Triggered. Slow slip on an offshore fault preceded the megaquake and its tsunami last March.

SEISMOLOGY

A Tantalizing View of What Set Off Japan's Killer Quake

Japanese scientists combing through the vast jumble of seismic signals recorded in the days before the great magnitude-9.0 earthquake that ravaged their homeland have just sorted out more than 1000 newly recognized earthquakes. The find reveals how the lethal offshore fault slipped slowly just before it ripped loose. That slow slip now appears to have loaded the fault to the breaking point, triggering the devastating quake last March.

The work—the fruit of decades of intensive monitoring around Japan—gives seismologists a much-anticipated peek into a fundamental mystery: "How does a big earthquake happen?" asks seismologist Lucile Jones of the U.S. Geological Survey (USGS) in Pasadena, California. Although it is a long-sought precursor to a big quake, the slow slip "is not a tool for prediction," she quickly adds, at least not by itself. It does, however, suggest that this time, in this place, Earth held one clue that a big quake was imminent. Researchers' next step—learning whether such a clue is rare or commonplace—will require close looks at many more earthquakes.

To get a clear view of what preceded the Tohoku-Oki quake, researchers had to pick out much smaller quakes from the seismic record that standard methods had missed. The standard earthquake catalog contained 333 identifiable quakes in the same area in the month before the magnitude-9 quake.

But with so much going on seismically, many other quakes must have remained buried in the seismic records. So seismologist Aitaro Kato (http://scim.ag/A-Kato) and his colleagues at the Earthquake Research Institute (ERI) at the University of Tokyo in effect filtered out much of the record's noise. They used the fingerprint-like seismograph wiggles of each of the known 333 quakes to go fishing for computerized matches in the churning sea of signals that is the seismic record. They pulled out 1416 matches, more than quadrupling the number of quakes whose timing and location might speak to what the fault had been up to.

It turned out that before a north-south, 500-kilometer length of fault ripped loose in the magnitude-9 quake, the fault just north of the great quake's starting point slowly slipped, not once but twice. Sections of faults that will eventually rupture in large quakes are generally stuck tight, with not even small patches breaking in small earthquakes. But some fault segments are just slick enough for their opposing sides to slowly slide past each other. When the slip comes episodically, it is called slow slip, a slow earthquake, or a silent quake.

Slow slip generates no seismic waves; researchers can directly monitor truly silent quakes only by exquisitely precise measurements made on or in the crust by instruments such as tiltmeters. Such measurements are not routinely made on the sea floor. But if the slipping fault has a few small sticky spots, they will snag and then break free in small quakes. Among the 1749 quakes the ERI group ended up with, about 25 turned out to be quakes that repeat on the same fault patch as long as slip continues.

By following the location, timing, and size of the repeating earthquakes that they had found, the ERI group could track any slow slip before the magnitude-9 quake. A first episode of slow slip began in mid-February about 40 kilometers north of the megaquake's starting point, or epicenter. It progressed south until it reached the megaquake's eventual epicenter by the end of February and stopped. Nothing happened, not until 9 March, when a magnitude-7.3 foreshock struck at the starting point of the first pulse of slow slip. That set off a second, faster pulse of southward slow slip. This time, when the slip about reached the eventual megaquake's starting point, the magnitude-9 quake let loose.

From that sequence of events, the ERI group concludes that the second pulse of slow slip "may have" triggered the megaquake. That makes good sense, other seismologists say. Earthquakes let go when enough stress accumulates to break the fault. The Tohoku-Oki segment of fault had been slowly accumulating stress for about a millennium when the second slow-slip pulse delivered a load of stress equivalent to about one-quarter of that released in the magnitude-7.3 foreshock. That, apparently, was the last straw.

So that's how at least one great earthquake seems to have happened. "It suggests there's a lot more going on there than we suspected," says seismologist William Ellsworth of USGS in Menlo Park, California. But Kato of ERI is the first to caution that they have not found the key to earthquake prediction. For one thing, prediction would require knowing how close to failure the locked fault segment had become. That has proved devilishly difficult to determine.

And then there is the as-yet-unknown frequency of slow-slip precursors. "You can't expect a slow precursor—like the Japanese have been expecting—for all events," says seismologist Hiroo Kanamori of the California Institute of Technology in Pasadena. "Prediction on the basis of slow slip must be extremely difficult."

Not that slow slip couldn't cause a bit of a stir. If a similar sequence were detected off the U.S. Pacific Northwest, where a similar megaquake struck in 1700, "it would certainly be setting alarm bells off," Ellsworth says. As it happens, says seismologist Jeffrey McGuire of Woods Hole Oceanographic Institution in Massachusetts, he and colleagues will soon be installing a tiltmeter in the sea floor off the Pacific Northwest that would detect any slow slip there in real time. So with luck, they will at least know when something unusual gets going.

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Published by AAAS