High Country News
For people who care about the West

Utah's ancient Lake Bonneville holds clues to the West's changing climate

by Douglas Fox

A curious horizontal line runs across the range -- a notch cut into the mountains like a railroad bed, visible from many miles away. It snakes around every gully and ridge, 600 feet above the playa where the Donners hauled their wagons. Floating Island Mountain, visible to the east above a perpetual mirage, also shows this line. The same thing can be seen across much of Utah, inscribed into every mountain and hill like a celestial constant.

That line records the shores of a massive lake, called Lake Bonneville, which once sprawled across the region. You can spend half a day driving across Bonneville's dusty beds on Interstate 80, beneath hundreds of feet of vanished water, without ever coming up for air. The lake's irregular tendrils stretched for 150 miles east-west and 250 miles north-south; it covered modern-day Salt Lake City and reached across the Nevada and Idaho borders. "This thing used to be the size of Lake Superior," says Jay Quade, a University of Arizona geologist who has spent much of his life exploring these deserts. "It was an inland ocean."

The sagebrush, rabbitbrush and Mormon tea that grow here today subsist on just five inches of rain a year. But as Quade climbs a gully on the west flank of the Silver Island Range, some strange shapes loom into view -- apparitions of a wetter past. In one place, hundreds of stone fingers protrude from the rock like branching coral. Elsewhere, a row of turrets resembling tropical sea sponges clings to the gully's walls, their beige shapes conspicuous against the gray background. Their curves vaguely evoke a living, aquatic origin. The same stuff drapes, petrified and cracking, over the crests of nearby ridges like a six-inch layer of mud.

This spongy stone, called tufa, was laid down by algae. "This whole area was covered in algal soup," says Quade. Today, it sits 600 to 800 feet above the dusty plains that surround these mountains, but for thousands of years those algal mats basked in sunlight just below the water's surface. The Silver Island Range was truly an island; only its upper slopes rose above the water.

The rise and fall of seas seems like something that could only have happened far back in geologic time -- hundreds of millions of years ago, in a world populated by unrecognizable life forms. But Bonneville's waves lapped against these shores a mere 15,000 years ago. Human beings saw the dwindling lake when they arrived in the Great Basin 1,000 years later. This place has hardly changed since then. You can still see stones as small as a fist, draped in algal tufa, that haven't moved an inch since the inland sea evaporated thousands of years ago.

Scientists have studied Bonneville for decades, often for the pure joy of piecing together a mystery. But these days, the study of Bonneville is taking on new urgency. Climate models predict that the American West will become drier as global temperatures rise, but no one knows how much drier -- whether droughts will be merely a minor inconvenience, or catastrophes that could depopulate the likes of Salt Lake City, Las Vegas or Phoenix. "Predicting what's going to happen with rainfall is very tricky business," says Wallace Broecker, a prominent climatologist at Lamont-Doherty Earth Observatory in New York. "We still don't do it very well."

This is where Bonneville comes in. It provides a window into the past -- and possibly the future. As the last ice age wound down 30,000 to 10,000 years ago, temperatures seesawed wildly. Lake Bonneville is a perfect place to study how wetness in the Great Basin changed as a result of those temperature swings: The lake's water levels rose and fell by hundreds of feet during this time. Quade and his fellow geologists have come to the Silver Island Range to read this record of shifting moisture. Their initial results are not reassuring: As the West warms up, it will likely become substantially drier than it is today.

Europeans probably noticed Bonneville's high-and-dry shores the first time they visited the Great Basin, but it has taken 200 years for people to accept the idea of an inland sea.

In 1853, Edward Griffin Beckwith, a U.S. Army lieutenant, led an expedition to Utah to map routes for the transcontinental railroad. The dry shoreline, he wrote, "attracted the observation of even the least informed teamsters of our party -- to whom it appeared artificial."

Beckwith theorized that an arm of the Pacific Ocean had once reached deep into North America to form those shores. It was a radical idea. The bottom of the lake sat 4,000 feet above sea level -- a fact that Beckwith was well aware of -- so the continent would have had to have risen nearly a mile to reach its present elevation. But to Beckwith that probably seemed less outlandish than the only other alternative -- the possibility that the Utah desert once received so much rain and snow that it drowned in 900 feet of water.

Grove Karl Gilbert, a scientist with the U.S. Geological Survey, dispelled the idea that the Pacific had invaded Utah. Gilbert spent most of the 1870s exploring the Great Basin, and his men mapped 500 miles of Bonneville's shores using surveying telescopes. They found multiple concentric rings of shorelines up and down the mountains, formed as the lake rose and fell. They showed that Bonneville was hemmed in by mountains on all sides -- except at one point. Thirty miles north of the Idaho border, they found a spot where Bonneville had poured through a mountain saddle into Idaho's Snake River Valley -- and ultimately into the Pacific. The lake overflowed at this point for around 500 years. But then a catastrophe occurred 18,000 years ago. The waters pouring through this mountain saddle eroded their way through rock into a soft layer of gravel below. Lake Bonneville burst its geologic waistband.

Within days, the water chewed a channel 350 feet deep in the soft, underlying strata -- unleashing a flood 40 times greater than the flow of the Mississippi River. Over 1,200 cubic miles of water gushed out over the next few weeks, overflowing the Snake River Canyon, blasting soil from bedrock and rolling boulders -- some the size of automobiles -- for 200 miles downstream. Bonneville's water level dropped by 350 feet, to the depth of the newly cut channel. The lake stayed at that level for another 2,000 or so years before slowly receding another 550 feet -- down to the level of the modern Great Salt Lake.

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Jack Oviatt, a geologist at Kansas State University, has spent 35 years carbon-dating snail shells, driftwood and algal tufa rocks at the lake's various shorelines to assemble the timeline of these ups and downs. That history provides a good framework, but refining it further will help scientists do a better job of reconstructing the climate. "We know the general picture, but we don't know the rates of change between these lake stands," says David McGee, a geologist post-doc from the University of Minnesota who is studying Bonneville along with Quade and several others. "We don't know the responses of the lake to big, sudden climate shifts."

Even as the great ice sheets started retreating around 25,000 years ago, temperatures in the Northern Hemisphere went through a series of dramatic swings: rapid cooling during so-called Heinrich Events, when ice sheets dropped armadas of icebergs into the North Atlantic and caused it to cool, followed by heat waves when temperatures in Greenland soared by as much as 15 degrees Fahrenheit over just a few decades. Knowing how Bonneville and other ancient lakes responded to these swings would enable scientists to build climate models with a better chance of predicting what will happen to rain and snowfall in the West over the next 100 years.

Unfortunately, Bonneville's shorelines provide only fragmentary evidence of the lake's status at specific points in time. What Broecker has long sought is a continuous record of its changes. Tree rings provide this kind of smooth record, but they generally don't go back further than several thousand years -- whereas the most interesting parts of Bonneville's history happened in the more distant past. In 2007, Quade, a longtime friend of Broecker's, found the solution in an unlikely place.

That fall, Quade was busy moving his research lab from one building to another. As he sorted boxes, he came across a canvas sack inside a rat-gnawed wooden chest. Inside the sack, he found several hunks of dingy yellow-white layered crystalline stone in Ziploc bags. Quade had pried them from the walls of a cave in northern Utah in 1994. Back then, they were a mere curiosity -- the kind of pure carbonate crystals that only seem to grow in dark nooks and crannies. Quade brought them home, stashed them in the trunk, and forgot about them. But by the time he rediscovered them in 2007, they had become valuable clues for deciphering Bonneville's history and the story of how water in the West responded to temperature changes in the past.

Those rock layers were laid down as Lake Bonneville rose and flooded the cave. The calcium, magnesium, iron, and carbonate in the water gradually precipitated out of it and coalesced into crystals -- much as mineral deposits form bathtub rings. The layers represented thousands of years of history compressed into six inches. New methods of analysis would allow that history to be read at an accuracy of 30 to 50 years -- 10 times better than would have been possible with standard radiocarbon dating. If Quade could find those same mineral bathtub rings in other caves around Utah, then he could build the most detailed account yet of how Bonneville contracted and expanded as temperatures rose and fell.

Broecker helped Quade snag funding for the project from the National Science Foundation. Quade teamed up with David Madsen, the archaeologist from the University of Texas at Austin who first brought him to the cave where he found the minerals in 1994. He also connected with Broecker's former Ph.D. student, McGee.

The group visited the Silver Island Range this spring in search of more bathtub rings. They spent nights in Wendover, a town on the Nevada-Utah border with a split personality, where a 50 foot-tall cowboy in flashing red lights welcomes you to the gambling-and-massage side of town. Each morning, they drove out to the mountains past the Bonneville Salt Flats, where rocket-propelled automobiles have blasted out numerous land-speed records.

Jay Quade wears a fragrant sprig of sagebrush in the band of his cowboy hat, replacing it every day while in the desert. He wears leather boots now, but used to do his fieldwork in flip-flops. ("You learn to walk differently," he says; "you place your feet a lot more carefully.") Before that he was a middle-distance runner at the University of New Mexico, where he once galloped 800 meters -- roughly half a mile -- in 1 minute 49.8 seconds. He spent most of his childhood in Reno; when he was 6, his father, a wealthy securities trader, moved the family there from Los Angeles to start a new career as a self-taught geologist, determined to escape what he called "the pernicious influence of money." Quade hiked avidly, scavenging flecks of gold from streams and abandoned tailings piles. When he was 15, he and his friends found the wreckage of a plane on a remote mountain ridge east of Lake Tahoe.

On a cool May morning, Quade powers effortlessly up the slopes of the Silver Island Range, only occasionally using his hands as he climbs outcrops and slippery gravel chutes. His rock hammer swings at his hip. McGee stays near his side, as do two Ph.D. students who are fortunate to have bodies 25 years younger.

After 30 minutes of scrambling -- and two surprised rattlesnakes -- the group reaches the level platform of a shoreline halfway up the mountain; from a distance, it stood out prominently, but up close it fades into an obscurity of rocks, bushes and sheep dung. "The lake would have been perched here while it was overflowing into the Snake River Basin," says McGee, "just when we think this area was at its wettest."

"It must have been fantastic fishing," says Quade. He gazes across a salt flat that would have been buried under hundreds of feet of water, at a parallel shoreline on another mountain 10 miles away.

The four disappear in different directions in search of promising rocks, the tap-taps of their rock hammers echoing through the still morning air. Just as a fly relies on its proboscis, geologists experience much of the sensory world through their hammers. A rock that has lain for long in the elements will hide beneath a dark rind of oxidation; a whack from a hammer breaks it in half, revealing its layers and its true identity.

The group climbs higher as intriguing rocks are found, GPS readings are taken, and drawings are sketched in notebooks. Gray clouds darken the sky; the slope steepens.

The slanted slabs of the Silver Island Range make for good climbing. The stone grabs hold of your hands as though its cracked, ceramic surface is covered in razor-sharp Velcro.

Now and then you look down at a rock that has sliced open your finger and see its surface jumbled with the broken, cylindrical stems of fossil sea lilies or the scallop-shaped shells of fossil brachiopods. The Hansen Creek dolostone -- the name that geologists give to the rock that these mountains are sculpted from -- coalesced from a shallow ocean floor that teemed with life 450 million years ago. "If you look at this rock microscopically, it's all shells and shit," says Quade. "It's a recycled graveyard. It's passed multiple times through the backside of a worm."

The residue of that past life has dyed the rock in shades of gray. As Quade scrambles up a scree slope, he pauses, cracks a stone with his hammer, and holds the broken half to his nose like a succulent grapefruit. "Pheew!" he exclaims. He hands it over. It exudes the sewer smell of decaying organic matter. "The Hansen Creek dolostone always stinks," he says. "It's full of petroleum."

The much younger algal tufa that clings to the mountain is also chockfull of organic remains; bake the stone in an oven and it darkens from beige to gray like a piece of burning garlic bread. The Silver Island Range has lived many lives, and tracing each stage of each life requires the tenacity of a sleuth.

McGee and Quade occasionally find that the mountain has surreptitiously betrayed the unwritten agreement between geologists and the Earth: the basic principle that the oldest stuff is on the bottom, and each succeeding layer is therefore younger.

On the wall of an overhung grotto, the two men puzzle over an apparent contradiction: A layer of bathtub ring mineral is sandwiched beneath what appear to be older layers of tufa and dolostone. They dig with their rock hammers into the base of the wall, and soon come up with a theory: Layers began to weather and peel away from the wall while it was exposed to open air; the lake then rose and fell multiple times, filling the spaces between the peeling layers with bathtub rings and tufa. The mountain, in other words, has reshuffled its deck of layers midway through the game.

McGee sketches the scene in his notebook and drops some rocks in a sack. Back in Minnesota, he will test the team's interpretation. He'll saw each rock in half and polish it to highlight its wispy layers. He'll grind out samples of each layer using a dental drill and dissolve the powdered rock in acid. He will purify a few thousand rare atoms of uranium and thorium and then measure the age of the layers by counting those atoms, using a machine called a mass spectrometer that accelerates each atom to 450,000 miles per hour and smashes it into a detector.

By measuring the composition of each layer, McGee can see how the lake's salinity changed over time. By comparing amounts of heavy and light oxygen isotopes, he can gauge how the balance between water flowing into the lake and its evaporation shifted whenever the lake had no outflow. He might even be able to sample some of Bonneville's ancient water: Tiny droplets of it are still trapped inside these minerals, in pockets no wider than a few red blood cells. McGee hopes to bore into those pockets, one by one, with a laser.

A new, more detailed version of Bonneville's history will emerge only gradually. Rocks from one site may produce errors from any number of sources -- contamination from groundwater percolating through a cave, for example, or incomplete mixing of Lake Bonneville, leading to different levels of salt or certain oxygen isotopes in different parts of the lake. But do these same analyses at enough places along the lake's hundreds of miles of shoreline, at enough different elevations that the water would have occupied at different times, and the errors will gradually sort themselves out. The relationship of Bonneville's water level to global climate swings will eventually become clear.

Suddenly, the clouds open up. Heavy-bellied raindrops pelt rocks, hats and notebooks. McGee, Quade and the two students scramble down a gravel chute and head for the trucks a mile away.

Those mineral bathtub rings are an unexpected gift to anyone who wants to understand the history of Bonneville, and of wetness in the West. But they aren't foolproof. Now and then, the lake's water became fresh enough that it stopped laying down minerals. McGee and Quade see it in the rocks that they've already dated: One layer is sometimes far younger than the layer just beneath it, with no sign of the 1,000 years in between. If you want a record of those thousand silent years, you have to look for other indicators, such as the shells of critters that lived during that time, or layers of mud that settled into caves.

One day, McGee and Quade go looking for these other clues an hour's drive east of the Silver Island Range, on a 2,700-square mile forbidden zone called the Utah Test and Training Range, run by the U.S. Air Force.

Our military-owned Chevy Suburban bumps down dirt tracks that wind through a desert plain lush with waist-high grass and sagebrush, past a 1970s-era F-4 Phantom fighter-bomber, a row of Army Jeeps perched on concrete platforms, and a concrete building shattered on one end. Some of this is old hardware of no further use to the military; other objects are high-quality replicas built by a special military team using plywood and other cheap materials to create realistic stage sets for soldiers as they practice firing machine guns or dropping bombs.

Cathedral Cave, today's destination, sits several hundred feet above the plain, sunk into the base of a limestone cliff. It takes 10 minutes of breathless scrambling up a steep slope to reach it. A band of fossils runs across the cliff and intersects the cave -- Mesozoic coral broken off in an ancient storm, strewn on the seafloor and frozen for eternity in three inches of petrified mud. Cathedral Cave sat as far as 750 feet below the surface of Lake Bonneville. The story of this year's expedition begins deep in its bowels.

Quade sidefoots his way down a dusty slope into the cave. He walks through a vaulted room whose walls are covered in knobby tufa reminiscent of organ pipes in a church, and picks his way to the dark, narrow rear of the cave. The light of his headlamp falls on a crystalline crust of stone that covers the walls and ceiling. The beige crust has broken in places, revealing a six-inch cross-section.

These beige crystals formed all over the cave, but only here in its darkest recesses are they free of the silt or fossil algae that would complicate Quade and McGee's chemical analyses. Quade accidentally stumbled upon these super-clean crystals when he first visited Cathedral Cave in 1994. "I wandered back here and was mesmerized," he says. The rocks that sat for 13 years in his sample chest came from this spot.

Alternating layers of calcite and aragonite record 9,000 years of history when the cave was flooded. These mineral layers are capped with evenly spaced calcite knobs the size of coat buttons. On top of them lies a fine dusting of white crystal aragonite, like an autumn morning frost. The buttons formed over a period of 600 years as the lake contracted, grew salty, and fell below the cave; the frosting reveals one final hurrah when the lake briefly crested again above the cave for another 200 years before drying out for good. McGee and Quade are analyzing them for any clues that they might hold. But for the moment they are simply beautiful. "It's good that this cave is protected," says Quade. "Otherwise people would have destroyed this stuff."

The geologists already have samples of these minerals; they've come today to tease apart layers of silt, animal remains, and debris on the cave floor. The group begins digging two pits. Dust that tastes of acrid rat urine billows into the air.

Taking turns, they dig through two feet of dirt; through rocks fallen from the ceiling; more dirt; several inches of hard tufa which are chipped away with rock hammers; and below that, a layer of mud. A debate ensues about whether the mud was laid down when the lake was only a few feet above the cave, or several hundred feet above it.

"You want to taste some?" Quade asks. He hands over a pinch of mud that's creamy to the touch. But the tongue's exquisite sensation, a sort of oral Braille, magnifies its grit, revealing sharp-edged grains of silt too fine for calloused fingers to sense. These grains must have washed in during rainstorms from higher up on the mountain, when the cave was just below the shoreline - or so the geologist's diagnostic palate would indicate.

Guleed Ali, a Ph.D. student from Lamont-Doherty, finds a millimeter-long snail shell in the damp silt. "Two shells is going to be enough for a carbon date," McGee tells him -- giving them a chance to date when the lake level sat just above the cave. Pretty soon everyone is sitting, sorting through bits of silt on notebooks and clipboards for other clues that might reveal its age.

Madsen holds up a mud clod containing tiny white shells of crustaceans called ostracods, which give clues about the salinity of the lake. "The way you tell the different species apart is the size of their penis," he says. "Those aren't preserved here, so we don't have to worry about it." A few moments later, he cups the minuscule vertebra of a fish in his hand -- "probably a Utah chub or a redside shiner," he says.

Cathedral and other caves have provided a record of how the region's ecosystems evolved as Bonneville climbed up and down the mountains starting around 30,000 years ago. Archaeologists have found thick mats of limber pine and spruce needles laid down by water. They have also found seeds and stems of meadow- and marsh-dwelling currant bushes, cinquefoil and bulrush crammed into packrat burrows and cemented together with crystallized urine.

The caves also reveal when humans arrived, leaving behind charcoal, antelope bones, scraping stones, and in the case of Danger Cave in the Silver Island Range, a veritable biblioteca of dried turds. "Tens of thousands of turds of all shapes and sizes," said Madsen when we visited Danger Cave several days earlier. Archaeologists used to reconstitute them in water to study them: One team of researchers tried to distinguish their culinary contents based on aroma. Each one represents a day in the fecal diary of the people who arrived as Lake Bonneville waned around 14,000 years ago. There are short, squat turds stuffed with bat hair that seem to cry out for Metamucil, and high-fiber, narrow-gauge turds made almost entirely of a marsh plant called pickleweed that grew near the water's edge.

The pronghorn antelope that the early human inhabitants ate still roam the area today. But many of the other species preserved in Danger and Cathedral Cave are nowhere to be seen. The limber pine and spruce climbed several thousand feet up the slopes of the Silver Island Range as they chased the retreating rainfall. Eventually, those islands of cool, wet climate evaporated off the tops of the range's 7,000-foot peaks, and the trees became extinct around here. Today, only junipers and one tiny stand of piñon pine grow atop the Silver Island Range. The only limber pine and spruce in the region reside in the Pilot Range, the Oquirrh Range, the Wasatch Range and other mountains where peaks above 9,000 feet still wring enough moisture from the air to sustain the trees through hot summers.

The Great Basin in the time of Bonneville wasn't just a wetter place. The greater amount of water flowing and seeping through its mountains and hills supported what biologists call a more productive ecosystem: It could sustain more tons of plants and animals per acre than today. That means it could probably have sustained more humans, too.

Bonneville's history reflects a global truth. Look at a map of the world and you see that many of the great deserts occupy two latitudinal bands 15 to 35 degrees north and south of the equator. These bands include the Mojave, Sonoran and Chihuahuan deserts of North America; the Sahara, Namibian and Kalahari deserts of Africa; the Saudi and Persian deserts of Asia; and the Simpson and Sandy deserts of Australia. These global desert belts arise from a massive atmospheric conveyor belt called the Hadley cell, which lifts warm, moist air from the equator, and wrings the moisture out as rain or snow over the tropics as the air rises to 40,000 feet. The Hadley cell then dumps the dry air back down to the earth's surface further north and south -- creating deserts with cloudless skies.

The dry beds of Bonneville sit at the northern edge of this arid zone today. But they didn't always."The way you make Lake Bonneville is bring Oregon down here," says Quade. "You've got to bring Oregon down here climatically."

The Laurentide Ice Sheet, a slab of ice several thousand feet thick that would cover modern-day Canada and the Great Lakes, may have done this during the last ice age. The Laurentide diverted a northern belt of wet air called the jet stream southward, away from what is now Oregon and

Washington -- pointing it at Utah instead. As that fire hose of moist air hit the 10,000-foot crest of Utah's Wasatch Mountains it dumped snow, forming the glaciers and rivers that fed Lake Bonneville.

Bonneville's heyday may represent the wet extreme of what the Great Basin is capable of experiencing. It is easy to assume that the deserts and arid mountains of today represent the other end of that spectrum -- the dry extreme. But there is reason to think that today's condition is only the middle of that range -- that the West can, and will, become much drier.

Satellite studies suggest that rising temperatures have caused the Hadley cells to widen by 100 to 300 miles over the last 30 years. If this trend continues, the atmosphere's conveyor belts will dump their dry air farther and farther from the equator, shifting the most intense bands of dryness from northern Mexico toward Nevada, Utah and Colorado. Rising temperatures will also reduce precipitation directly by increasing the capacity of air to hold water, says Richard Seager, a climate dynamicist at Lamont-Doherty. "By the middle of the century, models are predicting a 10, 15, 20 percent reduction in precipitation" in the West, he says.

It may sound minor, but in the West, small change carries the day. Lake Bonneville, for instance, may have covered eight to 10 times the area of modern lakes in the area such as the Great Salt Lake, and it should have needed eight to 10 times as much precipitation to keep it alive. But Broecker increasingly believes that Bonneville survived on a supply of rain and snow that was only two or three times as large as that of today.

It comes down to an obscure tenet of watershed hydrology, called the "Budyko curve" after the Russian scientist who developed it in the 1950s. Budyko is a mathematical line that relates the amount of precipitation that falls in an area to the amount of runoff that pulses through its rivers and streams. It is not a straight line; it bends like a boomerang. That bend means something important: It says that the more rain and snow that falls, the greater proportion of it actually percolates into rivers, streams and lakes without evaporating first. This happens because heavier precipitation overwhelms the ability of sunlight to evaporate water -- solar radiation literally can't zap away the water molecules quickly enough if they all arrive at once. It could explain how Lake Bonneville was able to form: Increasing precipitation by only two- or three-fold may well have meant that the lake received eight times as much runoff.

So Budyko turned the Great Basin into an aquatic paradise 30,000 years ago -- a mega version of southern Utah's Lake Powell that Quade wishes he could have visited with a fishing pole -- but it portends a darker vision of the future. It means that as less precipitation falls, the percentage lost to evaporation will rise.

"If there's a 10 percent decrease in rainfall, you get a 30 percent decrease in runoff," says Broecker. "If you decrease rainfall by a factor of two, you would get six times less runoff. The Western U.S., I think, is in for some big trouble." The drought that occurred across the Southwest in the early 2000s provides one possible harbinger of those fears. It browned over 4,000 square miles of juniper-piñon woodland and shriveled reservoirs to record lows before subsiding around 2005.

Even worse droughts are possible. Forty-four years ago, an airplane crashed into Walker Lake in western Nevada, 300 miles southwest of Bonneville. When crews dragged the lake for the plane's wreckage, they encountered a surprise: Their nets caught on the stumps of trees still standing on the lake bottom under many feet of water. Walker is a natural, closed-basin lake much like Bonneville. It is fed by the Walker River, which carries snowmelt from the eastern Sierra Nevada. Those lake-bottom trees could only have grown if conditions were so dry that the lake disappeared.

Scott Stine, a paleoclimatologist at California State University, East Bay, has found similar stands of dead tree stumps up and down the bed of Walker River -- Jeffrey pines, a species incapable of surviving in even a few inches of standing water. These trees are about 900 years old. Their very existence speaks of a drought that was so severe that both the river and the lake virtually ceased to exist for 100 years.

The kind of natural variation that produced this drought, the 1930s Dust Bowl, and last decade's juniper-piñon die-off will continue into the future. But if Seager and Broecker are right, they will occur against a drier backdrop. The droughts will be drier, and so will the wet periods between them.

Lake Bonneville held around 5 trillion tons of water at its peak. As that weight vanished into the atmosphere, the underlying crust of the earth sprang back up like a rebounding couch cushion. Bonneville's bed arched up 200 feet in the center, lifting the Oquirrh Range, the Silver Island Range, and a dozen other mountain chains that it once surrounded. The indentation that Bonneville left in the earth's crust is almost gone now, and other signs are fading, too.

One afternoon, Ali sits on a pile of rubble at the mouth of a cave no larger than a doghouse. Below lies the playa that the Donners crossed 165 years ago, raked by winds that lift clouds of dust hundreds of feet in the air.

Ali and Quade have had a disappointing day. A series of caves and grottoes that must, in the past, have been coated in the minerals they seek turned out to be bare instead -- stripped clean by the elements.

Here at the doghouse cave, Ali and Quade managed to scavenge a handful of rocks -- one of the best finds of the trip, in fact. But far more of the stuff lies strewn down the hillside at Ali's feet -- dislocated, fragmented, useless. The exquisitely layered mineral that they did manage to collect here survived only because it formed in a protected spot when the cave was submerged -- deep in cracks that permeated the cave's ceiling. The bedrock later crumbled away, making the layers visible.

For people seeking to uncover Bonneville's secrets, the target is shifting. The same process that exposed these precious minerals for discovery is also slowly obliterating them. The work of the geologist is to chase these retreating signs even as 99.9 percent of them have already vanished. Ali flicks another rock down the rubbish pile. "This stuff is eroding away," he says. "Ten years from now, this could all have been gone."

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