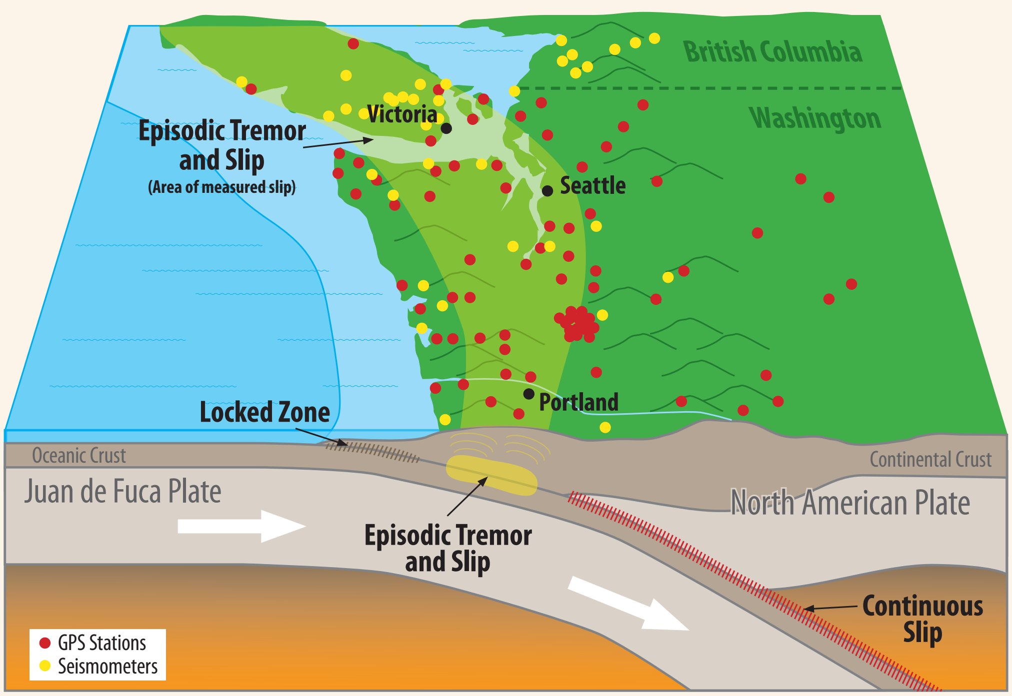
Episodic Tremor and Slip

IN 2002, SCIENTISTS DISCOVERED THAT TECTONIC plates in the Pacific Northwest are moving in mysterious ways: Sections of the plates are gently shifting a few centimeters every 10 to 20 months and releasing a weak seismic tremor. Episodic Tremor and Slip—as the researchers dubbed the phenomenon—can release the same amount of energy as a magnitude 7.0 earthquake. But, because the energy releases over a one- to two-week period, no one feels the quivering of plates slipping past each other. Scientists are now racing to understand how and why tremor and slip occurs in the Earth's crust and if it is related to big earthquakes.

What is Episodic Tremor and Slip?

Episodic Tremor and Slip occurs at some subduction zones – places where a denser tectonic plate descends beneath a lighter continental plate. At the Cascadia subduction zone, which extends from southern British Columbia to northern California, the Juan de Fuca plate begins to descend beneath the overriding North American plate just off the coast. Episodic Tremor and Slip occurs about 25 to 40 kilometers (15 to 25 miles) below the surface along the boundary between these two plates.

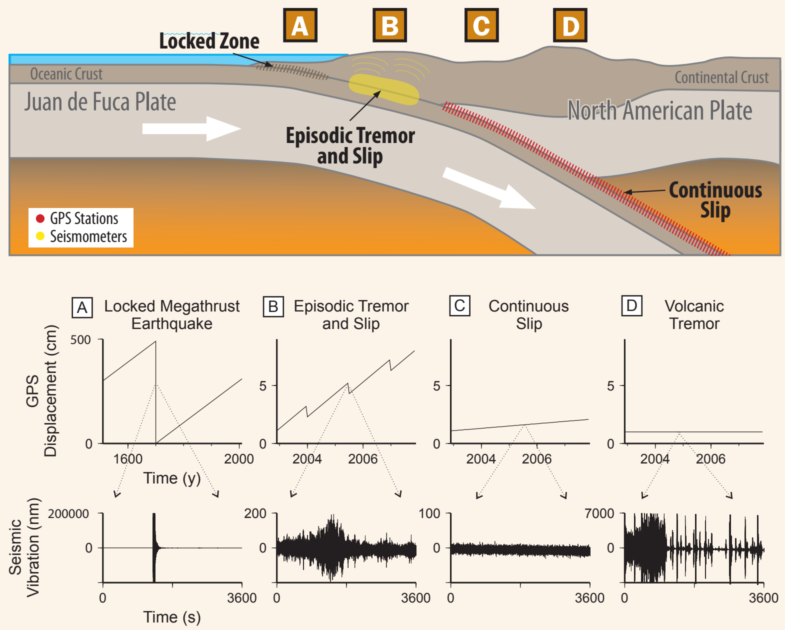
Careful analysis of the relative positions of GPS instruments near the edge of the North American plate relative to those in the interior found that some instruments occasionally moved back toward the trench, instead of towards North America as would be expected along the convergence boundary in the Pacific Northwest. This gradual release of the built-up elastic strain is now referred to as slow slip episodes.



EPISODIC TREMOR AND SLIP

A map of the Pacific Northwest and cutaway cross-section exposing the two tectonic plates underneath the surface. The red dots represent locations of GPS stations, and the yellow dots represent locations of seismometers. The light green shape on the map shows the approximate area where GPS stations on the surface have measured episodes of slip. During each episode, a portion of this area slips slowly, gradually releasing built-up elastic strain and sending tremor vibrations to the surface.

Episodic Tremor and Slip



Graph courtesy Michael Brudzinski, Miami University, Ohio

WHAT DO WE MEASURE?

Boxes A through D show locations of seismic and GPS instruments above each of the three zones of the plate interface and one near a volcano further inland. [A] Instruments above the locked zone record linear trends in GPS data that indicate accumulation of elastic strain energy for hundreds of years. Eventually, a great earthquake occurs, causing several meters of displacement in just a few minutes with very strong seismic shaking. [B] Instruments above the ETS zone record episodes of slow slip with only millimeters of GPS displacement that last a few weeks to months and small seismic vibrations that gradually emerge out of the background noise. [C] Instruments above the continuous slip zone record very little change in GPS displacement over time with very small, constant seismic vibrations that are likely due to local background noise. [D] Instruments near a volcano often see little change in displacement between eruptions, but they do record periods of volcanic tremor.

Further investigation revealed that the slow slip is episodic, sometimes with remarkably consistent frequency, such as the ~14 month recurrence interval seen between Seattle and Vancouver.

In addition to being recorded by GPS, slow slip typically corresponds to low-level seismic vibrations that can be detected by seismometers. The term non-volcanic tremor was applied to these weak signals as they gradually appear out of the background noise and often undulate with slowly varying amplitudes. Volcanoes generate a similar, but larger and more obvious tremor that has been recognized for many years.

Based on an analysis of non-volcanic tremor, it appears to be composed of swarms of so-called low frequency earthquakes, since typical earthquakes of similar magnitude would have more energy at higher frequencies. The swarm of seismic sources results in many overlapping signals on a seismogram, making it difficult to discern individual P and S waves typically used to estimate earthquake locations. These motions are consistent with slow slip motions that regularly relieve the built-up elastic strain along the fault and relax the deep crust.

What causes Episodic Tremor and Slip in subduction zones?

If tectonic plates were perfectly smooth, they would easily slide past each other. Instead, the plates are relatively rigid and jagged, so portions of the Juan de Fuca plate stick to the underside of the North American plate as it descends into the mantle. The exact way that the plates move past each other changes as the physical properties of the environment (temperature and pressure) change with depth. Near where the Juan de Fuca plate starts its descent, the edges of the plates lock together for hundreds of years and snap apart in great earthquakes of magnitude 9. At 50 kilometers (30 miles) in depth, the temperature is so high that the plates easily slide past each other. Episodic Tremor and Slip occurs in the area between these two sections at 25 to 40 kilometers (15 to 25 miles) below the surface.

What triggers Episodic Tremor and Slip is currently a mystery that researchers are trying to solve thorough careful analysis of the available data. Two current hypotheses are that the phenomenon is related to fluids that may lubricate the fault or to fluids migrating through the pore spaces in the rocks that weaken the rocks.

Why is Episodic Tremor and Slip so interesting?

The discovery of Episodic Tremor and Slip has a surprising benefit: it may help geologists improve assessments of the damage that could be caused by the next great subduction zone earthquake. Locating the area where Episodic Tremor and Slip occurs between the plates helps to define the eastern boundary of the locked zone that will snap apart in the next great earthquake. Understanding the location and extent of the locked zone will help geologists predict where the most intense shaking will occur and how intense it will be. There is also hope that Episodic Tremor and Slip might be related to the stress on the fault such that it could be an indicator of when the next big earthquake will occur.

How was it discovered?

Herb Dragert and Garry Rodgers, researchers at the Geological Survey of Canada, first discovered Episodic Tremor and Slip along a swath between the coast of the Olympic Peninsula and Vancouver Island. Since no one can feel Episodic Tremor and Slip happening, it was not discovered until geophysicists began placing high-precision Global Positioning Systems (GPS) units on the ground to continuously measure the motion of the North American plate.

MEASUREMENTS NEAR VICTORIA, BRITISH COLUMBIA

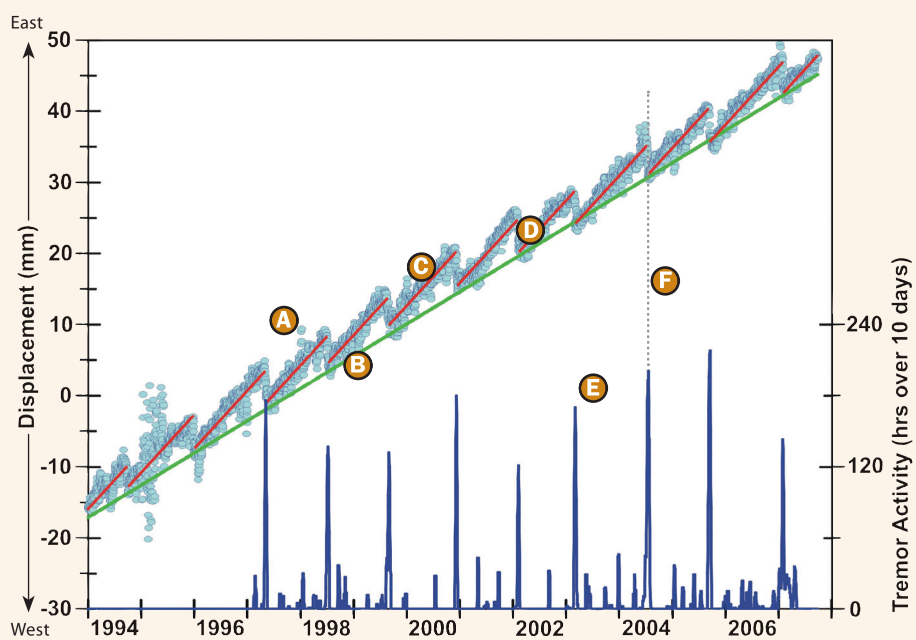


Figure courtesy Dragert and Rodgers, Geologic Survey of Canada

This figure shows the long-term measurements of Episodic Tremor and Slip from a GPS station and seismometers near Victoria, British Columbia. (Placed near location B in the figure on page 2.) A Each blue circle gives the measurement over one day of the east-west position of the Victoria GPS station. The measurement is relative to the interior of the North American plate. B The green line shows long-term east-west motion over the entire 14 year period. Prior to the discovery of Episodic Tremor and Slip, scientists thought that the edge of the North American plate was being squeezed landward in this continuous, steady fashion. C The red lines shows the measured average movement of the North American plate. For periods of 13 to 16 months, the ground moves at a faster rate relative to the long-term trend. D Here the GPS unit measured a short-term reversal in the direction of plate motion at this geographical location, representing slow slip on the boundary between the plates. E The tremor activity, although seen throughout each year, spikes at regular intervals. F Each episode of slip occurs at the same time as these spikes in tremor activity.

Episodic Tremor and Slip


Photo by Chuck Kurnik

How was it discovered? (continued)

The geophysicists expected the edge of the North American plate to move continuously towards the northeast, but then researchers noticed that the GPS units had recorded a single short-term reversal of motion towards the west. Researchers thought the equipment had malfunctioned, but then other GPS units started recording the same motion. The motion was in the same direction that the North American plate is expected to move during a subduction zone earthquake, but since they did not detect any seismic waves, Dragert and his colleagues dubbed the movement a "silent earthquake".

Researchers at Central Washington University then found that these "silent earthquakes" had occurred at regular intervals over the preceding decade. When the researchers filtered the recordings of seismic waves, they discovered a faint seismic signal buried in what seemed like background noise, like the type of signal often caused by traffic or wind. The timing of the seismic signal, the tremor, coincided with the timing of the slip. The key proof that it is indeed generated by a tectonic source is that the signals correlated at several stations over distances of up to 100 km (60 miles), whereas background noise is different at every station.

Where else does Episodic Tremor and Slip occur?

Scientists are discovering that Episodic Tremor and Slip occurs at other subduction zones around the world—places like Japan, Alaska and Mexico. Recently, researchers have discovered aspects of Episodic Tremor and Slip at other types of faults, like the strike-slip San Andreas Fault in California.

How does EarthScope help us study Episodic Tremor and Slip?

EarthScope is a decade-long national earth science program to explore the structure and evolution of the North American continent. EarthScope, as well as other scientific organizations, including the Geological Survey of Canada, the Pacific Northwest Seismic Network and the United States Geological Survey, are aiding researchers by vastly expanding their networks of GPS units and seismometers in the Pacific Northwest. The data from the hundreds of GPS units, borehole strainmeters and seismometers that EarthScope and other organizations have installed are helping researchers to improve our understanding of the phenomenon over a short period of time.

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