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In Past Tsunamis, Tantalizing Clues to Future Ones

By KENNETH CHANG

The Cascadia fault, a 600-mile-long collision between two chunks of the earth's crust off the Pacific Northwest coast, has been quiet for a long time, and that is not a comforting fact.

Major earthquakes occur somewhere in the world every year or two. Catastrophic tsunamis - giant waves generated by undersea earthquakes or landslides - strike less often, and some of the largest of tsunamis originate in places that do not, at first glance, appear particularly treacherous.

The devastating tsunamis created Dec. 26 by a magnitude 9.0 earthquake that killed as many as 150,000 people on the shores of the Indian Ocean caught the world off guard, including most tsunami experts.

"Here is something that we didn't foresee," said Dr. Costas E. Synolakis, a professor of civil engineering at the University of Southern California.

Dr. Synolakis said that experts would now take a closer look at the Indian Ocean and that he expected that they would find geological evidence of earlier tsunamis, which would allow scientists to estimate how often they occur. "We're going to have a much better idea of what the hazard is," he said, "because right now we don't know."

Observations of the destruction will also provide a check to their computer models and could provide insight into the earthquake, the first magnitude 9.0 in 40 years, that produced them. Like the Cascadia fault, the Indian Ocean fault is also at a place, known as a subduction zone, where one tectonic plate plunges beneath another, and up to 600 miles of the fault ruptured. The overlying plate jumped upward more than 15 feet, lifting the water above it and setting off the tsunami.

An earthquake about as strong as last week's struck Cascadia in 1700, sending tsunamis across the Pacific. Seismologists foresee a repeat. The question is, When?

There are warning systems in the Pacific and plans up and down the coast to cope with such a disaster, which is a situation far different from that on the shores of the Indian Ocean. Only in the last year or so did Dr. Phil Cummins, an Australian seismologist who was at the vanguard of concern, conclude that a disastrous tsunami was possible. When it occurred, he was still preparing a position paper that marshaled evidence of past tsunamis and pressed for an international warning system. He had already been urging awareness of the danger in presentations to scientists in Japan and Hawaii.

Tsunamis seem to be among the most mysterious of natural disasters, but scientists know a good deal about how they occur and are working to understand them better. Tsunamis follow the same laws of physics as ordinary surf waves generated by wind. The difference is size. For wind-driven waves, the distance between wave crests - the wavelength - is at most a few hundred yards. For tsunamis, that wavelength can be a hundred miles or more. Because the wavelength is so much greater than the ocean depth, the speed of the wave depends on that depth. In water 2.5 miles deep, the average depth in the Pacific, a tsunami travels almost as fast as a jetliner, 440 miles an hour.

Ships at sea notice nothing. As a tsunami races past, the ocean surface rises and falls slightly, a few feet at most, over a period of several minutes to a couple of hours. Underwater, the effects are more pronounced. The downward pressure of a surf wave dissipates a few hundred yards below the surface, while the pressure force of a tsunami extends to the ocean bottom.

That led the National Oceanic and Atmospheric Administration to develop instruments it has named tsunameters. With six deployed in middle of the Pacific since 2001 in waters 2.5 to 4 miles deep, the tsunameters can detect the perturbations in water pressure as a tsunami passes above.

When it detects something, it sends a signal by sound waves to a buoy on the surface. The signal is relayed to a satellite and then back to earth to tsunami warning centers in Hawaii and Alaska. "That whole thing only takes two minutes to get the signal through," said Christian Meinig, engineering division leader at the N.O.A.A.'s Pacific Marine Environmental Laboratory, which designed and built the tsunameters.

No significant tsunamis have yet occurred in the Pacific for the tsunameters to detect, but they have prevented a false alarm. In November 2003, a magnitude 7.8 undersea earthquake occurred near the Aleutian Islands, spurring officials to issue a tsunami warning. When the wave passed over a tsunameter, they saw it was small and canceled the warning.

While there is a good understanding of how tsunamis travel in the deep ocean, less is known about how they crash ashore.

Dr. Harry Yeh, professor of ocean engineering at Oregon State University, leaves tomorrow for India, one of several scientists who will survey the wounds of the tsunami on the coast. In particular, the scientists want to record the height of the tsunami waves as they crashed onto land. "Sometimes you can see by the scar marks on the tree," he said. Elsewhere, they might find mud marks on building walls or collect accounts from survivors.

"Those data are very perishable," Dr. Yeh said. As cleanup begins, the telltale signs are wiped away, and survivors' stories often change, as their personal memories are affected by what they have heard and read.

Videos captured of the tsunami seemed to pale next to the cataclysmic imaginings of Hollywood movies, but "looking at the videos, you would be fooled," said Dr. Synolakis of U.S.C.

For one, those who tried to videotape more imposing waves might not have survived. But also, unlike an ordinary wave, which quickly dissipates and rolls back out, a tsunami is a long sheet of water. "Behind the wave is a change in sea level coming in," Dr. Synolakis said. "The wave is coming and coming and coming. A three- or four-meter tsunami can be quite devastating."

One cubic yard of water weighs nearly a ton, and a tsunamis come ashore at speeds of about 30 miles an hour. An oncoming tsunami can hit a building with millions of pounds of force, said Dr. Peter E. Raad, a professor of mechanical engineering at Southern Methodist University in Dallas.

"And that's before you put anything in the water," he said.

Trees, automobiles and pieces of concrete all become lethal projectiles as they are swept along by the rushing water.

Computer simulations by Dr. Raad aim to improve the understanding of the rushing waters in order to construct buildings that better withstand tsunamis. For example, the lower floors may have walls that break away when hit, but the support columns may survive and hold up the upper stories, he said. A parking garage may be placed away from the beach to prevent cars from being swept away, he said.

Tsunamis caused by underwater landslides can be even more destructive. In 1998, seismologists were surprised when a modest magnitude 7.0 earthquake off Papua New Guinea was followed by a 30-foot-high tsunami that killed more than 2,100 people. The earthquake, it turned out, had caused nearly a cubic mile of sediment to give way.

Three-dimensional maps of the bottom of California's Monterey Bay show several sections that have given way - and others that have cracked and may collapse in the future. Some scientists have suggested that the outer edge of the East Coast's continental shelf is also prone to cave-ins.

Others, including Dr. Steven N. Ward of the University of California, Santa Cruz, have warned that the volcano Cumbre Vieja in the Canary Islands off northwestern Africa could be nearing one of its periodic collapses. As the volcano grows

through eruptions, the sides become unstable and eventually fall into the ocean. During the last eruption in 1949, a two-mile-long crack opened up and one side of the volcano slid 10 feet.

"Geologically, we're getting close to the end," Dr. Ward said. "It's really the cycle of life for these volcanoes. They grow too big, they collapse."

In Dr. Ward's computer models, when Cumbre Vieja collapses - and that may not happen for hundreds of thousands of years - about 100 cubic miles of rock will slide into the ocean at speeds greater than 200 miles per hour, and the splash will generate tsunamis 300 feet high crashing into the northwestern coast of Africa. Waves 40 feet high will reach New York. Other scientists have pointed out that such catastrophic landslides are very rare - Cumbre Vieja last collapsed 500,000 years ago - and that there is no geologic evidence of such mega-tsunami in the past. They suggest that the landslides will not accelerate quickly enough to produce the waves Dr. Ward envisions.

Even more catastrophically - and even more rarely - may be tsunamis caused by asteroids' crashing into an ocean. In 1998, researchers at Los Alamos National Laboratory reported that a three-mile-wide asteroid hitting the middle of the Atlantic Ocean at 40,000 miles per hour would send tsunamis that would crash tens of miles inland.

Such asteroid impacts, fortunately, occur only every 10 million years or so.

The tsunami that hit Washington State in 1700 was not of such gigantic proportions, but it was big. And evidence of it was recognized only two decades ago.

Until a couple of decades ago, the Cascadia fault, where a piece of ocean floor the size of Oregon and known as the Juan de Fuca plate disappears beneath North America, was also considered a low seismic threat. Oregon and Washington have far fewer earthquakes than California, and few in the northern states have caused much damage.

In 1987, Dr. Brian F. Atwater, a geologist with the United States Geological Survey, discovered near the mouth of the Columbia River and in several other estuaries in Washington the scars of a large tsunami, including spruce tree forests that had suddenly turned into salt water tidal flats when the land elevation dropped several feet. "There must be tens of thousands of stumps in the estuaries," he said.

Dr. Atwater also found layers of sand that had been washed in. Radiocarbon dating and examination of the tree rings placed the trees' death in 1700.

Historical records from Japan pinned down an exact date and almost an exact time for the earthquake - 9 p.m. Jan. 26, 1700. The Japanese documents described 10-foot waves that washed away about a dozen houses in a fishing village on the east coast of Japan nine hours later.

Computer simulations by Dr. Kenji Satake of the Active Fault Research Center in Japan indicate that for 10-foot waves to reach Japan, the Cascadia earthquake that generated them was huge, between magnitude 8.7 and 9.2, rupturing the entire 600-mile fault. The 1700 earthquake was not a singular event in the Cascadia subduction zone. Dr. Atwater's sediments show evidence of seven earthquakes there in the past 3,500 years ago. For now, the Juan de Fuca and North American tectonic plates are locked tight against each other, accounting for the seismic lull.

But as the Juan de Fuca plate pushes inexorably to the northeast, pressure along the Cascadia is building, seismologists are certain that it will break again, most likely unleashing another volley of tsunamis. The interval between earthquakes has been roughly 300 to 1,000 years. It has been 305 years since the 1700 earthquake. Scientists will not be surprised if one occurs tomorrow, or several centuries from now.

"Geologically soon," said Dr. Yeh of Oregon State, "is 1,000 years or 100 years."



DigitalGlobe/Agence France-Presse - Getty Images

Satellite images of Banda Aceh, Indonesia, before the tsunami struck, top, and after.

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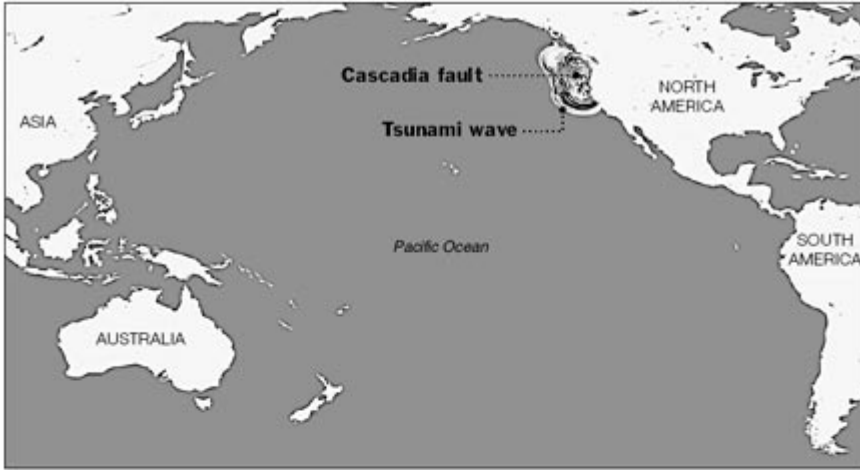
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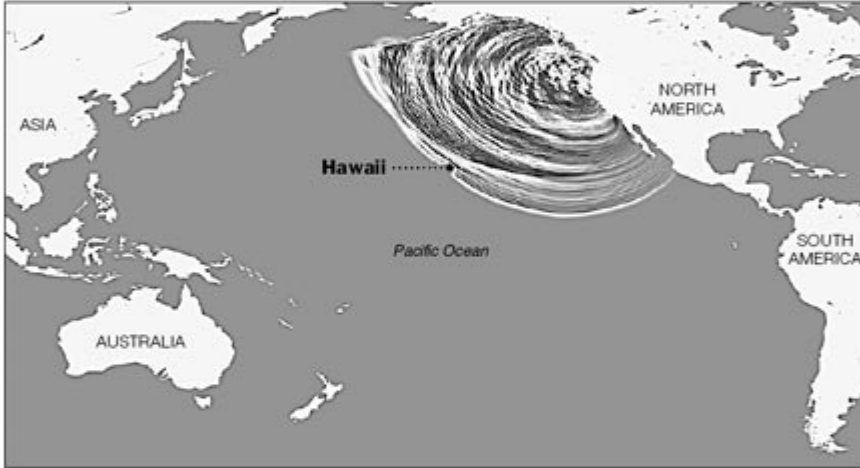
In 1700, a Tsunami Closer to Home

On Jan. 26, 1700, an earthquake of magnitude 9.0 ruptured the 600-mile Cascadia fault off the West Coast, sending a massive tsunami across the Pacific Ocean. Below, a computer model of the tsunami:

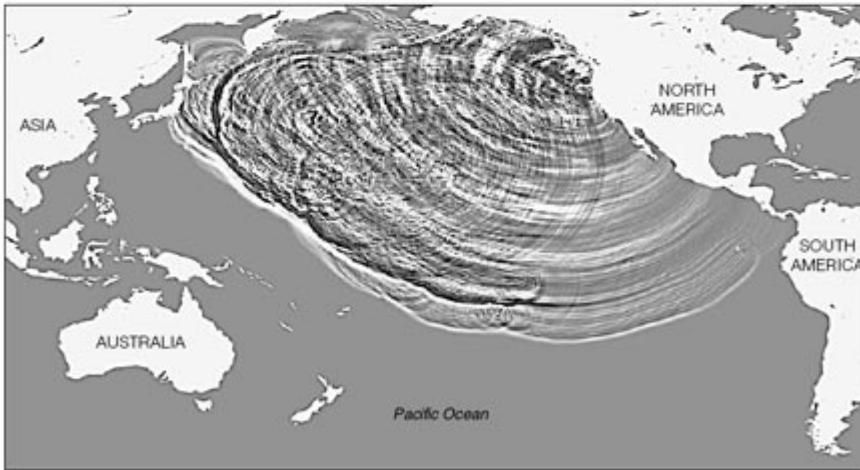
1 hour after earthquake



5 hours after earthquake



10 hours after earthquake



18 hours after earthquake

