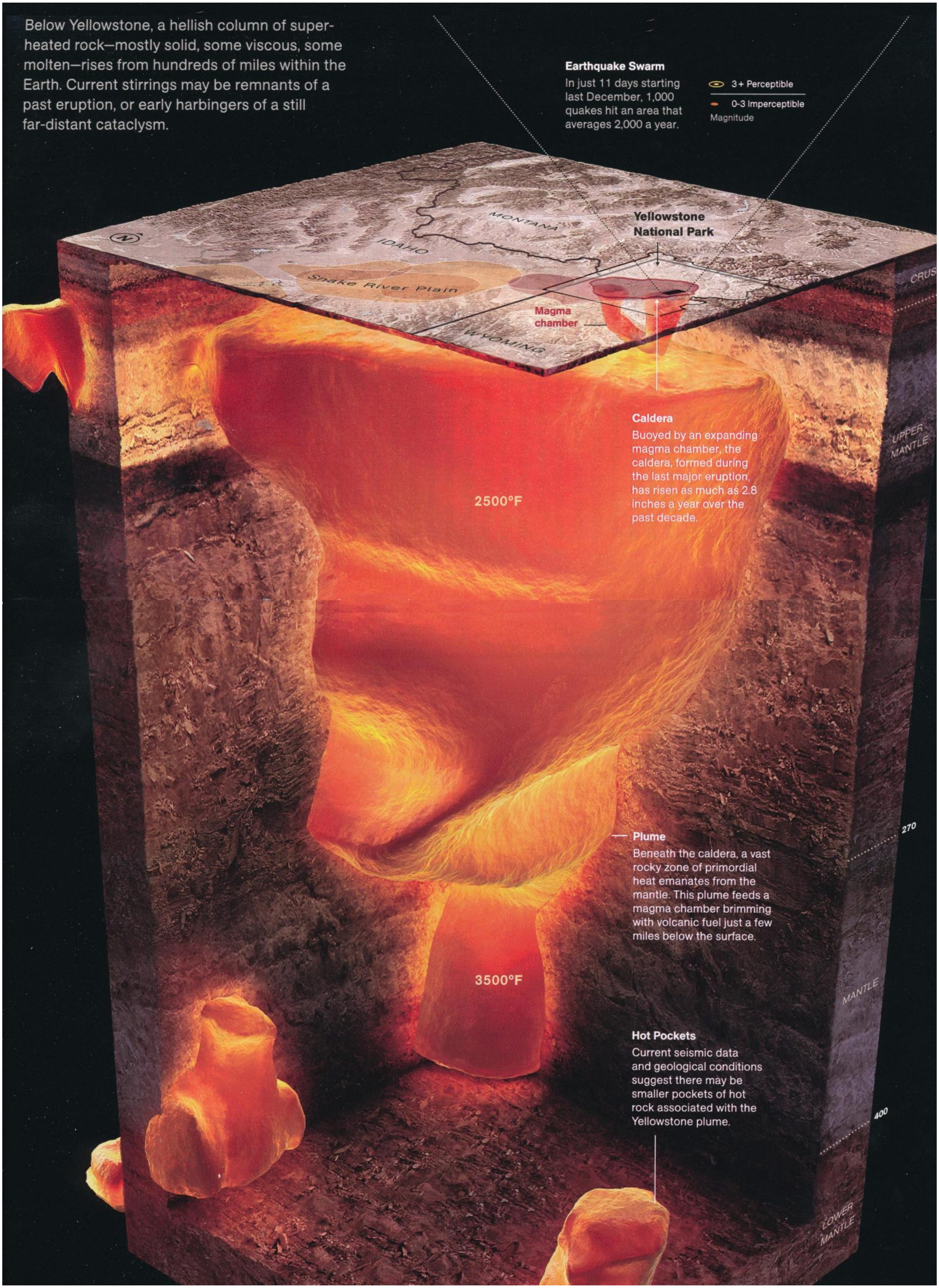
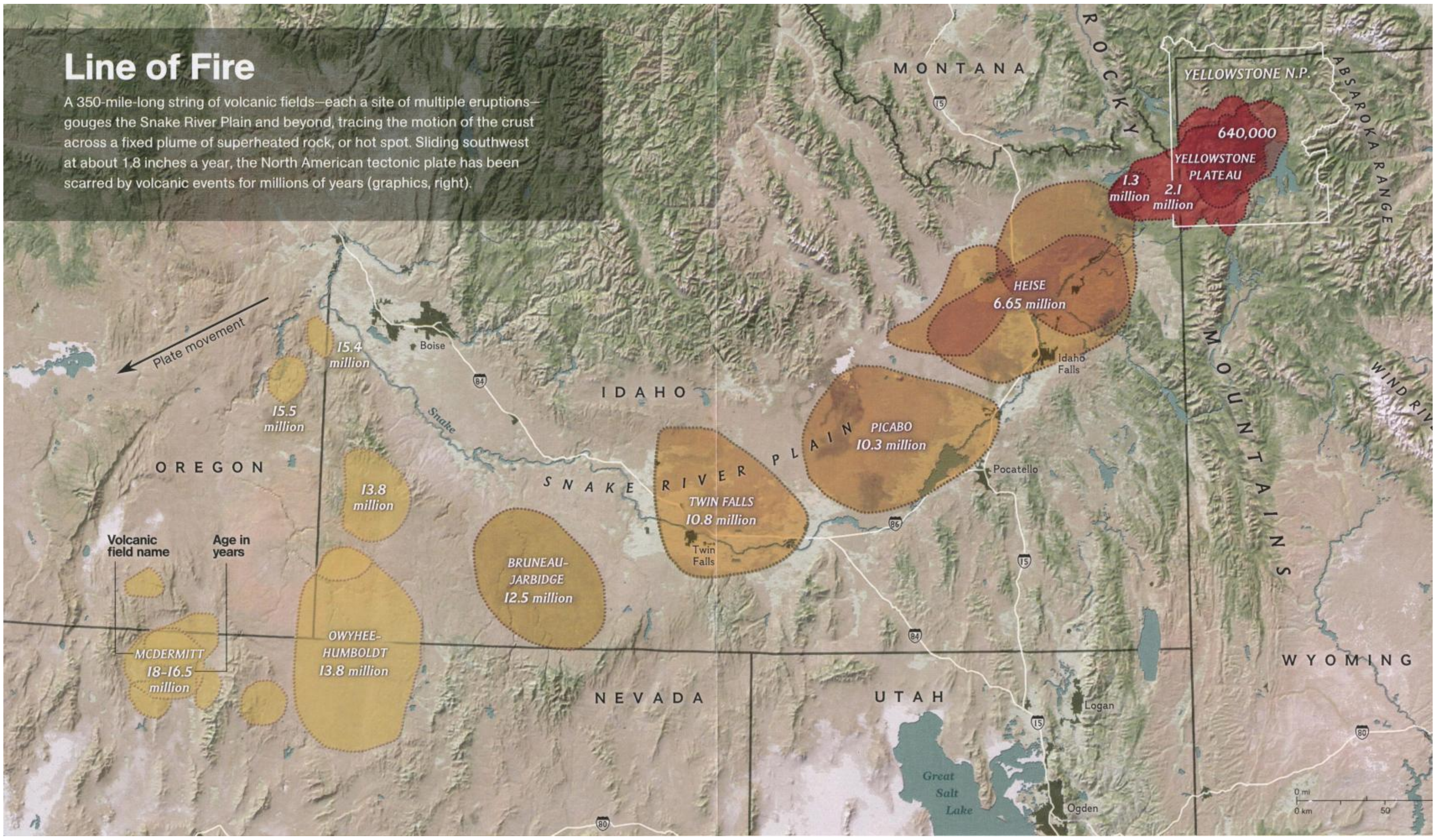


Sketch of the mantle plume beneath Yellowstone…

information is based on seismic studies.

Line of Fire

A 350-mile-long string of volcanic fields—each a site of multiple eruptions—gouges the Snake River Plain and beyond, tracing the motion of the crust across a fixed plume of superheated rock, or hot spot. Sliding southwest at about 1.8 inches a year, the North American tectonic plate has been scarred by volcanic events for millions of years (graphics, right).



Previous locations where molten plume material has explosively reached the Earth's surface.
The plume has remained in approximately the same location…
the North American Plate has moved over the top of the plume.

By Joel Achenbach
Art by Hernán Cañellas

On August 29, 1870, a 30-year-old Army lieutenant named Gustavus Doane, part of an exploratory expedition in the Yellowstone region in the territory of Wyoming, scrambled his way to the summit of Mount Washburn above the Yellowstone River. Looking to the south, he noticed that something was missing from a stretch of the Rocky Mountains: mountains. For miles and miles, the only elevations were in the distance, forming parentheses around a huge forested basin. Doane saw only one way to explain the void. "The great basin," he wrote, "has been formerly one vast crater of a now extinct volcano."

The lieutenant was right: Yellowstone is a volcano, and not just any volcano. The oldest, most famous national park in the United States sits squarely atop one of the biggest volcanoes on Earth. Doane was wrong, however, in one crucial respect. Yellowstone's volcano is not extinct. To an unsettling degree, it is very much alive.

There are volcanoes, and then there are supervolcanoes. The latter have no agreed-on definition—the term was popularized in a BBC documentary in 2000—but some scientists use it to describe explosions of exceptional violence and volume. The U.S. Geological Survey applies the term to any eruption ejecting more than 1,000 cubic kilometers (240 cubic miles) of pumice and ash in a single event—more than 50 times the size of the infamous Krakatau eruption of 1883, which killed more than 36,000 people. Volcanoes form mountains; supervolcanoes erase them. Volcanoes kill plants and animals for miles around; supervolcanoes threaten whole species with extinction by changing the climate across the entire planet.

No supervolcano has erupted in recorded human history, but geologists have pieced together what an explosion must have been like. First, a plume of heat wells up from deep within the planet and melts rock just beneath the crust of the Earth, creating a vast chamber filled with a pressurized mix of magma, semisolid rock, and dissolved water vapor, carbon dioxide, and other gases. As additional magma accumulates in the chamber over thousands of years, the land above begins to dome upward by inches. Fractures open along the dome's edges, as if burglars were sawing a hole from beneath a wooden floor. When the pressure in the magma chamber is released through the fractures, the dissolved gases suddenly explode in a massive, runaway reaction. It's like "opening the Coke bottle after you've shaken it," says Bob Christiansen, a U.S. Geological Survey scientist who pioneered research on the Yellowstone volcano in the 1960s. With the magma chamber emptied, the surface collapses. The entire domed region simply falls into the planet, as though the Earth were consuming itself. Left behind is a giant caldera, from the Spanish word for "cauldron."

The "hot spot" responsible for the Yellowstone caldera has erupted dozens of times in the past, going back some 18 million years. Since the hot spot is rooted deep in the Earth, and the tectonic plate above it is moving southwest, ghostly calderas from the more ancient explosions are strung out like a series of gigantic beads across southern Idaho and into Oregon and Nevada, the subsequent lava flows forming the eerie moonscapes of the Snake River Plain.

The last three super-eruptions have been in Yellowstone itself. The most recent, 640,000 years ago, was a thousand times the size of the Mount St. Helens eruption in 1980, which killed 57 people in Washington. But numbers do not capture the full scope of the mayhem. Scientists calculate that the pillar of ash from the Yellowstone explosion rose some 100,000 feet, leaving a layer of debris across the West all the way to the Gulf of Mexico. Pyroclastic flows—dense, lethal fogs of ash, rocks, and gas, superheated to 1,470 degrees Fahrenheit—rolled across the landscape in towering gray clouds. The clouds filled entire valleys with hundreds of feet of material so hot and heavy that it welded itself like asphalt across the once verdant landscape. And this wasn't even Yellowstone's most violent moment. An eruption 2.1 million years ago was more than twice as strong, leaving a hole in the ground the size of Rhode Island. In between, 1.3 million years ago, was a smaller but still devastating eruption.

Each time, the whole planet would have felt the effects. Gases rising high into the stratosphere would have mixed with water vapor to create a thin haze of sulfate aerosols that dimmed sunlight, potentially plunging the Earth into years of "volcanic winter." According to some researchers, the DNA of our own species may pay witness to such a catastrophe around 74,000 years ago, when a supervolcano called Toba erupted in Indonesia. The ensuing volcanic winter may have contributed to a period of global cooling that reduced the entire human population to a few thousand individuals—a close shave for the human race.

For all their violence, the supervolcanoes have left little behind beyond a faintly perceptible sense of absence. The Yellowstone caldera has been eroded, filled in with lava flows and ash from smaller eruptions (the most recent was 70,000 years ago) and smoothed by glaciers. Peaceful forests cover any lingering scars. The combined effect makes it almost impossible to detect, unless you've got a good eye, like Doane had, or a geologist whispering in your ear.

"You're seeing two-thirds of the entire caldera," says Bob Smith. "The size is so immense that people don't appreciate it." Smith is a University of Utah geophysicist and a prominent expert on the supervolcano at Yellowstone. We're standing atop Lake Butte, an overlook at the east end of Yellowstone Lake, one of the best places to see the caldera. But I don't see it. I can see the lake spread out for miles beneath us and a few little hills to the north—old lava domes. But I can't follow the caldera rim visually because much of it is beneath the lake and because of the sheer scale of the thing—roughly 45 miles across. Like Doane atop Mount Washburn, I see only distant mountains on the horizon on either side and between them, to the west, the "unmountains," the emptiness where the land swallowed itself in the course of a few days.

The effects of the past eruptions are nevertheless profoundly felt in the present. The lodgepole pines that dominate the park's forests are adapted to growing in nutrient-poor soils, like those in the Yellowstone caldera. So too are the white-bark pines, whose nuts sustain grizzlies and black bears.

And of course, the land to this day is literally boiling over. The trout that riot in the rivers would not be so abundant without the warming effects of the hydrothermal springs at the bottom of frigid Yellowstone Lake. The park roils with geysers, fumaroles, mud volcanoes, and other hydrothermal activity. Half the geysers on the planet are in Yellowstone.

The hydrothermal features change constantly in temperature and behavior, with new ones popping up in the forests, spewing clouds of steam visible from airplanes, exuding vapors that have been known to kill bison on the spot.

In spite of this "most violent gaseous ebullition," as one early explorer put it, the volcano beneath Yellowstone was long thought to be extinct, as Doane believed, or at least in its dying days. Indeed, after federal surveys in the late 19th century, the volcanic nature of Yellowstone received little scientific scrutiny for decades. Then in the late 1950s, a young Harvard graduate student, Francis "Joe" Boyd, became intrigued by the presence of a welded tuff—a thick layer of heated and compacted ash, which he realized was a sign of pyroclastic flows from an explosive, geologically recent eruption.

In 1965 Bob Christiansen found a second distinct welded tuff; the next year he and his colleagues identified a third. Using potassium-argon dating, they determined that the three tuffs were the result of three distinct eruptions. Each created a giant caldera, with the most recent eruption largely burying signs of the previous two.

Then one day in 1973, Bob Smith and a colleague were doing some work on Peale Island, in the South Arm of Yellowstone Lake, when Smith noticed something odd: Some trees along the shoreline were partially submerged and dying. He had worked in the area back in 1956 and was planning to use the same boat dock as on the earlier trip. But the dock was also inundated. What was going on?

Intrigued, Smith set out to resurvey benchmarks that park workers had placed on various roads throughout the park beginning in 1923. His survey revealed that the Hayden Valley, which sits atop the caldera to the north of the lake, had risen by some 30 inches over the intervening decades. But the lower end of the lake hadn't risen at all. In effect, the north end of the lake had risen and tipped water down into the southern end. The ground was doming. The volcano was alive.

Smith published his results in 1979, referring in interviews to Yellowstone as "the living, breathing caldera." Then in 1985, heralded by a "swarm" of mostly tiny earthquakes, the terrain subsided again. Smith modified his metaphor: Yellowstone was now the "living, breathing, shaking caldera."

In the years since, Smith and his colleagues have used every trick they can devise to "see" beneath the park. Gradually, the proportions and potential of the subterranean volcanic system have emerged. At the shallowest level, surface water percolates several miles into the crust, is heated, and boils back up, supplying the geysers and fumaroles. About five to seven miles deep is the top of the magma chamber, a reservoir of partially melted rock roughly 30 miles wide. Basaltic magma is trapped inside the chamber by denser, overlying rhyolitic magma, which floats on top of the liquid basalt like cream on milk. By looking at the way sound waves created by earthquakes propagate through subsurface rock of varying densities, the scientists have discovered that the magma chamber is fed by a gigantic plume of hot rock, rising from the Earth's upper mantle, tilted downward to the northwest by 60 degrees, its base perhaps 400 miles below the surface. When the plume pumps more heat into the chamber, the land heaves upward. Small earthquakes allow hydrothermal fluids to escape to the surface, easing the pressure inside the chamber, which causes the ground to subside again. After the 1985 earthquake swarm, Yellowstone fell eight inches over the course of a decade or so. Then it rose again, faster this time. Since 2004, portions of the caldera have surged upward at a rate of nearly three inches a year, much faster than any uplift since close observations began in the 1970s. The surface continues to rise despite an 11-day earthquake swarm that began late in 2008, causing a flurry of apocalyptic rumors on the Internet.

"We call this a caldera at unrest," Smith says. "The net effect over many cycles is to finally get enough magma to erupt. And we don't know what those cycles are."

So, the colossal question: Is it going to blow again? Some kind of eruption—perhaps a modest one like Mount Pinatubo's in the Philippines, which killed 800 people in 1991—is highly likely at some point. The odds of a full, caldera-forming eruption—a cataclysm that could kill untold thousands of people and plunge the Earth into a volcanic winter—are anyone's guess; it could happen in our lifetimes, or 100,000 years or more from now, or perhaps never. Bob Christiansen, now retired, suspects the supervolcano may be safely bottled up. For most of its history, the Yellowstone hot spot has formed calderas in the thin crust of the Basin and Range area of the American West. Now the hot spot is lodged beneath a much thicker crust at the crest of the Rockies.

"I think that the system has more or less equilibrated itself," says Christiansen. Then he quickly adds, "But that's an interpretation that would not stand up in court."

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