Scientists explain source of mysterious tremors emanating from fault zones

Entire buildings tilt because of ground failure after the Niigata, Japan, earthquake. Credit: NGDC

Tiny tremors and temblors recently discovered in fault zones from California to Japan are generated by slow-moving earthquakes that may foreshadow catastrophic seismic events, according to scientists at Stanford University and the University of Tokyo.

In a study published in the March 15 issue of the journal *Nature*, the research team focused on weak seismic signals known as "non-volcanic tremor" and "low-frequency earthquakes," which seismologists say may be useful in forecasting the likelihood of potentially destructive mega-quakes of magnitude 8 or higher.

"Non-volcanic tremor is a weak shaking of the Earth that was discovered about five years ago in Japan," said Gregory C. Beroza, professor of geophysics at Stanford and co-author of the Nature study. "It's often accompanied by low-frequency earthquakes [LFEs]—small temblors of magnitude 1 or 2. Some people believe that LFEs and tremor are separate phenomena, but what we've shown in this paper is that they are actually the same thing. Tremor is simply a swarm of low-frequency earthquakes, but rather than happening quickly and impulsively like ordinary earthquakes, tremor shakes the Earth for hours, days or even weeks at a time."

Destructive zones

To date, non-volcanic tremor and LFEs have been found primarily in subduction zones—seismically active faults where two tectonic plates meet and one plate constantly dives beneath the other. The most destructive earthquakes ever recorded have occurred in subduction zones, in places such as Chile, Japan, Alaska, Washington state and British Columbia. A recent example was the devastating 2004 earthquake near Sumatra, where a magnitude 9.2 temblor triggered powerful tsunamis that killed more than 200,000 people.

These violent mega-thrusts occur every 100 to 600 years, depending on the location. Recent studies suggest that giant quakes, which form at relatively shallow depths, are preceded by a series of much deeper events called slow (or silent) earthquakes, which displace the ground without shaking it. A slow earthquake can last days, months or years without being felt at the surface.

"In Japan, the deep section of the fault where slow earthquakes form is particularly significant, because it lies next to the shallower locked portion of the fault, where big quakes periodically strike," Beroza said. "So each time a slow earthquake happens, it adds stress to the locked section and increases the likelihood of a magnitude 8 mega-thrust. Therefore, knowing when a slow earthquake has occurred could be useful in seismic hazard forecasting."

Tremor trauma

But detecting slow quakes is a difficult task, he added. That's one reason why seismologists were particularly excited by the recent discovery of non-volcanic tremor and LFEs in the subduction zone near Shikoku, Japan.

"Shikoku experiences a big earthquake every 100 years or so," said Stanford graduate student David R. Shelly, lead author of the Nature study. "The last one happened in 1946, a magnitude 8.1 event that killed 1,330 people, and the next big one could strike in less than 40 years."

Seismologists believe that since the violent 1946 fault rupture, Shikoku has experienced a series of slow earthquakes every six months or so. These events, which can last a few days or up to two weeks, cause an imperceptible shift in the Earth's crust equivalent to the ground displacement produced by an ordinary earthquake of magnitude 6. Although harmless on the surface, these slow-slip events may be causing stress to accumulate in the adjacent locked section of the fault, scientists say.

Concerned about the hazards posed by earthquakes, the Japanese government installed a network of highly sensitive seismic instruments 10 years ago throughout the region. This advanced technology soon led to the discovery of slow earthquakes accompanied by LFEs and non-volcanic tremor in the Shikoku fault zone. Since then, some seismologists have proposed using LFEs and tremor to monitor slow earthquakes and assess seismic hazard. Others maintain that these weak signals are of little use in earthquake forecasting.

"Some people draw an analogy between non-volcanic and volcanic tremor," Beroza said. "In volcanoes, fluids moving through shallow conduits cause the Earth to vibrate. But in earthquakes, waves are generated by slip on a fault. That's the fundamental earthquake mechanism."

Fluids vs. slip

Is non-volcanic tremor a vibration caused by fluids moving deep in the subduction zone, or is it a seismic signal produced when the fault slips during a silent earthquake? To find out, Shelly pored over hundreds of seismograms recorded in the Shikoku region between 2002 and 2005. His analysis revealed an almost perfect correlation between tremor events and low-frequency earthquakes.

"David found that the wiggles that tremor makes on seismographs matches the wiggles of the low-frequency earthquakes," Beroza explained. "This demonstrates that tremor is actually a swarm of hundreds of thousands of LFEs, each of which is caused by slip on the deep part of the fault—the same mechanism by which regular earthquakes are generated but with a twist. The slip in deep tremor happens more slowly than in ordinary earthquakes."

This insight may open new avenues of research for predicting earthquake hazards, Shelly said. "We now understand that tremor is generated directly by slip on the deep extension of the fault," he said. "Combining this understanding with our new ability to locate tremor precisely in time and space, we can now track the details of how slip evolves during a weeklong slow-slip event. This could also improve our ability to predict the effects on the shallower, earthquake-generating portion of the subduction fault and potentially lead to an improved ability to forecast a major earthquake there."

Besides Japan, non-volcanic tremor also has been detected under California's San Andreas Fault and in the Cascadia subduction zone, which stretches from northern California to British Columbia. Cascadia includes four heavily populated urban areas—Portland, Seattle, Vancouver and Victoria, B.C. In 2003, Canadian scientists discovered that slow quakes and tremors in Cascadia occur like clockwork every 13 to 15 months. Scientists worry that these predictable slow events are loading stress on the locked portion of the fault, where a devastating magnitude 9 earthquake is expected to strike sometime in the next 300 years.

"In early February, Cascadia experienced one of those slow events, and the Canadian Geological Survey issued a public warning based on increased tremor activity," Shelly noted. "The survey announced that there was a greater likelihood of a major earthquake in the next two or three weeks based on the activity of the tremor. Fortunately, the earthquake didn't happen, but the real utility of the warning was to get people thinking about earthquake hazard in that region. It shows that tremor is starting to be used for earthquake forecasting."

The study, "Non-Volcanic Tremor and Low-Frequency Earthquake Swarms," by D. Shelly et al., appears in the March 15 issue of *Nature*.

Source: Stanford University