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Episodic Tremor and Slip

Geological Survey of Canada.

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Episodic Tremor and Slip

Introduction

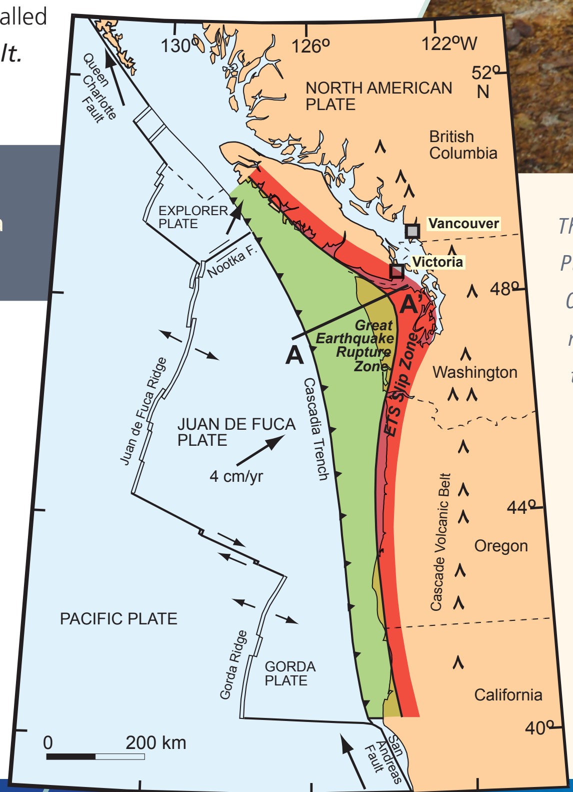
Episodic Tremor and Slip (ETS) is a process that occurs deep below the Earth's surface along faults that form the boundaries of tectonic plates. It involves repeated episodes of slow fault slip of a few centimetres over a period of several weeks, accompanied by seismic tremors. Tremors appear on seismic records as prolonged, intermittent ground vibrations, similar to those caused by windstorms. They differ from earthquakes which generate large, sharp, shock waves that subside very quickly.

Setting up a GPS antenna for a temporary station near Myra Falls Mine on Vancouver Island. This region requires more detailed monitoring because it is close to the epicentre of the magnitude 7.3 Vancouver Island earthquake in 1946.

The Cascadia Subduction Zone

In 2003, Natural Resources Canada scientists discovered the link between slow fault slip and seismic tremors while studying the Cascadia Subduction Zone (CSZ), Canada's most active earthquake region. Running from northern Vancouver Island to northern California, the CSZ is the boundary between the Juan de Fuca and North American plates. Offshore, beneath the Pacific Ocean, the Juan de Fuca Plate is being forced under, or ***subducted*** beneath, the western edge of the North American Plate. The zone of contact between the two plates is called a ***subduction fault.***

Tectonic plates on the western coast of Canada and the United States.



This map shows the boundary between the Juan de Fuca Plate system and the North American Plate which forms the Cascadia Subduction Zone (CSZ). The CSZ stretches from northern Vancouver Island to northern California and from the offshore Cascadia Trench to the inland Cascade Volcanic Belt. The large arrows show the direction of motion of the oceanic plates with respect to North America. The smaller arrows show relative motion across other plate boundaries. The line with the triangular teeth indicates the Cascadia Trench where the oceanic Juan de Fuca Plate begins its descent beneath the North American Plate. Line A-A' marks the location of the crustal cross-section shown on page 2.

Fault - A spot where the Earth's crust has broken and slid along a plane.

Tectonic plates - Large pieces of the Earth's crust that move slowly in various directions. Tectonic plates are 10 to 60 kilometres thick and can be continent-sized (thousands of kilometres across) or much smaller (hundreds of kilometres across). Victoria sits on the western edge of the North American Plate.

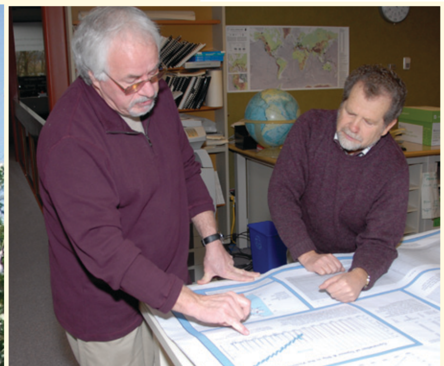
Great Earthquake - An earthquake measuring magnitude 8 or greater.

Earthquake prediction - A prediction specifying the exact location, time and magnitude of an impending earthquake. Forecasting an earthquake is often described in terms of statistical probability. For example, a forecast might say that during a certain week, a great earthquake on the CSZ is 30 times more likely than normal.

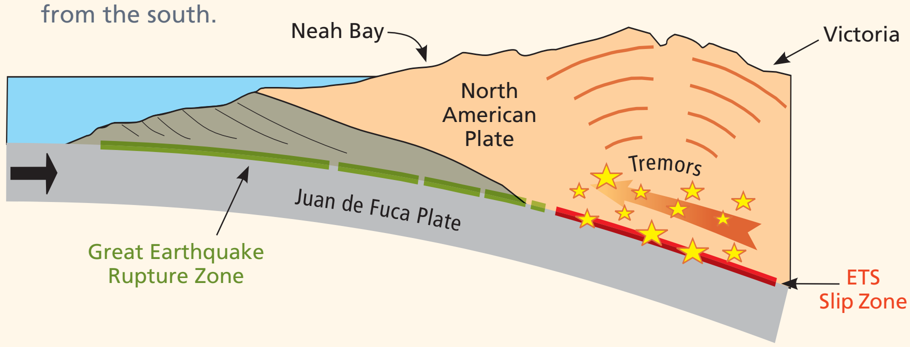
Strainmeters - Sensitive devices used to measure very small changes in stress acting on bedrock. Stress changes are produced not only by plate tectonics, but also by tiny differences in the surface load caused by precipitation or changes in atmospheric pressure.

The Great Earthquake Cycle: A Stick-Slip Story

The Juan de Fuca Plate and the North American Plate do not simply slide steadily past each other. Rather, they are held by friction in a locked zone, along the upper portion of the subduction fault. Every 500 to 600 years on average, the stress becomes too great in the locked zone and it finally ruptures. In just minutes, centuries worth of accumulated energy is released, causing a magnitude 8 or 9 earthquake. These earthquakes are known as megathrust or great earthquakes. They can involve 10 to 20 metres of fault movement, along the hundreds of kilometres that make up the fault line. After a great earthquake, the two plates become locked together again and the stick-slip cycle is repeated.



Crustal cross-section of the Cascadia Subduction Zone viewed from the south.



This drawing shows the locations of the great earthquake rupture zone (green) and the ETS slip zone (red) between the descending Juan de Fuca Plate and overlying North American Plate. The arrow pointing to the right indicates the motion of the Juan de Fuca plate, towards North America. Tremors (yellow stars) are located on and above the slip zone. They are activated by slipping and generate low-level vibrations that spread to the surface. The arrow above the slip zone pointing to the left shows the direction of slip for the overlying North American Plate. The amount of slip diminishes to nothing at the upper edge of the slip zone.

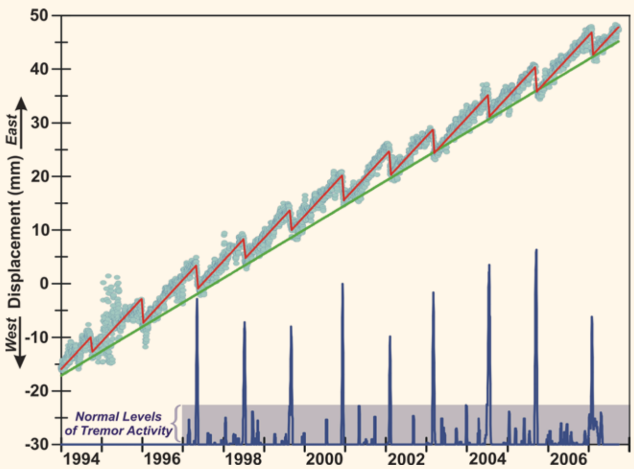
ETS on Canada's West Coast

Since 1991, automated Global Positioning System (GPS) instruments, anchored into bedrock, have been continuously monitoring the gradual eastward squeezing of the coastal edge of southwestern British Columbia that results from the locked zone. More recently, using improved GPS data and analysis tools, scientists discovered more subtle stick-slip behaviour in a deeper portion of the subduction fault, now referred to as the ETS slip zone. ETS is observed as very small, slow slips that occur far more frequently than the massive, sudden shifts that characterize a great earthquake.

Across the locked zone, extending down to depths of 15 to 20 kilometres, plate convergence has been pushing the coastal edge of the North American Plate inland for hundreds of years (as part of the great earthquake cycle). However, at depths between 25 and 45 kilometres, the subduction fault sticks for periods of about 15 months and then slips several centimetres over a couple of weeks. On the surface, the GPS instruments record the effects of this deep sticking and slipping.

On Vancouver Island, episodes of deep slip are accompanied by seismic tremors that are recorded by the same network of seismographs used to measure earthquakes. Unlike an earthquake's shockwaves, ETS tremors persist like background chatter for the duration of the event. These chattering tremors, combined with deep plate slip, signal an ETS event is under way. Both the slow fault slip and the tremors are so minute that they are only detectable with specialized equipment.

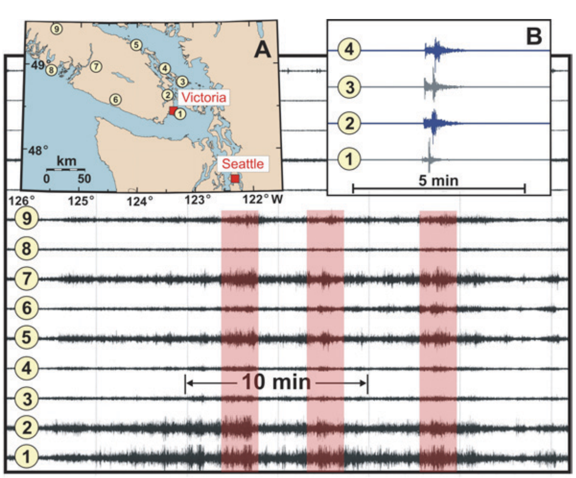
Westward motion of the Victoria GPS Station matches bursts of tremor activity.



Sloped saw-toothed line: The blue dots show the day-by-day changes in the location of the Victoria GPS station in an east-west direction. The long-term upward trend (green line) indicates that, on average, this site moves east at a rate of five millimetres per year. The red saw-tooth line shows that for about 15 months, the GPS site moves more rapidly east than the long-term average. However, at the end of each 15-month period, the site moves west about four millimetres over a period of two weeks. These temporary reversals or breaks mark ETS events.

Spikes at bottom of figure: Bursts of tremor activity occur throughout the year but seldom exceed 20 hours of tremors over any 10-day period. During ETS episodes, tremor activity is seen to increase by a factor of 10 or more (large spikes), demonstrating the close relationship between tremor and slip.

Seismic tremor records during a typical ETS event.



Seismic tremor records during a typical ETS event as observed at nine seismograph stations on Vancouver Island. A tremor record examined at a single station alone appears much like random vibration noise that can be generated by windstorms. However, examining multiple records from different stations together shows that this "noise" has coherent bursts that move across the network (see shaded portions for examples). Therefore these signals must have a common cause within the Earth. Note that recording sensitivities differ at each station. Inset A shows the locations of the seismograph stations; Inset B shows the seismic records for a typical local earthquake at the first four stations.

The Importance of ETS

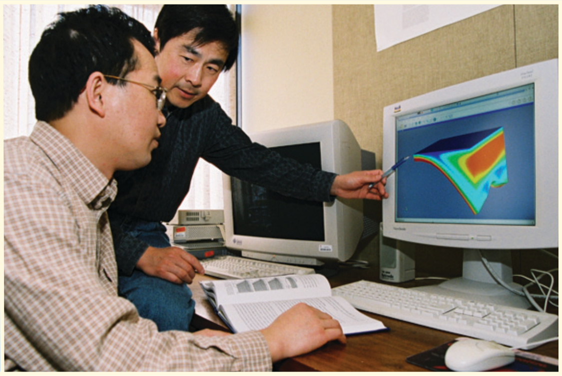
Although all aspects of ETS are not yet fully understood, ETS episodes in the CSZ may lead to improved estimates of **where** and **when** the next great earthquake is likely to occur on Canada's west coast.

Where: By mapping out the areas on the subduction fault where stress is not accumulating over the long term, ETS events define the eastern or landward limit of the zone that will rupture during the next great earthquake. This provides a more accurate estimate of how close the rupture could be to major west coast cities and of the potential shaking which could be experienced in these urban centres.

When: Although ETS does not currently help us predict earthquakes, it does provide a basis for improved earthquake forecasting. Each ETS episode adds a small amount of stress to the locked portion of the subduction zone. As the stress increases and approaches a critical level, an ETS event may provide the additional stress needed to overcome the friction on a fault, triggering a great earthquake. Consequently, an ETS episode increases the likelihood of a great earthquake.

Research Continues

Researchers are investigating possible relationships between the location and timing of ETS events and the many earthquakes that occur off the subduction fault between the North American and Juan de Fuca plates. Minuscule changes in regional tectonic stress are measured with highly sensitive strainmeters which have been placed in 200 metre deep drill holes. This information, combined with the region's GPS and seismic data, is used to determine the physical processes involved in ETS.



Government of Canada work on plate tectonics is undertaken by Natural Resources Canada's Earth Sciences Sector.

For more information about Episodic Tremor and Slip visit the Natural Resources Canada website:
www.gsc.nrcan.gc.ca/geodyn/ets_e.php

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