**THE NEW YORKER** [**Annals of Seismology**](http://www.newyorker.com/magazine/annals-of-seismology)[**JULY 20, 2015 ISSUE**](http://www.newyorker.com/magazine/2015/07/20)

**The Really Big One [ADAPTATION]**

*An earthquake will destroy a sizable portion of the coastal Northwest. The question is when.*

**BY**[**KATHRYN SCHULZ**](http://www.newyorker.com/contributors/kathryn-schulz)

When the 2011 earthquake and tsunami struck Tohoku, Japan, Chris Goldfinger was two hundred miles away at an international meeting on seismology. As the shaking started, everyone in the room began to laugh. Earthquakes are common in Japan—that one was the third of the week—and the participants were, after all, at a seismology conference. Then everyone in the room checked the time.


The next full-margin rupture of the Cascadia subduction zone will spell the worst natural disaster in the history of the continent.

ILLUSTRATION BY CHRISTOPH NIEMANN; MAP BY ZIGGYMAJ / GETTY

Seismologists know that how long an earthquake lasts is a good indicator of its magnitude. A 1989 earthquake in California, which killed sixty-three people and caused six billion dollars’ worth of damage, lasted about fifteen seconds and had a magnitude of 6.9. A thirty-second earthquake generally has a magnitude in the mid-sevens. A minute-long quake is in the high sevens, a two-minute quake has entered the eights, and a three-minute quake is in the high eights. By four minutes, an earthquake has hit magnitude 9.0.

When Goldfinger looked at his watch, it was quarter to three. The earthquake was not particularly strong. Then it ticked past the sixty-second mark, making it longer than the others that week. The shaking intensified. At a minute and a half, everyone in the room got up and went outside.

The earth snapped and popped and rippled. The quake passed the two-minute mark. The trees were making a strange rattling sound. The flagpole atop the building he and his colleagues had just vacated was whipping through an arc of forty degrees. The building was base-isolated, a seismic-safety technology where a structure rests on movable parts instead of its foundation. Goldfinger lurched over to take a look. The base was lurching, too, back and forth a foot at a time, digging a trench in the yard. His watch swept past the three-minute mark and kept going.

Oh, sh\*t, Goldfinger thought, although not in dread, at first: in amazement. For decades, seismologists had believed that Japan could not experience an earthquake stronger than magnitude 8.4. In 2005, however, a Japanese geologist had argued that the nation should expect a magnitude 9.0 in the near future—with catastrophic consequences, because Japan’s famous earthquake-and-tsunami preparedness, including the height of its sea walls, was based on incorrect science. The presentation was met with polite applause and afterward mostly ignored. Now, Goldfinger realized as the shaking hit the four-minute mark, the planet was proving the geologist right.

For a moment, that was pretty cool: almost immediately, though, it became extremely uncool; every other seismologist standing outside knew what was coming. One of them pulled out a cell phone and started streaming videos shot by helicopters that had flown out to sea soon after the shaking started. Thirty minutes after Goldfinger first stepped outside, he watched the tsunami roll in, in real time, on a two-inch screen.
In the end, the magnitude-9.0 Tohoku earthquake and the tsunami that followed killed more than 18,000 people, triggered the meltdown at the Fukushima nuclear power plant, and cost an estimated two hundred and twenty billion dollars.

**M**ost people in the US know just one fault line by name: the San Andreas, which runs nearly the length of California and is perpetually rumored to be on the verge of unleashing “the big one.” That rumor is misleading, no matter what the San Andreas ever does. Every fault line has an upper limit to its potency, determined by its length and width, and by how far it can slip. For the San Andreas, one of the best understood fault lines in the world, that upper limit is roughly an 8.2—a powerful earthquake, but, because the Richter scale is logarithmic, only 6% as strong as the 2011 earthquake in Japan.

Just north of the San Andreas, however, lies another fault line. Known as the Cascadia subduction zone, it runs for seven hundred miles off the coast of the Pacific Northwest, beginning near Cape Mendocino, California, continuing along Oregon and Washington, and ending around Vancouver Island, Canada. The “subduction zone” part refers to a region of the planet where one tectonic plate is sliding underneath (subducting) another. Tectonic plates are those slabs of mantle and crust that, in their drift over hundreds of thousands of years, rearrange the earth’s continents and oceans. Most of the time, their movement is slow, harmless, and all but undetectable. Occasionally, at the borders where they meet, it is not.

Take your hands and hold them palms down, middle fingertips touching. Your right hand represents the North American tectonic plate, which contains Canada, the US, and parts of Mexico. Your left hand represents an oceanic plate called Juan de Fuca. The place where they meet is the Cascadia subduction zone. Now slide your left hand under your right one. That is what the Juan de Fuca plate is doing: slipping steadily beneath North America. When you try it, your right hand will slide up your left arm, as if you were pushing up your sleeve. That is what North America is not doing. It is stuck, wedged tight against the surface of the other plate.

Without moving your hands, curl your right knuckles up, so that they point toward the ceiling. Under pressure from Juan de Fuca, the stuck edge of North America is bulging upward and compressing. It can do so for quite some time, because continent plates are young and made of rock that is still relatively elastic. (Rocks, like us, get stiffer as they age.) But it can’t do this forever. There is a solid unmoveable mass at the center of the continent that will *not* bulge, and sooner or later, North America will rebound like a spring. If, when that happens, only part of the Cascadia subduction zone gives way—your first two fingers, say—the magnitude of the resulting quake will be somewhere between 8.0 and 8.6.*That*’*s* the big one. If the entire zone gives way at once, an event called a full-margin rupture, the magnitude will be somewhere between 8.7 and 9.2. That’s the *very* big one.

Flick your right fingers outward, forcefully, so that your hand flattens back down again. When that next very big earthquake hits, the northwest edge of the continent will drop, losing, within minutes, all the height and compression it has gained over centuries. Some of that shift will take place beneath the ocean, displacing a huge quantity of seawater. The water will surge upward into a huge hill, then promptly collapse. One side will rush west, toward Japan. The other side will rush east, in a colossal liquid wall that will reach pacific coast, on average, fifteen minutes after the earthquake begins.

When the next full-margin rupture happens, most major coastal cities in Washington and Oregon and some seven million people will suffer the worst natural disaster in the history of North America. Roughly 3,000 people died in San Francisco’s 1906 earthquake. Almost 2,000 died in Hurricane Katrina. FEMA projects that nearly 13,000 people will die in the Cascadia earthquake and tsunami. Another 27,000 will be injured, and the agency expects 1,000,000 displaced people, and that another 2,500,000 will need food & water. “This is one time that I’m hoping all the science is wrong, and it won’t happen for another thousand years,” Murphy says.

In fact, the science is solid. We now know there’s a 33% chance of the big Cascadia earthquake happening in the next 50 years. The odds of the very big one are roughly 10%. What’s most worrisome is this: 30 ago, no one knew that the Cascadia subduction zone had ever produced a major earthquake. Forty-five years ago, no one even knew it existed.
**I**n May of 1804, two Americans set off from the east coast of the new world on America’s first official cross-country expedition. A year and a half later, they reached the Pacific Ocean and made camp. Native Americans had lived in the Northwest for millennia, but they had no written language. The newcomers took the land they encountered at face value: land that was vast, cheap, temperate, fertile, and, to all appearances, remarkably benign. 150 years passed before anyone suspected that the Pacific Northwest was not a quiet place but a place in a long period of quiet.

The first clue came from geography. Almost all of the world’s most powerful earthquakes occur in the Ring of Fire, the area of the Pacific that runs from New Zealand up through Indonesia and Japan, across the ocean to Alaska, and down the west coast of the Americas to Chile. Not until the 1960’s, with the rise of the theory of plate tectonics, could geologists explain this pattern. The Ring of Fire, it turns out, is really a ring of subduction zones. Nearly all the earthquakes in the region are caused by continental plates getting stuck on oceanic plates—as North America is stuck on Juan de Fuca—and then getting abruptly unstuck. And nearly all the volcanoes are caused by the oceanic plates sliding deep beneath the continental ones, eventually reaching temperatures and pressures so extreme that they melt the rock above them.

The Pacific Northwest sits in the Ring of Fire, yet not once in recorded history has it caused a major earthquake. In comparison, other subduction zones produce major earthquakes occasionally and minor ones all the time: magnitude 5.0, magnitude 4.0, and so on. You can scarcely spend a week in Japan without feeling this sort of earthquake, yet you can spend a lifetime in many parts of the Northwest and not feel so much as a quiver. The question facing geologists in the 1970’s was whether the Cascadia subduction zone had ever broken its eerie silence.

In the late 1980’s scientists found the answer, and another major clue in the Cascadia puzzle. Their discovery is best represented in a place called the ghost forest, a grove of western red cedars on the banks of a river near the Washington coast. When I paddled out to it last summer, it was easy to see how it got its name. The cedars are spread out across a low salt marsh, long dead but still standing.

What killed the trees in the ghost forest was saltwater. It had long been assumed that they died slowly, as the sea level around them gradually rose and submerged their roots. But, by 1987, a scientist who had found evidence in the soil layers of a sudden change, suspected that that was backward—that the trees had died quickly when the ground beneath them plummeted. To find out, he examined samples of the cedar trunks and found that they had all died simultaneously: all trees had final rings dated to the summer of 1699. They concluded that sometime between summer 1699 and spring 1700 an earthquake had caused the land to drop and killed the cedars. That time frame came more than a hundred years before written history was recorded in the Pacific Northwest. The story should have ended there.

It did not; however. The Japanese have kept track of their tsunamis since at least 599 A.D. In that history, one very strange incident stands out: In one year of the Genroku era, a 600 mile-long wave struck the coast, levelling homes, breaching a castle moat, and causing an accident at sea; however, no one felt the ground shake before it; the wave had no discernible origin. When scientists began studying it, they called it an “orphan tsunami”.

Finally, in 1996 scientists matched that orphan to its parent—and filled in the blanks in the Cascadia story. On the night of January 26, 1700, a magnitude-9.0 earthquake struck the Pacific Northwest, causing sudden land drops, drowning coastal forests, and, out in the ocean, lifting up a wave half the length of a continent. It took roughly 15 minutes for the Eastern half of that wave to strike the Pacific Northwest coast. It took ten hours for the other half to cross the ocean to the east. It reached Japan on January 27, 1700: by the local calendar, same day their “orphan” tsunami was recorded.

Once scientists had reconstructed the 1700 earthquake, previously overlooked accounts also came to seem like clues. In 1964, Chief Louis Nookmis, of the Huu-ay-aht First Nation in British Columbia, told a story, passed down through seven generations, about the eradication of Vancouver Island’s Pachena Bay people. “I think it was at nighttime that the land shook,” Nookmis recalled. According to another tribal history, “They sank at once, were all drowned; not one survived.” A hundred years earlier, Billy Balch, a leader of the Makah tribe, recounted a similar story. Before his own time, he said, all the water had receded from Washington State’s Neah Bay, then suddenly poured back in, inundating the entire region. Those who survived later found canoes hanging from the trees. In 2005, scientists collected and analyzed Native American reports of earthquakes and saltwater floods. Some of those reports contained enough information to estimate a date range for the events they described. On average, the midpoint of that range was 1701.

It does not speak well of European-Americans that such stories only counted as evidence after other science verified an event. Still, the reconstruction of the Cascadia earthquake of 1700 is wonderful science. It was wonderful *for* science. And it was terrible news for the millions of inhabitants of the Pacific Northwest.

We now know that the Pacific Northwest has experienced 41 subduction-zone earthquakes in the past ten thousand years. If you divide ten thousand by 41, you get two hundred and forty-three, which is the average number of years that elapses between earthquakes. That timespan is dangerous both because it is too long—long enough for us to unknowingly build an entire civilization on top of our continent’s worst fault line—and because it is not long enough. Counting from the earthquake of 1700, we are now 315 years into a 243 cycle.

It is possible to debate that number. The intervals are only averages. It is not possible, however, to dispute the size of the problem. The devastation in Japan in 2011 was the result of a difference between what science predicted and what the region was prepared for. The same is true for the Pacific Northwest—but here the difference is enormous. The gap between what we know and what we should do about it is getting bigger and bigger, and the action really needs to turn to responding.

**T**he first sign that the Cascadia earthquake has begun will be a compression wave, a fast-moving, high-frequency wave, audible to dogs and certain other animals but experienced by humans only as a sudden jolt. They are not very harmful, but they are potentially very useful, since they travel fast enough to be detected by sensors 30-90 seconds before other seismic waves. That is enough time for earthquake early-warning systems, such as those in Japan, to automatically perform a variety of lifesaving functions: shutting down railways and power plants, opening elevators and firehouse doors, alerting hospitals to halt surgeries, and triggering alarms so that the general public can take cover. The Pacific Northwest has no early-warning system. When our earthquake begins, there will be, instead, a cacophony of barking dogs and a long moment before the surface waves arrive. Surface waves are slower, lower-frequency waves that move the ground up and down and side to side: the real shaking.

Soon after that shaking begins, the electrical grid will fail everywhere in the Cascade region. If it happens at night, the catastrophe will unfold in darkness. In theory, those at home when it hits should be safest; it is easy and relatively inexpensive to earthquake-guard a private dwelling…but most people in the Pacific Northwest have not done this. Everything made of glass will shatter instantly. Anything indoors and unsecured will lurch across the floor or come crashing down. Refrigerators will walk out of kitchens, unplugging themselves and toppling over. Water heaters will fall and smash interior gas lines. Houses that are not bolted to their foundations will slide off and begin to collapse.

Across the region, other, larger structures will also start to fail. Until 1974, Oregon had no seismic code, and not one suited to a magnitude-9.0 earthquake until 1994. The vast majority of buildings in the region were built before then. It is estimated that 75% of all structures in the state are not designed to withstand a major Cascadia quake. It is calculated that 1 million buildings—more than 3,000 of them schools—will collapse or be compromised in the earthquake. So will half of all highway bridges, and two-thirds of railways and airports; also, one-third of all fire stations, half of all police stations, and two-thirds of all hospitals.

The shaking from the Cascadia quake will set off landslides throughout the region. It will also cause a process called liquefaction, where seemingly solid ground starts behaving like a liquid, to the detriment of anything on top of it. 15% per cent of Seattle is built on liquefiable land, including 17 day-care centers and the homes of some 34,500 people. So is Oregon’s critical energy-infrastructure hub, a stretch carries ninety per cent of the state’s liquid fuel and which houses everything from electrical substations to natural-gas terminals. Together, the sloshing, sliding, and shaking will trigger fires, flooding, pipe failures, dam breaches, and hazardous-material spills. Four to six minutes after the dogs start barking, the shaking will subside. For another few minutes, the region will continue to fall apart on its own. Then the wave will arrive, and the real destruction will begin.

Among natural disasters, tsunamis may be the closest to being completely unsurvivable. The only likely way to outlive one is not to be there when it happens: to steer clear of the vulnerable area in the first place, or get yourself to high ground as fast as possible. For the seventy-one thousand people who live in Cascadia’s inundation zone, that will mean evacuating in the narrow window after the earthquake and before the tsunami. They will be notified to do so only by the earthquake itself, and they are urged to leave on foot, since the earthquake will render roads impassable. Depending on location, they will have between 10 and 30 minutes to get out. That time line does not allow for finding a flashlight, tending to an injury, searching for loved ones, or being a Good Samaritan. “When that tsunami is coming, you run,” the Oregan Seismic Safety Committee says. “You protect yourself, you don’t turn around, you don’t go back to save anybody. You run for your life.”

The time to save people from a tsunami is before it happens, but the region has not yet taken serious steps toward doing so. Hotels and businesses are not required to post evacuation routes or to provide employees with evacuation training. In Oregon, it has been illegal since 1995 to build hospitals, schools, firehouses, and police stations in the inundation zone, but those which are already in it can stay, and any other new construction is permissible: energy facilities, hotels, retirement homes.

These lax safety policies guarantee that many people inside the inundation zone will not get out. Almost a quarter of Oregon’s coastal population are senior citizens. Almost a third of the state’s population is disabled, and that number is higher in many coastal counties. “We can’t save them; I’m not going to sugarcoat it and say, ‘Oh, yeah, we’ll go around and check on the elderly.’ No. We won’t.” Nor will anyone save the tourists. Washington State Parks in the inundation zone see an average of 17,000 visitors a day. It’s estimated that up to 150,000 people visit Oregon’s beaches on summer weekends. “Most of them won’t have a clue as to how to evacuate,” he says. “And the beaches are the hardest place to evacuate from.”

A grown man is knocked over by ankle-deep water moving at 6.7 miles an hour. The tsunami will be moving more than twice that fast when it arrives. Its height will vary with the contours of the coast, up to more than a hundred feet at highest. It will look like the whole ocean, elevated, overtaking land – not like a classic wave. Nor will it be made only of water—not once it reaches the shore. It will be a five-story slurry of pickup trucks and doorframes and cinder blocks and fishing boats.

To see the full scale of the devastation when that tsunami recedes, you would need to be in the international space station. FEMA’s expected search-and-rescue operations are based on the agency’s official planning scenario, which has the earthquake striking at 9:41 A.M. on February 6th. If, instead, it strikes in the summer, when the beaches are full, their numbers could be off by a horrifying margin

Estimates say it will take between 1 and 3 months after the earthquake to restore electricity, a month to a year to restore drinking water and sewer service, six months to a year to restore major highways, and 1.5 years to restore health-care facilities. On the coast, it will be much longer. Those estimates do not apply to the tsunami-inundation zone, which will be uninhabitable for years

How much all this will cost is anyone’s guess, but whatever the ultimate figure, the economy of the Pacific Northwest will collapse. Crippled by a lack of basic services, businesses will fail or move away. Many residents will flee as well. A mass-displacement and a long-term population downturn are predicted.

**T**his problem is two-way. The Cascadia subduction zone remained hidden from us for so long because we could not see deep enough into the past. It poses a danger to us today because we have not thought deeply enough about the future. That is no longer a problem of information; we now understand very well what the Cascadia fault line will someday do. Nor is it a problem of imagination. As movies show, we excel at imagining future scenarios, including awful ones. But such movies are a form of escapism, not a plan of action. That problem is not specific to earthquakes, of course. How should a society respond to a looming crisis of uncertain timing but of catastrophic proportions? How can it begin to right itself when its entire infrastructure and culture developed in a way that leaves it profoundly vulnerable to natural disaster?

The last person I met with in the Pacific Northwest the superintendent of schools for Seaside district, which lies almost entirely within the tsunami-inundation zone. Of the 4 schools that he oversees, **one** is relatively safe. When the tsunami comes, the other 3 will be as much as 45 feet below sea level.

In 2009, he said, he found some land for sale outside the inundation zone, and proposed building a new K-12 campus there. Four years later, to foot the bill, the district proposed a tax increase for residents of $2.16 per thousand dollars of property value. The proposal failed. Dougherty tried seeking help but came up empty. The state makes money available for seismic upgrades, but buildings within the inundation zone cannot apply. At present, all Dougherty can do is make sure that his students know how to evacuate.

Some of them, however, will not be able to do so. At one school the children will be trapped. “They can’t make it out” Dougherty said. On one side lies the ocean; on the other, a wide, roadless bog. When the tsunami comes, the only place to go in is a small ridge just behind the school. At its tallest, it is 45 feet high—lower than the expected wave in a full-margin earthquake. I asked about the state’s long-range plan. “There is no long-range plan,” he said.

Dougherty’s office is deep inside the inundation zone, a few blocks from the beach. All day long, the ocean rises up and collapses. Eighty miles off the coast, ten thousand feet below the surface of the sea, the hand of a geological clock is ticking. All across the region, seismologists are looking at their watches, wondering how long we have, and what we will do, before geological time catches up to our own. ♦

QUESTIONS TO CONSIDER:

1. What parts of the article were familiar to you?
2. What parts of the article stood out to you most?
3. What is the name of the fault that Vancouver sits on top of? What is happening at this fault that will cause a major earthquake?
4. How did the Ghost Forest, Japan’s recorded history, and Native American stories contribute to our understanding of our seismic history?
5. It seems people are almost more fearful of a post-earthquake tsunami than an earthquake itself. Should they be? Why/why not?
6. Is your family prepared to survive for the service outage after the tsunami? How long of a period could you endure?
7. What now?