions because they hunt deer, nilgais, and wild pigs that devour their crops. The forest department's community programs help foster coexistence by installing solar streetlights, digging bore wells, and vaccinating livestock. The department has also built 14,500 metal machan platforms for farmers to watch safely over their fields. The ultimate goal is to create a system that allows the lions to thrive while keeping local communities healthy and safe.

But now, Gir's lions are moving across 13,514 square miles, an area about the size of Taiwan, and their numbers continue to grow. With every cub born, conservation becomes more complex. "Social carrying capacity" will ultimately determine the extent of their rebound, Yadvendradev Jhala says. "The cost-benefit of having lions in your neighborhood."

More broadly, preserving the huge tracts that lions need to survive protects the entire spectrum of life they live beside. That land sequesters water needed by millions of people. Forested lands provide a buffer against flooding and pull carbon from the atmosphere. "Under the umbrella

To encourage repopulation of the lions' natural prey—axis deer and sambars—workers often pull invasive plants like cassia and lantana, replacing them with nutrient-rich native grasses throughout the forests.

of this flagship species," Ram says, "we are conserving this ecosystem."

On my final day in Gir last April, we spotted Jai and Veeru lying under a bush, sleeping through the brutal 107-degree premonsoon-season heat. The land looked almost



post-apocalyptic, bare and desiccated, the rivers that had gushed in December now dry. Climate change is hitting India hard, with soaring temperatures and humidity, unpredictable monsoons, and increasing torrential downpours.

It again raised the issue of how to best ensure the long-term survival of these lions. While Bengal tigers have 58 reserves spread across the nation, Jhala says, India's lions have just one national park to themselves, without people.

For the world's last 891 Asiatic lions—and counting—there's still Gir. □



A large pride of three lionesses and 10 cubs saunter through Gir. In recent years, a combination of innovative monitoring and management techniques has helped protect nearly 900 Asiatic lions in the region.





These
BUTTERFLIES
Have
FAKE HEADS

Scientists are just starting to learn
how the insects developed distinctive,
facelike markings on their wings.

Photograph by
JOEL SARTORE

→ A FAKE HEAD MIGHT sound like a magician's prop, but for some butterflies it's a lifesaving illusion. Many species—including the Bartram's scrub-hairstreak, which lives exclusively in Florida's pine rocklands, one of the world's most critically endangered habitats—display markings on the back of their hind wings that resemble a face. A bright patch of color, faux "antennae," an eyespot, head-shaped contours, and convergent lines combine to look like a creature staring upward. The system works to misdirect attacking predators. "Butterflies may suffer some wing tear but are able to continue to live, fly, and reproduce," says researcher Tarunkishwor Yumnam. With a colleague at the Indian Institute of Science Education and Research Thiruvananthapuram, Yumnam recently studied more than 900 butterfly species and found that four of those five false features evolved together, which suggests that a

common pressure drove their evolution. It's possible the butterflies also enhance the effect with a little acting: Yumnam hypothesizes that the butterflies' hind wing rubbing might mimic flicking antennae, thus amplifying the ruse. Survival, as ever, involves using one's head.

—KELSEY NOWAKOWSKI





SCIENTIFIC NAME

*Strymon acis
bartrami*

COMMON NAME

Bartram's
scrub-hairstreak

AVERAGE LIFESPAN

1-3 weeks
(adult stage)

DIET

Flower nectar

WINGSPAN

1 inch

CONSERVATION

STATUS
Endangered

MAP: MATTHEW W. CHWASTYK, NGM STAFF.
SOURCE: USFWS



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.



At the edge of Portage Lake in Alaska's Chugach National Forest, 40 million cubic yards of bedrock move about six feet each year. A sudden collapse would produce a life-threatening tsunami.



WORDS BY CHRISTIAN ELLIOTT
PHOTOGRAPHS BY COREY ARNOLD

LESSONS OF A
LANDSLIDE
DETECTIVE

Across our warming world, the ground is growing less stable.
And in Alaska, landslides are now striking more often
than ever. Now, one maverick geologist is racing to understand
where the next big ones might strike.



FROM ATOP A NARROW ledge some 2,000 feet high, the tiny white speck of a 144-passenger tour boat stands out against the jade surface of Alaska's Portage Lake as it putters up to the face of a steep glacier that towers over the shoreline. On the far end of the lake, just out of view, is the visitor center, a 1980s brutalist mass of glass and concrete hanging out over the water. Below this ledge is a slow-moving landslide. It's not a landslide as you might picture one—a rapid flow of dirt and debris rushing downhill after heavy rain. Instead,

it's a mass of bedrock moving around six feet per year, which could accelerate to a sudden collapse. If that happens, a resulting tsunami in the water below could capsize the tour boat, wipe out the visitor center with a wave several hundred feet high, flood the valley, and maybe spill over Portage Pass, a narrow gap between the Chugach and Kenai Mountains, inundating an airstrip and a cruise ship terminal four miles beyond us.

Geologist Bretwood Higman—Hig to everyone else, including his wife—puts the chances of collapse in any given year at one in 30. He's taken Robes Parrish, the Chugach National



Independent geologist Bretwood “Hig” Higman, seen here on Portage Lake, is on a mission to install custom landslide monitoring instruments across Alaska to protect residents and visitors, and understand the landslide risk.

toward the glacier below. That means the base of the mountain is shifting faster than where we are at the top—leaving the part we’re standing on precariously supported in midair. “And that scares the crap out of me,” he says.

The mountain could continue to slide slowly for decades or, with little notice, suddenly accelerate and then collapse catastrophically. So Hig unzips his hiking backpack and pulls out a custom-made sensor, contained in a simple screw-cap mason jar. Government geologists like Parrish often have to pick their battles, working with both state and federal officials to first identify potentially dangerous weak spots along mountains like these and then commission formal studies to determine if the potential risk warrants further tracking. As an independent geologist who specializes in diagnosing deep-seated landslides and the tsunamis they can generate, Hig has developed his own tools and techniques to challenge the bureaucracy that can slow down government scientists, like those at the U.S. Geological Survey. “[He] provides a service that, frankly, the USGS can’t,” Parrish says.

Over the past decade, Hig has become known as something of a scientific vigilante, calling public attention to landslides whenever governments seem slow to respond while simultaneously working to determine how scientists can get better at knowing when and where the next big one will hit. The race to prevent such catastrophes has never been more urgent: As Alaska warms several times faster than much of the world, the Portage Glacier and many others are retreating at an unprecedented rate. They leave valley walls unsupported, a phenomenon called de-buttressing. At the same time, stabilizing permafrost is thawing and rain events are trending heavier and more frequent. The

Forest’s new geologist, and me along for fieldwork on the landslide, having brought us to this ledge only after we scrambled over the hundreds of vertical feet of loose, slowly slipping bedrock. It’s research Hig is eager to get done as quickly as possible, for obvious reasons.

“Here’s the part that’s tearing itself apart,” Hig says. The tundra ahead splits wide open. A patch of green mountain heather is interrupted by a gaping chasm. We watch as fresh snowmelt streams through large shards of slate, disappearing into a series of cracks. Hig believes that far below our feet some 40 million cubic yards of bedrock are creeping

Near Glacier View in southern Alaska, 75 miles outside Anchorage, a slow-moving landslide collides with a thicket of trees, toppling them.

rock in many locations is already weak—Hig calls it “Chugach Crud.” Alaska’s mountains are literally falling apart.

Around the world, more places with glaciers, including Norway, New Zealand, Switzerland, Iceland, Greenland, the Himalaya, and Chile, are seeing deep-seated landslides as a growing threat. In Alaska, however, these processes are happening at a scale that makes the landscape an invaluable laboratory. Tsunamigenic landslides in the state have increased roughly tenfold in just the past 10 years, according to Hig’s research, which includes landslides that have been dated back to the 1850s.

Today the planet’s top landslide scientists flock to the region and often embed with Hig, whose no-frills approach to fieldwork extends to his steady diet of trail mix and his trail-running shoes that are held together with fishing line. Alaska has so many landslides, international scientists can pick and choose the best one to answer their specific research question. On the coast, they can study how glacial retreat leaves fjords unstable or, further inland, track how permafrost thaw “unglues” landmasses held together by ice. Together with Hig, they’re hoping to learn more about why slopes fail and how to stay ahead of the next collapse.

“The most likely scenario is something really, really bad is going to happen before we are on top of any of it,” Hig says. “And I want to be able to say I did something that was really helpful. And the odds are not really with me on that.”

I**N LATE 2015**, roughly 180 million tons of rock crashed into Taan Fiord, a tributary of Icy Bay along the southern coast of Alaska. The impact generated a wave that ascended more than 600 feet up a slope and stripped forest from eight square miles of Wrangell-St. Elias National Park. The



fjord, Hig says, was unoccupied at the time, but it empties into Icy Bay, which is well trafficked by cruise ships. As an international group of scientists scrambled to investigate, Hig volunteered to plan logistics. The researcher already knew Alaska as few other geologists do.

Hig had grown up in Seldovia, an isolated village of stilt homes along Alaska’s Kenai Peninsula that is accessible only by boat or bush plane. As a graduate student at the



University of Washington, he had been one of the first tsunami scientists on the scene in Sri Lanka after the 2004 Indian Ocean tsunami killed more than 200,000 people. He remembers entering village after village that had 99 percent fatality rates. Decades of tsunami research hadn't saved any lives. Hig thought of his own hometown, itself in a tsunami inundation zone. "It was profoundly influential to be in this place that just had been

so devastated," he says. "You're in this world that's just been torn apart."

After receiving his doctorate in 2007, Hig set out with his wife, Erin McKittrick, on a year-long, 4,000-mile trek by foot, ski, and pack raft from Seattle to the Aleutian Islands on the far southwestern tip of the state. Now, both realms of expertise were colliding. "He does these very dangerous things that have a very thin margin of error, but he's very scientific about all of



www.victorymin.org

Victory Bible Camps
www.victorymin.org
745-4203

Alpine Camp Frontier Camp S.A.L.T. Program Ranch Camp

Blue Bird



In cold mountainous regions, permafrost thaw and glacial retreat are accelerating the risk of deep-seated landslides. In Glacier View, a peak overlooking Victory Bible Camp appears to be growing unstable.

them,” says Noah Finnegan, a geomorphologist who studies landslides in California, and a college friend of Hig’s.

The Taan Fiord investigation concluded that the landslide was due in part to glacial retreat, a factor researchers were just beginning to consider at the time. But after academic papers were published and the scientists went home, Hig was left with a nagging feeling. Alaska has a lot of retreating glaciers, and the landslide-generated tsunami at Taan Fiord wasn’t even the most dramatic on record. In 1958, an estimated 40 million cubic yards of rock slid into Lituya Bay, an inlet in what’s now Glacier Bay National Park. The impact generated the highest wave crash ever recorded on Earth, reaching more than 1,720 feet above the shoreline and killing five people.

Hig wondered: Could other mountains spontaneously collapse? He began obsessively

studying publicly available satellite imagery, laser-imaging datasets, and historical aerial photos for signs of movement. He chartered helicopter and fixed-wing plane flights to conduct his own aerial surveys. The research didn’t come easily; Hig is colorblind and dyslexic. But it didn’t take him long to find something. In June 2019, his sister Valisa, then an artist in residence with the Chugach National Forest, was boating when she noticed a mile-long section of slope near the retreating Barry Glacier hanging precariously above the water.

Hig pulled up satellite images and zoomed in on the Barry Arm fjord, comparing the current view with the historical record. Then he panicked. The entire slope appeared to be sliding toward the water at about 85 feet per year. By his estimate, the landslide—a 650 million-cubic-yard chunk of sliding

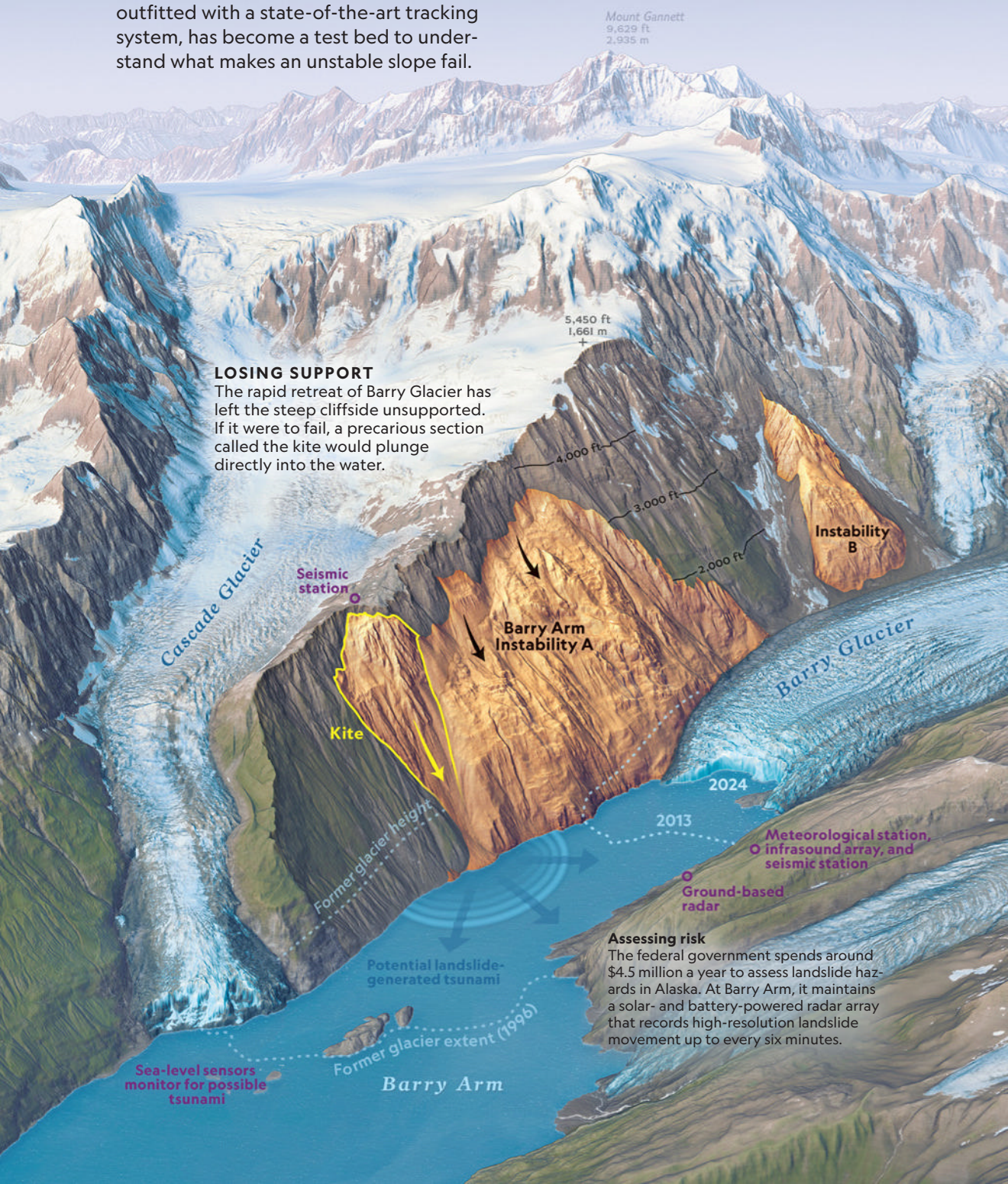


Hig’s \$300 radar instrument, housed in a mason jar, bounces a signal off a nearby reflector plate to continuously monitor landslide movement. The sensor then transmits its data wirelessly.

SCALE VARIES IN THIS OBLIQUE VIEW; BARRY GLACIER HAS RETREATED AROUND TWO MILES SINCE 1996.

HOW A CLIFF CRUMBLES

A 1.5-mile-wide landslide above Alaska's Barry Arm fjord could one day collapse and generate a 500-foot-high tsunami. The site, outfitted with a state-of-the-art tracking system, has become a test bed to understand what makes an unstable slope fail.



Mount Gannett
9,629 ft
2,935 m

5,450 ft
1,661 m

LOSING SUPPORT

The rapid retreat of Barry Glacier has left the steep cliffsides unsupported. If it were to fail, a precarious section called the kite would plunge directly into the water.

Cascade Glacier

Seismic station

Kite

Former glacier height

Potential landslide-generated tsunami

Former glacier extent (1996)

Barry Arm

Barry Arm Instability A

Instability B

Barry Glacier

2024

2013

Meteorological station,
infrasound array, and
seismic station

Ground-based
radar

Assessing risk

The federal government spends around \$4.5 million a year to assess landslide hazards in Alaska. At Barry Arm, it maintains a solar- and battery-powered radar array that records high-resolution landslide movement up to every six minutes.

Sea-level sensors
monitor for possible
tsunami





LEARNING FROM LANDSLIDES

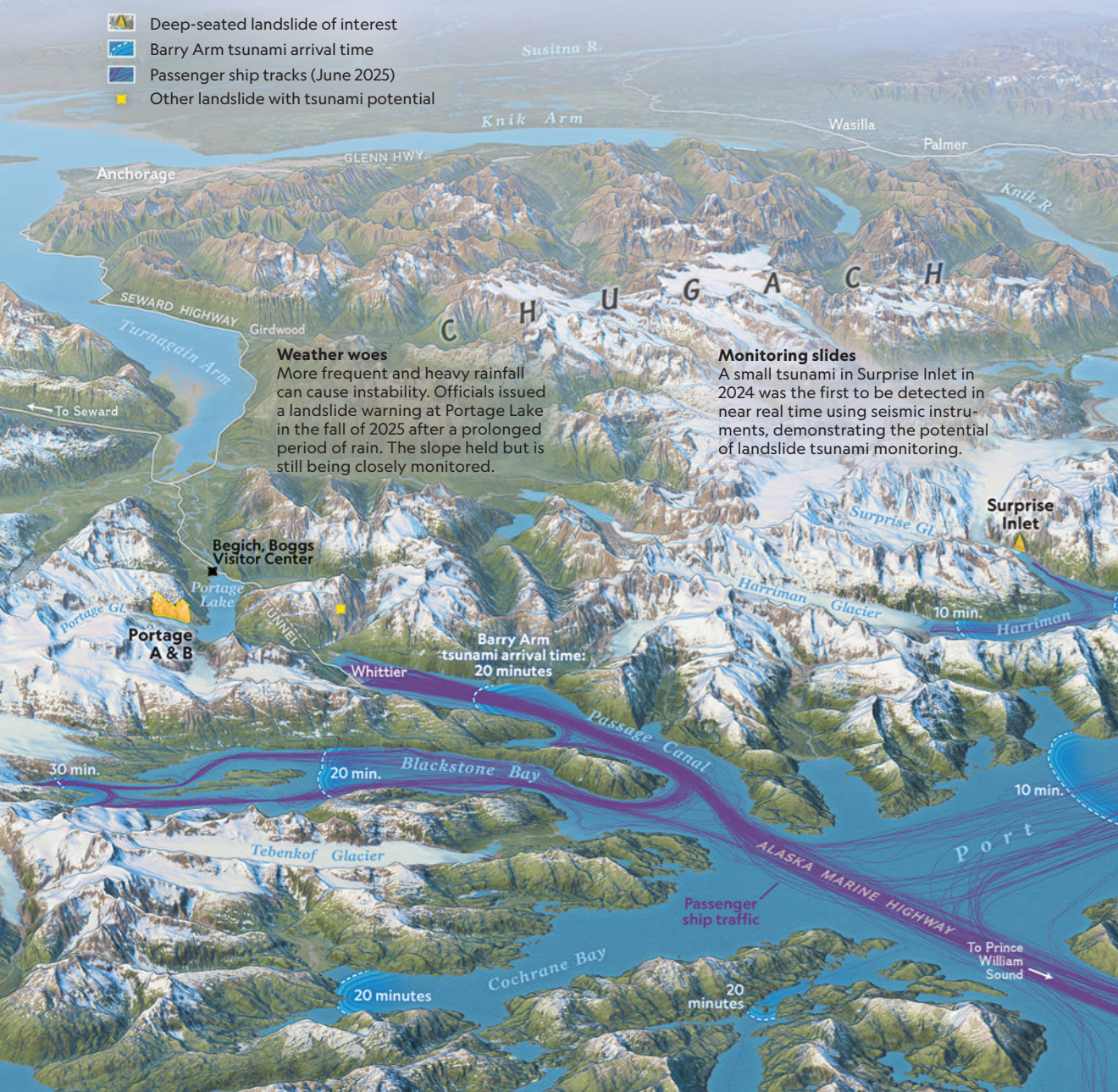
Alaska's rapidly shifting landscape attracts international researchers to study slides that most resemble their part of the world. Retreating glaciers, permafrost thaw, and more intense weather are all factors in more frequent, deep-seated landslides. Knowing how landslides work here can help global communities prepare for the worst.



Mt. McKinley (Denali)
20,310 ft 6,190 m

A L A S K A R A N G E

-  Deep-seated landslide of interest
-  Barry Arm tsunami arrival time
-  Passenger ship tracks (June 2025)
-  Other landslide with tsunami potential



Weather woes

More frequent and heavy rainfall can cause instability. Officials issued a landslide warning at Portage Lake in the fall of 2025 after a prolonged period of rain. The slope held but is still being closely monitored.

Monitoring slides

A small tsunami in Surprise Inlet in 2024 was the first to be detected in near real time using seismic instruments, demonstrating the potential of landslide tsunami monitoring.

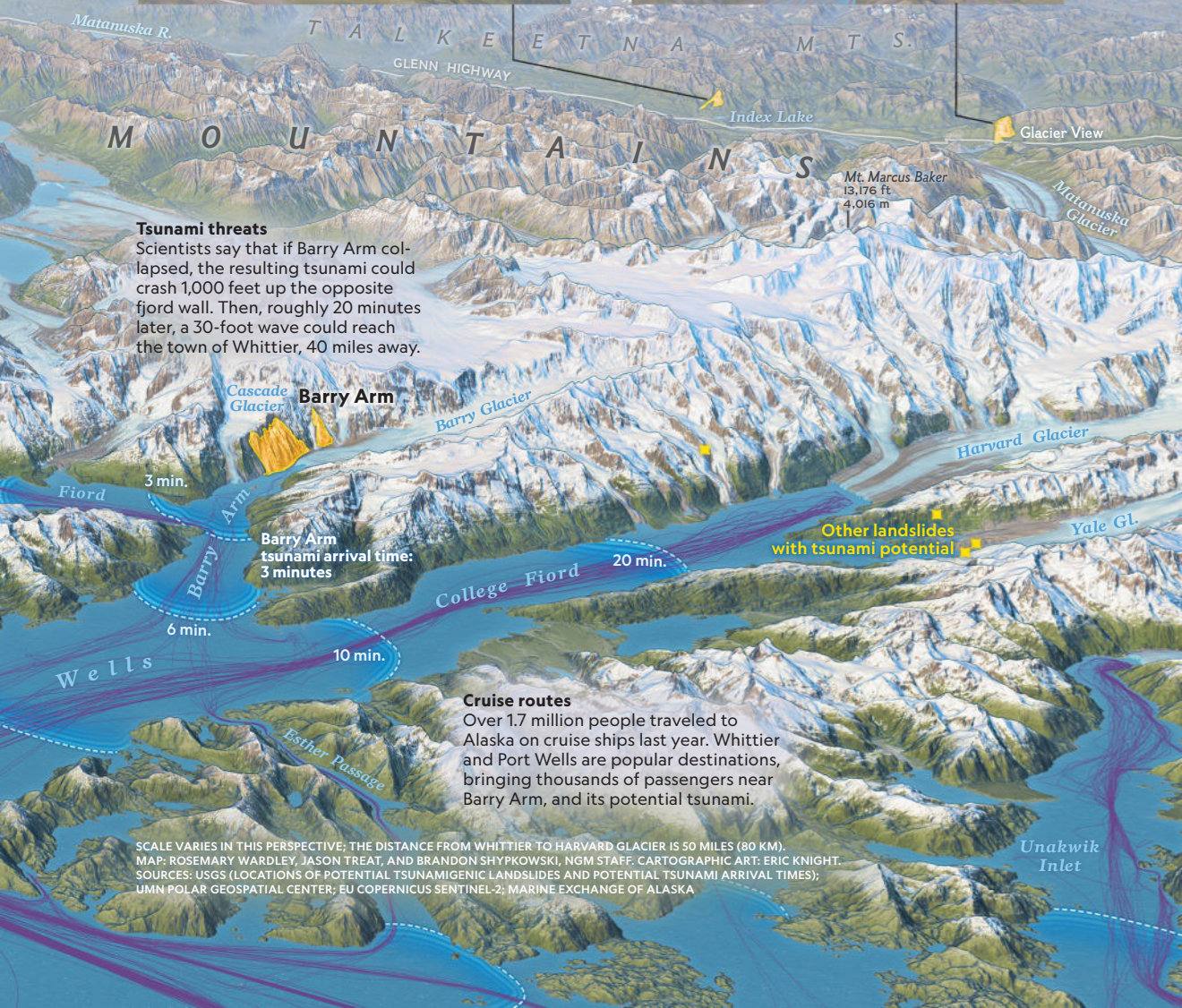
INDEX LAKE LANDSLIDE

Victory Bible Camp sits directly below a thawing slope. It's now being monitored with Alaskan geologist Bretwood "Hig" Higman's equipment, which shows it moving nearly half an inch per day.



MATANUSKA NARROWS INSTABILITY

The weak rock above Glacier View's only highway is held together by the strength of ice. Its potential collapse threatens to block the road and isolate the small community.



Tsunami threats

Scientists say that if Barry Arm collapsed, the resulting tsunami could crash 1,000 feet up the opposite fjord wall. Then, roughly 20 minutes later, a 30-foot wave could reach the town of Whittier, 40 miles away.

Barry Arm

Barry Arm tsunami arrival time: 3 minutes

Cruise routes

Over 1.7 million people traveled to Alaska on cruise ships last year. Whittier and Port Wells are popular destinations, bringing thousands of passengers near Barry Arm, and its potential tsunami.

SCALE VARIES IN THIS PERSPECTIVE; THE DISTANCE FROM WHITTIER TO HARVARD GLACIER IS 50 MILES (80 KM).
MAP: ROSEMARY WARDLEY, JASON TREAT, AND BRANDON SHYPKOWSKI, NGM STAFF. CARTOGRAPHIC ART: ERIC KNIGHT.
SOURCES: USGS (LOCATIONS OF POTENTIAL TSUNAMIGENIC LANDSLIDES AND POTENTIAL TSUNAMI ARRIVAL TIMES);
UMN POLAR GEOSPATIAL CENTER; EU COPERNICUS SENTINEL-2; MARINE EXCHANGE OF ALASKA

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Barry Arm.**

bedrock—could completely dislodge within five years, generating an initial 500-foot wave. The surge could quickly cover the 40-mile distance southwest to Whittier, sending a 30-foot swell to swamp the town. All told, Whittier's 275 residents would have no more than 20 minutes to evacuate uphill around a freight rail yard that separates the town from the shoreline. If cruise ships were docked at the town's terminals, though, several thousand people would be at risk.

Hig wrote to a local Forest Service manager and suggested closing the area to recreational traffic. "Wow, the images are striking," the manager wrote back. But, he informed Hig, the Forest Service would neither close the area nor issue a warning.

"I'm kind of naturally inclined to be contrary to authority," Hig says. So he enlisted the help of Anna Liljedahl, a Swedish permafrost hydrologist for the Woodwell Climate Research Center based in Alaska, and drafted an open letter to state officials signed by a dozen other researchers. Weeks went by. "They were not releasing the information," Liljedahl tells me. Worrying a collapse could be imminent, the researchers decided to share their letter with the press. And on May 15, 2020, the entire state of Alaska, including those in the inundation zone, learned about the Barry Arm crisis from a *New York Times* article with the headline "It Could Happen Anytime."

The impact on the local tourism industry was immediate: There was a sharp decline in boat traffic near Barry Arm. Kelly Bender, former co-owner of Lazy Otter Charters, a water taxi and sightseeing company, who is now the city's chamber of commerce president, remembers feeling blindsided. "I tried to be gentle," she says about her later discussions with Hig. "But this just put us into a tizzy."

The alarm bell, by some accounts, galvanized Congress to pass the Landslide Preparedness Act, which authorized the U.S. Geological Survey to study and implement new tracking measures at Barry Arm. Soon federal and state officials were working together to triage the situation. Initially, Hig and Liljedahl were included in the working group's meetings. But Hig says that disagreements over bureaucracy and how to communicate with the public led to a falling-out.

Still, he got results. The working group eventually installed a suite of high-tech instruments that now act as an early-warning system. It includes a synthetic aperture radar array to map landscape changes, infrasound sensors to listen for rockfall, seismometers to monitor ground movement, high-resolution cameras, and tidal gauges to register water surges—all powered by solar panels and large batteries that can keep everything running through the snowy, gray winter. In all, the federal government spends more than three million dollars annually monitoring the landslide.

For any independent scientist, that federal action would be a huge victory. But Hig doesn't think it's enough. In 2024, a series of five landslides collapsed into Surprise Inlet in Prince William Sound, a short distance from Barry Arm; the site had not been flagged as an imminent hazard. The same year, in Kenai Fjords National Park, another undiscovered slide triggered a tsunami that swept under the occupied guest cabins of a nearby lodge. A year later, in 2025, a slide in Tracy Arm fjord generated a wave that ran up nearly 1,600 vertical feet of terrain, carried away the gear

of kayakers camping on a nearby island, and threatened a cruise ship. It also was not on any state or federal watch list.

Barry Arm is far from the only threat, but it's the only major landslide risk area in Alaska that's getting such focused scientific attention. Hig thinks the next horrible disaster will "most likely" be somewhere else.

PERCHED ON the narrow ledge above Portage Glacier, buffeted by wind, Hig pulls a rock drill from his battered backpack, drills into the boulder, slides a steel anchor into the hole, and bolts the mason jar full of radar electronics to it. Close by he has anchored a metal reflector about the size of his palm.

The contraption essentially bounces radar off the reflective surface and transmits the distance reading over a local radio system to a computer. For Hig, the technological solution arrived after he watched a childhood friend in Seldovia tinker with a cheap radar sensor to monitor the oil level in his household fuel tank. The same sensor, he realized, could be mounted next to a landslide and aimed at the moving portion to track its movement in real time.

Having forgotten a sledgehammer, Hig whacks the whole assembly with a rock, driving the anchor into the boulder. The piece of slate breaks after three hits, an irony that isn't lost on the geologists. Parrish wields a caulk gun, attempting to waterproof the sensor against the deep snowfall that will drift over this spot in the winter.

In all, each mason jar instrument costs about \$300. Hig hopes the basic construction will fare well against goats and the jaws of curious bears, which have demolished enough scientific instruments in the area that there are now academic papers tracking the phenomenon. He also hopes that the price might encourage more at-risk communities to invest in the devices. It's an idea that's already being implemented in the Philippines, where a researcher named Roy Kaimo has worked with some

locals to install relatively cheap tilt sensors in the ground to measure changes in incline on more than 50 landslides. Several villages now monitor and service their own early-alert systems, deciding if and when they would evacuate their homes should heavy rain or an earthquake accelerate unstable rocky slopes.

Parrish certainly sees the appeal. "We don't need to spend however many millions they're spending at Barry Arm on each and every possible landslide," he says. "That's why I like Hig's approach, where he's really trying to scale this in a very modest way."

At the Portage Glacier site, the Forest Service plans to use his data to augment an existing system staff use to monitor risks that takes into account weather and rockfall sightings. But Hig has also spent several years working in Glacier View, a community of 375 residents about two hours outside Anchorage. There, he's learned that just identifying slow-moving landslides isn't enough to save communities. You also have to convince the people who live there that they're at risk. In some ways, that's proved even trickier than the cutting-edge science.

In 2023, Hig emailed Bill Billmeier and Betsy Young, a pair of former backcountry guides who run an aerial imaging and geospatial data company out of Glacier View. He'd noticed signs of deformation in the valley's mountains and wanted to compare notes on an area eventually known as the Matanuska Narrows Instability that was situated on a slumping mountain above the town. As with Barry Arm, Hig grew apprehensive. "This one has just bumped way up my 'terrifying' list," he wrote to them in an email. Hig calculated roughly 130 million cubic yards of weak rock were held together largely by the strength of permafrost. In the worst-case scenario, the landslide would take out the only highway and Glacier View's internet and power lines—and dam the Matanuska River far below, causing flooding in the valley and, once the dam broke, a surge of water toward communities downstream.





A safety program manager with the Forest Service takes in the view from the Begich, Boggs Visitor Center on Portage Lake. If a slow-moving landslide in the surrounding mountains collapses, the impact could generate a tsunami that completely inundates the tourist area.

At first, Hig thought this might be the perfect test case for his new sensors and a chance to right his mistakes at Whittier. There would be no press releases or letters to officials. No blindsiding residents. This time, he'd go to the community first.

In mid-2023, Hig attended a community council meeting with a poster and a slide presentation, hoping to charm everyone with his transparency. He likes to say that he's an open book, and so are his instruments, in their clear glass jars, which appeal to an Alaskan culture that values canning and a good-quality weld.

It went well enough at first. The council voted to send a letter to borough and state officials asking for assistance to fund studies. They stockpiled 30 days of food supplies for tourists who might end up trapped in Glacier View. They formed a geology committee and explored the ways that a rural community might secure more federal funding for disaster preparedness.

Then Hig recruited Susan Conway and Costanza Morino, two European geomorphologists interested in permafrost landslides, to study Glacier View more deeply. They covered slopes with GPS sensors and flew drone surveys. Their research helped Hig identify areas that could benefit from his real-time monitoring system and drove home the urgency of this kind of work. "The quantity of landslides in Alaska is quite impressive. The mountains seem to be falling apart," Morino says. It's puzzling, she notes, given how many permafrost degradation landslides there are in Alaska, that they haven't received more scientific attention. "There should be more people working on this."

On the coast, the landslides are more clearly linked to de-buttressing glaciers. Inland, in places like Glacier View, there are other mysteries. Although these mountains appear to be held in place by permafrost, clearly some fail before the permafrost has fully thawed. It's possible, Hig says, that the more a slope moves, the more thaw accelerates due to

friction, triggering a feedback loop. In Denali National Park, a slide of this type destroyed the only road through the park at its halfway point. By studying Alaska, Morino and Conway hope to inform proactive management in places like the northern Arctic and the Himalaya where permafrost hasn't degraded to the same degree yet.

After their fieldwork, Morino and Conway organized a workshop that brought together state scientists, borough employees, and locals. "I had a bit of a goose bump," Morino says. "When you talk with people face-to-face about the fact that something might happen, you feel a little bit of responsibility."

That's when everything fell apart. The scientists presented a map of Alaska with a cluster of red dots over Glacier View. Each highlighted a permafrost landslide with some degree of movement. The borough's emergency manager warned residents they could be stranded for roughly 90 days without help if a landslide destroyed the highway. It all was suddenly too real.

"The tone of it changed," says Sarah Barton, a Glacier View resident. Instead of welcoming the information, some locals began voicing concerns about the research's impact on property values and insurance coverage. "It was an awkward time," Barton says. "And I think it still is in some ways."

In late 2024, the council considered an anonymously submitted resolution that some interpreted as a ban on public discussion of landslide hazards in the community—with an apparent threat to sue if any ongoing research negatively affected the community. The council members rejected the resolution but voted to disband the geology committee and hired a lawyer to protect themselves from liability. "It was really upsetting," says Young, who was on the geology committee. "It's hard not to take that as a threat: 'If you talk about this, we might sue you.'"

For his part, Hig defends emphasizing worst-case scenarios. While uncertain, they highlight the stakes for gathering more data to

A sightseeing boat
carrying more than 100
passengers cruises on
Portage Lake beneath a
rocky outcrop near where
Hig's sensors are installed.







According to Hig, many of Alaska's peaks may only be "mountainous" because they're frozen in place. Recent deterioration might signal trouble for the Himalaya, Andes, or other frigid ranges.

**Some
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rule them out. And some in Glacier View still share that opinion, including Mike Dreiske, the director of nearby Victory Bible Camp, who has always been vocally in favor of Hig's research. Dreiske encouraged Hig to install five mason jar sensors on a landslide and allowed him to place antennas atop the Miracle Lodge, one of the camp's main buildings, to assist in data collection.

On a warm morning in July 2025, Hig meets Dreiske inside Miracle Lodge's bustling dining hall. They're surrounded by dozens of kids of all ages who have shown up for breakfast. Some of the older campers are wearing ranch-themed flannels and boots, while some younger ones are still dressed in animal-print onesies. The camp, which occupies an isthmus set between two lakes and has 80 buildings, draws 160 campers a week when at capacity. Meanwhile, the steep slope of the mountain far above us has become a moonscape littered with the disintegrated remnants of once frozen boulders. The peak is slowly splitting as it thaws, sloughing down toward the valley.

Over coffee, Hig mentions how quickly the landslide above us is moving, and says one instrument shows it "ripping along" at half an inch per day.

Dreiske looks startled. "A day?" he says loudly. Despite his word choice, Hig assures him that this qualifies as "slow-moving"—it's the sort of shift anyone would easily outrun.

Still, some of the rock is moving at a rate of 30 feet per year, leaving the mountain peak increasingly unsupported. If it maintains that speed, it would take the landslide about a century to reach the camp. Unless it collapses catastrophically; then it could arrive in minutes.

Hig admits he doesn't know which will happen. All he and Dreiske can do is watch and monitor for anything alarming. "If it means that it increases insurance or we can't have insurance, I can't control that," Dreiske says at one point. The recent flash flood that occurred at a Christian camp in Texas, killing 27, was still fresh in his mind. "If it means something catastrophic happens and it wipes this place off, I can't control that. But if I can make sure there's nobody here, that I can control."

WITH ENOUGH sensors collecting real-time data, Hig hopes that scientists will start to make progress on the biggest question in landslide science: What causes a slope to suddenly collapse?

For now, though, triggering is "a total black box," says Finnegan, Hig's longtime friend who studies slow-moving landslides, including one in California's Diablo Range, outside San Jose. Engineers typically interpret landslide creep as a "transient evolution towards catastrophic failure," Finnegan says. Or, in simpler terms: More movement is scarier. This idea underlies some scientists' approach to landslides, but researchers are learning that it might not be quite right. Only about a quarter of the slides Hig has studied exhibited precursory signs before collapse. Sometimes a slope collapses right after it stops moving. Or a stationary section collapses after the movement nearby slows down.

Based in part on Hig's research, Finnegan is developing a different model for predicting collapse. It draws on seismology principles often noted by researchers studying earthquakes. As faults shift, some rock types appear to be weakened by sliding movement,

but others are strengthened. So a constant slow creep at fault lines sometimes releases stress that would otherwise cause an earthquake, stabilizing the system.

By the same token, it's possible some giant slides might become more stable as they move. To learn more, scientists are conducting laboratory tests on the rocks that make up different slides and trying to observe more slopes in real time. This is where Hig's real-time monitoring comes in. "As we document more and more of these cases, I think signals will start to emerge from that chaos," says Finnegan, who has deployed similar instruments at his own test sites in California.

In Alaska, officials are aware of the increasing hazards and are working closely with federal authorities to prioritize the most concerning landslides. Dennis Staley, a USGS geomorphologist, says the agency hopes to build on its monitoring efforts at Barry Arm and deploy a more economical suite of sensors on slides across the state. But some experts admit that they are often trailing behind Hig, envious of his speed and lack of hierarchy, and frustrated when he unexpectedly draws attention to a new hazard.

"I don't think I could work with a lot of Higs," says Michael West, who runs Alaska Earthquake Center and the statewide seismic monitoring system for landslides. "But the world needs people like that. The world needs instigators."

In that way, getting through to just one person like Dreiske at Victory Bible Camp holds a larger accomplishment for Hig. It starts a chain of potentially lifesaving action that grows in momentum. The borough's emergency services department is collaborating

with Hig and the camp on monitoring and emergency planning, and the camp now covers some of the costs associated with Hig's work. Another recent victory: Hig has secured \$25,000 in funding and a five-year commitment from Parrish and the Forest Service at Portage Lake to continue work on a risk-assessment dashboard officials can use in deciding whether to evacuate the visitor center. Real-time data from the sensors that he recently installed will soon appear in the system, and officials there have begun developing evacuation protocols and plan to soon hold preparedness drills for staff.

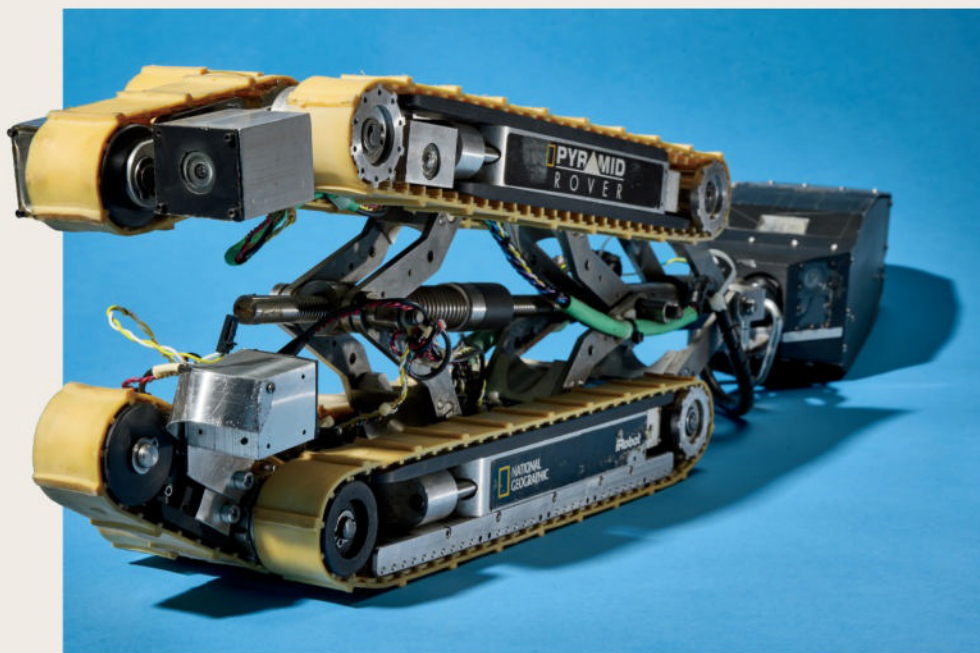
In September, the Forest Service put those plans to the test when, after a stretch of unseasonably warm days, over a foot of rain fell on the landslide. A tour boat captain observed increased rockfalls in the area, so the Forest Service decided to evacuate and closed the area early for the season. Meanwhile, Hig's newly installed instruments showed that the terrain temporarily sped up tenfold before slowing back down. This is the kind of real-time data that will arrive automatically to guide decisions. After a year of federal government cuts and turnover, it's another essential win for the intrepid geologist. One place in Alaska—a popular tourist destination—is a little bit safer.

If Hig celebrates these wins, he doesn't show it. He knows that, like a landslide, it can all collapse in an instant. "I live in unending fear that I'm going to just drive home some message really successfully and it's going to turn out to be counterproductive," Hig says. "Nonetheless, I still think I have a better chance of having a positive impact if I do try, rather than abandoning the effort." □

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PYRAMID ROVER, 2002

THE CUTTING-EDGE

Robot That Probed
AN ANCIENT PYRAMID

➔ **IN THE HEART** of the Great Pyramid of Giza, in a room called the Queen's Chamber, a mysterious shaft not much wider than a dachshund leads diagonally up and into darkness. How to explore it? In September 2002, National Geographic TV producers sent in the Pyramid Rover, a scissoring Swiss Army knife of a robo-crawler, with treads to grip both floor and ceiling. Its engineers, from the company iRobot, arrived in Giza toting a dozen-plus cases of parts and a milling machine for making modifications on the fly. After a few false starts and some upgrades, the rover crept about 210 feet up the shaft until it was halted by a limestone slab. It drilled through, then snaked in a camera, revealing a small chamber to a TV audience watching live. The space was empty, but along the way, the rover recorded masons' marks in red ocher dating back 4,500 years—evidence of minds thinking through tremendous challenges. —RACHEL SLADE

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Foreword by
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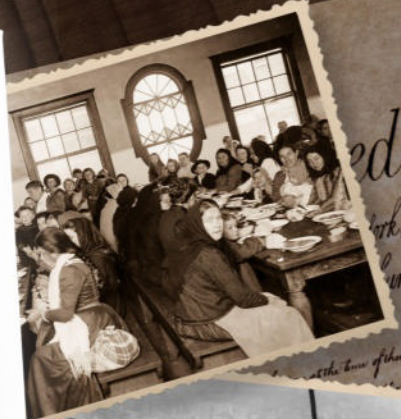
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LOST

AMELIA EARHART'S
THREE MYSTERIOUS DEATHS
AND ONE EXTRAORDINARY LIFE

RACHEL HARTIGAN



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