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Not My Fault: How a great Cascadia earthquake might remake the Pacific Northwest Coastline

Lori Dengler for the Times-Standard
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"Ghost forest" of Sitka spruce trees near Neskowin in Tillamook County, Oregon that may have been submerged roughly 2000 years ago in a past Cascadia earthquake (photo Rob Degraff)

This week marks a decade since I retired from teaching at is what is now called Cal Poly Humboldt. My final 106 Earthquake Country lecture was on May 7, 2015. That lecture included a summary of the earthquakes that had occurred during the term. The largest was and deadliest that semester was a M7.8 in Nepal and a wrap on earthquake hazards.

I organized hazards in categories according to primary causes: shaking due to the passage of seismic waves, fault rupture displacing land on either side of the fault, and land elevation changes producing permanent raising or lowering of the ground. While each was the result of fault slip, the underlying physics in each case is different – seismic waves are triggered by the "kick" the fault rupture gives to the ground, fault displacement can move the ground on opposite sides of the fault many tens of feet for great quakes, and elastic rebound of stressed ground can produce noticeable changes in elevation.

My 106 students knew about ground shaking as almost all had felt a quake before entering my classroom. Most had some idea of fault slip although often with erroneous ideas of faults swallowing people or dropping California into the ocean. Almost no one was aware of how land levels could change both during earthquakes and in the long intervals between them. In the past two decades as public awareness of a great earthquake on the Cascadia subduction zone has grown, there has been much outreach on shaking hazards and tsunami potential but little focus on how the land might change and its implications.

Two weeks ago, a paper was published in the Proceedings of the National Academy of Sciences about the likely scale of Cascadia land level changes and how earthquake-produced subsidence needs to be included in sea-level rise discussions and coastal planning. It was a large team effort led by Tina Dura of Virginia Tech who I worked with when she was a postdoc at Humboldt. The paper quantifies how the areas vulnerable to coastal flooding are likely to expand in the Cascadia region from North Coast California to Washington and exacerbate climate-change induced rising seas. It has garnered much media attention but also some confusion on the implications.

Abrupt earthquake-triggered land changes are not a new idea. The earliest written accounts of great earthquakes causing the land to rise or fall are from China and date back to nearly 4000 years. Oral histories of peoples around the globe contain earthquake stories and some describe how they cause the land to change. Some of these come from land you may be currently living on.

Deborah Carver, good friend and wife of geologist Gary Carver, spent decades researching the Wiyot, Yurok, and Tolowa earthquake/tsunami stories. She found a Humboldt Times article published in 1855 stating "The Bay Indians have a tradition that this bay was produced by an earthquake which swallowed up the land, destroyed a large and powerful Indian tribe- only a few escaping." She found published and unpublished stories from UC Berkeley anthropologists Goddard, Waterman, and Kroeber collected in the early 20th century (stories in link below).

The Yurok stories of Earthquake and Thunder who ran up and down the coast stomping the ground and allowing the ocean to come in were first thought to be of mythic and cultural relevance, but not descriptions of actual events. But physical evidence of repeated downward jerks of Humboldt Bay and a better understanding of the earthquake cycle has changed that assessment. The land can drop suddenly in earthquakes and in shallow places like Humboldt Bay, a few feet of subsidence will greatly expand its area.

To understand why the ground drops or rises in great subduction zone earthquakes like Cascadia, think elasticity. Stretch a rubber band or other elastic material and let go. It returns to its original shape. All that deformation was stored in the material and ready to snap back as soon as the pull stopped. Crustal rocks are likewise elastic to some degree. If you squeeze or stretch them over decades or centuries, they store that energy just like a rubber band. An earthquake suddenly releases the pull or push, and the ground can quickly return to its previous shape.

In subduction zones like Cascadia, the squeezing lasts for a very long time. Gravity is constantly pulling the subducting slab downwards. This pull is resisted by friction that is locking the subducting slab to the overlying plate. In most of Cascadia, it's the Juan de Fuca plate being pulled down and to the east and Oregon and Washington that are stuck on top. That pull can be measured – slowly shifting the surface upwards and in an eastnortheast direction. It takes very sensitive instruments to measure the distortion, the amplitude is on the order of an inch or two per century. But the area being squeezed is very large and when the locked zone is suddenly broken in a great earthquake that squeezed zone suddenly relaxes causing the land to drop.

The classic example of this subsidence is the 1964 M9.2 Alaska earthquake. George Plafker of the USGS spent months mapping coastal changes in detail after the earthquake and documented for the first time the systematic regional elevation changes a great earthquake can produce (see Not My Fault 5/24/2017 for more detail on Plafker's work). An area roughly 500 miles long and 300 miles wide had changed in height. Areas more than 80 miles from the continental shelf and edge of the subduction zone had dropped and areas closer to the rupture had risen.

Many people have worked on this pattern of uplift and subsidence in great quakes since 1964. I saw firsthand the effects in 2005 when I studied the 2004 Andamans-Sumatra earthquake and again in 2010 and 2011 working in Chile and Japan. Each earthquake is unique, and the areas of uplift and subsidence depends on the size of the earthquake, the orientation of the fault rupture and the distance from the coast. The coastal areas I visited had dropped between one and six feet, causing additional damage to infrastructure and exacerbating tsunami impacts.

Dura's group focused on post-quake earthquake subsidence and how it contributes to sea level rise. This makes sense as all of the Oregon and Washington coasts are far enough away from the continental shelf and the rupture tip to be in the down-dropped areas. Her team examined paleoseismic data from coastal wetlands and the majority of data suggests roughly 6 feet of co-seismic subsidence. There are a few sites in C Oregon with values as low as 1.5 feet and one near the mouth of the Columbia River that is nearly 9.

The picture becomes more complicated in our part of Cascadia south of the Oregon border because we are closer to the continental shelf and where the Cascadia megathrust fault breaks the seafloor surface. Plafker found that the zone closer to the tip of the fault generally uplifts during great quakes. He found this not only in Alaska, but in his re-examination of the even larger M9.5 Chile quake in 1960. But the pattern isn't smooth because it is influenced by secondary faults which may also rupture in a great earthquake.

Such is likely the case in Humboldt County where splay faults off of the subduction zone are exposed on land. Faults like the Little Salmon that runs along the base of Humboldt Hill, the Fickle Hill fault in Arcata, and the Mad River fault zone from McKinleyville to Trinidad may all influence what goes up and what does down in our area. The general picture in the Humboldt Bay area from both coring and the Yurok and Wiyot oral history is co-seismic subsidence on the order of one to three feet. The Cape Mendocino area where the subduction zone breaks the sea floor very close to the coast shows repeated evidence of uplift. But uplift is generally not well-preserved in the geologic record.

I agree with Tina and colleagues that coseismic land level changes deserve higher planning priorities but not only for sea level rise but also in short term earthquake response planning. County and city planners need to take earthquake land level changes into consideration in the siting of future development andmaking zoning decisions. In

Humboldt County, we can't predict exactly what will go up or down or by how much, but I am sure the result will be disruption of roads, our port, and other infrastructure that will likely take months to years to repair.

Note: the paper "Increased flood exposure in the Pacific Northwest following earthquake-driven subsidence and sea-level rise" can be read at https://www.pnas.org/doi/10.1073/pnas.2424659122 You can access Deborah Carver's compilation of North Coast native earthquake stories at https://npshistory.com/publications/redw/native-stories-earthquakes-tsunamis.pdf

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