GEOLOGY

Thermal Features Bubble in Yellowstone Lake

Newly discovered vents, spires, and other features make the seemingly placid lake a center of geothermal activity—and raise the possibility of dangerous blowouts

Yellowstone Lake has always seemed a haven of normality amid the thermal oddities of surrounding Yellowstone National Park. Visitors check out the earth's heated contortions at Mammoth Hot Springs and Old Faithful, then go to Yellowstone Lake to fish trout. And although scientists have been investigating the park's thermal wonders for decades, only now are they focusing on the 350-square-kilometer water body. On the deep bottom, researchers have discovered a panoply of unusual hydrothermal vents, spires, craters, and domes—activity so intense that the calm lake now appears to be the true centerpiece of the park's geothermal features.

Venting much of the park's heat and affecting creatures from bacteria to bears, the submerged geothermal features promise to shed new light both on Yellowstone's complex subterranean workings and on the biology of extreme environments. Unfortunately, they also appear prone to massive explosions of steam and may be much more dangerous than huggable favorites like Old Faithful. "It's a startling discovery," says John Varley, Yellowstone's director of research. "It would be the most spectacular part of the park, if you could see it."

Geologists, geochemists, geophysicists, and biologists are now zeroing in on the lake, probing it with thermal surveys, scuba gear, a small remotely operated vehicle (ROV), and high-resolution sonar. With 40% of the bottom surveyed, this summer several teams plan a big push to cover more, and the National Park Service is hosting a major conference in October to present the results. Biologists, for instance, are hoping for more data on the unusual organisms clustered in and around the vents and are planning to take biological samples with a snakelike "vental rooter." "I think there are layers of unseen creatures down there," says microbiologist Russell Cuhel of the University of Wisconsin, Milwaukee (UWM).

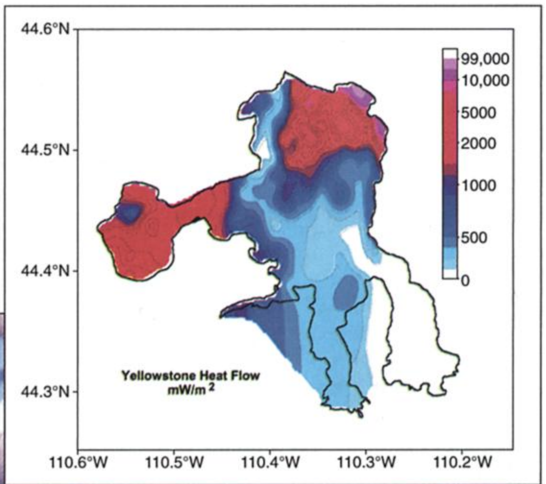
Hydrothermal pressure cooker

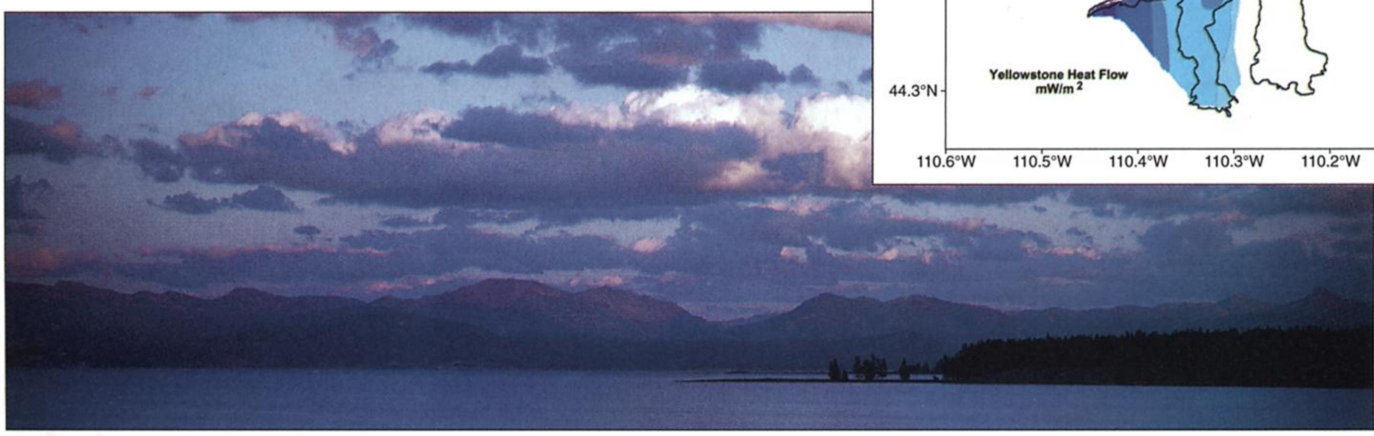
Yellowstone Lake straddles a corner of one of Earth's largest and most active volcanic calderas, so it makes sense that it hosts volcanism-related features. However, the scale and variety now being brought to light are far beyond expectations. The lake is literally a hot spot, says geophysicist Robert Smith of the University of Utah in Salt Lake City, who presented decades' worth of data on its heat flow at the fall 2000 meeting of the American Geophysical Union in San Francisco. Although the whole Yellowstone caldera is hot—it consistently puts out an average of 2 watts of heat per square meter—some spots in the lake radiate 20,000 times the average background. Overall, the lakebed may account for 20% of the 8987-square-kilometer park's heat. Lake water, thought to reach a maximum depth of 120 meters, is cold near the bottom, about 4 degrees Celsius, but in some localities Smith and his partner David Blackwell of Southern Methodist University in Dallas have found sediments hitting 118 degrees just 3.5 meters beneath the lake floor.

Seismic profiling suggests that the heat comes from huge pockets of high-pressure steam circulating up from magma chambers. These pockets are peculiar to the lake, because they are kept from exploding only by the weight of the water. "It's like a pressure cooker: Lift the lid, and it will blow you away," says Smith.

And evidence is building that the lid has repeatedly been lifted in the recent past. For decades, scientists thought that the lake's level had steadily sunk since glaciers receded 12,000 to 15,000 years ago—a trend that would be expected to allow steam to escape gradually and thus prevent giant blowouts. But long-term measurements of the caldera's ground level now show that the bed of the Yellowstone River, which drains the lake, "breathes" up and down heavily with magmatic processes, cyclically damming and undamming the outflow, says Daniel Dzurisin of the U.S. Geological Survey (USGS) in Vancouver, Washington.

Even in the short term, the elevation of the outflow rose nearly a meter from 1923 to 1984, then deflated, then started rising again in 1995. And on longer time scales, water levels apparently go through huge fluctuations—as does the pressure, or lack thereof, on the steam pockets. That idea is bolstered by the discovery of old beaches both above and below the current shoreline and separated by as much as 30 meters elevation, say USGS geologist Ken Pierce of Bozeman, Montana, and National Park Service archaeologist Ken





Hot spot. Serene vistas of Yellowstone Lake like this one *(above)* don't reveal that the lake is radiating a sizable amount of geothermal heat—more than 1 watt per square meter in most of its area—as shown in a map of heat flow *(top)*.

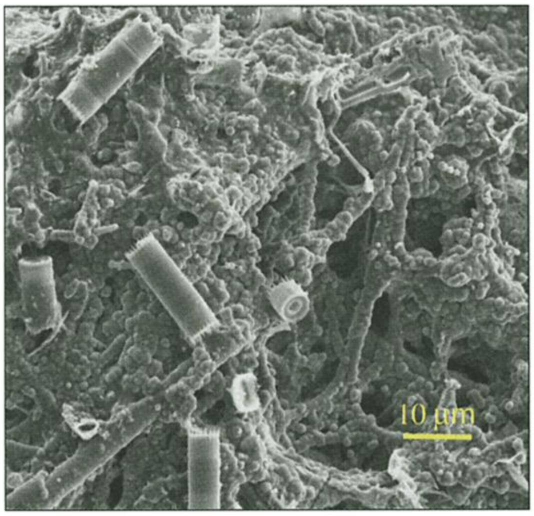
CREDITS: (TOP TO BOTTOM) DAVID BLACKWELL AND ROBERT SMITH; ERIC AND DAVID HOSKING/CORBIS

Cannon. Stone tools tied to paleo-Indian cultures plus carbon dating of organic material in the beaches suggest major up-and-down cycles of 1000 to 3000 years.

All this fluctuation may trigger immense buildups and explosive releases of steam. A USGS bathymetry team led by Lisa Morgan of Denver, Colorado, has taken a close look at several lake bays plus separate nearby lakes and confirmed that they are deep blowout craters, lined with shattered breccia. These include Mary's Bay, which blew up 10,800 years ago, and Indian Pond, dated at 3000 years old. Under one old beach, jumbled projectile points and a buried layer of large pebbles point to a tsunami-like wave correlated with the Mary's Bay blowup. And since 1997, Morgan's team has also spotted dozens of smaller craters—still radiating heat—on the lake floor.

Blowouts could also follow movements in a large fault line recently observed to run into the lakebed, notes geologist William Locke of Montana State University in Bozeman. Whatever the trigger, says Pierce, "you don't want to be around when something happens."

Thus there's "a possibility"—although not "a probability"—that picnickers might look up some afternoon to see a tsunami bearing down, admits park geologist Paul Doss. He plans to take precautions, especially because the USGS has also spotted domelike structures on the lakebed, apparently pumped up by steam—possible precursors of craters. Some are only a few meters across, but one is a kilometer long and peaks at 50 meters. There are no such domes known on dry parkland, possibly because steam there escapes gradually, says Morgan, who wants to put tiltmeters on the domes to warn of sudden growth.



Spire-builders. A chunk of a silica-rich spire reveals the cylindrical shells of diatoms.

Mysterious spires

Starting in 1997, the USGS and a UWM team headed by biogeochemist Val Klump also started spotting more benign features: forests of mysterious pinnacles and spires, apparently formed by hydrothermal activity, jutting 6 meters or more from deep canyons and craters. One set of spires is lined up in a 0.4-kilometer-long rank, possibly aligned with a fault. Too narrow to be clearly resolved by sonar, the spires were missed by surveys until the ROV shared by the USGS and UWM took down a video camera.

Such spires are seen chiefly in seas, not lakes, and their formation in Yellowstone remains something of a mystery. Most ocean spires occur when hot fluids emerge from a hydrothermal vent and loads of metallic sulfide minerals precipitate into the cold water. Precipitation may be partly responsible for the Yellowstone spires, but other processes are apparently at work too. A retrieved 1.5-meter chunk is mostly silica, like the rocks below, but contains what look like silicified remains of bacteria, as well as the siliceous shells of diatoms. Dried, the chunk is like a sponge, weighing only a few pounds; a computerized tomography scan done by the UWM team suggests that the interior is a maze of interconnecting spaces, unlike the weighty sea spires, which have a central channel like a chimney. Morgan thinks that organisms may have formed the labyrinthine structures directly over vents, while other researchers think microbes and diatoms may have simply drifted down from the water column. UWM's Cuhel suggests that sediment may have squeezed up through cracks in the dying glaciers to form the spires; one fragment is dated at 11,000 years, just after the ice receded.

The puzzle is made all the more difficult by the fact that no one has yet found a spire actively venting. Within the park there are a few similar-looking structures now on dry land, for example in Monument Geyser Basin, that may have been formed underwater years ago, says Morgan.

Although the spires appear dead, there are at least 150 hot vents in the lake, many swarming with creatures. Some vents have built themselves little fingers or beehive piles of minerals, while others are just dark, quarter-size holes in the sand, bubbling hot fluids or gases. Some are much hotter than Yellowstone's land vents, says Klump, whose team has scuba-dived to shallow vents and now uses an ROV to reach deeper ones. The vents pour out carbon dioxide, methane, hydrogen sulfide, and iron—all possible grist for the metabolisms of various microbes—as well as mercury, thallium, barium, arsenic, molybdenum, tungsten, boron, and lithium, which the organisms may not find quite as desirable.

The ROV has in fact spotted bacteria and other creatures swirling around vents "like little cyclones," says Cuhel. Meterwide fissures display the colors of the rainbow along their length, depending on the specialized kinds of bacteria living there. Samples show dozens of strains including a new sulfur- and heat-loving genus, *Thermodesulfovibrio*, described in 1994 by microbiologist James Maki of Marquette University in Milwaukee, Wisconsin. Nearby, stringy white mats of more common chemosynthesizers like *Beggiatoa* cling to any available substrates, including stray tree branches. Diners on the bacteria include sizable water fleas, hydra, and snails, as well as worms that live by the squirming handful in the sediments. Identical species are normally found in shallow water, but at the food-heavy vents, they appear to have adapted to live in far denser colonies as far down as 100 meters.

The grazers are in turn pursued by 5- or 8-centimeter predatory leeches, which are sometimes found "fried"—apparent victims of hot-water blasts, says UWM invertebrate ecologist Jerry Kaster. At one vent dubbed the "Trout Jacuzzi," native cutthroat trout—usually cool-water, near-surface dwellers—have been observed charging bacterial mats, although no one knows what if anything they are eating. The only organisms missing are weird macrofauna such as the giant mussels and tubeworms seen at deep-sea vents; the lake is too young for such organisms to have evolved.

The vents' effects may even filter up to land. USGS geochemist Pat Shanks has shown that lake water has high concentrations of arsenic and mercury, probably derived from the vents; he has also shown that trout, topping the aquatic food chain, concentrate mercury, sometimes near the federal danger zone of 1 part per million. The trout in turn feed ospreys, otters, and grizzly bears—not to mention people—and a couple of lakeside bears have turned up with elevated mercury levels in their blood. Whether wildlife—or tourists—suffer any ill effects is unknown, but at least for the animals, the benefits may outweigh the drawbacks, suggests Morgan: "Because of all the nutrients going to the bacteria and going up the chain, there may be a lot more food in the system."

In any case, Yellowstone Lake may need more protection from humans than vice versa. Since news of the spires leaked out in the *Billings Gazette* last year, recreational divers have been pressing officials for maps; they want to go down and take a look. So far, Doss and Morgan have stonewalled, fearing visitors might cause damage. "It could be dangerous down there," says Doss, "but it's also very beautiful and delicate."

–KEVIN KRAJICK

Kevin Krajick is the author of *Barren Lands: An Epic Search for Diamonds in the North American Arctic.*

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