

Scientists dig deep in Tohoku fault to crack earthquake's secrets

Nine months of data from the world's deepest observatory agree with lab measurements on a controversial quake parameter.

Right after the magnitude-9 Tohoku earthquake shook Japan's north-eastern coast on 11 March 2011, Emily Brodsky and Jim Mori phoned each other from across the Pacific Ocean and decided "yes, this is it."

For several years, they had been on the lookout for an earthquake to study up close. Brodsky, a geophysicist at the University of California, Santa Cruz (UCSC), recalls that at a workshop in 2008, "we said we are going to wait until we get the right earthquake, because it's expensive and difficult. We also said we are not going under water, because it's crazy." What made the Tohoku earthquake compelling for the researchers—despite its having occurred under water—was the fault's enormous slip, some 50 meters at the sea floor. Nor did it hurt that Japan had mapped the sea floor in the fault region before and after the earthquake.

By April 2012 an expedition—the

Japan Trench Fast Drilling Project, or JFAST—costing about \$26 million and involving 30 scientists from Japan, the US, and eight other countries had set sail to drill into the fault. The speedy mobilization was thanks to the Integrated Ocean Drilling Program (IODP), the international marine research organization that sponsored JFAST. Scientists are now analyzing the data they collected from three boreholes up to 855 meters deep that start nearly 7000 meters below sea level.

The main goals of JFAST were to retrieve core samples from the Tohoku fault zone and to measure the temperature on the fault plane as a means to estimate frictional stress during the earthquake. "What are the physical mechanisms involved in the huge slip?" asks Mori, a professor at Kyoto University's Disaster Prevention Research Institute and co-chief scientist on JFAST. "It's hard to imagine a rock surface slip-

ping 50 meters. We wanted to investigate the physics of that. No one has drilled a fault with such huge fault displacement before, so almost anything you learn or see will be interesting."

Feats of engineering

For two months 150 scientists, drilling engineers, technicians, and crew members worked aboard the *Chikyu*, Japan's deep-sea drilling vessel. To drill the boreholes, "you connect pieces of pipe, each about 35 meters long. Everything is happening on the ship," says Mori. "Handling the long drill pipe is challenging. Pressures are high on the ocean floor; seeing what's going on with the camera was difficult."

During the first trip, team members drilled one hole to find the fault and another to retrieve core samples up to 9 meters long. They went back in July and drilled the third hole, into which they dropped a string of 55 temperature sensors. Spaced with increasing density going down to and across the fault at about 815 meters below the sea floor, the sensors logged temperature every 20 minutes. Nine months later, the team went back to robotically pull up the sensors. "There are lots and lots of reasons this [experiment] should not have worked. It's a real testament to JAMSTEC engineering that it did work," says Brodsky. JAMSTEC, the Japan Agency for Marine–Earth Science and Technology, managed the JFAST expeditions and operates the *Chikyu* as Japan's contribution to the IODP. (For more on IODP's drilling activities, see the article by Susumu Umino, Ken Nealson, and Bernard Wood on page 36.)

Small friction, large slip

The degree of frictional stress during an earthquake is controversial, says Mori. "Some say it should be high, because rocks are strong and it's hard to make a fault move." If the friction is high, it should melt rocks at the sites of earthquakes. "We have found some melted rocks at land earthquakes, but not as many as expected," he explains. Measurements at earthquakes in Taiwan and Sichuan, China, showed low friction, but only gave upper limits. "So getting a value of friction was a main goal."

The JFAST team measured temperature to estimate friction. The temperature probably went up several hundred



A string of 55 temperature sensors was successfully recovered from an 855-meter-deep borehole more than 7000 meters below sea level in the Tohoku fault.

degrees at the fault at the time of the earthquake, Mori says. "By a year later, we are looking at a few tenths of a degree. It's a simple conduction experiment. Rock holds heat pretty well." Patrick Fulton from UCSC explains, "We see an extra bump in the temperature that indicates extra heat at the fault. Since we know that the fault slipped 50 meters, based on the extra heat we can back out what the friction was during the earthquake. It was low." The small friction could have contributed to the large slip, he says. "And large slip and [the earthquake's] shallow depth probably contributed to the large tsunami."

The JFAST friction measurements are consistent with laboratory experiments. Kohtaro Ujiie, a structural geologist at the University of Tsukuba, says that by sandwiching fault-zone material between a pair of rock cylinders and holding one fixed while rotating the other, "we reproduce high-speed shearing, and measure the shear stress in the fault-zone material." Those experiments use about half a gram of fault-zone material.

The researchers also found the clay content in the fault-zone samples to be unusually high. Says Ujiie, "We think the low friction of the Tohoku material is due to the abundance of weak clay."

The huge slip observed in the Tohoku earthquake is rare. "We have fewer than 10 examples in the known history," says Shuichi Kodaira, a JAMSTEC scientist. Predicting earthquakes is still not possible, he says, "but at least we know the frictional properties of this earthquake, so we can understand why it occurred."

The JFAST researchers plan to install a pressure sensor at the opening of the observatory borehole—the one where temperature sensors were—to monitor

fault movement. Another group is studying the much deeper Nankai Trough seismogenic zone south of Japan. "We have the same science goals," says Mori. The two projects are complementary, he adds. "Ours is unique in that we are drilling into the fault and making direct measurements after the earthquake. For the Nankai project, there are plans to drill to a fault several kilometers below the sea floor before the major earthquake occurs."

Toni Feder

Livermore program accelerates cancer diagnostics

Lasers could eventually replace accelerator mass spectrometry for many biomedical applications, but they haven't yet.

A former Lawrence Livermore National Laboratory (LLNL) chemist is attempting to commercialize an accelerator-based measurement technology, developed at the lab, that predicts whether some cancerous tumors will respond to a widely used chemotherapy agent. If the test is approved for use, patients who won't respond to the drug would be spared from having to

endure the toxic side effects and could pursue other therapies.

The technology employs radiocarbon tracing using accelerator mass spectrometry (AMS) to determine if the chemotherapy agent carboplatin will be effective in treating individuals with bladder and lung cancer. Carboplatin is effective in nearly two-thirds of patients with those cancers, but there is

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