The Hot Spot Beneath Yellowstone Park

Photos and text by Chris Linder

The spark that ignited the fiery volcanic heart of Yellowstone National Park began more than 30 million years ago. Two of Earth's colossal continental plates, centered over what is now the American West, began drifting apart. They stretched Earth's crust in an east-west direction, forming long north-south mountain ranges with wide basins in between.

Some 14 million years later, a magma chamber formed beneath this thin area of crust. It sent plumes of magma surging toward the surface, kicking off a series of mammoth volcanic eruptions. These eruptions left a trail along the Snake River Plain as the North American Plate moved westward over the hot spot, at the rate of slightly less than two inches per decade.

About 2.1 million years ago, the area that is now Yellowstone moved over this magma chamber and was rocked by a massive volcanic eruption. The blast spewed volcanic ash and gas into the atmosphere and caused the ground above to collapse into a mammoth bowl called a caldera. As the plate continued to drift, smaller eruptions occurred 1.3 million and 640,000 years ago, forming two more calderas. The third eruption created what is known today as the Yellowstone Caldera, which stretches over a 30-by-45-mile oval in the park that includes the northern half of Yellowstone Lake.

More than three million tourists who annually visit Yellowstone can see the area's steaming fissures, bubbling mud pots, and explosive geysers from many roadside stops. But beneath the surface of Yellowstone Lake, hidden from view, is a fount of volcanic activity. It heats fluids that rise and spew in hydrothermal vents on the lake floor. The northern part of the lake hosts the largest known hydrothermal explosion craters in the world. These are generated when pressure in the hydrothermal circulation system suddenly drops, causing catastrophic steam explosions that can excavate craters more than a mile in diameter.

Enter WHOI geophysicist Rob Sohn, who has spent his career studying hydrothermal vents that typically form over magma chambers beneath the seafloor. Sohn saw an opportunity to investigate what is happening at the bottom of Yellowstone Lake, using technology normally used in the deep ocean.

"The vents on the floor of Yellowstone Lake are three hundred to three hundred fifty feet deep, and so until recently we didn't even know they existed," Sohn said. "And, of course, they're very hard to observe."

He joined experts in Yellowstone volcanology and geology with scientists who study deep-sea hydrothermal systems for the Hydrothermal Dynamics of Yellowstone Lake project.

In July 2016, the HD-YLAKE team began its multiyear project on Yellowstone Lake. It deployed underwater instruments to monitor heat and motion on the lake floor and collected samples with a newly developed remotely operated underwater vehicle. The team also extracted a series of long cores of sediments from the lake floor, which hold clues to past events in the lake's geologic and climate history. Some cores were nearly 40 feet long, digging into deeper sediments that extend further back in time—up to 15,000 years ago, when glaciers were beginning to recede from Yellowstone.

"By bringing these two groups of people together in Yellowstone Lake," Sohn said, "we have a really exciting opportunity to make a huge increase in our understanding of these vents."

This research was supported by the National Science Foundation and the U.S. Geological Survey's Yellowstone Volcano Observatory. Work was completed under an authortized Yellowstone Research Permit.

The North American Plate has slowly moved westward over an active magma chamber, leaving a trail of past eruptions on the landscape. The hot spot now lies beneath Yellowstone Park.

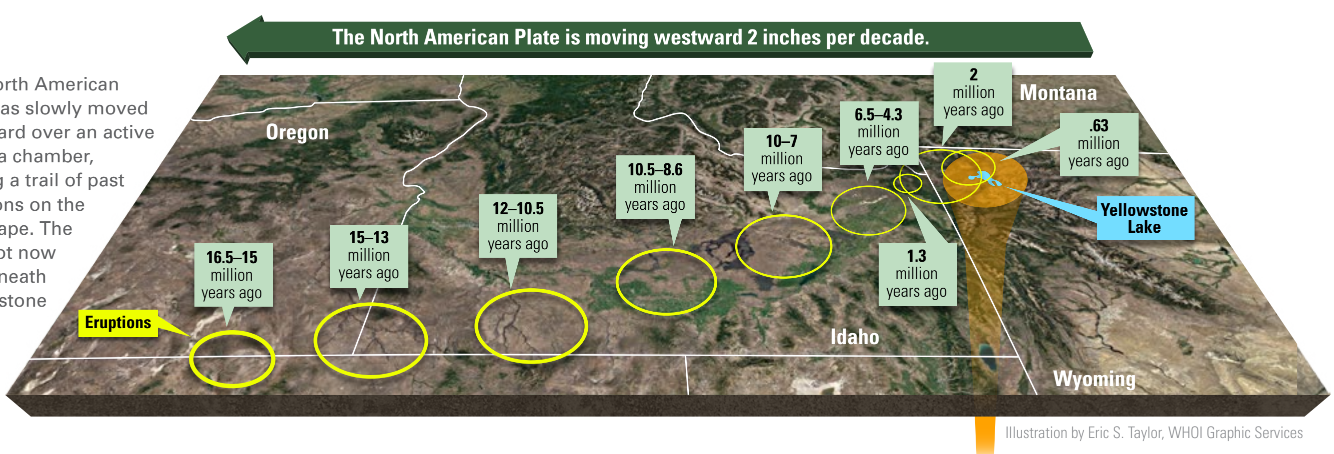
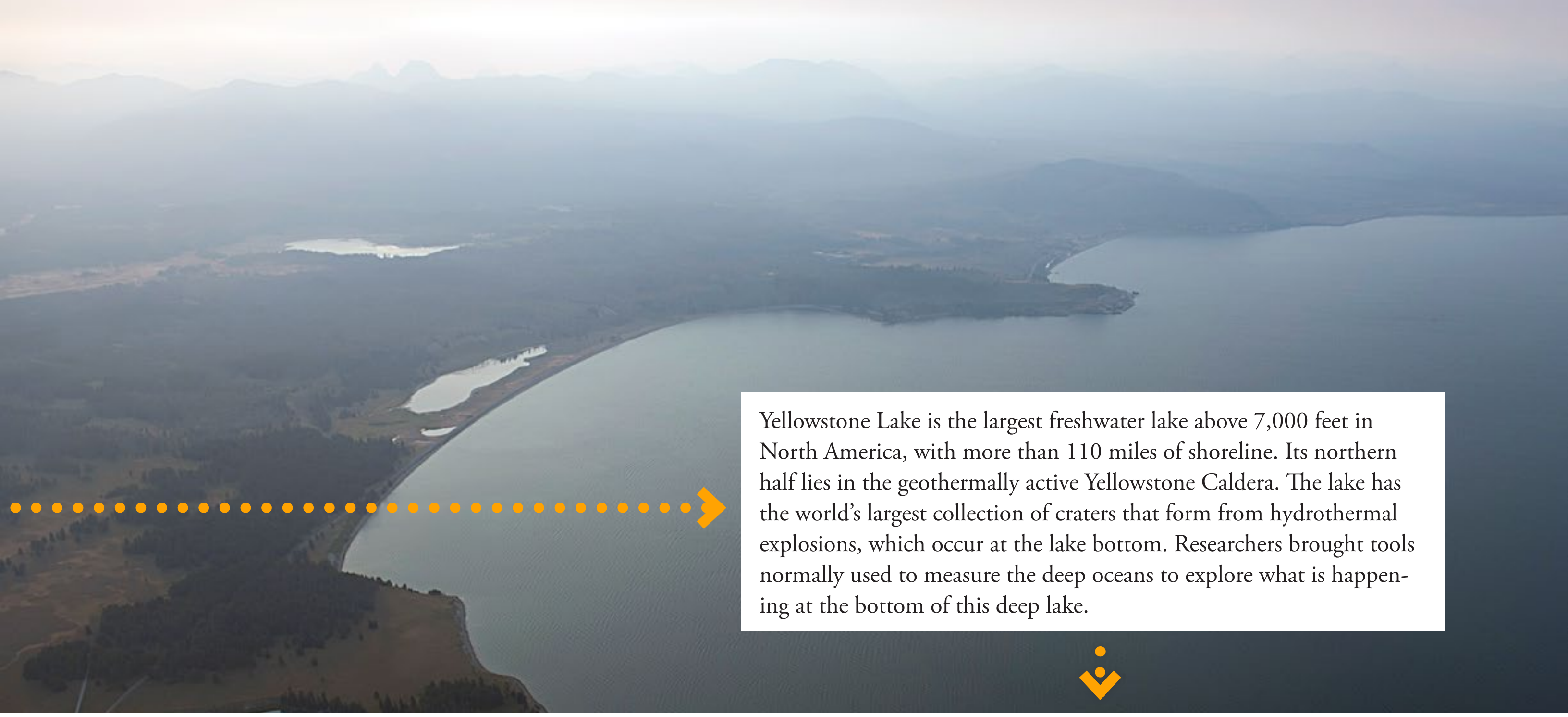
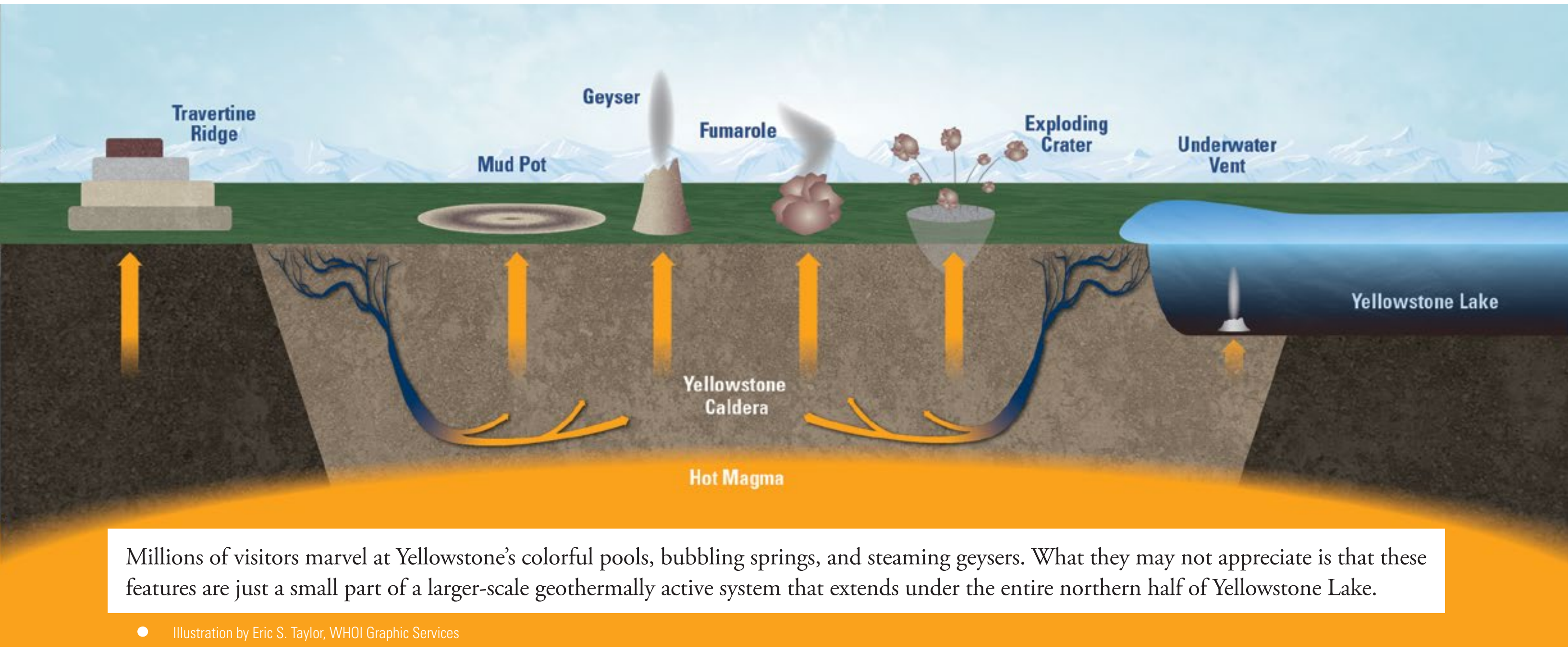


Illustration by Eric S. Taylor, WHOI Graphic Services



Yellowstone Lake is the largest freshwater lake above 7,000 feet in North America, with more than 110 miles of shoreline. Its northern half lies in the geothermally active Yellowstone Caldera. The lake has the world's largest collection of craters that form from hydrothermal explosions, which occur at the lake bottom. Researchers brought tools normally used to measure the deep oceans to explore what is happening at the bottom of this deep lake.



Millions of visitors marvel at Yellowstone's colorful pools, bubbling springs, and steaming geysers. What they may not appreciate is that these features are just a small part of a larger-scale geothermally active system that extends under the entire northern half of Yellowstone Lake.

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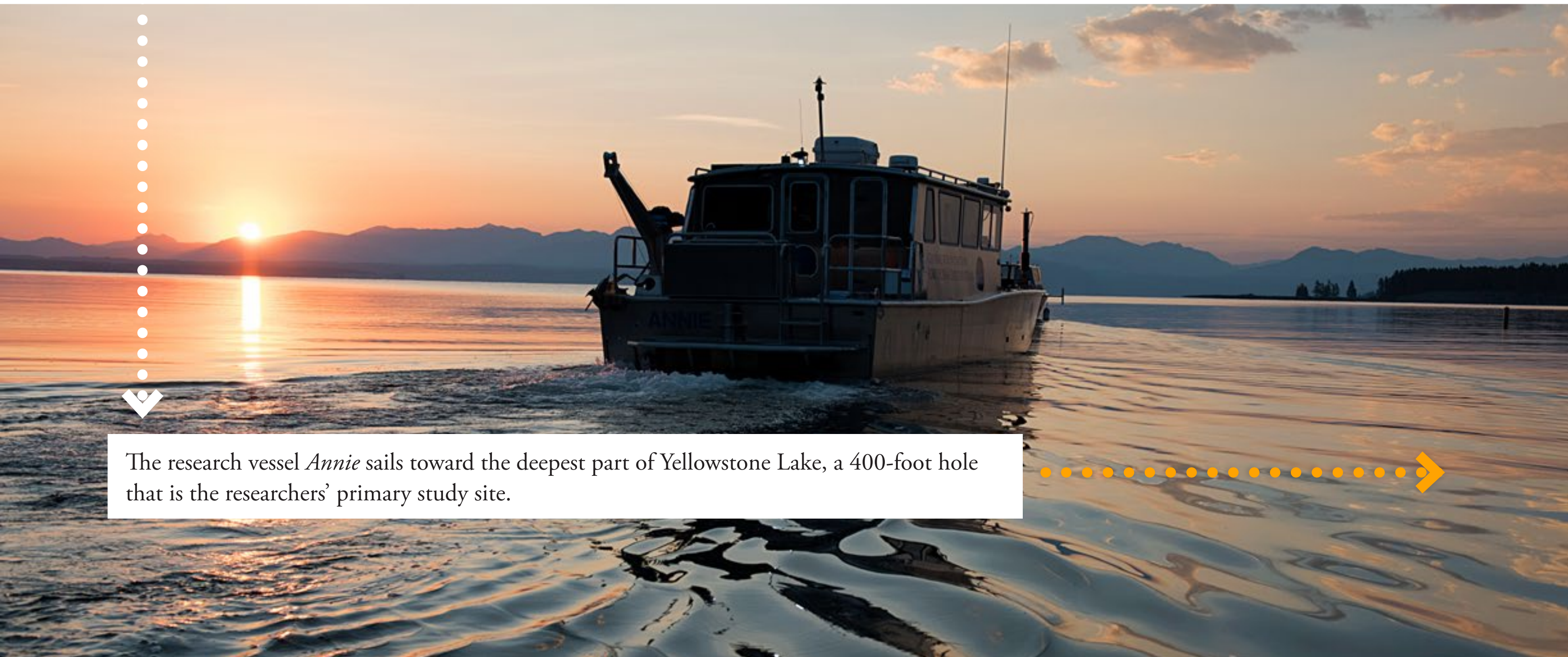
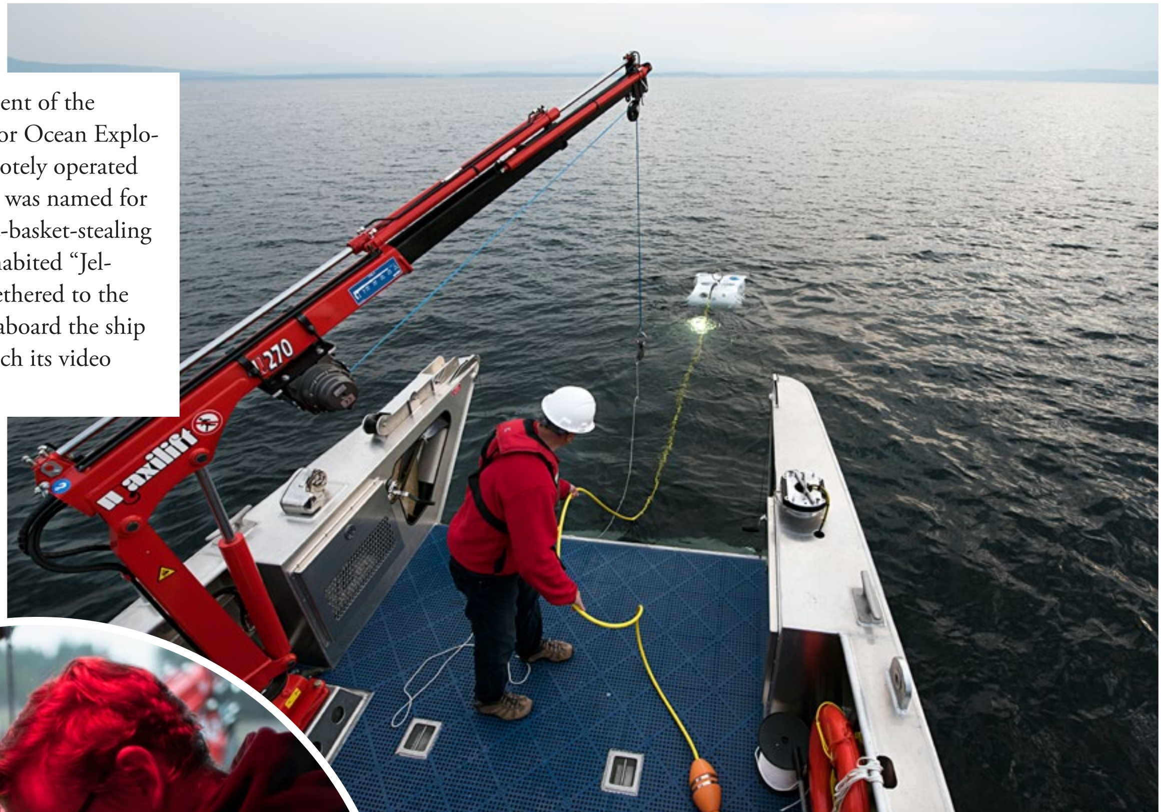


The research vessel *Annie* sails toward the deepest part of Yellowstone Lake, a 400-foot hole that is the researchers' primary study site.



Dave Lovalvo, president of the Global Foundation for Ocean Exploration, lets out a remotely operated vehicle called *Yogi*. It was named for the inquisitive picnic-basket-stealing cartoon bear that inhabited "Jellystone." The cable tethered to the vehicle allows pilots aboard the ship to drive *Yogi* and watch its video feeds in real time.

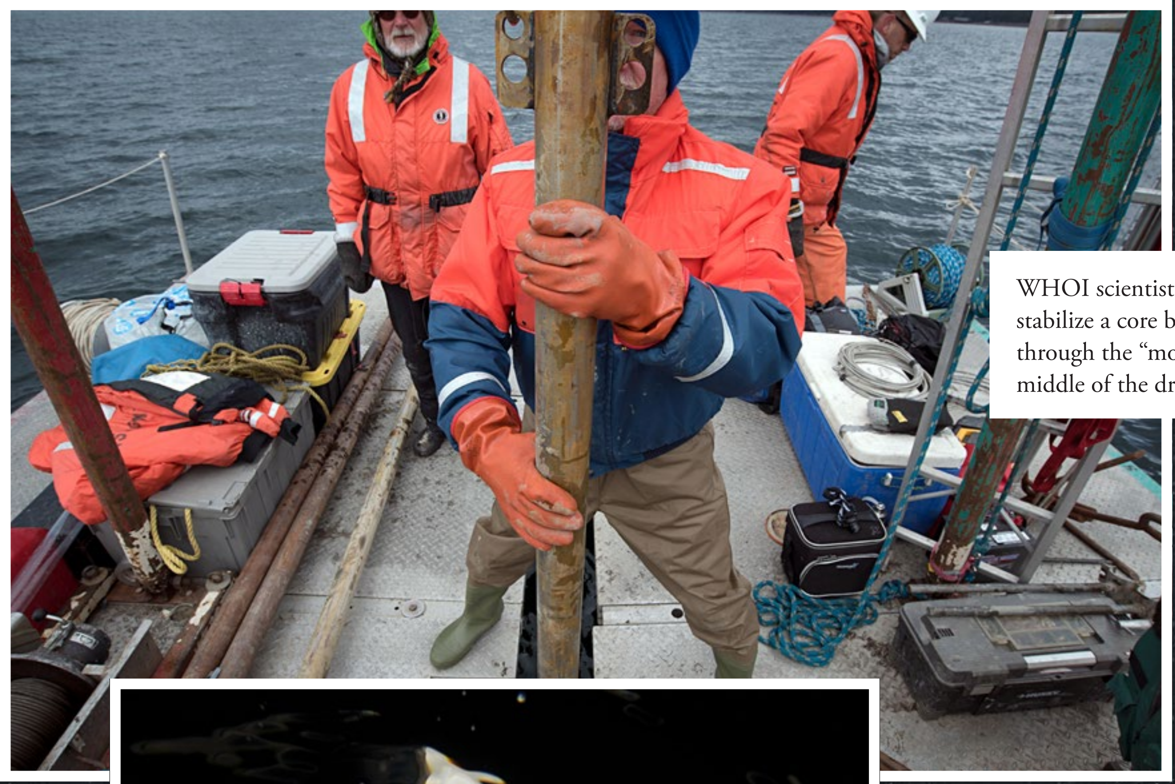
WHOI geophysicist Rob Sohn, chief scientist of the multiyear research project, takes careful notes onboard the research vessel *Annie*.

In a blacked-out control room on *Annie*, Todd Gregory (left) operates *Yogi*'s manipulator arm. Dave Wright (middle) drives the vehicle, while Andy O'Brien (right) observes. Chief scientist Rob Sohn (standing) records data. The crew is using *Yogi*'s manipulator arm to place a probe into the lake floor to measure heat migrating up through the lake bottom. The probe will remain in the bottom for a year, measuring how the heat flow varies over time at different locations. The heat comes directly from the magma chambers that underlie Yellowstone Caldera and is more than 1,000 times hotter than the average for similar sites in North America.

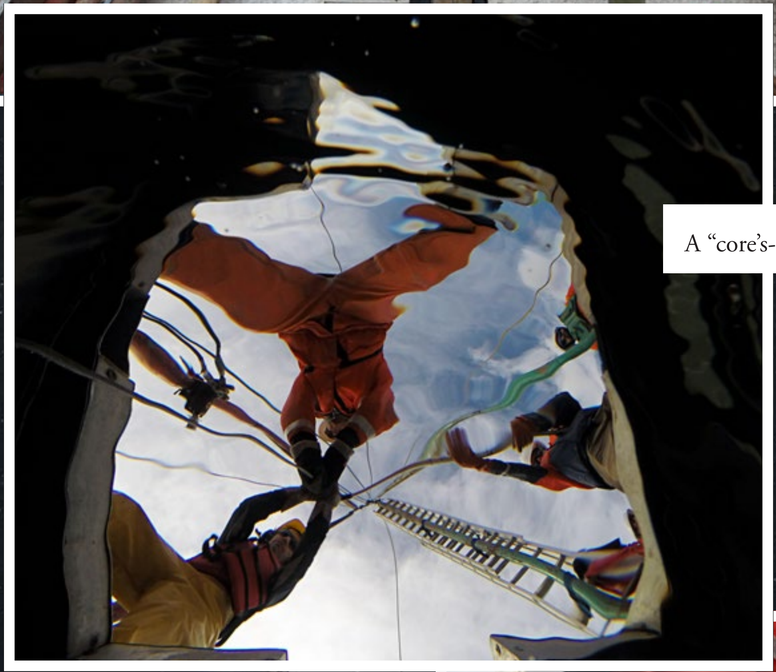
The research team battled freezing rain and sleet to construct a floating drilling platform to collect long cores of sediments from the lake bottom. The team included Lisa Morgan and Pat Shanks from the U.S. Geological Survey, Sheri Fritz and Sabrina Brown from the University of Nebraska, Cathy Whitlock and Chris Schiller from Montana State University, Ryan O'Grady and Mark Shapley from the LacCore National Lacustrine Core Facility at the University of Minnesota, and Rob Sohn from WHOI. Retired Montana high school teacher Michael Baker and visiting scientist Dan Conley from Lund University in Sweden also volunteered to help with fieldwork.

It took eight people to push a tall metal A-frame for coring operations into place on the deck of the coring vessel. The team cored six sites with different geological features in Yellowstone Lake to give them an unprecedented look at the postglacial geological history of the lake region, including the processes that form large hydrothermal explosion craters.

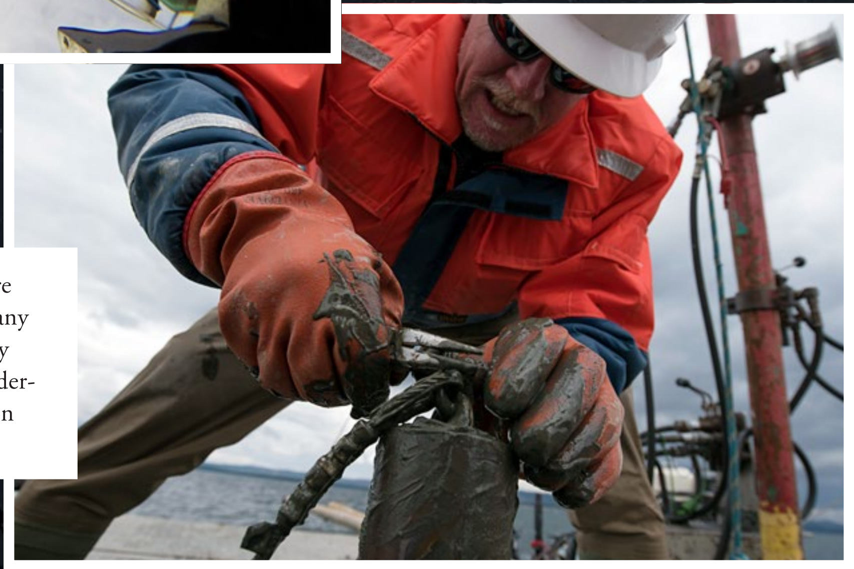
Normally winds build up over the lake in the afternoon. But on the first coring day, the lake was flat calm, and the team got right to work.



WHOI scientist Rob Sohn helps to stabilize a core before it is deployed through the "moon pool" in the middle of the drilling platform.

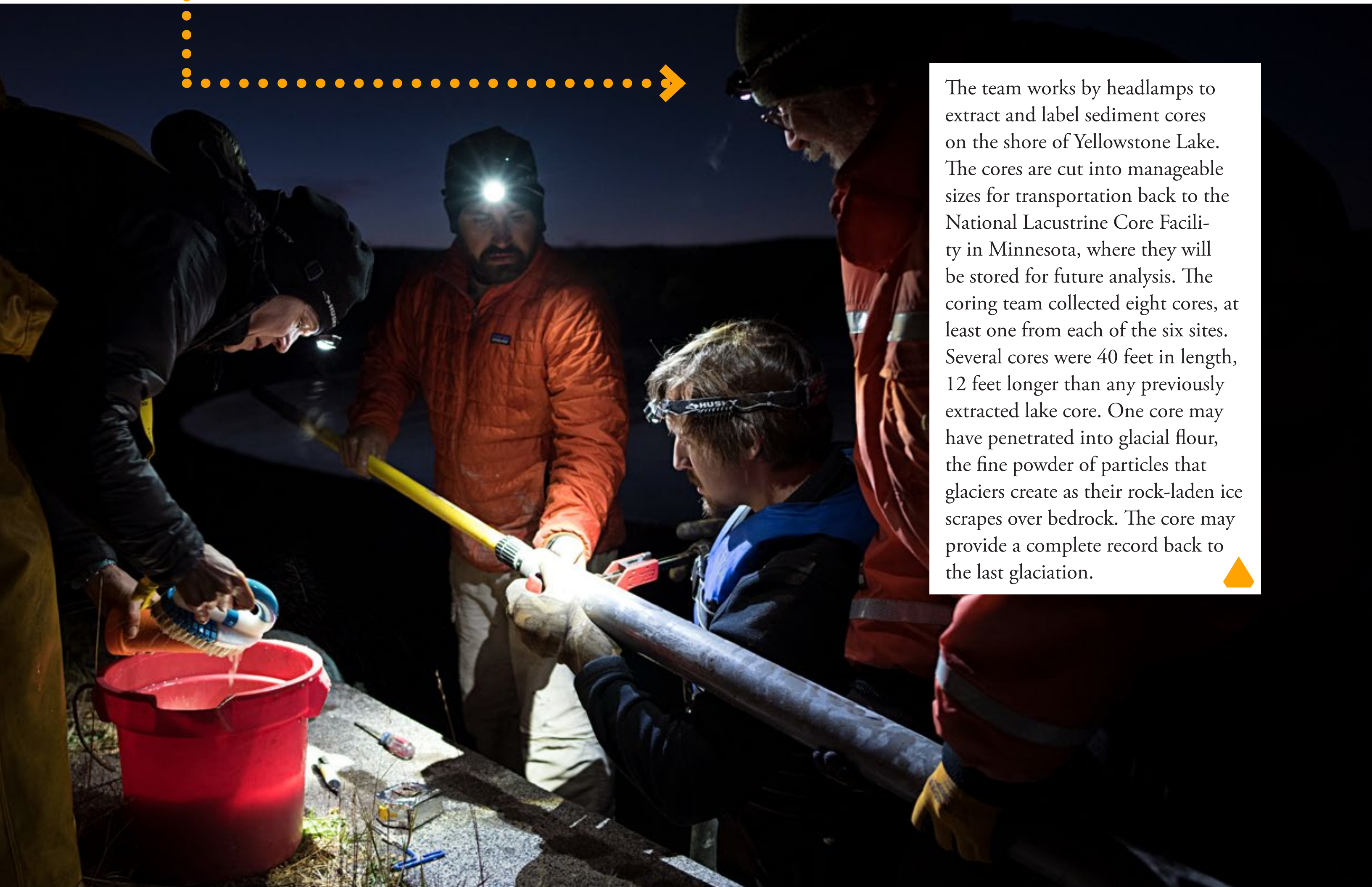


A "core's-eye view" up through the moon pool.



Rob Sohn wrestles with a muddy shackle after a core was successfully retrieved from the lake bottom. Many cores contained significant amounts of gas, probably carbon dioxide, that had bubbled up because of underlying geothermal activity and had become trapped in the sediments.

Ryan O'Grady and Mark Shapley from the LacCore National Lacustrine Core Facility secure cores to the deck as an afternoon thunderstorm builds over the lake. Weather is a relentless foe in September, as high winds and thunderstorms can form with little warning.

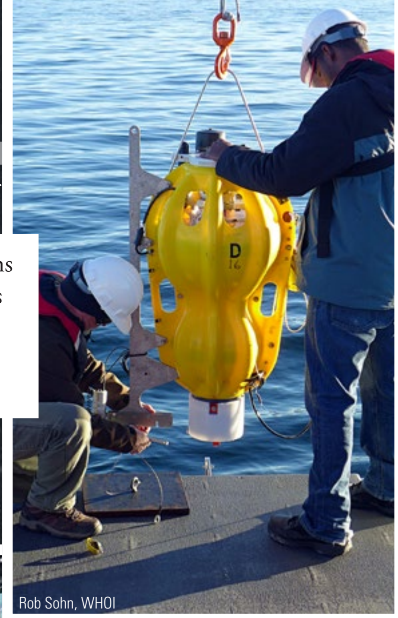


The team works by headlamps to extract and label sediment cores on the shore of Yellowstone Lake. The cores are cut into manageable sizes for transportation back to the National Lacustrine Core Facility in Minnesota, where they will be stored for future analysis. The coring team collected eight cores, at least one from each of the six sites. Several cores were 40 feet in length, 12 feet longer than any previously extracted lake core. One core may have penetrated into glacial flour, the fine powder of particles that glaciers create as their rock-laden ice scrapes over bedrock. The core may provide a complete record back to the last glaciation.

Expanding the Scientific Arsenal

by Lonny Lippsett

For the first time, HD-YLAKE scientists used ocean-bottom seismometers (OBSs) to detect motions on a lake bottom, adapting them for fresh water. MIT-WHOI Joint Program graduate student Paris Smalls (right) steadies the OBS while WHOI engineer Tim Kane sets the anchor. Next summer the researchers will deploy a network of ten OBSs in Yellowstone Lake to try to detect hot gases percolating up through lake sediments.



Rob Sohn, WHOI

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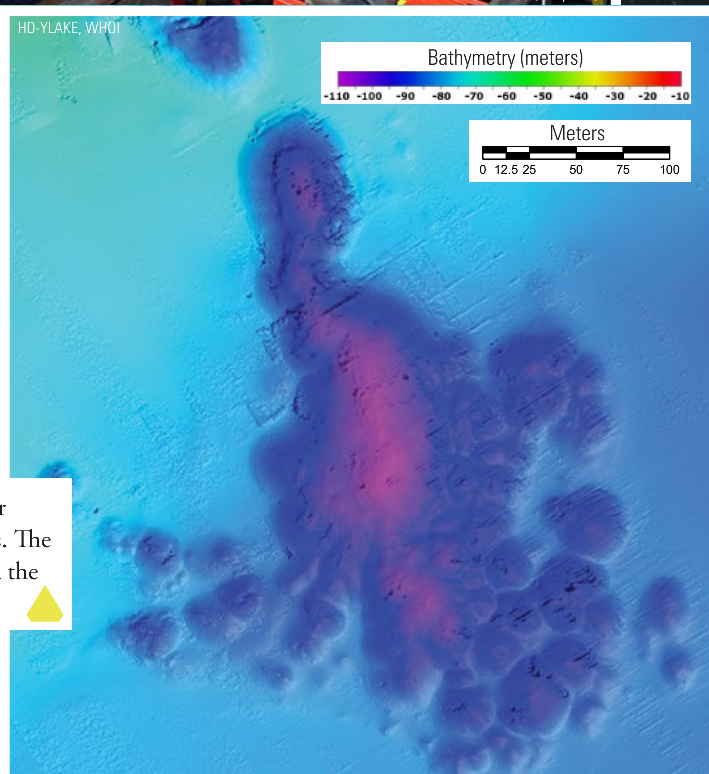
WHOI engineer Greg Packard (above right) and consultant Greg Kurras brought in WHOI's autonomous underwater vehicle REMUS. They obtained high-resolution maps of the lake floor (right), showing pockmarks created by hot fluids discharging at the bottom.



HD-YLAKE, WHOI

Enter WHOI scientist Maurice Tivey, who towed a magnetometer near the lake floor to measure telltale magnetic properties of rocks. The data may reveal clues to chemical reactions near the lake floor and the formation of underlying lava flows deeper down.