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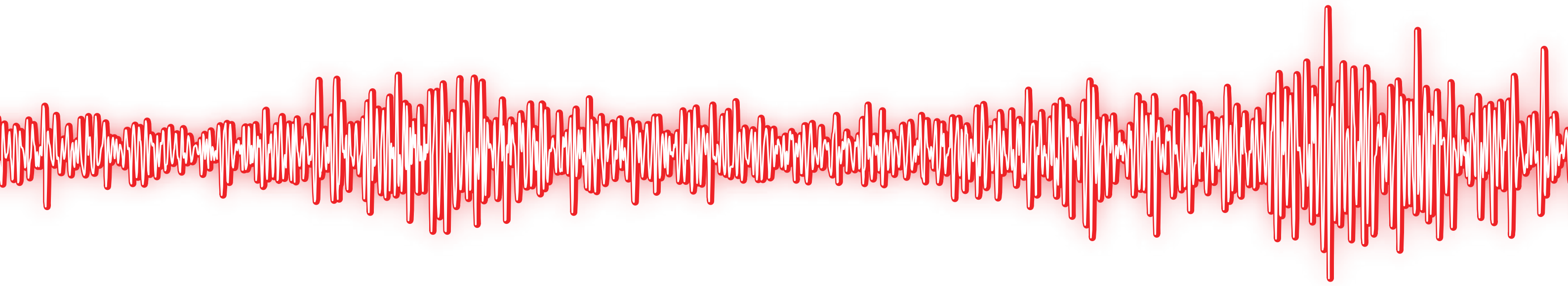

The secret chatter of giant faults

An imminent swarm of tiny quakes beneath western North America could help seismologists prepare for a big one — but only if they can learn to interpret the tremors, finds **Naomi Lubick**.

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For the past few weeks, seismologists at the University of Washington in Seattle have been on high alert. Any day now, they expect a flurry of microtremors deep under the nearby Olympic Peninsula, just as occurs roughly every 12–14 months. And when that wave of vibrations comes along, the researchers will be ready to catch it.

Over the past year, the seismology team has set up an elaborate net — an array of more than 100 seismic sensors planted in the ground throughout the peninsula's mountains. When those instruments start picking up signs of the tremors, the researchers will rush back out to install extra seismometers above the spots where the earth is shuddering. Every few days the scientists will tend to the sensors, replacing batteries and downloading data, with the hope of capturing as much information as possible about the seismic events underfoot.

The quakes will pass within a few weeks without anybody feeling them. But for seismologists, these swarms of tremors, sometimes called non-volcanic tremors, are among the most significant discoveries of the past decade because they could yield insight into the behaviour of destructive faults. Researchers first noticed them in 2002 in Japan, and a year later teams in the Pacific Northwest detected them beneath the Cascadia region near Seattle.

The Cascadian tremors are attracting interest because they hail from deep beneath the coast, along a massive fault that is thought to have unleashed earthquakes approaching magnitude 9. Researchers hope that the detailed measurements they are about to make will help them monitor activity along the fault. It may be possible to use the recurring swarms as a probe to track changes in stress underground; the tremors may even yield clues about the timing and location of future large quakes.

"It's pretty exciting," says Greg Beroza, a geophysicist at Stanford University in California, who is watching for the results from the University of Washington team. The regularity of the quakes lets researchers prepare for them, providing an exceedingly rare chance to study seismic events in great detail. "If you had told me 10 years ago that there was going to be some kind of activity, happening on deep faults, that we could predict was going to happen again soon with some regularity, I would have told you that you were crazy," says Beroza.

Elusive signals

The seismic trace of a tremor looks different from that of a classic earthquake. The latter starts with a bang — a burst of high-frequency energy that rapidly tails off. Tremors are tamer; their vibrations are rich in low frequencies, and they come and go with less fanfare. These characteristics, and the weakness of the tremors, make them hard to spot. Preliminary observations of tremors have come from Alaska and Mexico, among other places, but information remains sketchy because only a few places have networks of seismometers sensitive enough to catch them.

Tremor swarms can help researchers spy on dangerous faults.

Seismologist Kazushige Obara of the University of Tokyo Earthquake Research Institute was the first person to spot tremors, using signals recorded by a permanent monitoring array buried below the Earth's surface[1]. The Japanese government established the country-wide network of 600 monitors after the devastating 1995 Kobe earthquake; the instruments are sunk more than 100 metres below ground, to shield them from human-made noises — such as the rumble from trucks — that can drown out the tremors' vibrations. When Obara detected extremely deep microearthquakes lasting for several weeks, 30 kilometres beneath Japan, researchers around the world pored over their own data to see whether they could spot similar traces.

Tremors in Japan occur mostly along junctions between tectonic plates where one dives or 'subducts' beneath another. The same structure underlies the Pacific Northwest, along what is known as the Cascadian subduction zone, which stretches from Vancouver Island in British Columbia, Canada, to northern California (see 'The origin of tremor swarms'). Here, the Juan de Fuca plate is slipping beneath the North American continental plate. Since the last huge quake, which is thought to have occurred in 1700, the dangerous part of the Cascadian subduction zone has remained locked, but researchers expect it to give way cataclysmically within the next century.

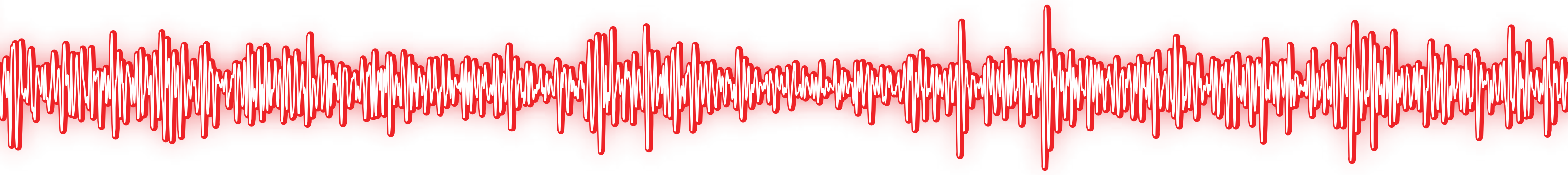
With that risk in the background, researchers are especially interested in capturing tremor swarms as a way to spy on what is happening deep down in the subduction zone. Last year, they missed their chance. The University of Washington team expected the swarm to occur in August, but it arrived in early May, before many of the instruments were in the field. The researchers recorded bits of the event using a permanent array, but in much less detail than they had hoped.

This year, they are better prepared. Once their permanent array picks up the first signs of the tremors, they will head out to augment the network above the swarm. Each completed array will consist of about two-dozen seismometers stationed 200–300 metres apart in remote areas, away from human noise. The team's work is supported by a US$500,000 grant from the US National Science Foundation to Earthscope, a non-profit research consortium.

"The experiment we have out now will be unprecedented with regard to what we can see," says John Vidale, a seismologist at the University of Washington and one of the lead scientists on the project.

The team's network, called an 'array of arrays', can pinpoint the source of the tremors by comparing when the seismic waves arrive at each seismometer, says Vidale. "As with your ears, you can tell which direction a sound is coming from," he explains.

The origin of tremor swarms is generating intense debate. In Japan, seismologists have observed that tremors come from the plane where the plates meet, the subduction-fault boundary, which also gives birth to mammoth quakes. But in Cascadia, seismic signals indicate that some tremor may also occur above



the fault plane, according to Honn Kao and his colleagues, geophysicists at the Pacific Geosciences Centre in Sidney, British Columbia[2].

Deep origins

Locating the source of the vibrations could help researchers to understand the physical processes that create them. The tremors originate tens of kilometres underground, where Earth's cold crust is pulled into the warmer mantle. Rocks in the upper crust are brittle enough to break under stress, which leads to earthquakes. But those in the mantle are so hot that they warp under pressure instead of cracking. Tremors seem to happen in the complex zone where the subducting plate has warmed enough for its rocks to become malleable.

A study published this week[3] could help to explain the process that produces tremors under parts of Japan. Satoshi Ide, a seismologist at the University of Tokyo, suggests that tremor behaviour beneath Shikoku island could be controlled by the types of rock present in the subduction zone there. Ide found that the locations of some tremors line up in stripes matching the direction in which the subducting plate has travelled during the past 10 million years. He hypothesizes that these bands could trace the path left by seamounts, the remnants of former volcanoes embedded in the oceanic plate that is diving under Japan.

If he is right, the seamounts could influence the behaviour of tremors in two possible ways, he says. They might snag on the overlying plate as the crust slides into the mantle, creating occasional bursts of tremors. Alternatively, their chemical composition might cause them to act as lubricants, like lumps of grease, smoothing out the movement of the plates and turning what could have been catastrophic ruptures into bumpy jitters.

Beroza calls Ide's findings preliminary, but "a really important result" that indicates how the properties of the rocks along faults might be preserved for millions of years and affect the occurrence of tremors today. As in Japan, tremors in Cascadia sometimes occur in bands that might reflect some characteristic of the subducting rocks.

Researchers are trying to determine what conditions create tremors instead of full-blown earthquakes, using data from old and new laboratory experiments that test how friction, porosity and other attributes of rock change under pressure. These studies could help reveal what controls the movement of faults at subduction-zone depths, says geophysicist Paul Segall of Stanford University.

Quake clues

Scientists also wonder how tremors relate to larger earthquakes on the same faults. The better-observed tremor events in Japan and Cascadia tend to be close to the parts of subducting plates that produce great earthquakes; the tremors originate below the 'locked' areas that store up energy for future large quakes.

Joan Gomberg, a geophysicist at the University of Washington, says researchers are looking for changes in tremor patterns that may hint at stress shifts in a fault. If such connections emerge, seismologists could start to monitor tremors for signs that precede a big earthquake. They have found some intriguing clues but nothing solid so far. The San Andreas Fault in California, for example, has experienced tremor events alongside earthquakes of magnitude 1 or 2, but direct associations between the two have yet to be confirmed[4].

Meanwhile, Obara and his colleagues plan to put out an extra monitoring system, to gather more details about tremor events beneath Japan. And researchers in Cascadia are ready to pounce when the swarm hits.

"These things happen almost like clockwork, but not exactly," says seismologist Ken Creager of the University of Washington, recalling last year's disappointment when the team missed the tremors. This year, he is more confident. "We'll catch it one way or another." ■

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THE ORIGIN OF TREMOR SWARMS

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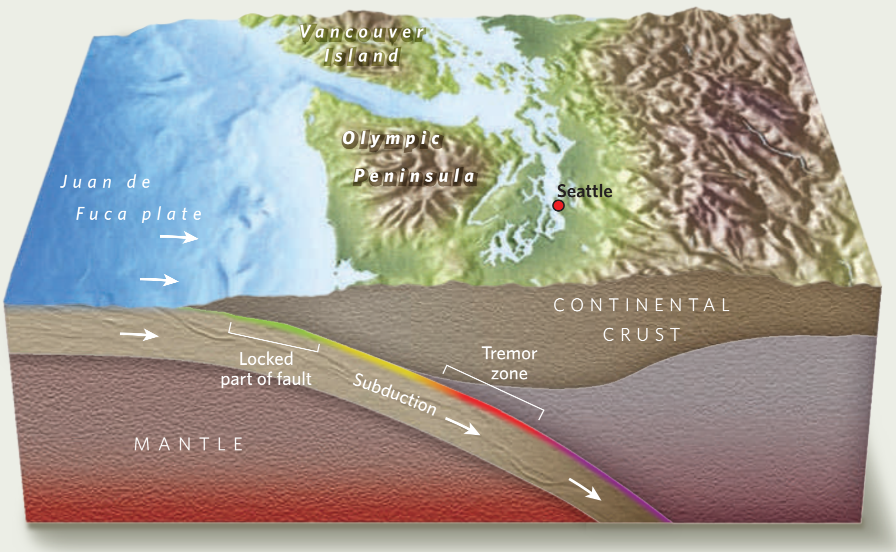

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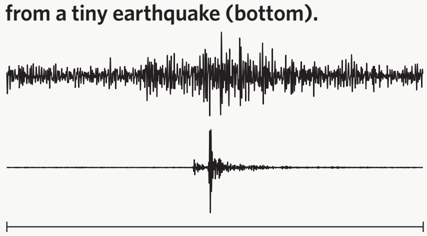
A patch of oceanic crust is slipping beneath the North American tectonic plate along the Cascadia subduction zone. The upper part of the fault plane between the plates is locked, building up stress that will be relieved in a huge earthquake. The lower part of the fault or nearby regions produce swarms of tremors roughly every year; studies of the regular tremors might help seismologists keep tabs on the state of the subduction zone.

Seismic signals from a tremor (top) and from a tiny earthquake (bottom).



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