

A rumbling truck enables a clearer view of Yellowstone's most active magma chamber

Seismic imaging reveals that the chamber is just 3.8 km belowground and capped by a layer of volatile-rich magma.

The Mud Volcano section is one of Yellowstone National Park's most hydrothermally active regions. Gas and hot fluids percolate up from deep underground to form the unique muddy features that give the region its name. The ground inflates and deflates, movement of magma beneath the surface creates swarms of small earthquakes that last months or years, and emissions of helium isotopes from Earth's mantle signal an even deeper driver of all the activity near the surface. Until recently, estimates of the depth belowground to the top of the magma chamber spanned the rather large range from about 3 km to 8 km. That's because underground imaging relied on signals from distant earthquakes that couldn't provide a high-resolution view. But for Earth scientists trying to understand the region's eruption hazard, the difference between 3 km and 8 km has major implications for how magma behaves.

Now a study by Chenglong Duan and Brandon Schmandt, both at Rice University, and their colleagues has shown that the top of the magma chamber is on the shallower side, at about 3.8 km down, and is capped by a thin layer of magma that contains supercritical volatiles, including water, sulfur, and carbon dioxide. "Yellowstone is famous for its hydrothermal features and gas emissions. That makes sense if you have a really shallow magma reservoir with its top at 4 kilometers," Schmandt says. The researchers obtained their clearer view by creating their own seismic waves rather than relying on those from earthquakes.

In 2020, they deployed about 650 small cable-free seismometers along a stretch of road that crosses the edge of the Sour Creek dome, as shown by the densely clustered black dots in figure 1. Then, along the same stretch of road,

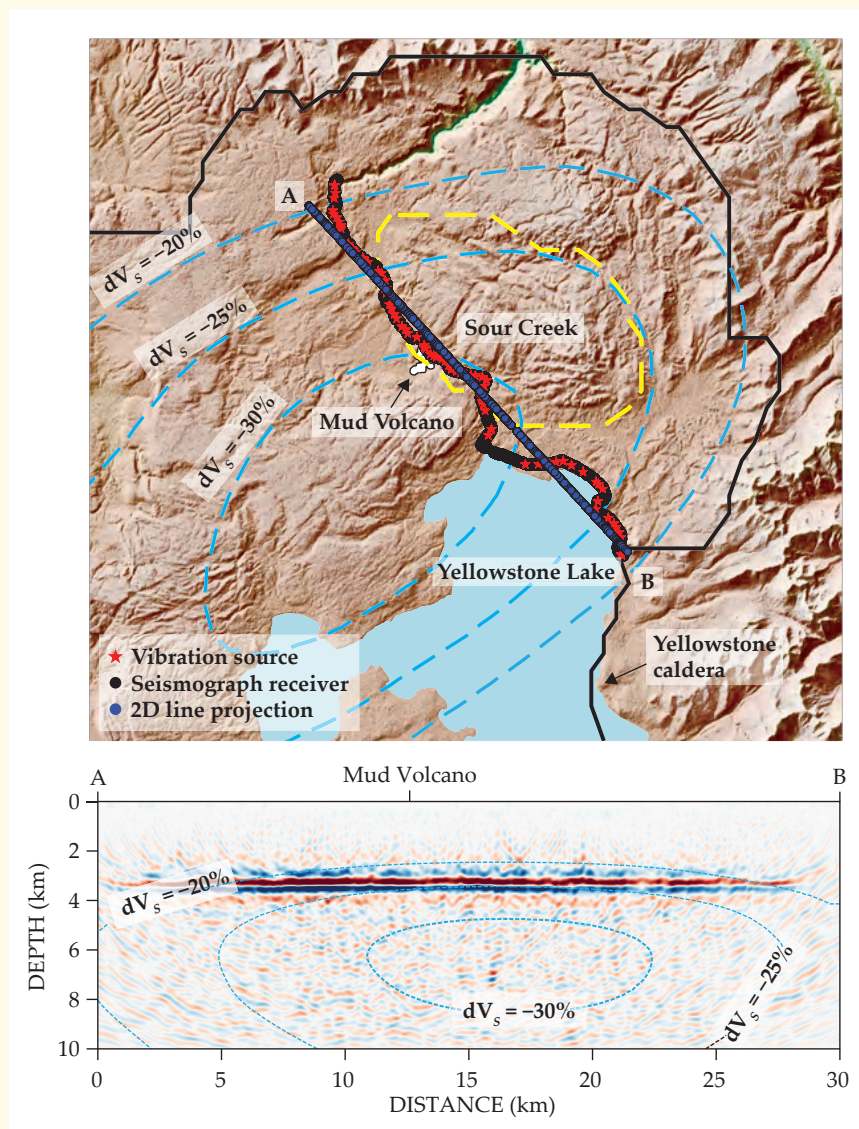


FIGURE 1. THE MAGMA RESERVOIR beneath the Sour Creek resurgent dome (upper panel, yellow dashed line) in Yellowstone National Park was imaged in unprecedented detail using vibrations sent into the ground along a 30 km stretch of road. Seismic imaging revealed an abrupt roof to the magma chamber about 3.8 km underground, and the researchers determined that the top of the reservoir contains a mixture of supercritical water, magma, and solid mineral crystals (lower panel, red line). The Mud Volcano section of the park exhibits the most chemical evidence of ongoing input of deep magma, as measured from gases and fluids that come to the surface. Previous studies used signals from distant earthquakes to estimate the density of the magma chamber, averaged over large areas. Those measurements of decreasing shear wave velocities (dV_s), which indicate higher fractions of melt, are contoured with blue dashed lines (both panels). The edge of the Yellowstone caldera—a depression left after the volcanic system's last super-eruption about 630 000 years ago—is outlined in black (upper panel). (Figure adapted from C. Duan et al., *Nature* **640**, 962, 2025.)



FIGURE 2. A TRUCK-MOUNTED METAL PLATE uses about 220 000 N of force to send vibrations into the ground across a frequency sweep of 6–30 Hz. Analysis of how the high-frequency vibrations move through the ground has provided a refined view of the Yellowstone magma reservoir in the northeast section of the park. (Photo courtesy of Brandon Schmandt, taken under Yellowstone National Park research permit YELL-2020-SCI-8146.)

they created the vibrations for their measurements: A large truck, shown in figure 2, lowered a metal plate to lift it off the ground and use almost its full weight to send the signal into the earth. The plate vibrated through a range of frequencies over a span of 40 seconds, and the process was repeated 20 times at each site. All of the measurements were collected at night both to avoid bothering

visitors to the park and to reduce extra noise from traffic.

The high frequencies used—from 6 to 30 Hz—enabled the researchers to get a sharper picture of what is happening below. But extracting an accurate view requires a lot of data processing to see through the noise. Active-source seismic imaging of volcanic systems has excelled in ocean settings: A ship can send well-

defined signals into the water, which carries the vibrations in a predictable way, and tow a line of receivers behind it to collect measurements. But on land, there are more confounding factors: A road is needed, the vibrations scatter off the surroundings in less predictable ways, and more sources of noise obscure the targeted signals. The unique setting of the national park, with easy access to roads, was part of what made the latest study possible. Improvements in the past decade to small, easily deployed seismometers and to data processing methods also enabled the work.

The study's finding doesn't change the current hazard assessment for the region, but it does provide better context to understand future monitoring data. Decompression of magma as it moves up in the crust can lead to a buildup of volatiles that will sometimes trigger eruptions. But for now, the imaging suggests that the magma chamber is channeling fluids and gases to its surface in a manner that promotes stability. (C. Duan et al., *Nature* **640**, 962, 2025.)

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