High Country News

SPECIAL ISSUE

DEEP TIME IN THE WEST

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The view from the South Rim of the Grand Canyon, looking northwest. Recent research suggests that the asteroid impact that created Meteor Crater also caused a major landslide, damming the canyon 56,000 years ago. (*See story on page 10.*) **Roberto (Bear) Guerra**

Know The West.

High Country News is an independent, reader-supported nonprofit 501(c)(3) media organization that covers the important issues and stories that define the Western U.S. Our mission is to inform and inspire people to act on behalf of the West's diverse natural and human communities. High Country News (ISSN/0191/5657) publishes monthly, 12 issues per year, from 119 Grand Ave., Paonia, CO 81428. Periodicals, postage paid at Paonia, CO, and other post offices. POSTMASTER: Send address changes to High Country News, Box 1090, Paonia, CO 81428. All rights to publication of articles in this issue are reserved. See hcn.org for submission guidelines. Subscriptions to HCN are $45 a year, $47 for institutions: 800-905-1155, hcn.org. For editorial comments or questions, write High Country News, P.O. Box 1090, Paonia, CO 81428 or editor@hcn.org, or call 970-527-4898. For correspondence addressed to High Country News, HCN or to the editors, permission to publish will be considered implicit unless specifically stated otherwise.

EDITOR'S NOTE

The long view

Winter is settling over the rolling hills of North Idaho, where I live. Snow ices the limbs of the bare aspens outside my window, while perfect flakes fall from the flat gray sky. This weather is my reality today, but it is also ephemeral; the blanket of snow will probably melt in a week or two. Three days ago, we were still awaiting the season's first snowfall.

In fact, everything in my view is ephemeral. The largest aspen? Probably 15 years old. The window I'm looking through? Installed about 35 years ago. And beneath the snow, the hill my house sits on is made of loess, silt blown in to the Palouse region from elsewhere periodically over the last 2 million years. That's the blink of an eye in geologic time, though considerably longer than humanity has existed.

To help readers understand how incredibly recently humans appeared, John McPhee, in his 1981 book *Basin and Range*, suggests spreading your arms out wide and imagining that the distance from fingertip to fingertip represents 4.5 billion years — the age of Earth. In comparison, he writes, the 300,000 years since *Homo sapiens* evolved is so brief that "in a single stroke with a medium-grained nail file you could eradicate human history."

In this special issue on deep time, we go beyond that sliver of fingernail, taking a long view of the West, exploring what it was like thousands, millions and even billions of years ago, and how that history is still visible — and consequential — today. Several of the stories in this issue are grounded in Wyoming, home to the oldest rock exposed at the planet's surface in the Western U.S.: the 3.45 billion-year-old Sacawee gneiss. Other stories offer new insights into the history of places like the Grand Canyon, how pronghorn survived the Pleistocene and an inside view of how scientists came to understand plate tectonics.

While we do cover some current happenings, think of this issue as an invitation to take a break from the churn of day-to-day, season-to-season, election-to-election urgencies. Instead, consider the forces and phenomena that have shaped our world over a much longer time frame. We hope that widening our focus beyond the scope of human enterprises deepens your understanding of the West. After all, even as our species spurs ecological and climatic chaos, Earth will continue to transform and remake itself over and over again, just as it has for billions of years. Our aim is to celebrate that deep past — and implicitly acknowledge the deep and wide-open future of the West, too.

Emily Benson, science & climate editor

RECENT STORIES AT HCN.ORG

Alex Vanderstuyf / National Park Service

The West's vanishing porcupines
Scientists are racing to figure out why porcupines are disappearing from their former stomping grounds.
By Shi En Kim

Morgan Lee / AP Photo

Western climate litigants keep fighting
After disappointing losses in Alaska and Montana, an Indigenous-led climate case is making strides in New Mexico.
By Amal Ahmed

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SPECIAL ISSUE:
DEEP TIME IN THE WEST

Special thanks to former HCN *intern Ollie Hancock, who first suggested the idea that became this special issue.*

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OTHER MATTER

ON THE COVER

A geologic timescale of Earth focused on the landscapes, flora and fauna of the Western U.S. **Alex Boersma / HCN**

Geologic past | See how the West is remade throughout Earth's history.

Grand Staircase-Escalante National Monument preserves fossils of rare *Triceratops* relatives and other dinosaurs (*page 7*).

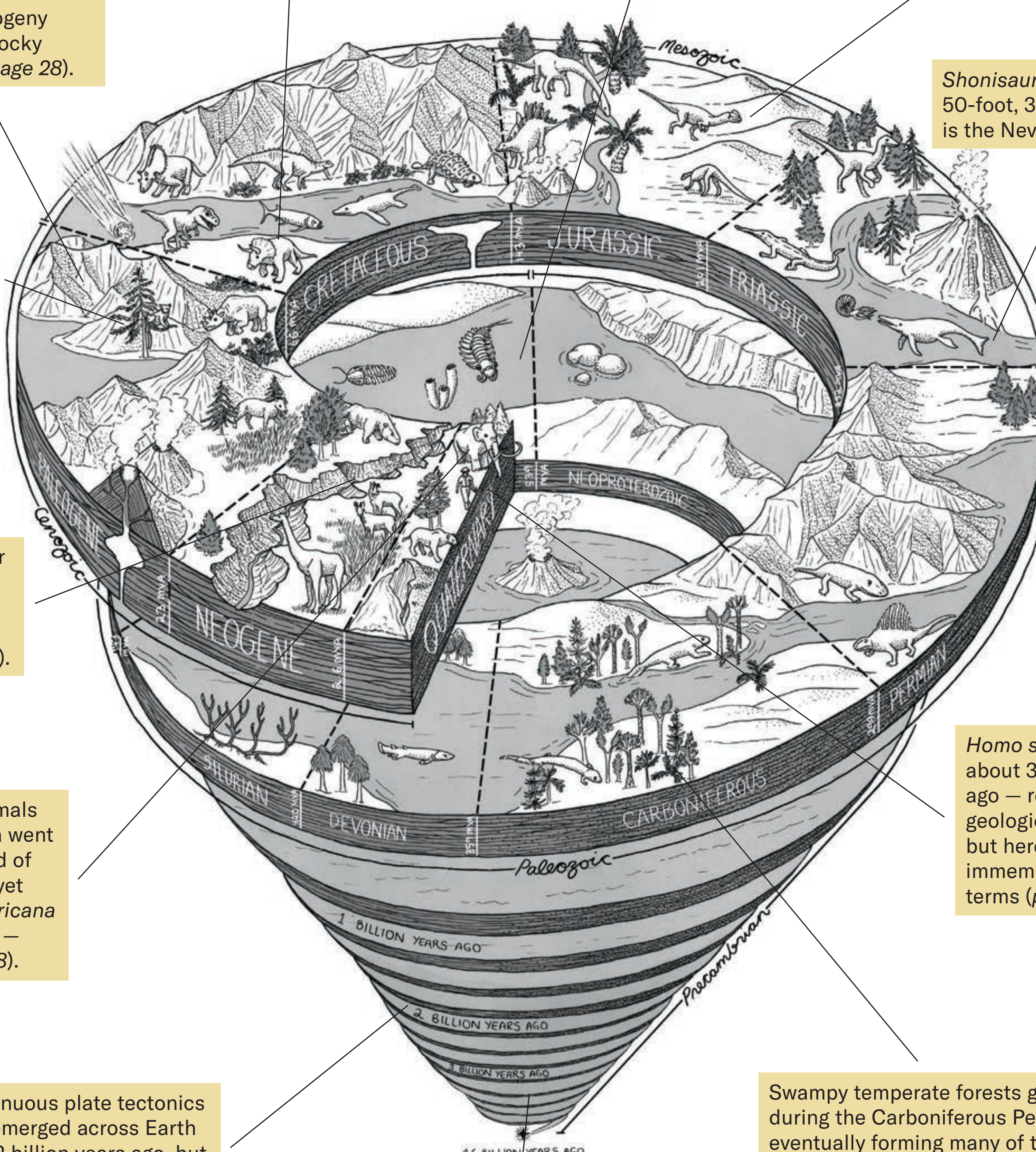
Almost every animal group that survives today arose during the Cambrian explosion (*page 25*).

The West was covered in desert and sand dunes during the early Jurassic Period.

An episode of tectonic upheaval called the Laramide Orogeny formed the Rocky Mountains (*page 28*).

Shonisaurus popularis, a 50-foot, 35-ton ichthyosaur, is the Nevada state fossil.

Weathering shaped Independence Rock in Wyoming (*page 48*).



Early conifers such as *Walchia* grew during the Permian Period.

The Colorado River began carving the Grand Canyon 5 million to 6 million years ago (*page 10*).

Homo sapiens evolved about 300,000 years ago — recently by geologic standards, but here since time immemorial in human terms (*page 12*).

Most large mammals in North America went extinct at the end of the last ice age, yet *Antilocapra americana* — the pronghorn — survived (*page 38*).

Continuous plate tectonics had emerged across Earth by 2.2 billion years ago, but scientists didn't discover it until the 1960s (*page 18*).

Swampy temperate forests grew during the Carboniferous Period, eventually forming many of the West's coal deposits.

The stone adorning Seattle's Exchange Building is 3.52 billion years old (*page 46*).

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GRAZING GOBBLES UP PUBLIC LANDS

So let me get this straight: My public lands and tax dollars are being wasted to support 50,000 outdated ranchers and a few billionaires so they can continue to destroy what little biodiversity we have left in the West ("Free Range," December 2025)? Livestock and people literally outnumber mammals on this planet, and we've killed more than 50% of our wildlife. Cattle play big in this destruction, and in the West we're down to less than 10% of public lands that are truly wild. All this for 2% of our beef? Why not leave the ranching to those who actually own the land they run cattle on, and let the wildlife have the public land? And then, when wild populations recover, hunt them sustainably? The meat is much healthier, with no work or antibiotics needed. And the rest of the wildlife could get a chance to recover too.

Julie Smith
Golden, Colorado

Your recent work on grazing rights and land use in the West is spot on. As a longtime agriculturalist and outdoors enthusiast, I have seen the devastating effects of overgrazing, predator control, and more recently the consolidation of grazing in the hands of fewer but wealthier "ranchers."

Thomas Hurst
Sodus, Michigan

FINDING MEANING IN METAL

Great work on "Precious Metalheads" (November 2025). I read the article with interest that turned to inspiration. The article's opening section was incredibly moving. I also appreciate your inclusion of a playlist.

Since reading your article, I've shared it with friends, some but not all of whom are metal fans, with lots of positive feedback.

At a time when everything feels precarious, I wanted to say thank you for your heartfelt, inspiring work.

Andy Roth
Winthrop, Washington

What a fantastic coalition of educators and musicians working together to give pride of identity to the vulnerable while making good memories that will last a lifetime. And I get it! Music also allowed me a different frame of reference from the ordinary. (Or, as my mom often said, "Christina walks to a different drummer.") The hum of bees in honeysuckle and dances of dragonflies over a frog pond occupy some of my best memories. That, and the Beatles.

Chris Bartolini
Portland, Oregon

I just read your article about the Fire in the Mountains Festival. Thank you for writing about this. I am Native (Paiute and Shoshone) and have been a metalhead for quite some time. People in my hometown didn't get the urge of belonging I felt; the music seemed so angry and demonic to them. As I started going to shows and getting involved with the community, I found people who got it. It has given me a place to be and belong — just being myself, which is hard to find anymore. I even got to the point of being the "token metal guy" in a street punk band for a few years, where I was the singer. I've only recently gotten into Indigenous Metal. I instantly connected. This is a story that needs to be told, and you did a great job. I found myself crying multiple times while reading it. Luckily, no one else is working in my office today.

Brian Newman
California

"Why not leave the ranching to those who actually own the land they run cattle on, and let the wildlife have the public land?"

MY TEETH, MY CHOICE

While I appreciate the article "A toothless conspiracy theory" (November 2025), I want to chime in that nobody should be medicated without their consent, and that is essentially what they are doing when they fluoridate the water. I have talked to plenty of dentists that agree that while fluoride is effective as a topical application, ingestion is not recommended. Regardless of one's opinion on the matter, the real issue here is nonconsensual medicating, which they should not be doing. Everyone should get to decide what they put in their bodies.

Rosada Martin
Arcata, California

WE'RE ON THIS JOURNEY TOGETHER

I first cried reading your October editor's note, "Responsible Escapism," then cried again as I read it to my husband, and then again to my intergenerational family gathered for Thanksgiving. Your editorial is also us, living our lives on this planet, and my family's different life experiences, ages ranging from 16 to 79. It is so important to acknowledge each other's challenges, joy and peace. I am grateful to be the oldest and continuing to learn and grow as we journey together.

Thank you for helping us understand where we are and "how then we shall live" each and every day of our lives.

RS LaSalle
Bigfork, Minnesota

Unmet scientific potential

Grand Staircase-Escalante's age-old geology faces modern threats.

BY SHI EN KIM

IF YOU TRAVELED BACK in time, you wouldn't recognize Grand Staircase-Escalante National Monument. More than 250 million years ago, this place was an ocean. Over time, the churning of Earth's crust raised the seabed, and it became dry land. Dinosaurs reigned on the young plain as it toggled between desert and tropical climes, then stood witness when an invading ocean severed the continent. The channel receded after 34 million years, and the continental plate continued to rise to form the high deserts of today.

The landscape has been a meticulous archivist, and its stratigraphy reveals a geologic history between 30 million and 300 million years old. The extraordinary preservation of all these years in the monument's rocks, landforms and fossils makes Grand Staircase-Escalante special. Now, however, it is threatened by the Trump administration's land-management policies.

Geologists say that no other terrestrial record of this time period is as complete. Wind and water have whittled the cliffs and terraces that expose its various chapters, creating an open book for scientists to explore. President Bill Clinton invoked the Antiquities Act in 1996 to establish the nearly 1.9-million-acre monument in hopes of enabling researchers to piece

The erroding terraces of Smoky Mountain in the southeast reaches of Utah's Grand Staircase-Escalante National Monument. **Elliot Ross**

> *"It is the most famous storybook of the history of our planet."*

together the Earth's complex past using the landscape's sweeping geologic record.

But according to scientists, the national monument, which is overseen by the Bureau of Land Management, has yet to fully deliver on its mission. Insufficient resources and the federal government's shifting priorities — including the administration's recurring threats to downsize the monument — have kept it from reaching its full scientific potential.

"It is the most famous storybook of the history of our planet," said Colorado State University geoscientist Joel Pederson. But "the research that could be done in Grand Staircase has not yet come to fruition."

GRAND STAIRCASE-ESCALANTE'S time as a national monument has led to many discoveries. The uncanny resemblance between the Moqui marbles — pea-to-grapefruit-sized ancient concretions of iron pulled from groundwater — and some Martian rocks observed in 2004 confirmed that our planetary neighbor also had a watery past. Scientists have also identified 30 new species of fauna from fossils here that include dinosaur skin, tracks and marble-sized bird eggs. Many of these fossils have not been found anywhere else in North America, a mystery that confounds scientists.

And Grand Staircase-Escalante may hold the key to other scientific questions. By understanding how life evolved under different climes, for example, scientists can gain insight into how life might fare in a warmer future. But increasingly, the paleontologists who dig here face heightened challenges to conducting their research.

The monument suffers from chronic underfunding, which threatens managers' ability to protect fossils and other specimens from vandalism and theft. Since its inception, its budget and staffing levels have shrunk by at least three-quarters. The nonprofit Grand Staircase-Escalante Partners reported that, since January, the national monument has lost multiple backcountry rangers, rangeland technicians and its only in-house paleontologist. The BLM declined to respond to questions about Grand Staircase-Escalante's management or budget.

Flip-flopping federal policies have added to the uncertainty. During his first term, President Donald Trump nearly halved the size of the monument and opened the rest to drilling and mining. President Joe Biden restored its original borders, but in July, the House of Representatives proposed funding only half of the monument's acreage — in effect, restoring Trump's original reduction.

The Trump administration justified this by declaring an "energy emergency," though many doubt that Grand Staircase-Escalante's natural resources are worth extracting. During Trump's first term, no mining company leased lands within the national monument. The Interior Department is also considering shrinking or eliminating five more national monuments, including Chuckwalla and Bears Ears.

Surrendering any section of Grand Staircase-Escalante, whose rocks exquisitely document deep time, would be an immeasurable loss. Retired geologist Marjorie Chan likens the landscape to nature's version of the *Venus de Milo*, the famous armless Greek sculpture of Aphrodite that is now protected in the Louvre. "How much time did nature take to sculpt all this?" Chan asked. Grand Staircase is worth fighting for, she added, "because you're never going to be able to get that reproduced again."

Shi En Kim is an editorial fellow at HCN *covering science, environment and society.*

Some fossils discovered at Grand Staircase-Escalante have been found nowhere else in North America, confounding scientists. "If a dinosaur had enough time, it could have walked from Alberta to what's now the Rio Grande," said Randall Irmis, a paleontologist at the University of Utah and the Natural History Museum of Utah. Maddie Connolly, a volunteer with the Natural History Museum of Utah, prepares a tibia and metatarsal from a tyrannosaurid for transport at a dig led by Irmis in 2022 (*opposite*). The serrated tooth of a tyrannosaurid is delicately prepared for collection (*opposite below*). Moqui marbles are scattered across a Navajo sandstone bed (*below*). These iron oxide-coated sandstone spheres, which are formed over millions of years through mineralization, are found across the national monument. **Elliot Ross**

The crater and the canyon

The surprising link between two of Arizona's iconic landscapes.

BY EVAN HOWELL

THE COLORADO RIVER flows through Marble Canyon in jade-colored plumes, snaking through narrow terracotta cliffs. This is the stretch of the Grand Canyon where rafters begin their journeys. After launching at Lees Ferry, Arizona, and rounding the next bend, they find themselves surrounded by little more than rock and wind. Nothing in this quiet corridor hints that it once lay submerged beneath an enormous lake.

Had you been rafting Marble Canyon 56,000 years ago, you might have looked up and seen something strange growing larger in the sky: An asteroid streaking across the horizon and slamming into the desert about a hundred miles southeast, punching a gaping hole known today as Meteor Crater.

Now, in a recent study published in *Geology*, retired University of New Mexico geologist Karl Karlstrom and his colleagues conclude that the asteroid's impact shook

Meteor Crater, Arizona (circa 1980).
Dale Nations / Northern Arizona University, Arizona Geological Survey

Marble Canyon hard enough to dislodge great chunks of stone and send a landslide tumbling into the river. The debris formed a natural dam that backed up the Colorado for over 50 miles to near present-day Lees Ferry. The water swelled to the size of today's Lake Mead, flooding canyons and caves, leaving traces nearly 300 feet above the modern river.

When Arizona Geological Survey geologist Kyle House first read the study, he thought: "No way. How could it have taken this long to figure this out?"

IN THE 1960s, Karlstrom's father, also a geologist, and several other scientists entered Stanton's Cave, 32 miles downstream of Lees Ferry. Inside, they found loose sediment and driftwood nearly 150 feet above the river. Later, U.S. Geological Survey geologist Richard Hereford developed a hypothesis: Something must have dammed the river, forming a lake. But with just the Stanton's Cave evidence and a squint-to-see-it possible ancient dam site 20 miles downstream at Nankoweap Canyon, the younger Karlstrom "never believed (Hereford's) story, frankly."

Then, in 2019, researchers in Australia and New Zealand reanalyzed the driftwood using modern techniques, pushing its age from 43,700 years old to about 56,000. That number raised eyebrows: One of the collaborating scientists had stopped at Meteor Crater on a road trip months earlier and watched a visitor-center film. He remembered the timing of the impact — also about 56,000 years ago.

The team asked Karlstrom, who had spent decades studying the canyon, to help them research the connection. As they sifted through Marble Canyon's caves, many of which Karlstrom knew from guiding river trips in the 1970s, he came around on the lake hypothesis: The sediment-choked nooks and crannies sat at elevations that could only be explained by a large lake. However, establishing a clear link to the meteor impact was another matter.

LIKE LAWYERS ARGUING a case, researchers must establish overlapping timelines to link prehistoric events. But that's not as simple as tossing a rock into a machine and reading off an age. Working in deep time requires a large toolkit, with each tool tuned to different slices of Earth's history.

Radiocarbon dating is a tried-and-true method for material up to about 50,000 years old; any older, and the signal fades. "We were pushing the limits," Karlstrom said of the driftwood's age. So the team added luminescence dating of cave sediment, which revealed the time elapsed since it last saw sunlight. Those ages overlapped, within error, with the ages of both the driftwood and the crater, which was also dated using multiple methods.

"They do make a pretty strong case," said Ryan Porter, a geologist at Northern Arizona University who was not involved in the study. But the aligned ages alone can't rule out other landslide triggers, he said, like an earthquake or the canyon shedding a cliff on an ordinary day. Still, when asked whether a meteor impact could have rattled the Grand Canyon enough to set off a landslide, Porter didn't hesitate: "Oh, 100%. There's no question about that."

The authors concede that other explanations for the dam are possible, but outside experts agree that the driftwood wasn't carried in by a flood or left behind as the canyon was excavated. "In geology, you don't absolutely prove," said Karlstrom. "You eliminate other possibilities."

THIS IS HOW that day might have unfolded. When the asteroid slammed into the Kaibab Limestone, the same formation that rims the Grand Canyon, the shaking was equivalent to a magnitude-5.4 earthquake. Shock waves rippled to Marble Canyon, weakening to about magnitude 3.5 — still strong enough to have dislodged Kaibab blocks and debris, damming the Colorado River at Nankoweap Canyon. The water then slackened and began to fill its narrow container.

Today, Glen Canyon and Hoover dams provide a vital lifeline to the parched Southwest. But no dam lasts forever. Sediment chokes reservoirs, surging water erodes barriers. For now, how long the ancient dam endured, and how, exactly, it failed — suddenly or otherwise — remain mysteries, evidence that the long geologic story of the Grand Canyon still holds many secrets.

Evan Howell is a Colorado-based journalist covering earth sciences. He holds a master's degree in geology and spent a decade as a senior geologist.

Our place in history

'Time immemorial' appears in many stories about Indigenous communities, but what does it actually mean?

BY B. "TOASTIE" OASTER

RECENTLY, WHILE READING a draft of a story by another writer for this magazine, I tripped over a familiar phrase: *time immemorial*. If you read (or write) Indigenous affairs journalism, it comes up a lot. As in *Indigenous cultures have been here since time immemorial* — I've seen it so often it disappears into the wallpaper, an invisible cliché. But this time, I realized I had questions. Why do Indigenous affairs writers — myself included — rely on this phrase so much?

Natives have been told our whole lives — in classrooms, through academic research and in popular myth — that humans first migrated into North America around 12,000 years ago. Native histories consistently disagree, however, asserting that humans were here much earlier than that. Using the phrase *time immemorial* is a way to push back; it succinctly communicates longevity without quibbling over exact numbers and dates. But when overused, it can come off as pandering or sanctimonious, a dog whistle for progressives — which could irritate some readers who might otherwise care about Indigenous sovereignty and suffering. When writers appear to slip from reporting to soapboxing, they risk sacrificing credibility.

Isn't there another way to say this? I wondered. I left a comment on the draft for the story's editors and embarked on a side quest to find an alternative to the phrase *time immemorial*. First stop, Harvard.

"I take it to mean the deepest possible kind of human memory," Harvard history professor Philip J. Deloria (Yankton Dakota descent) told me. "Beyond recorded history, beyond oral tradition, beyond oral memory, into what we call the deep past." Western science has long asserted that humans populated the Western Hemisphere around the Clovis era — named for an archaeological site near Clovis, New Mexico — by migrating over a land bridge across the Bering Strait sometime around the end of the last ice age.

Since the 1920s, Deloria said, anthropologists and archaeologists have connected Clovis spearpoints with melting ice and the extinction of a lot of Pleistocene megafauna. Together, they suggest a pretty tidy story of humans migrating into North America.

Non-Natives have used this narrative to undermine the legitimacy of Indigenous land title and to characterize Natives as being no different from their colonizers — just another batch of recent arrivals who kill everything in sight. "It was a very anti-Indian way of seeing things," Deloria said. The Clovis-first story and the Bering land bridge theory quietly and conveniently justify settler colonialism.

But correlation is not causation, and the idea that the Bering land bridge is how humans first reached the Americas is now under increasing scrutiny. Still, it has persisted as scientific canon in education and popular thought alike. "It was elegant because it lined up so well," said Deloria. "But the problem with it, the trap that these guys laid for themselves, was if you found anything that was earlier than that, the theory was screwed."

And that, I learned, is exactly what happened.

IN 1963, AT THE CALICO Early Man Site in California's Mojave Desert, world-famous archaeologist Louis Leakey studied a cache of what looked like stone tools — including flint-knapping debris, blades, piercing tools and hand axes — that he dated to over 20,000 years ago, possibly even hundreds of thousands of years ago. But instead of overturning the Clovis-first story, the findings kneecapped Leakey's professional reputation, and his marriage.

"Even the most well-known global expert on human evolution got called a crazy old man when he published on this, and that site is still denied by a lot of people," Algoma University archaeology professor Paulette Steeves (Cree-Métis) told me. In her book *The Indigenous Paleolithic of the Western Hemisphere,* Steeves asserts that for the past century, academia has not just ignored but vigorously suppressed archaeological evidence of pre-Clovis humans in the Americas.

And not just at the Calico site: There's the Monte Verde site in Chile, the Cactus Hill site in Virginia, the Gault site in Texas, Meadowcroft Rockshelter in Pennsylvania, Chiquihuite cave and the Hueyatlaco site in Mexico. The latter particularly infuriates the colonial-minded, as it's potentially hundreds of thousands of years old. "It's bias," Steeves said. "It's embedded racism." And it's persistent: "To this day, when you do publish on an older site, before it's even published you are going to be severely, severely critiqued."

In the past century, any archaeologist publishing about pre-Clovis sites in the Americas was committing "career suicide," Steeves said. Many scientific findings simply didn't get published. Much of this evidence ended up characterized as pseudoscience, alongside ancient alien theories. Even today, some non-Native scientists continue to explain away Leakey's findings, arguing that the Calico artifacts were carved by the elements rather than humans.

But cracks are now showing in the settler-colonial narrative. When *Science* magazine published a 2021 report on 20,000-year-old human footprints near White Sands, New Mexico, it signaled institutional support for pre-Clovis human habitation here. "These findings confirm the presence of humans in North America during the Last Glacial Maximum," the report's authors wrote. The academy can no longer deny that *someone* was here during the last ice age, and before the makers of the Clovis spearpoints.

"*Time immemorial* is saying 'since the beginning of our people as a cultural group, as a community, and we don't know how long that is,'" Steeves said. "And maybe it's not important to us, but it sure as heck, in North and South America, is a lot more than 11,000 or 12,000 years.'"

Honoring the Ones Who Came Before Us, Seventh Generation Fund for Indigenous Peoples, Wiyot Territory, 2009. **Lyn Risling**

“Time immemorial is saying ‘since the beginning of our people as a cultural group, as a community.’”

Uumkun Kari Ôok (They are Still Here), 2016. We can feel the spirits of our ancestors living in baskets they wove from the Earth as we practice cultures and traditions passed down since time immemorial. **Lyn Risling**

Other disciplines also provide scholarly support for *time immemorial*. Some linguists, for instance, believe the language families of the Americas would have taken at least 30,000 years to develop. DNA researchers, Deloria told me, have found links between Indigenous South Americans and Austronesians.

Although civilizations rose and fell in North America, the oral histories preserving their legacies carry little currency with Western science, since they're not written records. But oral histories are not just legends or fanciful tales, and they're certainly not schoolyard games of telephone. They were memorized under the instruction of elders, Deloria said, and retold with a sense of responsibility toward the community.

The physical monuments of North American civilizations buttress the older timelines of the oral histories: The weathered remains of the tamped-earth step-pyramids of Cahokia and Poverty Point on the Mississippi River, which are now referred to as “mounds,” but once supported wooden temples overlooking cities; the remains of the Hohokam canals on Arizona's Salt River, hundreds of miles of technologically sophisticated agricultural irrigation in a system that *Popular Archaeology* says “rivaled the ancient Roman aqueducts”; and the Hopewell Ceremonial Earthworks, a series of earthen constructions that aligned with solar and lunar cycles.

Deloria said this is all evidence of North American Classical civilizations. But instead of designating a classical period in North American history, settler narratives routinely skirt this evidence, too, omitting it from classroom curricula and the popular imagination. Historians, Deloria noted, usually reserve the term *classical* for early Western European cultures. European Americans are allowed to lionize their predecessors, while North Americans are not. “If the Mediterranean gets to have Greeks and Romans, then we get to have our equivalents of Greeks and Romans,” said Deloria. By establishing the longevity of North American cultures, the expression *time immemorial* illustrates their sophistication as well.

I LIKE TO REPORT ON good news in Indian Country. But when there's good news for us, hateful comments often follow. It's strange to me. I feel proud when I think of Poverty Point and the Mississippian ancestors who built the Southeastern Ceremonial Complex, a religious culture that spread across the Southeast and even up to the Midwest and included the temples of Cahokia. They were part of a fruitful civilization that enjoyed the kind of freedom, abundance and stability that most contemporary Americans don't seem to believe ever existed anywhere on Earth. If America taught our histories in its schools, would Americans hate us less?

Our histories, which live on both in the soil and in our continued existence as cultures, undermine colonial stories like Clovis-first and the Bering land bridge populating the Americas. Without those stories, the Empire's legitimacy erodes — and the other stories they prop up, like white supremacy, American exceptionalism and the so-called “New World,” begin to collapse.

Not only were we here long before America, with its relentless, shortsighted oppression disguised as progress and its hateful, ahistoric vitriol, we will still be here long after it's gone. Arguing over the numbers with degree-wielding “debate me” bros is a fool's errand. *Time immemorial* sweeps the debate itself aside and makes space for our ancestors to speak their silent gravitas from beyond the grave, prophesying a future so beautiful it defies the colonized imagination. Though I'd initially set out to find an alternative phrase, *time immemorial* was revealing its power. “It's really important right now to decolonizing settler minds, to decolonizing education, and to decolonizing ourselves,” Steeves told me. “I hear some tribes say, ‘Oh, we've been here 10,000 years.’ You don't know that you haven't been here 50,000. So don't say 10,000. Say ‘time immemorial.’”

B. “Toastie” Oaster (they/them) is an award-winning journalist and a staff writer for High Country News *writing from the Pacific Northwest. They're a citizen of the Choctaw Nation of Oklahoma.*

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—Matt Doberstein, Sandwich, Massachusetts

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A wilderness warrior to the core

After 40 years of service and 80 years on Earth, **Andy Wiessner** — wilderness warrior, land wheeler-dealer and longtime friend to ***High Country News*** — is stepping off our board of directors.

Andy attended a one-room schoolhouse in Stowe, Vermont, and his mother, Muriel, let him and his sister run free in the North Country woods. Andy's father, **Fritz**, was a pioneering rock climber. Andy recalls being "dragged up all kinds of horrible peaks in the Alps" as a teenager, including Switzerland's Schreckhorn, whose name literally means the "horn of terror." He learned to love mountaineering, but says he never took to technical rock climbing.

With an undergrad degree from Dartmouth and a JD from Boston University, Andy went to Washington, D.C., in 1974 to work as a congressional staffer. It was the heyday of wilderness protection, and Ohio Rep. **John Seiberling**, a Democrat who headed the House Subcommittee on Public Lands, enlisted Andy to help survey — often by airplane or helicopter — Western lands that had been recommended for protection.

Tough duty. "I had the best job in the world," Andy said.

A writer for this publication posited in 1985 that Andy might have done more than any other individual to protect wildlands in the Western U.S. Seiberling told *HCN* that during the five years that he led the subcommittee, it processed legislation that added more than 200 areas in 34 states — a total of 64 million acres — to the National Wilderness Preservation System. "Andy Wiessner has worked on every acre," he said.

After leaving Capitol Hill, Andy moved West, taking a job with the Western Land Exchange Company (now the Western Land Group), which specializes in public-private land swaps. Andy said that "the public always got good land out of the deal," citing a trade he helped orchestrate with Plum Creek Timber Co. that traded out checkerboard lands around the Alpine Lakes Wilderness in Washington's Central Cascades. But the work sometimes spun up controversy.

A proposed land trade in Western Colorado put him cross-wise with his longtime friends **Ed and Betsy Marston**, the former publisher-editor team at *HCN*. Andy, who was working on behalf of billionaire Bill Koch, said the trade would have put valuable wildlife habitat around Blue Mesa Reservoir into public hands. But it would have blocked a popular trail into the Raggeds Wilderness, and Ed was an outspoken opponent.

The deal fell apart, and the friendship endured, but Betsy never changed her position on such land trades: "What it taught me was that land trades are usually proposed by the wealthy, and they are almost always bad for the public," she wrote.

At *HCN*, Betsy and others lauded Andy's fearlessness as a fundraiser. He was instrumental in rallying donations to purchase the building in Paonia, Colorado, that became *HCN's* headquarters in the early 1990s. (When our staff dispersed across the West decades later, we benefited yet again when we sold the building and used the proceeds to rebuild our digital infrastructure and underwrite the first few years of our family, medical and emergency leave program. Our Customer Service team still works out of a corner office there.)

Andy's fellow board members, past and present, note his lifelong passion for the West and his generous heart. "Andy fit perfectly with *HCN's* motto — a publication 'for people who care about the West,'" wrote **Dan Luecke**, a board president in the 1990s. "He did care deeply while at the same time not trying to impose his will — something that can happen with volunteer board members of public interest and nonprofit groups."

Wayne Hare, who served on the board from 2008 to 2021, called Andy "one of the kindest people that I have ever known."

Staff will always be grateful for Andy's hospitality. Over the years, his home in Old Snowmass became a de facto bed and breakfast for staff and board members, and he still loves to host fundraisers, leading the team making crostini appetizers in the kitchen and, after the guests have filed out, sharing his favorite pear brandy. One particularly memorable evening in 2021 saw 100 people gathered under a wedding tent on his front lawn to celebrate *HCN's* 50th anniversary.

Asked about his plans for the future, Andy is staying true to his roots: He'll put his energy into protecting wild places. "The older I get, the more I'm a fan of simply locking up lands," he said. "Because once we lock them up, human beings can't fuck with them anymore."

We will always be grateful for all that Andy has done for *HCN* and the West — and we look forward to welcoming new board members soon.

— Greg Hanscom, executive director & publisher

CAROLINA JOYCE

Andy Wiessner at home in Snowmass, Colorado, with Eloise *(top)*; with Dan Luecke and speaking in Boulder last year, where he was honored for his years of service to *HCN*.

CONTINENTAL SHIFT

THE SCRIPPS INSTITUTION OF OCEANOGRAPHY IN LA JOLLA, CALIFORNIA, was in chaos when 24-year-old Tanya Atwater arrived to pursue her graduate studies. It was January 1967, and a buzz of frenetic energy filled the air. Long rolls of paper printed with squiggles of magnetic data spooled down the hallways, retrieved from odd corners where they had lain covered in dust.

A few weeks earlier, a Cambridge geophysicist named Fred Vine had visited Scripps to explain a theory so new it didn't yet have a name. Some called it the Vine-Matthews Hypothesis; others referred to it as seafloor spreading. It was a critical advancement on the old, long-discredited notion of continental drift. The new theory would come to be known as plate tectonics.

Atwater stood out among the other scientists. For one thing, she was a woman in a field dominated by men. She was also a self-described "full-on Berkeley hippie ... barefoot, with beads and flowers." She had an undergraduate degree in geophysics and a knack for seeing the big picture.

Her first class was marine geology. The professor didn't bother with the syllabus. Chalk flew over the blackboard as he dove right into this "wonderful new idea," which had transformed the study of the oceans and would, in time, upend the story of the continents and how they came to be. No point in opening the textbooks; they were suddenly out of date.

A revolution was going on, and Atwater had stepped into the middle of it.

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THE IDEA THAT CONTINENTS ONCE FITTED TOGETHER like puzzle pieces had been around at least as long as accurate maps of the world had existed. But it was easily dismissed; until the mid-20th century, most geologists were "fixists" who believed the land masses hadn't budged since the beginning of time.

Yet all over the planet, paleontologists were finding similar rock layers cradling similar types of fossils. A reptilian creature from the Permian period showed up in both Brazil and southwestern Africa. One particular fern was scattered throughout the Southern Hemisphere. How had plants and land-bound animals crossed

THE WOMAN AT THE CENTER OF A GEOLOGIC REVOLUTION.

BY MELISSA L. SEVIGNY

COURTESY OF TANYA ATWATER

vast oceans to reach other continents?

In a 1915 book, German scientist Alfred Wegener offered a solution. Maybe the continents had once been joined and subsequently drifted apart. World War I was raging, so few people paid attention until the third edition of his book was translated into English, French, Spanish, Russian and Swedish. Scientists could now ridicule Wegener's theory of continental drift in six languages. According to Atwater, American geologists especially "pooh-poohed" the idea.

Still, the notion that continents drifted didn't go away.

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ATWATER HADN'T SET OUT TO BE PART OF A SCIENTIFIC REVOLUTION. "It was just a lucky chance of having the right background at the right moment in the right place," she said.

She was born in California on Aug. 27, 1942. As a girl, she liked to draw, but her dreams of becoming an artist took a turn when the Soviet Union launched *Sputnik* in 1957. "It was just so astonishing that science could put something into outer space," she said.

ABOVE: Tanya Atwater figured out how the theory of seafloor spreading applied to geological features on land.

Her engineer father and botanist mother encouraged her newfound interest. When a recruiter from the California Institute of Technology visited Atwater's high school, she asked about science degrees. But Caltech didn't accept women; they would just get married, quit and waste their educations, Atwater remembered being told. She visited Harvard next, which pointed her toward the neighboring women's college, Radcliffe — a nonstarter, as she lacked the Greek or Latin prerequisites.

Never mind: The Massachusetts Institute of Technology would do.

MIT welcomed women into its science programs. When Atwater asked a professor why, he replied MIT-educated women would raise great children, which she took to mean boys. "I didn't even blink," she wrote in *Plate Tectonics: An Insider's History of the Modern Theory of Earth*, to which she contributed a chapter. "I guess I was used to it by then."

Atwater wandered through five majors in the next three years, churning through organic chemistry ("just horrible") and electrical engineering ("I kept electrocuting myself"). Then she enrolled in a field course in Montana. It was her first introduction to practicing geology in the field. She was in heaven; she hiked and marveled at the mountains, learning how their geometry fit together and translating that knowledge onto maps. *Could you actually get paid to do this?* she wondered.

"Anything that you study, you see much better than the rest of the world," she said. "Suddenly, the landscapes and the rocks, they were talking to me."

Still — *geology*. It was, in Atwater's words, a grubby and obscure field, totally removed from the slick, high-tech satellite dreams that propelled her into science. She had no memory for facts, and geology was all facts. What forces spit out volcanoes and crumpled mountains? At the time, professors had no explanation, and students drew arrows on their maps like "the hands of a capricious god shortening or extending our landscapes, willy-nilly." Was this to be her career?

She dropped out of MIT. She traveled and deliberated. All the while, the mountains kept talking.

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IF ATWATER HAD BEEN BORN IN THE VERDANT EAST, her career might have turned out differently. Much of California's landscape is stark and exposed. "In the West," she said, "the rocks are all standing up and yelling at you." She realized that if she was going to study geology, she needed to go back to her home state.

Atwater arrived at the University of California-Berkeley at the height of the Free Speech Movement. Berkeley was a hub of counterculture, civil rights and protests against the Vietnam War — "not a war that my generation could believe in," Atwater reflected. Students vanished from the hallways, taken by the draft, or dropped out to enlist in the Coast Guard and avoid being shipped overseas.

Atwater enrolled in geophysics, the study of Earth's processes. She transferred her math and physics credits from MIT and crammed as many geology classes into her schedule as she could. It wasn't an obvious time to dwell on slow forces and distant pasts. Enrollment in undergraduate geology programs was dropping, and students mostly ended up working in the petroleum industry. Amid a cultural revolution, it seemed to be a field as stolid and immovable as the mountains themselves.

She graduated with a B.A. in geophysics in 1965, and once again headed east, to Massachusetts, this time for a summer internship at the Woods Hole Oceanographic Institute. At the time, oceanography and geology were separate realms, with little communication between them. Atwater didn't know there was anything geologically interesting happening underwater; she was simply "drawn to the romance of going to sea."

When her colleagues began preparing for a meeting in Ottawa, Canada, Atwater asked if she could go. There, she heard geophysicist J. Tuzo Wilson give a lecture about a new kind of geologic feature. He called it a "transform fault."

A fault is a fracture in the Earth's crust. The simplest kind is when one block of earth rises or drops vertically in relation to another. But a transform fault, Wilson explained, is defined by horizontal movement rather than vertical. Along the seafloor, many such faults intersected "mid-ocean ridges," long chains of undersea mountains cloven by lava-spitting rifts. Mid-ocean ridges delineate the Earth's crust into large, rigid plates — plates that can move apart slowly as magma wells up between them. The edges aren't smooth lines, however; they're more jagged, and follow a sort of stairstep pattern, with transform faults linking separate ridges together like messy stitches in a seam.

Wilson had been a fixist until recently. Now he was declaring himself a "drifter" who believed the continents rode atop moving plates. He passed out paper diagrams to explain his hypothesis. "Cut

ABOVE: Atwater on a geology trip to Tierra del Fuego in 1989.

"ANYTHING THAT YOU STUDY, YOU SEE MUCH BETTER THAN THE REST OF THE WORLD. SUDDENLY, THE LANDSCAPES AND THE ROCKS, THEY WERE TALKING TO ME."

-TANYA ATWATER

ALL PHOTOS COURTESY OF TANYA ATWATER

here, fold here, pull here," read the instructions. The crowd laughed. Atwater felt embarrassed. A children's game, at a serious scientific meeting? But something about the diagrams hooked her imagination. In the privacy of her hotel room, she cut and folded and pulled.

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AMID ALL THE TALK OF THE OCEAN, one thing stuck with her. Wilson had mentioned an unusual transform fault that occurred on land — in Atwater's home state, in fact. It was the San Andreas.

Stretching 800 miles from Mendocino to the U.S.-Mexico border and reaching 10 miles deep, the San Andreas Fault is not a single crack in the Earth's surface but a network of fractures. It's most visible on the Carrizo Plain, a rumpled piece of grassland bordering the Temblor Range in central California. There, dry creek beds cut downhill toward the fault, reach it, and jump hundreds of feet sideways before continuing on.

Catastrophe prompted the first study of the San Andreas — the San Francisco earthquake of 1906. Thousands died; tens of thousands lost their homes to the quake and the fires that burned for days afterward. Smoke was still rising from the ruins when a geologist named Andrew Lawson assembled an Earthquake Investigation Commission. A decade earlier, Lawson had identified a fault in the San Andreas Valley. Now, his team painstakingly traced this fault on foot and horseback for hundreds of miles, documenting recently toppled statues and disjointed fences, roads and bridges. The commission concluded that the land on one side of the San Andreas had slipped northwesterly while the other side lurched to the southeast, causing the quake. In some places, the land shifted as much as 21 feet.

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THE IDEA OF CONTINENTAL DRIFT LANGUISHED FOR DECADES, largely ignored by the scientific community. But in 1963, the first real advancement on the concept came from an unexpected location: under the ocean. That year, Cambridge geophysicist Fred Vine and his colleague, Drummond Matthews, published an obscure paper in *Nature*. It pointed out magnetic anomalies on the ocean floor that, they claimed, could be explained by the signature of the Earth's magnetic field on freshly cooled lava. The patterns appeared in stripes, some with normal polarity — minerals within the lava pointed north, like tiny compass needles — alternating with stripes that had reversed polarity, in which the minerals pointed south instead.

Vine and Matthews inferred two things from the anomalies: Earth's magnetic field had, at various times in the deep past, reversed, and more importantly, the seafloor was spreading. Magma welled up at a mid-ocean ridge and bubbled through the long rift in the center. As it cooled, it took on the imprint of the Earth's magnetic field. More magma surfaced and shouldered the new rock aside. Over millions of years, a zebra-pattern formed on either side of the ridge, with stripes running parallel to it — bands of seafloor marked by alternating magnetic signatures.

The stripes had been documented by magnetometers that were towed behind research ships; oceanographers had amassed stacks of these measurements without realizing their importance. Vine and Matthews's work suggested that you could read them like a history book, albeit one missing any dates — assuming the seafloor really did spread, and the magnetic field really did flip. Using one radical unproven theory to justify another radical unproven theory was like trying to net wind or squeeze water. According to Vine, the idea "went over like a lead balloon." Other scientists called the work unconvincing, even heretical.

James Heirtzler, who led a team at Lamont Geological Observatory in New York that specialized in magnetic profiles, was among the critics. But then, in early 1966, two of his graduate students noticed a startling pattern in the magnetic data collected the year before on the *Eltanin*, a floating science lab devoted to exploring Antarctic waters. When they first brought Heirtzler the results, he refused to believe his eyes. It took him a month to accept the implications. Later that year, while passing through Santiago, Chile, he elbowed his way onto the agenda of an international scientific meeting about Antarctica to share the data.

Atwater was in Santiago, too, having moved there for a geophysics job. She'd been spending her days reading recordings of earthquakes

FAR LEFT: A view of Wallace Creek on the Carrizo Plain, showing how the creek bed shifted as a result of seismic activity on the San Andreas Fault.

LEFT: A group of students visits a section of the San Andreas Fault near Palmdale, California, with UCSB geology professor Arthur Sylvester.

in dramatic landscapes like the Atacama Desert, where, she said, "it was so quiet we could hear the roots of the tree groaning in the ground when the wind blew."

At the Antarctica meeting, Atwater was dozing through Latin-riddled presentations about plankton and other minuscule bits of marine life. When it was time for Heirtzler's presentation, Atwater recalled, "Everybody … snuck out to go to lunch. I'm sure there were other people in the room, but I remember being all alone at this talk."

Heirtzler showed a slide of the *Eltanin* data.

"It was just a line, a wiggly line," Atwater said. "But it was symmetrical." The data fit the ridiculed Vine-Matthews Hypothesis precisely. If volcanic rock really squeezed up out of a mid-ocean ridge and spread in either direction, and if it really were imprinted by the Earth's magnetic field, then the pattern would be symmetrical on either side of the ridge. "There may be no other natural phenomena where nature shows such order," Heirtzler wrote.

Even better, the profile had timestamps, of a sort. A U.S. Geological Survey research team in Menlo Park had recently measured the age and polarity of volcanic rock samples to work out a timeline for when the magnetic field randomly switched direction in the past 4 million years. It was meticulous research that many geologists dismissed as meaningless and fringe. Now, that calendar made it possible to interpret the groundbreaking *Eltanin* profile. Heirtzler showed the two datasets side-by-side: the zebra-stripe pattern and magnetic reversal timeline. "It matched perfectly," Atwater marveled. "It was ironclad." Seafloor spreading was real.

The revelation hit like a lightning bolt for the 24-year-old scientist who had remained in the emptying room. California was the epicenter of a radical new understanding of the Earth. She had to get back there.

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ARRIVING AT SCRIPPS IN JANUARY, Atwater plunged straight into the pandemonium caused by Fred Vine's recent visit. Students and professors pored over old magnetic profiles in search of symmetry and found it everywhere. "They'd been collecting magnetic data from the ships just because it was an easy measurement to make," Atwater said. "They dug them all out and looked at them again: '*Oh my God, there it is, the pattern!*'" Longtime fixists transformed, seemingly overnight, into drifters. The paradigm shift was in full swing — at least for those who studied the ocean floor.

"The people on land knew there was some revolution going on in the ocean," Atwater said. She put an inflection of contempt into her voice: "But, you know, *the ocean*."

Geologists didn't understand how seafloor spreading was relevant to their work. They needed a translator, and Atwater, with one foot on land and another at sea, was destined for that role. It didn't matter that she was still a student. Everything had been upended. As one of Atwater's contemporaries wrote, "The plate tectonic revolution was a great leveller: everyone found themselves in the same boat, regardless of age or experience."

Well, not *quite* the same boat. Women weren't allowed on boats.

It wasn't a rule, really, just a lingering superstition about bad luck and concerns over the propriety of shared bathrooms and cramped quarters. This was inconvenient, since Atwater belonged to the Deep Tow research group, which would soon sail over the Gorda Rift offshore of Northern California, towing instruments to collect new data. Previous research vessels had collected data close to the surface, but Deep Tow would drop a cable down to the bottom, outfitted with sonar, sounders, underwater cameras, a magnetometer and other instruments. The expedition would provide the closest look yet at a seafloor-spreading center. In closed-door meetings, Scripps scientists argued about what to do with "the girl." Atwater's advisor, John Mudie, cut to the chase: "She could sue you, you know."

"That's all it took," she said. She was going to the Gorda Rift.

To record data from the research ship, the students had to keep the scientific instruments just above the seafloor without bashing them into rocks or cliffs. It was a hair-raising task: "We all had to take turns pulling in and letting out the cable," she said, while others watched the readout of sonar images showing the undersea topography. To see real-time images of a mid-ocean rift, "the center fallen in and fresh lava pouring over the seafloor," brought clarity to everything Atwater had learned so far.

By this time Vine and Matthews had refined their hypothesis, describing how, thousands of miles from its origin in a mid-ocean ridge, the seafloor was swallowed by trenches, chewed up and recycled in the ever-moving mantle. They called this process, unromantically, a "conveyor belt." The seafloor was not static, but churning, seething and eternally young, at least by geologic standards. Atwater was seeing it for herself.

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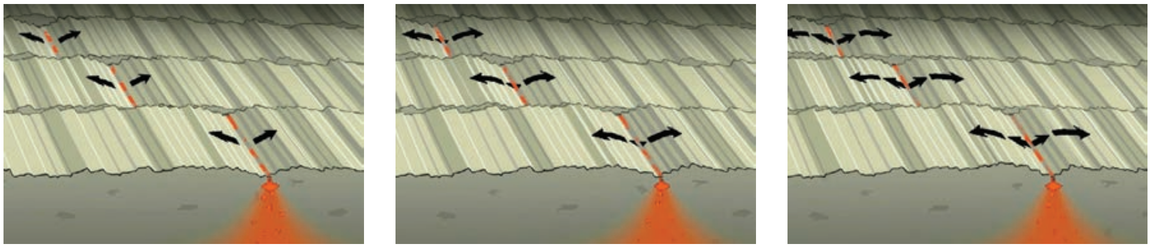
THE NEXT TURN IN ATWATER'S CAREER revolved around a sketch on a napkin.

One autumn evening in 1967, she was talking with a visiting scientist at a dance hall not far from Scripps. Between beers and blaring accordions, Dan McKenzie scrawled a diagram of the San Andreas

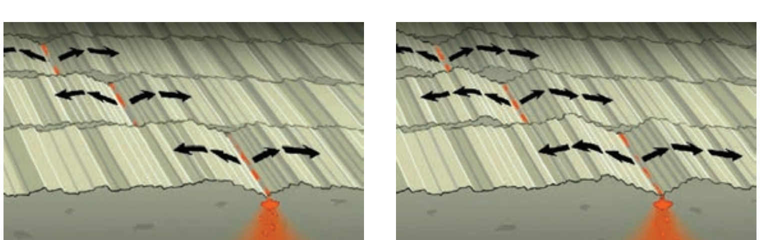
SEAFLOOR SPREADING
This sequence of images shows seafloor spreading from a mid-oceanic ridge connected by a series of transform faults.



TOP: Keeping an eye on geophysical instruments inside *Alvin*. "It's much more crowded than it looks," Atwater said of the interior of the submersible. **BOTTOM:** Atwater climbs into *Alvin* for a dive in 1978. The submersible fit three people, and it took about an hour to get down to the ocean floor.

Fault — the boundary between the Pacific and North American plates. McKenzie shared a secret: A third plate bordered the other two just off Cape Mendocino, California, one of the most earthquake-prone spots in the Lower 48.

McKenzie hadn't yet published his paper on what he called "triple junctions." For Atwater, the pieces clicked. Triple junctions, seafloor-spreading centers, transform faults: Altogether, "they were the key to the whole geometry of the ocean," she realized. Nobody had figured out how these newfangled concepts applied to geologic features on land; at this point, plate tectonics was an oceanic revolution. But there was a plate boundary on land: the San Andreas Fault. If she could explain how the San Andreas formed, she could bring the entire theory onto dry land.



ALL PHOTOS COURTESY OF TANYA ATWATER

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ONE SMALL PROBLEM. The timescale of magnetic reversals went back a paltry 4 million years, barely into the Pliocene. The San Andreas was older than that — some scientists speculated *much* older, perhaps 100 million years, though nobody knew for sure. Was it a fast-moving young fault, or a slow-moving old one? Atwater knew she could answer that question using the zebra-stripe patterns just offshore — if only she had reliable dates.

That work was underway at Lamont Geological Observatory under the guidance of James Heirtzler. In 1968, Heirtzler published a wildly speculative timeline for magnetic reversals for the last 85 million years, back to the Late Cretaceous, the age of dinosaurs. "Their best guess was very good," Atwater said. "But nobody knew if it was going to hold up or not. You have to put in a lot of weasel words, 'maybe this is so,' *blah blah blah,* 'but maybe that's so.'" She didn't want to write a paper chock-full of uncertainty.

Atwater went to Washington, D.C., that spring to talk about the Gorda Rift at an American Geophysical Union meeting. It was her first conference lecture, leading up to her first paper, which would appear in the prestigious journal *Science*. She was a rising star, flush with victory. Afterward, she joined a group of students who traveled from D.C. to New York to tour Lamont.

The glow of success winked out. "I was invisible," she wrote. "At every lab we visited, they introduced all the young men and skipped me, every time."

• • •

THAT AUTUMN, A RESEARCH VESSEL called the *Glomar Challenger* sailed over the Mid-Atlantic Ridge to drill holes and sample sediment. Fossils within the sediment samples they retrieved gave scientists a way to put dates to the bottommost, oldest layers. To everyone's surprise, Heirtzler's best guess for the past 85 million years was spot-on.

It was the missing piece. Within months, Atwater had abandoned her official work with Deep Tow and was immersed in the study of the San Andreas. It was the most intense period of her career. "There were nights I couldn't sleep," she said. "I'd call up my mentor at 2 in the morning." Her focus was a zebra-stripe pattern off the Pacific coastline that was an oddity. It was entirely one-sided: The pattern on the eastern side of the ridge was missing. The aberration bothered scientists; it looked like a flaw in the case for seafloor spreading.

McKenzie, the napkin-sketching scientist, proposed an explanation. The third plate — the one he revealed to Atwater in the dance hall — was the remnant of an older plate, called the Farallon, which once stood between the Pacific and North American plates. Over time, the Farallon had been pulled, or subducted, beneath the North American plate, carrying with it the missing half of the zebra pattern.

Atwater took up the story from there. Only after the Farallon had vanished, leaving a few fractured pieces behind, could the Pacific plate rub up against the North American, forming the San Andreas. Thanks to the *Glomar Challenger* research, she could trace every step of this speculative history as far back as 85 million years.

She didn't need to go that far back, however. Using magnetic data as the key, she unlocked the answer to a question that had dogged everybody. The San Andreas was younger than many had speculated, she determined; it couldn't be older than 23 million years. And with that piece of information, she showed how the unseen movements of plates shaped the geography and geology of California, thereby proving to geologists that plate tectonics mattered to their work.

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IN DECEMBER 1968, the Geological Society of America convened a five-day meeting at the Asilomar Conference Grounds in Pacific Grove, California, to discuss "the new global tectonics." Atwater was the only woman invited to speak.

"I might have been the only woman in the room," she recalled. Dressed in her usual flowers and beads, she stood in front of the jampacked room to present her findings. When she rambled over the time limit, the moderator tried to stop her. But a voice rose from the rapt audience: "Let her go on! This is great stuff."

Atwater kept going. When she finished, a skeptic challenged her. Could they really believe the San Andreas was that *young*? It was contrary to the opinions of many eminent geologists. Atwater was scrambling for a reply when another scientist shouted, "It's true! Believe it!" Ken Hsu had been aboard the *Glomar Challenger* for the deep-sea drilling expedition. He defended Atwater's findings with "all the passion of the newly convinced," she recalled.

The audience was stunned. Atwater was the first person to use the newly revealed secrets of the seafloor to explain a geological feature on land. She showed her colleagues that anywhere you had magnetic data, you could reconstruct the movement of Earth's tectonic plates across millions of years.

The movement of plates — what J. Tuzo Wilson called "the dance of the continents" — explained not just the San Andreas Fault, but California's pattern of earthquakes, the birth of the Coast Ranges, volcanism in the Cascades and the opening of the Gulf of California. No wonder she ran overtime. She tracked this story from the start of the Cenozoic Era, 66 million years ago, from the extinction of dinosaurs, to the rise of mammals, through the rending and suturing of continents and seas.

"I felt I had just been witness to the end of an era," one listener later recalled, "and the beginning of a totally new approach to understanding the dynamics of the Earth."

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SPEAKING INVITATIONS POURED IN. Atwater's ability to translate ocean science into earth science packed lecture halls. "I gave a bazillion talks everywhere," she said. "Everybody came, partly to see the girl geophysicist, but also to hear what the revolution could mean for them."

A year after she spoke at Asilomar, Atwater published her findings in *The Bulletin of the Geological Society of America*. Geology students everywhere were assigned to read it. Atwater was still a student herself, but she didn't find her new notoriety awkward.

"I knew I deserved it," she said.

Extra pages were stuffed in the backs of geology textbooks; then, new editions appeared with plate tectonics woven into every chapter. The movement of the plates gave an underlying logic to once-mysterious phenomena, such as earthquakes and volcanoes. It was no longer heresy to envision very different Earths in the deep past.

Atwater earned her Ph.D. in oceanography from Scripps in 1972. Two years later, her son, Alyosha, was born. It's a part of her story she thinks women need to hear. "When I was coming through," Atwater said, "I thought I had to choose: a family or a career. I had no idea that you could manage both."

She taught for seven years at MIT, then went back West to spend the rest of her career at the University of California-Santa Barbara, in view of the arid, pine-studded Santa Ynez Mountains, a section of the Transverse Ranges that rises between the Pacific and the San Andreas Fault. She descended to the ocean floor 12 times in a 6-foot submersible, the *Alvin*. Those day-long trips were launched from a catamaran where Atwater had to sleep on the floor until she convinced her colleagues it was OK to share the tiny bedroom with men. "There's still some of the same silliness," Atwater admitted, speaking about the experiences of women in science. But, she added, "for many years, I owned the ladies' room," at American Geophysical Union meetings. "Now I have to stand in line."

Atwater credits her parents for the conviction that she could be anything she wanted. "An awful lot of women didn't get that message," she said. She once worried about having switched majors so often. Now she feels that every step she took led her in the right direction. "You have to have some faith that it's going to work out."

Now a professor emeritus, she tags along on university field trips, sharing her love of geology with students across California's rugged mountains and jagged coastline. Since the mid-'90s, Atwater has used her artistic knack to create digital animations that explain plate movements, "showing all the things that I can see in my head." The animations explore Earth's history, from the global breakup of the supercontinent Pangea to the creation of California's Transverse Ranges and Channel Islands. She lives in the center of that gorgeous geography, which was caught between jostling plates 18 million years ago and twirled clockwise 110 degrees, a rotation that continues to this day.

Science, like the Earth, isn't static. Atwater keeps waiting for some new idea to overturn the theory of plate tectonics. "But it hasn't," she said, with a tinge of surprise in her voice. "We make more measurements and it's more precise. We never know for sure; we can never prove anything is true. But this is about as sure as you can get.

"It's a relief," she added, "since I spent my whole life on it."

Melissa L. Sevigny is an Arizona writer whose work centers on the intersections of science, nature and history in the Western U.S. Her most recent book is Brave the Wild River, *which won a National Outdoor Book Award and a Reading the West Award.*

What’s past is prologue

Three books anchor readers in deep time while contemplating the future.

BY ALKA TRIPATHY-LANG

JUST EAST OF WHERE the Colorado River used to trickle into the Gulf of California, the dunes of the Gran Desierto de Altar are slowly migrating. Sand blows up their gentle sides; at the top, grains tumble down, and the dunes creep stealthily along. Observing these incremental processes IRL can illuminate the story of rock outcroppings like the Grand Canyon’s Coconino sandstone, which features sweeping diagonal lines signaling the direction wind traveled 280 million years ago. As geologists say, the present is the key to the past.

But the rock record also documents far-reaching and sometimes global catastrophes, like the “Big Five” mass extinctions that irrevocably changed our planet, shaping everything that came after.

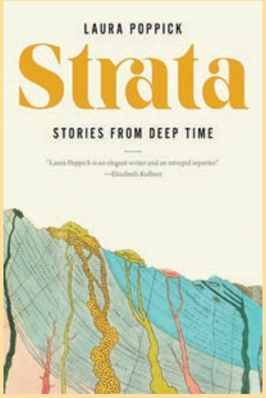
As it turns out, the past — with its mix of both incremental and catastrophic happenings — can inform our present, and even our future. But to grasp what the rocks have to say requires grappling with how a formation like the Coconino, which spans thousands of square miles, could have been deposited over millions of years. Learning how to think about what happened so long ago — venturing into “deep time” — can help us better understand the repercussions of our choices today. Here are three books that take us into the geologic past.

The term “deep time” was popularized by longtime *New Yorker* writer John McPhee in his first foray into Earth science, 1981’s *Basin and Range*. I recommend reading the lightly updated version in his 1999 Pulitzer Prize-winning five-books-in-one anthology, *Annals of the Former World*. The original *Basin and Range* was published when Reagan was president and revised in the Clinton era; since then, some numbers have been refined, and some concepts are no longer new. Yet more often than not, the stories McPhee tells retain their relevance.

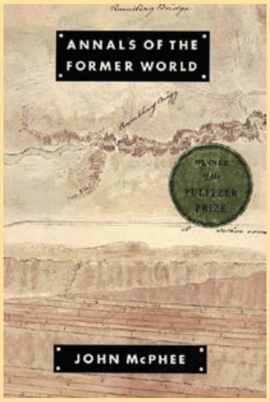
McPhee wanted to write about what he thought were the most interesting pieces of North America’s billions-year-old history “by describing events and landscapes that geologists see written in rocks.” He did so by tagging along with geologists as they crossed the continent on Interstate 80 from New Jersey to Nevada, where the book ends.

In Utah and Nevada, McPhee explores the emergence of long lines of mountains, called ranges, separated by similarly long valleys, or basins. Range, basin, range, basin, goes the pattern. “Faulting produced this basin,” a geologist tells McPhee. “Sediments filled it in.” That’s the simple version, anyway. It’s a story younger than dinosaurs, yet still millions of years old.

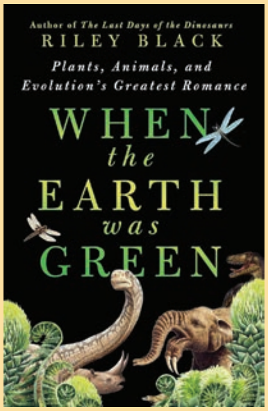
McPhee explores how the continent is “being literally pulled to pieces” between the Rocky Mountains and the Sierra Nevada. Not the first time, either: this rending of Earth, one of McPhee’s tour guides explained, happened 200 hundred million years ago



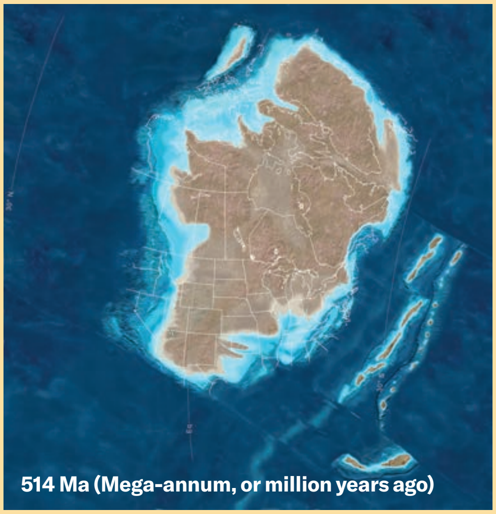
Strata: Stories from Deep Time
Laura Poppick
288 pages, hardcover: $29.99
W.W. Norton & Co., 2025.

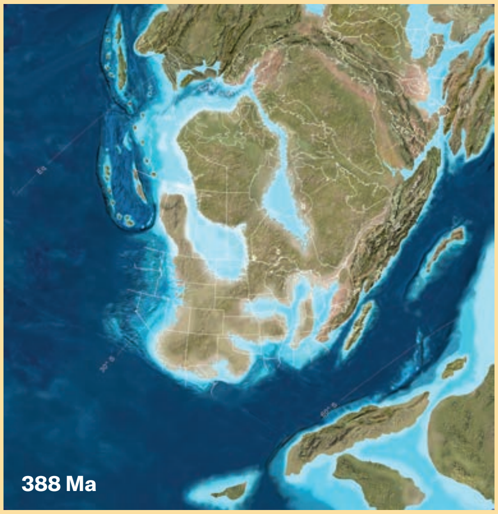


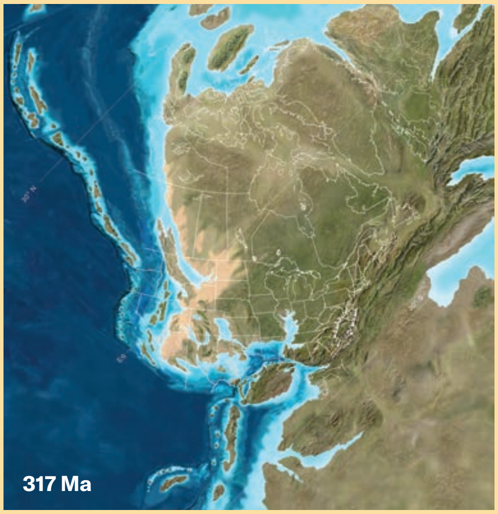
Annals of the Former World
John McPhee
720 pages, softcover: $30
Farrar, Straus and Giroux, 2000.



When the Earth was Green
Riley Black
304 pages, hardcover: $29.99
St. Martin’s Press, 2025.







"By way of comparison, just twelve million years or so of evolution produced humans, gorillas and chimps from the same common ancestor."

Map projections showing the paleogeography of North America as it culminated in the supercontinent Pangea, rifted from the very large continent Gondwana to form the Atlantic and was affected by various sea-level changes. ©2023 **Ron Blakey / Colorado Plateau Geosystems Inc.**

when the supercontinent Pangea began to rupture, eventually letting the Atlantic Ocean in. In the future, will Nevadans wave to Californians across a new sea?

McPhee takes detours aplenty, as when his geologist companion takes him to an abandoned silver mine in Nevada. They follow a treacherous road overlooking a valley that McPhee describes as being as special to the Paiutes as the Black Hills are to the Sioux. McPhee learns how 19th century miners took all the best silver but left potentially millions of dollars' worth of ore in the trash.

McPhee also veers into the vastness of geologic time. "People think in five generations — two ahead, two behind — with heavy concentration on the one in the middle," he writes. Geologists muse to McPhee about how we can measure deep time without truly comprehending the passage of millions of years.

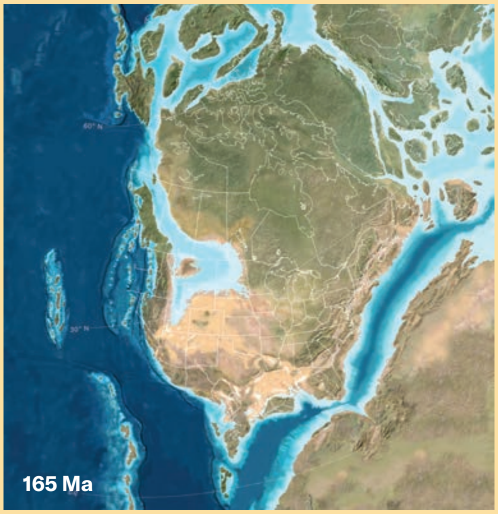
Consider McPhee's book a primer, an introduction to rocks, a way to understand how geologists "inhabit scenes that no one ever saw … archipelagos of aching beauty rising in volcanic violence to settle down quietly and then forever disappear — *almost* disappear."

Science journalist Laura Poppick explores some of the same history, writing with similar attention to detail as McPhee in her book *Strata: Stories from Deep Time*, published in July 2025. Yet Poppick's book, threaded with meditative prose, is entirely different: It is a story of deep time divided into chronological themes — air, ice, mud and heat.

Rocks between 2 billion and 3 billion years old contain clues regarding when and how oxygen first entered our atmosphere. Poppick goes to Minnesota to see rocks abundant in iron from that time of worldwide anoxia. For such iron deposits to exist, there must have been a time — about half of Earth's existence — *before* the ether held oxygen. The air billions of years ago set the stage for our existence and the way we live today, facilitating the formation of the iron we use for our "steel cars and kitchen appliances and medical devices and airplanes," she writes.

Around 540 million years ago, the Cambrian explosion of life occurred when almost every animal group existing today first came into being. Paleontologists track this evolution and how much was obliterated in mass extinction events by studying the fossils found in rocks.

Poppick details two of the Big Five major mass extinctions — one that happened 250 million years ago, and the next, about 50 million years later. Unlike the later dino-killing asteroid impact, both these die-offs seem to have been caused by immense volcanic eruptions in unfortunate locations. "The magma that welled up from the mantle sat directly beneath massive reservoirs of oil, gas and coal," Poppick explains. "As that



magma rose to Earth's surface, it burned and combusted those fossil fuels, releasing not only carbon dioxide but also toxic butanes and benzenes and ozone-depleting gases." This story of past catastrophes is a familiar one that may help us understand our sweltering future, "and how we might find a way out."

Modeling suggests that the seemingly endless summer in which dinosaurs ruled was hotter than it is today by between 14 and 25 degrees Celsius — between 25 and 45 degrees Fahrenheit warmer than we're used to. How did animals survive this hothouse? Poppick accompanied scientists to a secret site in Wyoming in search of remnants of the largest land animals that ever lived — long-tailed, long-necked sauropods like *Diplodocus*, *Brontosaurus* and *Apatosaurus*.

More than the bones themselves, these scientists are interested in the environment that nurtured these gigantic herbivores, and how it, and its denizens, changed over time. They've been studying ecosystems in the Morrison Formation — layers of sedimentary rock from New Mexico to Montana and beyond that have "spilled out more dinosaur bones than any other rock formation on the continent." It took about 9 million years for these rocks to be deposited, and so they contain 9 million years of dinosaurian history. "By way of comparison, just twelve million years or so of evolution produced humans, gorillas and chimps from the same common ancestor," Poppick notes.

Scientists studying the Morrison's layers puzzle out how sauropods and other dinosaurs flourished in that Jurassic warmth. "As we inch closer to a clearer picture (of that time), we deepen the intimacy with which we know Earth and its capacity to withstand heat," Poppick writes.

But to truly inhabit the Morrison, we should turn to a book published in February 2025. In *When the Earth Was Green*, science writer and paleontologist Riley Black infuses data with artistry to help us experience what ancient ecosystems might have felt like. Each chapter is written as a vignette accompanied by an appendix "detailing what we think we know, what we might guess at, and what simply struck (the writer's) fancy."

When Black imagines Utah 150 million years ago, we don't poke at the Jurassic leftovers that Poppick visited in Wyoming. Instead, we go time-traveling.

Black follows a hungry *Apatosaurus* feeding in a vast woodland, consuming carpets of horsetail and an ancestor of today's famously stinky ginkgo tree. The animal's long muscular neck lets her reach high into the canopy and down to the ground, while her great size protects her from being too bothered by predators.

"The fact that she exists at all is a testament to the strange nature of her habitat," with its towering conifers rising from a sea of ferns and cycads. Without this salad bar, sauropods could not have grown so big. This, Black tells us, "is an evolutionary dance between herbivores and plants."

Black's previous book, *The Last Days of the Dinosaurs*, explored the fifth of the Big Five extinctions in heart-wrenching detail by seconds, minutes, hours, days and years. In *When the Earth Was Green*, she focuses less on catastrophe and more on a day in the life of the creatures and plants that nudge each other as they co-evolve, leaving remnants of their intertwining stories sheltered in rocks.

With McPhee, you're on a road trip in the 1970s with a journalist and your weird geologist uncle who yells stuff like "*Shazam*!" when he sees cool rocks. You may not get all their jokes, but the ride is wild. With Poppick, you step through deep time by joining field trips, participating in research and visiting labs. This is how science happens — and it's surprisingly fun. Meanwhile, Black thrusts readers into almost dreamlike landscapes with her vivid descriptions of long-vanished worlds. She uses her imagination and knowledge to help you experience deep time.

"Our planet seems to be telling us to take a look back," Poppick writes. Each of these books help us do that, guiding us through deep time and prodding us to consider our place within it.

Alka Tripathy-Lang is a geologist and science writer based in Chandler, Arizona.

10 Wyomings

The oldest rocks in the Western U.S. tell stories of the Earth's history.

By Marcia Bjornerud
Illustrations by Jill Pelto

SOURCE: ROCKD APP

FOR MANY OF US HUMANS, OLD TREES — gnarled oaks or towering redwoods — are sources of psychological comfort. As elders who have weathered earlier times of crisis, they signify continuity and resilience. Their rings bridge present and past and remind us that our "now" is only one of many.

But for longer-distance time travel, we must seek out even more ancient ancestors. The ones with the longest memories, full of insights germane to our Anthropocene anxieties, are right here in our midst: the rocks beneath our feet. Although rocks have an understandable reputation for taciturnity, they are, in fact, speaking to us all the time, sharing their recollections about Earth's past, ready to reward patient listeners with perspective-altering memories. They represent Natural Intelligence — a mature counterpoint to the artificial kind.

Wyoming is an especially good place to listen to stories from deep time, because the rocks exposed at the surface include the oldest in the Western U.S. and span almost 80% of Earth's history, from 3.5 billion years ago to the present — among the longest and most continuous records of any place on the planet.

Those who spend enough time in the company of rocks may begin to feel that they are in dialogue with them. I am one of those: For 40 years, I've studied the language of rocks and found them to be wise mentors and matchless storytellers. Seeking existential reassurance at a disheartening time, I recently asked 10 Wyoming rock formations to share accounts of the Wyomings they knew when they were young.

Wyoming's oldest rock, the **Sacawee Gneiss***, was crystallized from magmas derived from melting of still older granitic rocks, none of which survive today.*

Sacawee Gneiss

FIERY FOUNDATIONS

Age: ca. 3.45 billion years (Paleoarchean Era)
Exposure: Granite Mountains

Sacawee: Hi. I'll go first because I was here first. I'm the original Wyoming. I've seen the planet itself change. Earth was utterly different in my youth: much hotter than today, roiling and restless, hadn't even fully adopted the practice of plate tectonics yet. The Earth I was born into had magmatic activity everywhere, no proper continents, just a few dozen islands of granite.

The only mementos I inherited from my ancestors are some crystals of zircon that survived from their own youth. I've offered some of those up for analysis.

Marcia Bjornerud: Yes, thanks for those. Zircon crystals are like tiny time capsules. We've figured out how to calculate their ages as the uranium in them slowly decays to lead. Some of the zircons you gave us record the time when you crystallized; that's how we know how old you are.

Sacawee: There were a bunch of us born around that same time. I have siblings in southern Minnesota and northern Michigan.

MB: I've met them: the Morton and Watersmeet Gneisses.

Sacawee: Yes, OK, I forget that you assign names to everyone. After we crystallized, we all went through the same arduous rite of passage below the Earth's surface — kneaded and folded almost to the point of dismemberment. Not something you mortals would survive.

As we warmed up and relaxed, we flowed and took on new forms — in truth, it was thrilling. Deformation and metamorphism left us with these spectacular stripes, which I wear proudly.

What we didn't realize then was that we were becoming the foundation for one of the first real continents.

MB: We call it the Superior Craton.

Sacawee: Now *that's* a good name.

MB: I'm afraid it's not a description — it's a reference to the biggest lake in North America.

Sacawee: The biggest lake in *your* time.

MB: OK, the biggest for now! But it *is* a great lake.

Sacawee: Anyway, we Superior siblings stuck together until about 2 billion years ago. Then, under the new plate tectonic regime, I got separated from the others when the crust split along a great rift zone and an ocean opened between us. Our paths diverged for a while, but a couple hundred million years later, plate motions shifted, and they started heading back my way. We ended up running right into each other, with a great mountain range rising along the seam where we collided.

MB: We call that mountain range the "Trans-Hudson" belt. We need these names to keep track of so many earlier geographies, and need to consult so many rocks to get the whole picture. Other landmasses were annexed to the Superior Craton around the same time, and that's when modern North America really began to take shape.

Eventually, like all mountains, the Trans-Hudsons were leveled by erosion. Their roots peek out in today's Medicine Bow Mountains in southernmost Wyoming, but most of the great Trans-Hudson range now lies deep beneath the Dakotas and Saskatchewan, buried under younger rocks.

Sacawee: Well, it's safer down there. Up here at the surface, I've had a taste of what it must be like to be mortal; I've been sandblasted by wind, gouged by glaciers, dissolved by rain. I'm being reincarnated, slowly, as sediment, which may one day become sedimentary rocks.

MB: We mortals can only envy the infinite cycles of rebirth and transformation you rocks take for granted.

Sedimentary rocks are the methodical archivists of the rock kingdom, recording the ever-changing conditions at Earth's surface. The **Nash Fork Dolomite** *was deposited as calcium carbonate mud in the shallow ocean waters that split the old Superior Craton.*

Nash Fork Dolomite

EMPIRE OF MICROBES

Age: ca. 2.1 billion years (Paleoproterozoic Era)
Exposure: Medicine Bow Mountains

Nash Fork: My Wyoming was a water world. It was an energetic place, an exciting time. Tides were much higher because the Moon was closer. And the day was shorter — just over 19 hours — because the Earth was spinning faster. There were no land plants, but the waters teemed with photosynthesizing cyanobacteria, which had by then begun to change the atmosphere.

MB: That's what we call the "Great Oxidation Event" — a huge inflection point in Earth's history. Before that, the planet's atmosphere was essentially just "volcano breath" — mostly carbon dioxide and water vapor.

Nash Fork: In my time, microorganisms were still learning to use oxygen, evolving novel strategies for living. They formed great shallow-water collectives — vast, lumpy mats of diverse microbial species coexisting symbiotically, with the metabolic wastes of some serving as the nutrients for others.

You humans call them stromatolites. I've heard you describe their shape as "cabbage-like," which is a bit rude — stromatolites are remarkable, complex, robust systems. You could pick up a few lessons from them, such as how diversity and deep recycling are essential to durable communities.

MB: Your stromatolites are spectacular. Geologists have declared your outcrops a "no-hammer zone."

Nash Fork: Thank you for that, but I've noticed that most humans have a terribly biased, "size-ist" view of the biosphere — you don't seem to think anything of interest was happening until the first animals appeared about 550 million years ago. Well, single-celled organisms dominated the biosphere for *long* before that. After they ushered in the era of oxygen, they buffered the chemistry of the atmosphere and oceans, keeping the Earth on an even keel for the next 2 billion years.

It was only after animals emerged, with their gigantic appetites and elaborate food webs, that the carbon cycle became prone to destabilization and the biosphere vulnerable to mass extinctions. I'm sure some of the others will tell you those horror stories.

The ancient ocean documented by the Nash Fork dolomite disappeared in the tectonic collision that built the Trans-Hudson mountains. After that, erosion outpaced deposition, and rivers incised deeply into the bedrock, leaving an irregular surface called the **Great Unconformity***. In Wyoming, the Great Unconformity represents a gap in the geologic record of more than a billion years.*

● ● Great Unconformity

GHOST WORLDS

Age: ca. 1.7 billion-500 million years (Mesoproterozoic Era-Early Cambrian Period)
Exposure: Bighorn and Wind River ranges; Shoshone Canyon east of Yellowstone

Great Unconformity: Frankly, I'm surprised you're even interviewing me. Geologists generally treat me as a nonentity. I'm an un-rock, a cipher, just an irregular surface. But I'm actually pretty famous: People marvel at me in the Grand Canyon. It took a lot of patience to dismantle all that rock, erase mountains and become what I am. I feel like that merits respect.

MB: I think geologists do respect you, but you represent absence — negative space — and we're not good at reading that.

Great Unconformity: I admit that I have some big gaps in my memory. What I do know is that sea level have been pretty low in my time, because if it had been high, I would have been covered with water, and sediment would have collected instead of eroded.

Toward the end of the period the Great Unconformity represents in Wyoming, the planet experienced a long and extreme cold spell called "Snowball Earth." Massive glaciers covered the continents, even in the tropics. With so much of the world's water locked up in ice caps, sea level was exceptionally low. When at last the Earth warmed up again, the ocean rose dramatically, flooding the denuded continents. The **Flathead Sandstone** *records the steady rise of the seas across Wyoming's deeply eroded landscape.*

● ● Flathead Sandstone

AN ADVANCING BEACH

Age: ca. 520 million years (middle Cambrian Period)
Exposure: Bighorn and Wind River ranges; Teton Pass

Flathead: I'm part of a great sheet of beach sand, now hardened into stone, that blanketed the continent in the aftermath of that fearsome ice age. I have counterparts across North America, all draped over the Great Unconformity: the Tapeats Sandstone in the Grand Canyon, the Sauk Sequence in Wisconsin, the Potsdam Formation in upstate New York.

The Wyoming I encountered was a bit austere — still no land plants — but what a wonderful variety of rocks exposed at the surface: contemporaries of Sacawee and Nash, and many others. A real range of types and temperaments! I'm still in contact with all of them today, and I mean that very literally. Anywhere the Unconformity and I are exposed together, you humans can see where I met these different rock formations and get a glimpse of the land surface as it was in those days.

MB: Yes, it's always a thrill to find you stretched out atop the Great Unconformity. Each outcrop is a portal into Cambrian time.

We geologists have long admired the creamy beauty you and other Cambrian sandstones share — you're almost entirely quartz, which must have been eroded out of granites and gneisses like Sacawee. Your sheer volume attests to the enormous amount of igneous and metamorphic rock that had to be weathered to yield so much quartz.

Flathead: Another tip of the hat to the Great Unconformity. A lot can be accomplished in a billion years.

MB: Until quite recently, though, we tended to dismiss you quartz sandstones as, um, rather inarticulate. Quartz doesn't have a good memory of its origins, and it seemed there was no way to track where, exactly, all your sand came from.

Flathead: I know; it took you a while to notice that a fraction of our sand grains area made of zircon.

MB: We call these "detrital zircons" — sedimentary particles that came from igneous and metamorphic rocks, typically carried by rivers over long distances before being deposited. They're rare needles in vast "haystacks" of quartz. Learning to interpret them has been like discovering whole libraries we didn't know existed. They've made it possible for us to reconstruct long-vanished drainage systems at the continental scale.

And to think that until recently we thought quartz sandstones had nothing to say!

Flathead: It's fine. You're young, and we're patient.

Later in the Cambrian Period, sea level rose even further, and the Flathead beach sands were buried by deeper-water carbonate rocks. Eventually, Earth's climate cooled, and the seas retreated again, exposing the landscape. The **Tensleep Sandstone** *records this re-emergence.*

Tensleep Sandstone

DESERT DUNES

Age: ca. 2.1 billion years (Paleoproterozoic Era)
Exposure: Medicine Bow Mountains

Tensleep: I'd like to point out that not all sandstones were laid down by water. I'm a sandstone, too, and my Wyoming was a barren dune field. Land plants existed in my time, but not in the desert where I was born. All I remember is the merciless wind — cruel and unrelenting. Look closely at my quartz grains — they're pitted and scarred to the point of opacity. Eventually, another sea rose and shielded me from that torment. What a relief! Then I had a few hundred million years of blissful sleep — until you humans discovered that I contain oil and started perforating me with drill holes.

MB: That water you speak of — the Phosphoria Sea on the western edge of the continent — was both your salvation and your nemesis. Without it, you probably would not have been buried and preserved in the rock record, but its exceptional biological productivity later made you a target for Anthropocene capitalists — because over time, that rich organic matter decomposed into petroleum that seeped down into your permeable dunes, now tapped by countless oil and gas wells.

Wyoming was still on the edge of the continent during this time: The sea that rose and shielded Tensleep formed a deep basin in parts of present-day Idaho, Utah, Nevada, Montana and western Wyoming. Upwelling coastal currents carried nutrients into the shallow waters and fostered an unusually rich marine ecosystem. The **Phosphoria Formation** *records this time of exceptional biological productivity.*

Phosphoria Formation

BIOLOGICAL BACCHANAL

Age: ca. 290 million years (early Permian Period)
Exposure: Outcrops along Hwy 191 north of Jackson and Hwy 28 south of Lander

Phosphoria: Let me tell you about that bountiful sea; its warm, sunlit waters deposited organic-rich mud that hardened into my shales and limestones. My Wyoming was a tropical marine paradise. Waters absolutely teeming with organisms: brachiopods, sea snails and sponges covering the seafloor like a living carpet; phytoplankton thriving at the surface, feeding exuberantly on nutrients from deeper waters.

MB: In a state of "phosphatic euphoria" — that's what I think of when I hear your name.

Phosphoria: About right. Oh, and the *fish*! So many sizes and varieties, schooling and darting. I managed to collect and preserve many of their scales. And there were some real weirdos — like those big bizarre ones with crazy tooth whorls on their lower jaw.

MB: Oh, my gosh, yes — we've named them *Helicoprion*. The name means "spiral saw." That fearsome coil of teeth might have been good for ripping through soft-bodied prey.

Phosphoria: Of course, what we didn't know then was that our beautiful ecosystem and most of its members were doomed. The entire world was about to crash.

MB: Yeah, the end-Permian extinction; I didn't want to bring it up. Great eruptions of lava in what is now Siberia spewed an enormous amount of carbon dioxide into the atmosphere, setting in motion a perfect storm of environmental calamities — abrupt global warming, ozone destruction, ocean acidification and anoxia, eventual ecosystem collapse — the most severe mass extinction in Earth's history.

Phosphoria: I'm glad I remember the world before all of that happened.

MB: Well, we in the Anthropocene have studied that world and its biodiversity with great interest, but mainly, I must admit, to plunder it. Your phosphate-rich shale deposits, some of the largest in the world, have been strip-mined for fertilizer, and the remains of your exuberant phytoplankton fuel our oil-driven economy. In a terrible irony, our dependence on ancient ecosystems like yours is leading us toward a reenactment of the Permian catastrophe.

The Permian extinction was a near-death experience for the biosphere. At least 80% of known marine species, including many in the Phosphoria Formation, went extinct. In Wyoming, the **Chugwater Group**, *easily recognized by its intense red color, records what happened next.*

Chugwater Group

POST-APOCALYPTIC LANDSCAPE

Age: ca. 240 million years (Triassic Period)
Exposure: Wind River and Bighorn mountains; Powder River Basin; Red Canyon Overlook

Chugwater: The world didn't end after the Permian extinction. My Wyoming was hot and dry, and vegetation was sparse. Rivers coursed across the arid landscape in braided patterns, dropping sand and silt along the way. Sometimes water pooled in brackish basins, and their brines permeated my river sediments, forming white lenses of gypsum.

MB: Although I know you represent that inhospitable environment, your brilliant red-orange hue always seems so warm and welcoming. Your color makes you easily seen from space! Wherever you crop out, you brighten the landscape.

Chugwater: That's sweet of you, thanks. I owe my vermillion to trace amounts of oxidized iron — or, let's just call it what it is: rust. Doesn't take much rust to stain everything!

MB: True, and it doesn't take much oxygen to make rust. We think that oxygen levels remained low for millions of years in the aftermath of the Permian apocalypse; marine photosynthesizers struggled to re-aerate the oceans. And some paleontologists even think that the reason dinosaurs gained an edge over other reptile groups was that their respiratory systems — which they passed on to modern birds — allowed them to breathe more efficiently.

Chugwater: In fact, I've got some of the oldest known dinosaur fossils in North America. My environmental circumstances made it difficult for me to hold on to entire skeletons, but I've preserved a few bones.

MB: Don't be so modest: Your fossils of a silesaurid femur and humerus have recently overturned the long-standing idea that dinosaurs were limited to the Southern Hemisphere until Jurassic time.

The **Morrison Formation** *is famous around the world for its dinosaur fossils.*

Morrison Formation

JURASSIC PARK

Age: ca. 50 million years (Jurassic Period)
Exposure: Como Bluff near Medicine Bow; Hwy 120 north of Thermopolis or north of Cody

Morrison: Yes, I've got the dinosaurs. Herbivores like stegosaurs, camarasaurs, apatosaurs and diplodocus, but some meat-eaters too, mainly allosaurs. Drives me crazy, by the way, that most of the dinos in the *Jurassic Park* movies are actually Cretaceous species, 80 million years younger than me.

My Wyoming was warm and semi-arid — I've been told it was a "Mediterranean climate," though of course the Mediterranean Sea didn't exist then. Flowering plants weren't around yet, but gymnosperms like ginkgo and cycads grew everywhere and managed to feed all those huge plant-eaters. Like Chugwater, I'm made of the fine-grained deposits of rivers and lakes that attracted thirsty creatures.

MB: The dinosaurs' melodramatic demise gets as much press as the creatures themselves. We humans seem to project our own fears onto the cataclysms of the past. The asteroid impact theory gained traction in the late Cold War years when the specter of nuclear holocaust loomed large in the public psyche.
Today, almost all geologists agree that a large rock from space did strike Earth at the end of the Cretaceous, but there is an emerging view that other factors — including a spike in greenhouse gases from volcanoes in India — also wreaked havoc on late Cretaceous ecosystems.

The periods just before and just after the dinosaur extinction 66 million years ago are well represented in Wyoming's rocks and landscapes. Around that time, over an interval of about 30 million years, an unusual tectonic episode called the Laramide Orogeny thrust up the mountains people think of as "The Rockies": the Bighorn, Wind River, Beartooth, Uinta, Granite, Laramie and Front ranges.

In most mountain-building events, the tectonic action is close to the site where two tectonic plates converge. The strange thing about the Laramide ranges is that they rose 800 miles inland from the plate boundary off the coast of Oregon and California. This probably had to do with the difficult subduction of an oceanic plate called the Farallon, which was apparently too buoyant to sink into the mantle, the vast region that lies beneath Earth's crust. The Farallon seems to have scraped along the base of the North American plate without encountering too much resistance until it hit the deep crustal roots beneath Wyoming — the ancient craton forged by the Sacawee Gneiss.

While this tectonic upheaval was happening, seas rose and fell, a massive space rock struck Earth, the dinosaurs perished and, eventually, the world experienced a period of dramatic upsurge in the concentration of carbon dioxide in the atmosphere and abrupt warming known as the Paleocene-Eocene Thermal Maximum. The **Green River Formation** *— considered by many Earth scientists to be a "distant mirror" for our own time — recorded the aftermath of this event.*

● Green River Formation

HOTHOUSE WORLD

Age: ca. 50 million years (Eocene Epoch)
Exposure: Fossil Butte National Monument

Green River: My exquisite fossils of leaves, insects, fish and amphibians are sold in rock shops around the world. They preserve exceptional anatomical details, sometimes even of soft tissues. And, hey, Nash Fork, I also have freshwater stromatolites! I accumulated as muddy sediment and organic matter at the bottom of a chain of ancient lakes, and I preserve detailed records of the plants and animals living in the water and along the shores.

My Wyoming was subtropical — hot and steamy. Even though the latitude was pretty close to what it is now, there were palm trees and crocodilians.

MB: Where pine trees and grizzly bears live today! That shows the power of greenhouse gases to govern climate. Somehow, long before fossil-fuel burning humans existed, gases from hydrocarbons were released in immense volumes. One possibility is that magmas erupting from the rift that opened the north Atlantic Ocean ignited coal beds. Another possibility is that massive amounts of methane were belched from the seafloor.

Green River: Well, I can't pin down the source of all that CO_2, but I can give you a quantitative estimate of its concentration in the atmosphere. My beds include a rare sodium bicarbonate mineral that only forms from evaporating waters when carbon dioxide levels are greater than about 700 parts per million.

MB: Wow — 700 ppm! That's much higher than our current value of 425 ppm, and we humans evolved in a world where CO_2 concentrations had never exceeded 350 ppm. Today, unfortunately, we're hurtling toward your number.

Green River: Thanks to some of my own coal seams and oil shale.

MB: Yes, the irony. Those who don't know the geologic past are doomed to repeat it.

Green River: We haven't really talked about the tectonic upheavals I saw. My lakes formed in the shadow of some of the great mountain ranges raised in my time — the Wind Rivers and Uintas.

Even as the mountains were growing,

erosion tried to tear them down, and thick piles of sediment accumulated between the ranges, including in my lake basins.

MB: And erosion "unburied" everyone else here, making all of you accessible to those of us who live at Earth's surface now. I'm grateful — otherwise we'd never have met.

Green River: Yes, it was exciting to see so many great rocks reappear, out in the elements being eroded again, perhaps becoming part of new formations. Coming full circle!

MB: Ah, that's a nicer perspective: Those who know the geologic past are *blessed* to repeat it.

Nearly 50 million years later, northwestern Wyoming experienced a round of explosive volcanic activity as the region drifted over a "hot spot"— a rising plume of semi-molten rock — in Earth's mantle. Three massive eruptions created what is now Yellowstone National Park. **The Huckleberry Ridge Tuff** *formed during the first and largest of these events.*

● Huckleberry Ridge Tuff

ASHES, ASHES

Age: ca. 2.1 million years (Pleistocene Epoch)
Exposure: Yellowstone National Park

Huckleberry Ridge: I guess I'm the youngster here, barely a rock, made almost entirely of volcanic ash. I'm the yellow stone of Yellowstone. As the product of an infamous "supervolcano," I'm viewed like a supervillain in a comic book. People are both fascinated and horrified by me — but they also don't quite believe that I'm real.

In the eruption that formed me, the ash column reached 30 miles into the atmosphere, emptying the magma chamber and leaving behind a giant depression, the Yellowstone caldera. The total erupted volume was almost 600 cubic miles. Two other massive eruptions followed in the next million and a half years. A recurrence, which is possible, would completely shut down all human activity in the midcontinent. It would be bad.

To be candid, however, I think you humans have more immediate concerns to attend to. I came into being during the last ice age, and have seen my share of climate oscillations. But the rapidity of changes in the past hundred years scares *me* — and I'm the supervillain!

MB: Thank you for your frankness; it's pretty sobering. And sincere thanks to the whole group. I'm deeply grateful to everyone for sharing your stories. So many Wyomings past, still very much present! It's a comfort and joy to feel your enveloping company — worlds within worlds. You remind us that landscapes aren't timeless — they're time*ful*.

The history you tell of is thrilling: continents forming and breaking up, oceans coming and going, ecosystems rising and falling, never-ending cataclysm and rebirth, the world continuously remaking itself.

But it's hard to know what to make of these narratives. Given everything you have seen over time, what advice can you give us humans? We are trapped in broken systems of our own making, paralyzed by discord and disillusionment. We're not sure how to know what is true anymore. Can you help?

Hello — is anyone there?

Have I been talking to myself?

Marcia Bjornerud, professor of geosciences at Lawrence University in Wisconsin, studies the physics of earthquakes and mountain building. Her books for popular audiences include Reading the Rocks, Timefulness, Geopedia *and* Turning to Stone.

LESSONS FROM AN

PRONGHORN OUTRAN THE PLEISTOCENE. CAN THEY GUIDE US THROUGH THE ANTHROPOCENE?

BY EMILENE OSTLIND

ONE SUNNY JUNE morning, I parked at a roadside pullout in western Wyoming and walked out into the sagebrush. Suddenly, two pronghorn fawns sprang up, almost out from under my feet, and sprinted away, zigzagging across the landscape at top speed. They were all spindly legs, their jackrabbit-sized bodies a blur. In a few seconds, they were hundreds of yards away and hidden from sight.

If they survived the summer and reached adulthood, they would become some of the fastest land animals on Earth. Adult pronghorn, a bit smaller than deer, can run seven miles in just 10 minutes, achieving short bursts of nearly 60 mph, much faster than horses or wolves. With their long thin legs and oversized hearts and lungs, they are built to cover ground in the wide-open sagebrush basins of Wyoming, my home state. Here, they have nibbled shrubs, dodged predators and flourished for tens of thousands of years.

Today, however, they must navigate rural housing and energy development, along with all the fences and highways that crosshatch their world. And habitat fragmentation isn't the only threat they face: The West is already much warmer than the ancient environment in which they evolved, and it's getting hotter every year.

The world where pronghorn have long lived — the world where I grew up and where I'm raising my children — is rapidly changing. Drought hits more often; winters are less snowy. Spring melt comes earlier, and streams run lower in late summer. We have fewer frost days, hotter summers, fiercer storms. The shifting temperatures and unpredictable precipitation mean that conifer forests are drying out, burning and dying, while rangelands are succumbing to invasive fire-adapted grasses. In 2024, over 1,300 square miles of Wyoming burned, more than double the acreage of other recent big fire years. Pronghorn feel these changes, too.

ICE AGE SURVIVOR

Take the pronghorn in northeast Wyoming's Powder River Basin, a vast furrowed sea of grass and shrub-covered bluffs more than 100 miles across. When lightning sparked a fire at its western edge in August 2024, high winds whipped the flames into a raging inferno that blackened hundreds of square miles in a day. Once the evacuation orders were lifted, ranchers returned to find that places long woven into their lives had been scorched almost beyond recognition. As the burned area cooled, wildlife managers and landowners discovered at least 70 dead and dying pronghorn, some lying near fences and others out in the open where the fire had overtaken them. North America's fastest land animal had been unable to outrun the flames.

When I read about those dead Wyoming pronghorn and saw photos of the charred earth stretching for miles, I thought about the future my kids will inhabit. In September 2018, I brought my first child home from the hospital under skies stained brownish orange from lingering wildfire smoke. I can't predict what this landscape will look like decades from now, but I know it won't be the same. My children will grow up in a world very different from the one we have lived in for generations.

This is not the first climatic shift pronghorn have faced, however. Their earliest North American ancestors appeared in the fossil record during the Miocene, some 20 million years ago, when the planet was warmer than it is today. Modern pronghorn evolved here later, during

A herd of pronghorn move south for the winter outside Pinedale, Wyoming. Their migration corridor is squeezed between the Green River and rural housing to about one-eighth of a mile wide, one of several bottlenecks along their route from Grand Teton National Park to Wyoming's Red Desert. **Joe Riis**

Paleoclimatologist Bryan Shuman at the University of Wyoming Geological Museum. **Jimena Peck / HCN**

the much colder ice ages. Some 12,000 years ago, the ice ages ended and North America suddenly warmed up. When that happened, most large mammals died out. But not pronghorn; they held on and adapted to the new conditions.

Researchers say that climate change may lead to "state shifts," where entire ecological systems — pine forest, say, or sagebrush steppe — are transformed into another. Will pronghorn survive a whole new set of climate-driven changes the way they did 12,000 years ago? Will we?

Perhaps the ancestors of the twin fawns that darted away from me that June day can help us answer those questions. If we can figure out how pronghorn survived, we might be able to learn how their descendents, and ours, can adapt to our unknowable future.

WILL PRONGHORN SURVIVE A WHOLE NEW SET OF CLIMATE-DRIVEN CHANGES THE WAY THEY DID 12,000 YEARS AGO? WILL WE?

WHEN SPRING SNOWSTORMS sweep through southeast Wyoming, I see groups of pronghorn at the edge of town, near the airport, bedded down beyond the highway right-of-way fences and peering through the sideways-blowing snow. They're migrating from their winter habitat toward their lusher summer fawning grounds, perhaps in the foothills of the mountains.

With their large eyes and antenna-like horns, pronghorn seem almost alien. But they are not so much from another world as from another time, remnants of the once-vast assembly of strange, now-extinct creatures that long ago roamed the icy, windswept basins of North America. I wanted to know more about the climate, plants and animals of those ancient times.

On the second floor of the University of Wyoming Geological Museum, a 10-foot-wide mural depicts the Laramie Valley during the Pleistocene, the series of ice ages that occurred between 2.58 million and 11,700 years ago. In a view looking toward the mountains from a bluff outside what is now my hometown, a muscular saber-toothed lion snarls at a massive bison whose long horns extend sideways like spears. Three mammoths with curved ivory tusks and heavy fur robes look on warily. Small scrubby plants blanket the tundra and a fringe of willows lines the Laramie River. Beyond it, glaciers reach down the drainages of the treeless Medicine Bow Mountains. Deep ice and snow cloak the mountain range, with familiar rocky peaks jutting into the sky above.

I found paleoclimatologist Bryan Shuman in a nearby university building, where he was settling into a new office. Boxes of books and papers surrounded his desk, their sedimentary layers containing stories of the past. A professor in the UW Geology and Geophysics Department, Shuman examines microscopic particles in lakebed sediment cores and diagrams ancient lake shores, piecing together the hydrology, climates and ecologies of environments as far back as the late Pleistocene.

Laramie is known for its cold temperatures, but Pleistocene Laramie was even colder. Shuman's research shows that here in the

Central Rockies, where more than a third of the world's pronghorn live today, year-round average temperatures during the coldest periods of the Pleistocene were as low as 18 degrees Fahrenheit colder than now — cold enough for the ground to freeze into wedges of permafrost that left polygon-shaped patterns on the ground, still visible outside of town.

The mural's depiction of ice and plant cover rings true. "We know glaciers were much more extensive," Shuman said. "There's very clear geomorphic evidence where the glaciers were." Not many trees lived in that frosty environment. Shuman showed me a graph plotting the temperature over thousands of years next to pollen meticulously extracted from lakebed mud layers. "You can see when it was really cold, it was mostly a grass- and sagebrush-dominated landscape," he said. Researchers have also found pollen from willows, perhaps similar to the low, shrubby willows that blanket the Arctic today.

The landscape was drier than it is today, too. Shuman uses ground-penetrating radar to map past lake shorelines as a clue to how wet the landscape was. "We are living in an unusually wet time. … This is probably the wettest time in the last 20,000 years, at least," for our region, he said.

The late Pleistocene here was also windy and "really dusty," according to Shuman. Glaciers pulverized rocks into silt that washed out with meltwater, dried and blew away. The Pleistocene wind eroded hollows in Wyoming, shaped dunes in the Great Plains, and deposited thick layers of glacial dust for hundreds of miles throughout the Midwest.

I tried to picture pronghorn, like those huddled against modern-day spring snowstorms, moving through an ancient landscape even colder, drier, windier and dustier than today's.

PLEISTOCENE PRONGHORN had more to worry about than the weather. Fossils show that even in that harsh environment, several of the big, strange predators that thrived in Wyoming hunted them — *Miracinonyx*, for example, the American cheetah, a 160-pound relative of the mountain lion with long legs ideal for running down and grappling with its prey. There was also the vicious American lion, at up to 1,000 pounds one of the largest cats ever to roam the Earth, and the powerful Beringian wolf with its heavy jaws and big teeth. Paleontologists examined isotopes in their fossils and found evidence that all three ate pronghorn.

Their bones were preserved in Natural Trap Cave, a vertical, bell-shaped cavern on the western flank of the Bighorn Mountains in northern Wyoming, whose opening is an oval hole about 15 feet across. Over the last 47,000 years, animals have stumbled into the hole and fallen more than 80 feet into the cave, where they either died of their injuries or starved. Since no scavengers could reach the carcasses, complete skeletons remain inside Natural Trap Cave, disturbed only by rising water or falling rocks. The cave's steady 42-degree Fahrenheit temperature preserves both DNA and bones.

Julie Meachen, a vertebrate paleontologist from Des Moines University in Iowa, has led a Natural Trap Cave research team since 2014. At the start of her first field season, she bumped up a rough four-wheel-drive road to the cave, where an experienced caver set up a rope system. "I was a little intimidated by rappelling in 80 feet," she told me. "I had never done anything like that before."

As Meachen lowered herself slowly into the cavern's mouth, she saw bones poking out of the walls. Researchers in the 1970s and '80s had found the remains of camels, cheetahs, horses and even mammoths in the cave, but no one had been inside it for decades. "We just knew that it was a treasure trove of fossils," she said.

Alongside the bones of Pleistocene lions, wolves and bears, paleontologists in the 1970s and '80s found pronghorn remains that were between 17,000 and 20,000 years old and indistinguishable from those of their modern descendants — along with evidence of at least 14 other large mammal species. There were modern bighorn sheep and coyotes, extinct Pleistocene herbivores that resembled stilt-legged horses, musk oxen and camels — even giant short-faced bears more than twice the size of modern grizzlies.

This past summer, Meachen's crew dug up a scapula, ribs and several vertebrae from a mammoth, whose skull may still be hidden under the dirt. The bones belong to one of at least three mammoths that fell into the cave during the Pleistocene, said Meachen.

Todd Surovell, an archaeologist at the University of Wyoming who studies hunter-gatherers, has worked on mammoth dig sites in Wyoming and written about late-Pleistocene extinctions. When I stopped by his campus office, he passed me a small Ziploc bag holding a walnut-sized piece of bone, smooth creamy white with jagged brown ripples on one side.

Natural Trap Cave near Lovell, Wyoming. Thousands of animals have fallen into the cave and perished there since it formed, making the site a treasure trove for paleontologists. **Mike Clark / The Billings Gazette**

"Mammoth ivory," he said. This particular tusk shard was from Alaska, he added, but "Columbian mammoths, there's a lot of them in Wyoming." Columbian mammoths — the biggest species of mammoth in the Americas — ranged from Canada to Mexico along the front of the Rockies."Just tons of mammoths," Surovell said.

I picture one of those 22,000-pound giants twisting its trunk around a tussock, stuffing grass into its mouth, its 16-foot-long tusks sweeping through the air while pronghorn tiptoed past, trying to evade lurking lions and bears. Such scenes played out for tens of thousands of years — until something drove most of those animals to extinction.

ON A GEOLOGIC TIMESCALE, the 7,000-year transition from the deep ice age to the Holocene, the epoch we're still in today, happened in an instant. But for pronghorn, the changes unfolded over many hundreds of lifetimes.

Around 17,000 years ago, the Earth's axis, which slowly wobbles on a 41,000-year cycle, was moving toward maximum tilt, letting in more summer solar radiation. The ice caps started melting, and as the white, reflective ice retreated poleward, the darker ground surface absorbed more heat from the sun. Shuman, the paleoclimatologist, pointed me to a textbook, *Earth's Climate: Past and Future*, which I pored over for days, trying to wrap my head around the end-Pleistocene warming and how scientists have studied it.

I learned that as the ice caps melted, an enormous amount of fresh water poured into the oceans, taking sediment and dust with it and eventually raising the sea level some 360 feet. All that water shifted currents and warmed the oceans, causing them to release carbon dioxide. Rising atmospheric carbon dioxide created a greenhouse effect, trapping heat from the sun and causing further warming.

"This chain of orbital changes, ice sheet changes, dust and ocean changes, all causes carbon dioxide to go up and down," Shuman said. Carbon dioxide, he added, "is probably the biggest single hammer on the system."

By about 10,000 years ago, atmospheric carbon dioxide had risen more than 40%, warming the planet by 7 to 11 degrees Fahrenheit. The center of North America got wetter. Grasslands became less dusty and arid; forests marched northward. Pine, spruce and fir flourished, according to pollen records. But what was good for trees was not necessarily good for megafauna. "A lot of the big things that used to be here just didn't survive," Meachen said.

Of the many dozens of large mammals that roamed Pleistocene North America, at least 59 — and possibly far more — went extinct. (Only 26 are still around today.) By one analysis, 72% of large mammal species disappeared from the continent, everything from horses and mammoths to giant beavers and ground sloths, as well as many predators.

"The bigger you are, the more likely you are to go extinct," Surovell said. "Very few small things go extinct." One analysis that he co-authored in 2009 found that it's likely all those animals died out between 13,800 and 11,400 years ago — a mere flash in the geologic time frame. I asked him what's changed since that paper came out. "It's only gotten stronger, the evidence."

Why so many large land mammals died out all at once is a great mystery, long debated and still unresolved. Scholars continue to investigate potential causes, ranging from the influence of humans to a possible asteroid impact or a disease that jumped between species. But scientists generally agree that abrupt climate change played a major role in driving down biodiversity.

AMONG THE SURVIVORS, one of the animals that has been here the longest is the pronghorn antelope. Antilocaprids have been on the continent more than four times longer than the cervids; the ancestors of deer, elk, moose and caribou entered North America around 4.8 million years ago. Ancestors of modern bovids — bison, bighorn sheep, mountain goats — showed up a mere 2.5 million years ago. But modern pronghorn, the only living descendant of the first Antilocaprids, are unique to North America, having evolved to thrive right here.

"In fact, they were survivors," said Christine Janis, professor emerita of ecology and evolutionary biology at Brown University. She studies animal evolution related to climate change over the past 20 million years and has authored many influential texts on fossil Antilocaprids and other

Julie Meachen helps set up a grid to document where fossils are found in Natural Trap Cave in 2021. **Mike Clark / The Billings Gazette**

An exhibit case on pronghorn in the UW Geological Museum (*right*). A pronghorn traverses fencelines in Gillette, Wyoming (*opposite*). **Jimena Peck**

hoofed mammals. The pronghorn's ancestors made it through earlier extinctions of ancient deer-like animals around 5 million years ago, she told me. "They survived along with things like horses and camels until all these guys went extinct at the end of the Pleistocene."

No one knows exactly how they did it, but everyone I asked had a theory. Meachen cited their ability to live with little water. "They were able to eat dry, scrubby vegetation that other big herbivores, like horses and bison, were not able to eat and make use of, and they were able to do that and have less water stress than other animals," she said.

"You know," Surovell added, "another thing that they probably benefited from was the extinction of the American cheetah."

Janis credited pronghorn's high-crowned teeth with enabling them to live on low-growing, gritty browse. Teeth that extend well above the gumline have plenty of room to slowly wear down, even if the animal spends its life chewing dusty Pleistocene plants. She also noted their small size, which allows them to reproduce faster than bigger animals. Whereas a huge camel or mammoth might have just one calf every few years, pronghorn typically have two fawns each spring. She put the survival lesson from pronghorn succinctly: "Be small and be adaptable in your diet. That's a good way to survive."

"BE SMALL AND BE ADAPTABLE IN YOUR DIET. THAT'S A GOOD WAY TO SURVIVE."

PRONGHORN HAVE SURVIVED many changes so far, and there's more to come. Each year, it seems, Earth's surface temperatures set new records for the hottest since record-keeping began. The greenhouse gases we are adding to the atmosphere today are expected, over the next 75 years, to drive a shift in global average temperatures far more rapid than the one that, over a span of 7,000 years, ended the ice ages, shrank the ice sheets, melted the permafrost and glaciers and transformed tundra into forests, in the process wiping out so many large mammals. "That's the type of magnitude change we're talking about," Shuman said, "except it's going to keep going into a warmer direction that's still hard to imagine."

The future feels precarious, both for pronghorn and for us. Planetary changes are happening at a speed likely not seen since an asteroid killed the dinosaurs some 66 million years ago. Can we adapt our own living systems to such rapid and massive changes?

As an inhabitant of this place and the mother of two other Wyomingites, I can barely stand to consider that question. Still, studying how pronghorn survived has shifted my perspective in some ways. I'm glad I didn't live in the arid, treeless, bitter cold of the deepest ice ages. I know that in places, increased precipitation has helped forests and even some animals, including pronghorn, thrive in these warmer modern times. I know that the Earth has sustained life for billions of years through many climates, from periods warm enough to support palm trees and crocodiles in Wyoming to millennia locked in snow and ice and back again. Part of the wonder of our planet is its dynamism and the way living systems continuously adjust. I know that, more easily than most animals, my children can alter their diets and, like pronghorn, survive in a range of climates and environments, even moving to new habitats if they must.

When that rangeland wildfire torched nearly 275 square miles in Wyoming's Powder River Basin in 2024, the 70 pronghorn that died left tens of thousands of survivors in the area. Those survivors birthed new fawns and fed on the green grass that sprouted in the burned areas the following spring.

Perhaps the lesson from pronghorn is not to yearn for the past or worry over the unknown future, but to face the day with attention and quiet care, noticing shifts in the wind and scents in the air. Pronghorn tell us to know our home habitats deeply and to shape our own patterns and behavior to align with the forces of the land. They tell me to read changes in how the snow drifts, notice which plants emerge after a soaking thunderstorm and realize that each spring will be different from the previous. They tell me to teach my children to recognize birdsong, learn how animals come and go with the seasons, breathe deeply, and keep moving forward with my feet on the Earth.

Emilene Ostlind writes about wildlife, landscapes and people from her home in Wyoming.

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Seattle rocks

A trip through deep time in the urban cityscape.

BY DAVID B. WILLIAMS | ILLUSTRATION BY RAVEN JIANG

I LEAD TOURS into deep time. Specifically, I take people around downtown Seattle to explore the stone that makes up our buildings. On the corner of Second Avenue and Cherry Street is an elegant six-story structure built with two-foot-tall blocks of rough-hewn sandstone, about 44 million years old, quarried in Tenino, Washington. The building rose soon after much of downtown Seattle burned to the ground in 1889, and the jagged stone gives it a feeling of rugged permanence, certainly what the city needed after the great fire.

Nearby on Fourth Avenue, 330 million-year-old oatmeal-colored limestone from Indiana adorns a social club listed on the National Register of Historic Places. Peering through a hand lens, I can tease out a diverse array of fossil invertebrates in the stone: conical horn corals, poker-chip-like crinoid stems and pieces of bryozoans, a colonial invertebrate that resembles Rice Chex. And up the street and one block over, 1.6 billion-year-old granite from Finland clads a 44-story skyscraper; on sunny days, its jigsaw-puzzle texture of red, white, black, clear and veined crystals shines with refulgent beauty. Standing on the street, I see the shallow seas, inexorable tectonic shifts and roiling magma that produced these rocks and marvel at the persistent geological change of our 4.54 billion-year-old planet.

I first discovered deep time in the urban environment when my wife and I moved to Boston from Utah's red-rock country. My love for all things geological had begun in Utah. Exploring its sandstone canyons solidified my bonds to the natural world, grounding me in the deep past and helping me understand what made this otherworldly landscape. In Boston, I felt disconnected; the only regional geology I knew was Plymouth Rock. But eventually, I noticed the stone in Boston's buildings. When I realized that Harvard Hall's sandstone, what Easterners call brownstone, was the same material as my beloved Utah red rocks — iron-stained sandstone — I reconnected with the geologic world that meant so much to me.

Then my wife and I moved back to my hometown of Seattle. In the city's downtown, I came across a beautiful stone consisting of pink and black blobs, layers and swirls, what I imagine it would be like to mix bubble gum and brownie batter, on the side of the Exchange Building at Second Avenue and Marion Street. I recognized it as gneiss, a metamorphic rock forged by immense pressure and temperature, which often produces layers of dark and light rock. Known as Morton gneiss and quarried in Minnesota, the multihued rock looked as if it was still in motion. I was astounded to learn it was 3.52 billion years old.

Touching that ancient but easily accessible stone, I knew I was connecting with some serious deep time. I was reaching far back in our planet's history to a time when plate tectonics, the central driver of Earth's geology, may not have operated as it does at present. Microorganisms were the only form of life. No plants or animals; few of the colors and little of the diversity of today. This stone on the side of a building told a story of when Earth was still a youngster and the planet we know and love now was no sure thing.

Seattle is not unique. Go to any city, and you'll likely find a similar variety of rocks — granite, marble, limestone, sandstone, slate and gneiss — rivaling any assembled by plate tectonics within such a small footprint. Generally, pure white or mottled cladding panels are made of marble, while fine-grained ones, often layered and featuring fossils that can range from the size of a pea to a cinnamon roll, are sandstone or limestone. Multihued or salt-and-pepper stone tends to be granite. Any basic guide to rocks and minerals should help you identify rock types.

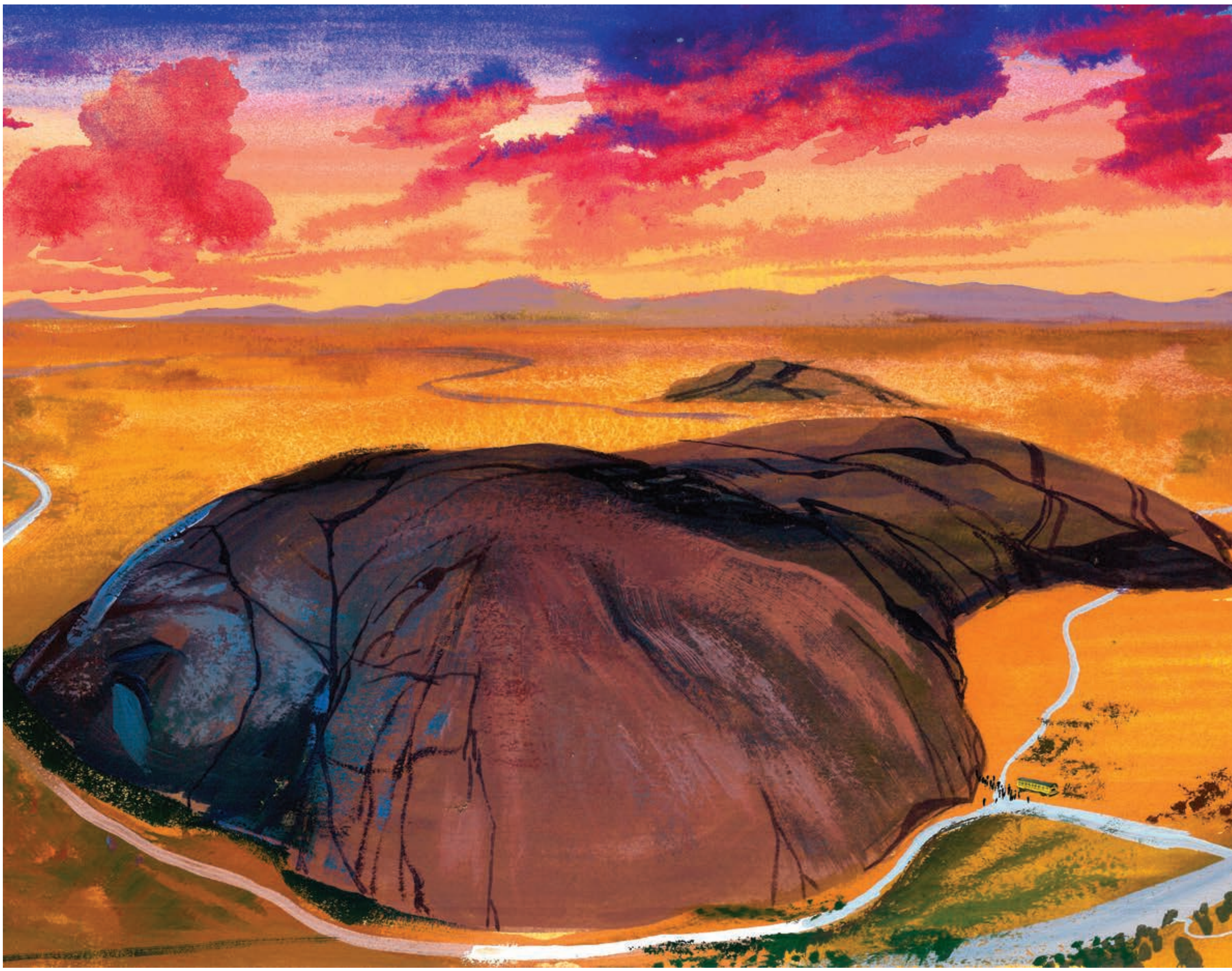
We are often told that the way to find nature is to go to the wild. But nature is all around us, even in the stones of our cities, for anyone willing to slow down and pay attention. And it's right in front of us, every day.

David B. Williams is a Seattle-based author whose books include Homewaters, Wild in Seattle *and* Stories in Stone. *He also writes the* Street Smart Naturalist, *a weekly Substack newsletter.*

This stone on the side of a building told a story of when Earth was still a youngster and the planet we know and love now was no sure thing.

TOWNSHIP AND RANGE

Exploring the intersection of race and family in the interior rural West.



Weathering time

How geology shapes the world, and us.

BY NINA MCCONIGLEY
ILLUSTRATION BY TARA ANAND

MY FATHER was a petroleum geologist. A lot of my childhood, he was gone, away on oil rigs in the Powder River Basin and remote parts of Wyoming, living in man camps long before cellphones. We had to wait days to talk to him. When he went into the nearest town to shower, he'd find a payphone and call us. I was always breathless with news.

"I got an A on my math test! I have a new crush on Matt! Sparky can now shake paws!"

My sister and I waited on the sidewalk when we knew he was coming home. We jumped up and down to greet him. He always smelled of gasoline and grease, and I carefully helped him carry his tools, the UV box and offset logs into the house. He brought me things he found on prairie walks: rocks, arrowheads, antlers and once, a piece of china from a long-abandoned homestead, optimistically decorated with a sprig of roses.

When I was in junior high, however, my father was suddenly around a lot more. There was an energy bust, and now it was my mother who worked long hours. Every morning, while my sister and I curled our hair and set it in a cloud of hairspray, my dad made us toast and drove us to school. At a traffic light he named "New Word Light," he taught us a new vocabulary word every day and asked us to use it three times that day. I still remember some of them: *troglodyte*, *ennui*, *pernicious*. Another corner was "Question Corner," where we could ask him about anything. My sister asked if there was a God, why is there hunger. I asked about the Vietnam War and what it was like to lose a parent. And on one of those drives he told me something incomprehensible: If Earth's history were compressed into a single 24-hour day, he said, humans would appear in only the last few seconds before midnight.

The last few seconds before midnight. And yet, in those seconds, we have left our mark.

WE TOOK REGULAR school field trips to Independence Rock, which we called the turtle of the prairie. It looks like a giant turtle shell nesting between sagebrush. It's an hour away from Casper, perfect for an elementary school day trip. We'd feel the wind shake the bus as we drove, and we ate a picnic lunch by the rock. It was where I learned to pee in the sagebrush.

My teacher solemnly explained that Independence Rock was known as the Register of the Desert; over 5,000 names were carved or painted on it during the Westward migrations. Pioneers, over half a million of them, passed through, and many of them literally left their marks on the rock. In 1961, the state of Wyoming designated it a national historic landmark.

The rock's highest point is 136 feet above the surrounding terrain, the height of a 12-story building. It covers 27 acres and is more than a mile in circumference — 700 feet wide and 1,900 feet long.

Fur trappers named the rock in 1830, before the pioneers, when they camped and had a party here on Independence Day. And before them, the tribes from the Central Rocky Mountains — Arapaho, Arikara, Bannock, Blackfeet, Cheyenne, Crow, Kiowa, Lakota, Pawnee, Shoshone and Ute — left carvings and petroglyphs on the red-granite monolith, which they called Timpe Nabor, the Painted Rock.

But it was the pioneers who carved their names into the granite. They left messages, and it became a kind of bulletin board on the trail. I love reading their descriptions of the rock. According to Wyohistory.org, in 1832, John Ball thought it looked "like a big bowl turned upside down," and estimated that its size was "about equal to two meeting houses of the old New England Style." Lydia Milner Waters thought "Independence Rock was like an island of rock on the grassy plain," while Civil War soldier Hervey Johnson reported that it looked "like a big elephant (up) to his sides In the mud." One man called it a huge whale, another an apple cut in half and turned over.

As a geologist's daughter, I marveled at it. Independence Rock is a granite boss — a term that makes me laugh, as I can't imagine a rock being the boss of anyone. In geology, however, a boss is an intrusive igneous feature — molten rock that was pushed up from deep below. As it was pushed, it became a big dome and weathered into its big rounded shape.

Wyoming is full of such ventifacts, rocks that have been molded by the wind — "wind-faceting," some call it. Over 50 million years ago at Independence Rock, exfoliation began. Water seeped into its fissures, and repeated freezing and thawing pried the grains apart. Thin sheets of crumbling rock washed away by rain and snow, exposing fresh rock below. Finally, around 15 million years ago, Independence Rock became a dome when windblown sand rounded its top.

I CALLED MY father while writing this to check my geology. So many of our car trips as children were filled with the Earth's facts. He'd point out a fault scarp or hand me a rock that looked like nothing and then tell me its story. My dad is 85 now, and I see in him a different kind of weathering: His face is shaped by the years he worked outside; his gait is a little less steady. But he still goes on dinosaur digs. He spent last week in the field, being shaped by the wind, much like the rocks he holds. And I jokingly tell him I am a ventifact: Wyoming wind probably shaped me more than anything.

We each are shaped by the things around us, our parents, education and the journeys we take. And it is geology that perhaps has shaped me the most, growing up in a place with rocks the size of skyscrapers, and wind and open space and sky like a theater.

In 9th grade, my teacher made us memorize the geologic time scale. In the car, between Question Corner and New Word Light, I would chant, *"Paleozoic, Mesozoic, Cenozoic!"* And then *"Jurassic, Triassic, Cambrian, Cretaceous!"* — words as foreign as my French class. My dad listened, registering everything I said. He was my own rock, on whom I left a mark. And I will be the same for my girls.

I think about deep time a lot. Humans are just a blip; we joined the party seconds before midnight. The turtle of the plains will be there long after I am gone — long after my dad is gone. And strangely, I find that comforting. Independence Rock has weathered the elements and graffiti and parties with fur trappers, and it still stands. I don't need to carve my name on a rock to say I once existed. Knowing there has been so long a history before us reassures me and gives me a kind of optimism. We can each serve as a monolith to others on their own journeys.

I cannot imagine living on this Earth without my parents, and yet I know that day will come. I am not saying my dad will live on in the rocks I hold. But, in a way, he will.

Nina McConigley is a writer and professor at Colorado State University and the author of How to Commit a Postcolonial Murder.

Heard Around the West

Tips about Western oddities are appreciated and often shared in this column. Write heard@hcn.org.

BY TIFFANY MIDGE | ILLUSTRATION BY DANIEL GONZÁLEZ

COLORADO

Humanity has long sought enlightenment at the top of mountain peaks. But ice cream is also a goal worth achieving, as folks who hiked up Colorado's 14,000-foot Huron Peak on Labor Day weekend discovered, Denver7.com reported. The identity of the guy giving out the frozen treats remains unknown, but he's truly what people are calling a "Legend Dairy" fellow, acclaimed as a hero by a Facebook group dedicated to summiting Colorado's "14ers." Lugging 60-pounds of ice cream and dry ice up a mountain may not qualify as conquering Everest, but it certainly impresses ordinary hikers like us. Talk about being a good humor man!

Blaine and Katie Griffin were almost at the top when other hikers told them about it. The couple worried that all the goodies would be gone by the time they got there, but fortune smiled on them in the form of ice cream sandwiches. Christopher Whitestone and his two kids were also blessed: "It definitely leaves a lasting impression for my kids as a very positive experience," Whitestone said. Although he did warn them not to expect a treat every time they hike up a mountain; there's plenty of ice atop Everest, after all, but none of the creamy delicious sort.

CALIFORNIA

Sometimes a distant relative or long-lost friend just drops by unexpectedly. Sequoia Park Zoo in Eureka, California, reported that a wild black bear "broke into" the facility and "paid a visit" to three of the zoo's captive black bears. "He was really, really interested in our three bears, and he introduced himself to all of them through the fence," Jim Campbell-Spickler, the zoo's director, told *SFGate*. "The interaction between them was really sweet, calm and curious. We think he was just looking for a friend." Perhaps bearing holiday greetings?

Christine Noel, the zoo's education curator, was first to spot the strange bear. "Overall, he was a very polite visitor." The Eureka Police Department and a warden from California's Department of Fish and Wildlife spent about 20 minutes trying to coax the bear away, but he eventually saw himself out through the perimeter gate and vanished into nearby 67-acre Sequoia Park. Exactly how the bear got into the zoo remains a mystery, although Campbell-Spickler believes he must have simply climbed up into a tree and, well, literally dropped in. It must be hard to text with paws, but maybe next time call first?

WASHINGTON

You never know what might wash up after days of inclement weather. Motorists driving along Blue Slough Road outside the town of Cosmopolis were startled to find their way blocked by a sassy sea lion that apparently made its way inland by way of a nearby river, *The Dodo* reported, and proceeded to put the "lie" into "sea lion."

When Police Chief Heath Layman first heard about the critter lounging in the middle of the road several miles from the ocean and refusing to move, he thought it was a joke. According to the Marine Mammal Center, sea lions "haul out" from the water either to rest after a hard day of foraging, regulate their body temperature, shed or avoid predators. In any case, officials from the Washington Department of Fish and Wildlife and the National Oceanic and Atmospheric Administration came out to see if they could help dislodge the beast. They finally managed to "haze" it off the road and back into the river, apparently by "making the creature uncomfortable enough to move," *The Seattle Times* reported. We hope they didn't do so by making rude personal remarks; everyone hates to see a grown mammal blubber. Whatever they did, however, it worked.

OREGON

Speaking of blubber, we have an update to our January 2021 coverage of Florence, Oregon's notorious exploding whale. Back in 1970, an extremely deceased sperm whale washed on shore and swiftly became an olfactory nuisance. On Nov. 12, officials decided to blow it up, thinking the carcass would be obliterated and scavengers handle the rest. Unfortunately, they miscalculated the amount of explosives needed, and huge chunks of blubber went torpedoing in every direction. "The blast blasted blubber beyond all believable bounds," as KATU News happily reported.

Florence has since dedicated a park in the whale's honor — the aptly named Exploding Whale Memorial Park — and last year, Mayor Rob Ward designated the month of November as an official Oregon holiday "to memorialize the exploding whale," the *Oregonian* reported. For more, um, chunks and tidbits, check out the "Official Unofficial Florence Oregon website of the Exploding Whale" at www.xplodingwhale.com.

Steven Kazlowski / Alamy

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#IAM THE WEST

GOURAV KHULLAR (HE/HIM)
Baum postdoctoral fellow for innovative astronomy at the University of Washington
Seattle, Washington

I was very much attached to the idea that my history is a blip — that my personal history, how I perceive it, was just a blip, seen against the history of the universe. A lot of astronomers sort of wrestle with what, exactly, that means. The work we do to philosophize and make an abstract version of the universe is so small compared to the ground realities of what our communities need. Our idea of deep time has actually shrunk in size compared to what you would have thought was potentially possible, because we know what deep time is, what the idea of billions of years of change looks like. And to us, it feels like our blip is all we have. For me, I think of a deeper appreciation of the life I'm living, the space I'm occupying and the time I get to spend with the people that I care about, because I know that this is a blip.

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