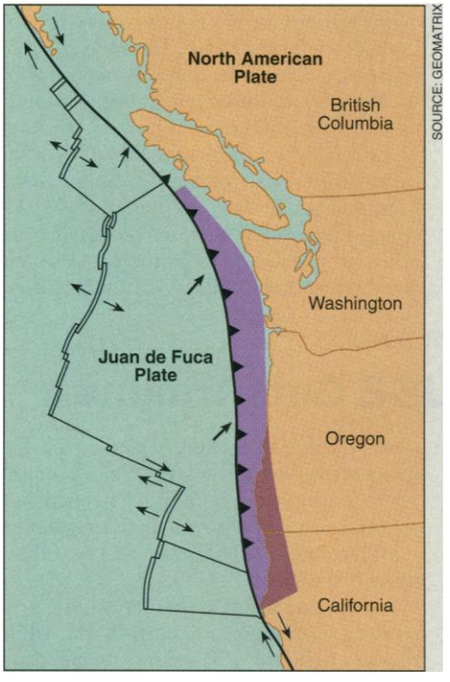
SEISMOLOGY

It's Official: Quake Danger in Northwest Rivals California's

To most motorists, the Astoria bridge over the Columbia River is a graceful curve, but to Steve Starkey, an Oregon State bridge engineer, it looks more like a question mark. The high, flexible steel structure was built decades before geologists realized that the collision of tectonic plates beneath the Pacific Northwest is capable of producing earthquakes greater than any in the region's historic record. In 1989, Starkey wondered whether this bridge and dozens of others along Oregon's crowded coast would survive such a cataclysm. The first step in finding out, he realized, was to pin hard numbers on the earthquake hazard facing the region—something that had never been done before.

Years earlier, seismologists had seen the outlines of the danger in the tectonic processes beneath the Northwest and the traces of great earthquakes in the geologic record (*Science*, 5 April 1991, p. 28). But Starkey, who is responsible for the seismic safety of the state's 2700 bridges, needed a more specific estimate of the largest quake his structures might have to withstand. He began pushing for a re-evaluation of seismic hazard in Oregon. The result, a $300,000 analysis by the San Francisco engineering firm Geomatrix Consultants, will be released this month and, says Starkey, is likely to become the basis of state earthquake policy by the end of the year. It's the first attempt to do for part of the Pacific Northwest what is routine for California: translate an understanding of the forces at work in the earth into forecasts of the size and frequency of earthquakes and the strength of ground shaking—the true measure of hazard. "It will reflect the state of the art as of 1994," says Robert Yeats, a geologist at Oregon State University who was a member of Geomatrix's advisory panel.

The study concludes that the Northwest coast from Vancouver Island down to northern California faces an earthquake hazard at least as great as that along the San Andreas Fault. "It clearly shows that the coastal area should be [considered] the equivalent of San Francisco and Los Angeles," says Ian Madin, Oregon's spokesperson on earthquake issues. But although the study concludes that earthquakes of magnitude 8 (M8) or above are a virtual certainty every few hundred years, it discounts a possibly grimmer scenario: an earthquake of M9 or greater—the size that would be generated if the entire 1100-kilometer collision zone ruptured at once. And while many seismologists generally agree with the report's findings, that conclusion is generating rumblings of its own.



The skinny on subduction. One model of the long, narrow region where tectonic plates in the Northwest are locked together, storing stress that will generate an earthquake.

Either way, the report marks a turning point in the attitude of a state that, until recently, believed it was no more at risk from earthquakes than from the monsoons of India. Nothing like the events contemplated in the report has taken place in the Pacific Northwest in historic times, after all. But earth scientists have long suspected that the region has its moments of violence. All along the Northwest coast, the Juan de Fuca plate, which floors the Pacific Ocean, is thrusting eastward under the North American Plate at an average rate of 4.5 meters every 100 years. Elsewhere, such subduction zones are notorious for producing earthquakes when the two plates lock together, accumulate stress, and then abruptly release it. The result can be as devastating as the 1923 earthquake off Japan's coast that killed more than 100,000 people.

In 1984, Thomas Heaton of the United States Geological Survey (USGS) and Hiroo Kanamori of the California Institute of Technology argued that the Pacific Northwest, or Cascadia, is little different from other subduction zones in spite of its long silence. The subduction zone, they argued, may be locked and may ultimately rupture in an earthquake. And 2 years later, Brian Atwater, a USGS geologist, uncovered the first evidence of past earthquakes: ancient coastal marshes and forests buried as parts of the shoreline abruptly subsided, presumably in an earthquake. Since then the evidence has piled up: more buried marshes, drowned forests, ancient tsunami deposits, and other signs of strong shaking (*Science*, 22 December 1989, p. 1562). Scientists date the most recent earthquake or earthquakes at 300 years ago; its signature is evident from Vancouver Island, Canada, to Humboldt Bay, California.

Given these warning signs, says Starkey, "we felt it was time for somebody to move on hazard assessment in Oregon." The usual place to turn for such assessments is the USGS. Its maps for the Pacific Northwest, however, don't take full account of the earthquake risk posed by the Cascadia subduction zone, and updated maps aren't due out until April 1996, says Madin. So Oregon state officials decided to contract Geomatrix for the analysis.

In sizing up earthquake danger in Cascadia, seismologists Kevin Coppersmith and Robert Youngs and their colleagues at Geomatrix faced a special challenge. The lack of modern earthquakes deprived them of the best tool for hazard forecasting—actual records of ground shaking. As a result, they had to rely on the geologic record of prehistoric earthquakes compiled by other researchers, along with geophysical clues about how the subduction zone is operating today.

Their conclusions about earthquake frequency won't raise many eyebrows. The analysis, which Coppersmith disclosed in July at a public meeting in Portland, found that each site along the coast experiences a great earthquake once every 450 years, plus or minus 200 years. But because the geologic record is incomplete and imprecisely dated, the Geomatrix team couldn't say whether the events strike in synchrony at every site—implying one giant earthquake all along the coast—or at different times.

From data on the subduction zone's behavior, however, Coppersmith and his colleagues come down firmly on the side of smaller, asynchronous earthquakes. They estimated the chance that the locked zone will rupture in a single, M9-or-larger earthquake at a mere 5%. Instead, they wagered that the zone is most likely to break either in two huge segments, generating M8.5 earthquakes, or in four segments, generating M8 earthquakes.

These predictions are based on the shape of the subduction zone's locked region, say Geomatrix analysts. To trace its width, they relied on data on crustal deformation, produced as stress rumples the Earth's surface, and on recent thermal modeling by Roy Hyndman and Kelin Wang of the Pacific Geoscience Center in Victoria, British Columbia. Hyndman and Wang measured the

amount of heat that rises to the Earth's surface from the hotter rock beneath. They then parlayed the results into an estimate of the temperature at the buried plate boundary.

This temperature in turn limits the eastward extent of the locked region; once the descending slab exceeds 350 degrees Celsius, Hyndman says, it becomes too plastic to store stress. The Juan de Fuca slab, Hyndman finds, is hotter than most subducting slabs, perhaps because it is made up of unusually young crust. And that, together with the deformation data, implies that the locked zone is narrow, just 50 to 90 kilometers across.

The next step was to estimate how this skinny, 1100-kilometer-long locked zone would break in an earthquake. To do so, the Geomatrix group surveyed the length-to-width ratio, or aspect ratio, of all recorded subduction-zone earthquakes of M7 or larger. These 53 earthquakes had a typical aspect ratio of 2:1, being twice as long as they are wide, says Coppersmith. The Cascadia zone's aspect ratio is more like 15:1, says Coppersmith, which he thinks would make a rupture along its whole length "bizarre."

But other seismologists aren't sure a subduction zone's aspect ratio can say much about its behavior. "From a geologist's standpoint, I would be reluctant to put those kinds of limits on what the zone is capable of doing," Atwater says. Heaton adds that among the largest subduction-zone earthquakes, with magnitudes of 8 and 9 rather than 7, high aspect ratios are more common; the M9.5 Chile earthquake of 1960—the largest on record—had an aspect ratio of about 6:1. And the M8.7 Aleutian Island earthquake in 1965 had an aspect ratio of about 10:1.

But whether Oregon's seismic future holds an isolated catastrophic quake or a set of merely devastating ones may be an academic issue. Magnitude 9 earthquakes are so rare that no one knows just how acutely they shake the ground or how to design for them. "Designing for an M8 already tests the limits of our knowledge," says Madin. And that's just what Starkey and his colleagues are anxious to do. "There will be problems with retrofit and construction of new bridges," he says, along with tougher building standards for coastal communities, which would bear the brunt of a great earthquake. "I'm assuming that people in Oregon will be adopting this map, will acknowledge the large ground shaking, and do something about it."

–Bernice Wuethrich

Bernice Wuethrich is a science writer in Washington, D.C.

SCIENTIFIC COOPERATION

Cuban Crisis Threatens Joint Research

Marine biologist Michael Smith has long been planning to go to Cuba in November as part of a 12-person expedition to gather data on fragile coral reefs off the island's northern coast. A vice president of the Center for Marine Conservation in Washington, D.C., Smith has visited Cuba several times in the past 5 years. But this time he's worried that his research, along with that of many other U.S. scientists, will become a victim of the latest round of verbal hostilities between the two countries. "I'm afraid this expedition will collapse," he says.

What's troubling Smith is a new U.S. policy that removes scientists from a list of occupations—journalists, diplomats, and humanitarian workers remain on the roster—who are allowed to spend money in Cuba on business-related expenses without prior approval. The new rule, issued on 25 August by the Treasury Department, is part of President Clinton's attempt to tighten the 35-year economic embargo against the Castro regime.

At stake are several dozen research projects now under way between 22 U.S. and Cuban institutions, as well as future collaborations. Many of the projects are designed to plug knowledge gaps in the fields of biodiversity, marine resources, and meteorology. "Cuba is an important part of the Caribbean that we've had very little data from until recent years," says systematist Don Wilson, director of biodiversity programs at the Smithsonian Institution.

Wilson, who has worked with Cuban colleagues for 3 years, plans a trip in concert with Smith's in November to establish several biodiversity monitoring sites throughout Cuba and to collect data that can then be compared to other Caribbean sites. "If we can't do this, we lose some of our ability to predict future problems" in Caribbean biodiversity loss, Wilson says.

The new rule doesn't prevent research collaborations, but it makes them more difficult by requiring scientists for the first time to obtain a license as well as a visa before traveling to Cuba. A Treasury spokesperson says the department will process applications "as quickly as possible," but many scientists fear the licensing process will put a damper on research. "Nobody knows how long these [license applications] are going to be held up in the bureaucratic pipeline," says mammalogist Ross MacPhee of the American Museum of Natural History, who discovered fossilized remains of a giant sloth that lived in Cuba about 18 million years ago, the first Tertiary-period land mammal to be found in the Greater Antilles.

ALFONSO SILVA LEE

Big loss. The endangered bee hummingbird, the world's smallest, is unique to Cuba. It is being studied in a joint biodiversity project.

Smith already knows how slow the government can be. He's been waiting more than 2 months for permission to join the Cuban Zoology Society and to enlist a Cuban scientist as a volunteer field worker. (Such licenses were required even before the new rules went into effect for acts that "form an association" with Cubans and entail spending money.) He's already submitted documentation for the November trip, which is a much more ambitious undertaking.

The new rule also contains a Catch-22 that discriminates against new projects. U.S. scientists must demonstrate that their research is "specifically related to Cuba...and there is a substantial likelihood of public dissemination of the product." To do so, says MacPhee, scientists "are going to have to show that they've made contacts with Cuban counterparts." The problem, he says, is that "the communications are so incredibly lousy in Cuba that it can take years to set up" a collaboration.

One group that has already spoken up against the change is the Inter-American Dialogue (IAD), a high-powered think-tank chaired by Javier Pérez de Cuéllar of Peru, former Secretary General of the United Nations, and Peter Bell, president of the Edna McConnell Clark Foundation. Following a meeting earlier this month of U.S. and Cuban scientists, the group urged the U.S. government to rescind the new rule, declaring that "the new regulations threaten to interrupt the limited though important cooperation between U.S. and Cuban scientists."

Scientists are hoping to persuade officials at the State Department to relax the policy that led the Treasury to issue the new rule. If they are unable to make their case, predicts Smith, "one of the casualties of the diplomatic crisis of the last several weeks is going to be scientific cooperation."

–Richard Stone