The Juan de Fuca Plate: A Sticky Situation

Is the Pacific Northwest headed for an earthquake of catastrophic proportions? The answer hinges on whether this oceanic plate is stuck or peacefully sliding

By RICHARD MONASTERSKY

With seismometers pressed firmly to the ground, geophysicists have been monitoring the Pacific Northwest, trying to detect some slight quiver from a reticent area known as the Cascadia subduction zone.

Stretching from northern California into British Columbia, this subduction zone is the junction between two huge plates of the earth's crust. Here, the continental North American plate rides over the smaller Juan de Fuca plate system, driving the latter down into the depths of the earth's mantle in a process called subduction. Above the zone, scientists have stationed sensitive meters, which each year record thousands of earthquakes centered within either one plate or the other. However, not even the smallest tremor originates from the interface where these two plates meet. And this silence has many scientists asking why.

At other subduction zones around the world, the plate interface is a dynamic pressure cooker, generating much seismic activity, including some of the greatest known earthquakes: Chile, magnitude 9.5, in 1960; Alaska, magnitude 9.2, in 1964; and Colombia, 8.8, in 1906. In each of these areas, the subduction process is a discontinuous, jerky affair. The oceanic plate sticks as it is forced to slide under the continental plate, building up a tremendous strain along this interface, which gives way periodically with an earth-shaking release of energy.

The quiescence along the Cascadia subduction interface has led many scientists to theorize that its subduction process was different: Perhaps the Juan de Fuca plate slides under the North American continent smoothly, without friction. Recent studies, however, have prompted the seismologic community to revise its earlier assessment.

Moreover, new findings indicate that this area may have hosted several significant prehistoric earthquakes, and if so will likely repeat itself. "As we began to look at more and more aspects of this problem, it has become clear that it's not so easy to assume that this zone is incapable of large earthquakes," says Thomas H. Heaton, a geophysicist with the U.S. Geological Survey in Pasadena, Calif. And given the present lull in activity at the plate interface, the Cascadian subduction zone may be storing up for a round of seismic rumbling that could rival the greatest earthquakes of this century.

Among subducting plates, the Juan de Fuca is a youngster. It originates only a few hundred kilometers offshore, where magma, or molten rock, slowly pours out of a ridge of mountains, creating the oceanic plates that spread away from the ridge in both directions. Because of the short distance between the ridge and the subduction zone, the rock situated on the leading edge of the Juan de Fuca plate is only 10 million years old when it plunges back into the earth's mantle. In contrast, at other subduction zones around the world, the rock of the subducting plate can grow to be over 100 million years old as it travels from birthplace to grave.

Just what happens within the subduction zone is the mystery that geoscientists are trying to crack. Two contrasting scenarios are possible, and the evidence has yet to point unequivocally in a single direction.

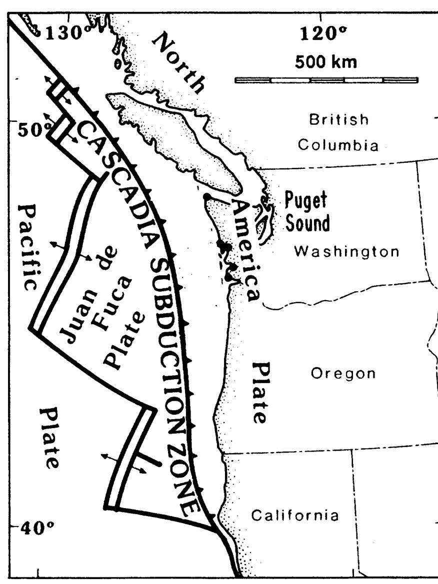
Because the Juan de Fuca plate is so young when it subducts, it is still relatively warm and buoyant compared with older subducting plates. For this reason, considerable strain may be building by forcing the buoyant oceanic plate to squeeze under the continental plate. On the other hand, if the plate is warm enough, then the rocks at the interface may be more malleable than brittle, enabling the plates to slide without locking together.

To help resolve the question between these two possibilities, Heaton turned to other subduction zones—such as those in southern Chile, southwestern Japan and Colombia — that also have young, relatively slow oceanic plates diving under a continental plate. "By comparing this zone with other areas around the world," says Heaton, "we've come to the conclusion that the places that look most similar to this zone have, in fact, had large earthquakes."

In a recent paper in SCIENCE, Heaton and colleague Stephen H. Hartzell used further comparisons to derive magnitude estimates for any imminent earthquakes along the Cascadia subduction interface. They calculated that if the entire length of the zone gives way at once, this area is due for an earthquake of magnitude near 9.5, which would equal the largest earthquakes of this century. If the zone unlocks in smaller sections, then a series of magnitude 8 earthquakes might ensue.

This argument-by-analogy has reawakened scientific interest in the Cascadia subduction zone by raising the possibility that this zone is seismically active and just waiting to break. However, the analogies cannot positively indicate whether residents of Seattle should fear losing their homes to a large, subduction earthquake.

Currently, researchers are exploring many other avenues to answer the Cascadian question. In one of the most direct approaches, geophysicists are attempting to determine if the subducting and overlying plates are locked together and are therefore storing energy for a future earthquake. Using lasers that shine across Puget Sound and other bodies of water, scientists can obtain precise measurements of the distances between widely separated points. Over the course of years, any decreases in these distances



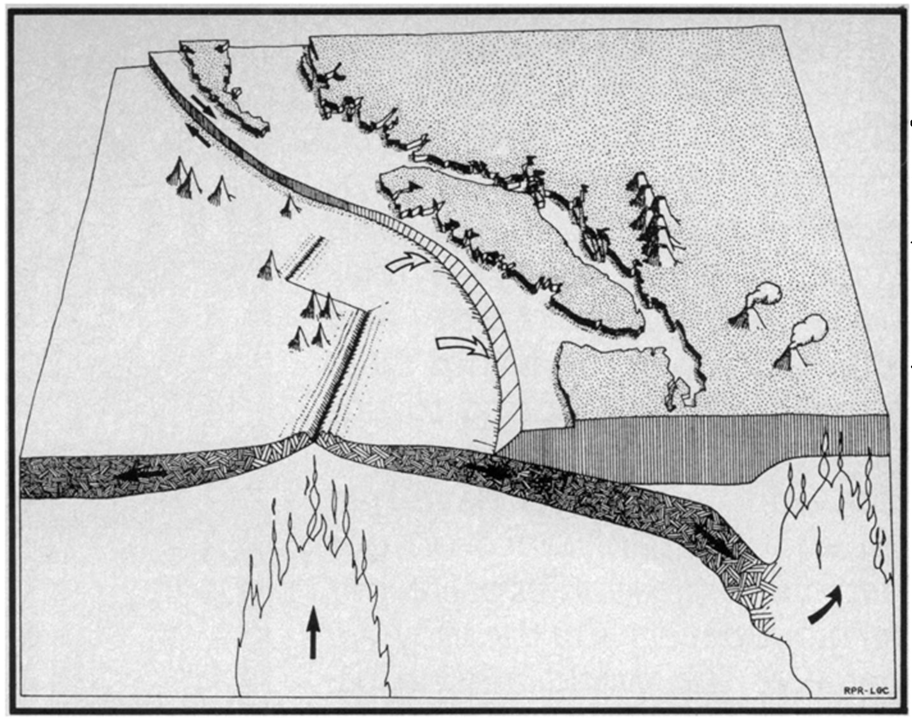
Atwater/Science

Map of Juan de Fuca plate showing position of subduction zone. Arrows indicate creation of oceanic crust at mid-ocean ridges.

would reflect a compression of the region – an indication that strain is building along the plate interface.

While some measurements suggest that the zone is locked, these results have yet to convince many scientists. "The problem is that the measurements are subject to a lot of inherent error," says Robert S. Crosson of the University of Washington in Seattle. "Unless you have very large strains, which we don't have, the measurements are difficult to interpret," he says. If scientists are actually observing a trend of increasing strain rather than an artifact of the experimental error, then future measurements of strain should be more conclusive, offering positive proof that the zone is locked.

In a more indirect approach, other scientists are plumbing the historical records of the area in an effort to assess the potential earthquake threat from the subduction zone. Written records, which date back only 150 to 200 years, show no evidence of an earthquake larger than a magnitude 7.5. Furthermore, Indian legends from times earlier are too ambiguous to indicate whether great earthquakes occurred. However, through the geologic record, scientists can reach back much farther into the earth's history. There, they are finding some of the most convincing evidence that great earthquakes previously rattled the Pacific Northwest.



Diagrammatic cross section of subduction zone. Juan de Fuca plate spreads away from mid-ocean ridges and sinks (white arrows) below North American plate. Where the vertical lines meet the hatched pattern indicates quiescent plate interface.

Brian F. Atwater of the U.S. Geological Survey in Seattle has found signs along the Washington coast of large-scale and rapid subsidence—a sinking of the earth's surface that often accompanies earthquakes. During great subduction earthquakes in Alaska (1964) and Chile (1960), scientists had seen subsidence transform lush, coastal lowlands into barren, muddy swamps by submerging large portions of the coast beneath the level of the water table. Atwater reports in the May 22 SCIENCE that the Washington coast must have suffered the same fate at least six times in the last 7,000 years.

Core samples at one site along the Washington coastline reveal a pattern of lowland soils covered abruptly by thick layers of mud. This pattern of subsidence – stacked six times, one atop another – resembles patterns in Alaska and Chile and was probably designed by a series of great Cascadia earthquakes, says Atwater.

Atwater has also identified sheet-like layers of sand deposited over the lowland soil. This pattern, he says, suggests that at least three of the earthquakes generated huge waves called tsunamis, which swept over the coastal areas, depositing sand in their wakes.

Atwater plans to take core samples from other areas of the Washington coast. His hypothesis is that if great earthquakes did cause these soil patterns, then similar evidence of submergence should extend for at least 100 km. If so, then the dates of the prehistoric subsidence could help scientists gauge when the next great earthquake will break across the area.

In the ocean, off the coast of Oregon and Washington, other researchers are also finding marks in the geologic record possibly left by prehistoric earthquakes. These turbidites, or the layered remains of great mud- and sediment-slides, lie at the foot of the North American continent where it slopes down to the ocean floor.

These sediments initially start farther in toward shore, on the edge of the continental shelf, where they accumulate over hundreds of years. Masses of sediments can grow on the shelf until they become unstable or some event disrupts them, and at this point they start sliding downhill. Mixing with water and gathering speed, the moving sediments become currents of extremely dense fluid—a fluid so dense that it hardly mixes with the surrounding seawater as it flows down the slope, stopping only when it reaches the ocean floor. At the floor, these slides, or turbidity currents, can deposit a 12-inch layer of sediments within 24 hours, says John E. Adams of the Geological Survey of Canada in Ottawa.

In an attempt to analyze the earthquake history of the region, Adams is reviewing cores taken from turbidites in the Pacific Northwest and comparing turbidite frequency with the dates of coastal subsidence. "In general, I can match Atwater's [subsidence] dates," he says, "although my time resolution with the turbidites is not so good."

The correlations between these two large-scale processes strengthens the evidence that large prehistoric earthquakes shook the Pacific Northwest, says Adams. Some scientists question this relationship between turbidites and earthquakes by raising the possibility that huge storms or other phenomena could have caused these slides. However, Adams believes that only subduction-style earthquakes could generate the kind of slides he is studying. "People don't appreciate the scale of just how big these earthquakes must be," he says.

Many scientists, for various reasons, have yet to be convinced that the Cascadian subduction zone is seismically active. Though the new research is rapidly eroding at the zone's previous, peaceful image, some of these researchers are waiting for historical analysis – especially of the subsidence record – to conclusively crack the Cascadian question. "The recent work by Atwater is totally new, and the potential outcome of that could change the whole picture," says Crosson. "It could point us in the direction [of the conclusion] that yes, there were large earthquakes."

If further analysis proves that the Cascadia subduction zone is locked, then the question remains: When will a large earthquake bring a cataclysmic end to the present quiescent stage? More refined studies of the geologic record might be able to determine the periodicity of the subduction-style earthquakes. By comparing the date of the last earthquake to the average return time, geologists should be able to statistically predict when the tension at the plate interface will next break – an event that could occur in our lifetimes, or perhaps in centuries to come. □