Current assessment of earthquake hazard in Oregon

by Robert S. Yeats, Department of Geology, Oregon State University, Corvallis, Oregon 97331

Five years ago, very few people were concerned about major earthquakes in the state of Oregon. Historical damaging earthquakes had been recorded in the adjacent states of Washington, Idaho, Nevada, and California, but not Oregon. This lack of concern is expressed today in seismic zoning maps, which put the state of Oregon in a lower seismic risk category than adjacent states.

Today, the earth science community appears to have reached a consensus that Oregon has been struck by large earthquakes in the past and therefore that Oregon is likely to be subjected to large earthquakes in the future. There is no agreement among earth scientists on whether Oregon will be subjected to a magnitude 9 or only a magnitude 7 earthquake. Nor is there compelling evidence for past large earthquakes directly beneath the heavily populated Willamette Valley. But the evidence found in marshes in estuaries on the Oregon coast is compelling enough for reevaluation of seismic zoning maps and of the seismic safety of critical facilities such as power plants, hospitals, and dams.

In evaluating earthquake hazards, it is not enough to show that crustal deformation has taken place in the recent past, because such deformation could take place slowly and smoothly, unaccompanied by earthquakes. It is necessary to show that deformation occurred in sudden jerks, as it does during an earthquake.

In Oregon and Washington, scientists have now shown that coastal marshes and coniferous forests have recently undergone sudden subsidence that killed the marshes and forests by inundating them with sea water. Sand commonly found overlying the marshland sediments shows strong evidence of having been deposited by a seismic sea wave, or tsunami. Sand of this kind has been reported from the Salmon River and Alsea Bay, Oregon, and from Willapa Bay, Washington.

Many attempts have been made to account for the buried marshes by nonseismic processes, notably gigantic, 500-year storms or a slow rise in sea level. Sea-level change in the last 5,000 years does not appear to be large enough to account for the marshland burials. Marshes on the East Coast and Gulf Coast of the United States have been subjected to great storms in the past, notably hurricanes, but these marshes do not show evidence of rapid burial. However, marshes around the Gulf of Alaska and in southern Chile do show evidence of rapid burial, including burial after the 1960 Chile earthquake (magnitude 9.5) and the 1964 Alaska earthquake (magnitude 9.2). We cannot completely exclude the possibility that the marshes could have been mantled with sand by a gigantic Pacific storm occurring during a time of temporary sea-level rise in the last few thousand years. But this explanation has very little support among scientists because it is unlikely that a great storm and a temporary sea-level rise would have coincided seven or eight times in the last 5,000 years.

The only note of caution about correlating marsh subsidence with earthquakes is the absence of evidence of strong shaking of marsh deposits that would be expected during a great earthquake.

The most recent great coastal subsidence event occurred 300 to 400 years ago, as dated by carbon-14, and is known to have inundated many marshes and forests from Grays Harbor in Washington to Alsea Bay in Oregon. Carbon-14 dates from partially submerged archeological sites are consistent with submergence during the most recent event as well as an earlier event 3,100 years ago. However, carbon-14 dates do not permit us to say whether a given subsidence event occurred in one earthquake or in several over a period of 50 years. We could calculate the magnitude of an earthquake rupturing the subduction zone from Grays Harbor to Alsea Bay, but this would be considered as a maximum possible event. Tree-ring dating could increase the time resolution, but only where the subsidence events are recorded by killed trees in lowland forests.

These probable subduction-zone earthquakes have occurred on average every 500 to 600 years, but there is so much variation in recurrence interval over the past 4,000 years that the average recurrence interval has little value in predicting the next earthquake.

Sediment cores from the abyssal sea floor at the foot of the continental slope west of Oregon provide evidence of strong shaking, perhaps related to the abrupt coastal subsidence. Sediments deposited on the continental shelf by major rivers, particularly the Columbia River, were apparently destabilized and sent down the continental slope as a high-density, sediment-charged flow analogous to a snow avalanche, but much larger. The most likely triggering mechanism was a giant earthquake. The cores also recovered deposits of ash from the Mount Mazama eruption that formed Crater Lake about 7,600 calendar years ago. Based on the number of turbidity-current deposits on top of the Mount Mazama ash, the average interval between successive turbidity-current deposits is about 500 to 600 years, with the most recent deposit about 300 years ago. These estimates resemble those for marshland subsidence events, adding support for the origin of both by great earthquakes.

Accurate repeated leveling surveys of Oregon highways provide evidence for deformation in the last 100 years. This releveling study is in its early stages, because the highways were last releveled in 1987, and the data are only partially analyzed. However, there is clear evidence of eastward tilting of the Coast Range toward the Willamette Valley, northward tilting of the coast between southern Oregon and Newport, and southward tilting of the coast between Astoria and Tillamook. We cannot say whether this deformation represents elastic strain accumulation prior to a future earthquake or whether this deformation has nothing to do with earthquakes. This is a profitable line of investigation, however, and future studies may lead to more definitive evidence from geodetic evidence of this kind.

Studies in the Willamette Valley have not yet produced evidence that the Portland Hills fault, Gales Creek fault, Corvallis fault, and other faults in the Valley are active and capable of producing earthquakes. In addition to these faults, there are broad folds in the Tualatin Valley and Portland basin. The faults are not long and throughgoing, as they are in California, but instead are relatively short and offset at right angles by other faults. The faults and folds are consistent with the observed stress field of western Oregon, which is characterized by the maximum compressive stress oriented north-south. These faults and folds clearly deform flows of the Columbia River Basalt Group deposited 16.5 to 12 million years ago. Most of these structures also deform semiconsolidated sediments that overlie Columbia River basalt, but these sediments are poorly dated. If these sediments are as young as a few hundred thousand years, then these faults would be shown to be capable of generating future earthquakes. Investigations to answer these questions are underway.

The only clear evidence for recent crustal earthquakes comes from the South Slough of Coos Bay, where marshes show evidence of at least eight burial events in the last 5,000 years. South Slough is in the axis of a syncline, or down-fold, and the buried marshes show that this syncline was formed by a series of earthquakes, possibly on a deeply buried fault that nowhere reaches the surface. Coos Bay is at the eastern margin of a zone of active faults and folds that extends north-northwestward offshore, parallel to the foot of the continental slope and not parallel to the coastline, which extends northward. These faults and folds respond to the northeastward subduction of the Juan de Fuca Plate beneath Oregon and are not in accord with the north-south principal compressive stresses measured elsewhere in western Oregon. Thus, we cannot apply the evidence for earthquakes at Coos Bay directly to the Willamette Valley, which is much farther inland from the trench.

Western Oregon has very few instrumentally recorded earthquakes, and most of these are in the Portland area, part of a zone that extends northward into Washington. Part of the reason for so few earthquakes is that Oregon has very few seismographs to record small earthquakes, as compared with adjacent states. For this reason, small earthquakes that could be recorded in Washington or California are not recorded in Oregon. However, the lack of larger earthquakes, magnitude greater than 2.5, is not an artifact of poor instrumentation. The Washington network has recorded many earthquakes in the North American crust and many more in the deep oceanic slab that is now being subducted, but none on the interface between the two plates, the place where subduction-zone earthquakes would occur. The absence of earthquakes could be explained by very smooth, frictionless subduction or by subduction having stopped entirely. Neither explanation is likely. The most logical explanation is that the subduction zone is completely locked and is building up strain for a future earthquake. Most of the San Andreas fault that ruptured in great earthquakes in 1857 and 1906 is seismically quiet, like the Willamette Valley. The Coos Bay region, with the only clear evidence for recent crustal earthquakes, is also seismically quiet. Even so, the compete absence of instrumentally recorded earthquakes on the subduction-zone interface is difficult to explain.

The lack of historical earthquakes should not be taken as evidence for low seismic hazard, because Oregon's recorded history spans less than 200 years, which is not sufficient time to be significant in earthquake-hazard evaluation. The submergence of archeological sites indicates that earthquakes affected Native American communities prior to the establishment of a culture that kept written records. The Armenian earthquake of December 1988 occurred in an area that had not had a major earthquake in 700 years, based on historical records. A large portion of that part of the San Andreas fault of California that ruptured in great earthquakes in 1857 and 1906 is now as seismically quiet as the Willamette Valley. The southern San Andreas fault has not had a major earthquake in several hundred years, and a long-range prediction experiment is now underway in that region.

In conclusion, the marsh evidence is convincing enough to issue a public warning about earthquake hazard in Oregon. We cannot say how large a subduction-zone earthquake could be, nor can we forecast when the next one might occur. We also have not been able to assess the earthquake hazard posed by local earthquake sources beneath the Willamette Valley. We are on the steep part of the learning curve, and there are many challenges ahead of us. □

The 15 most significant earthquakes in U.S. history

For National Earthquake Awareness Week, April 2-8, 1989, the U.S. Geological Survey (USGS) released a list of the 15 most significant earthquakes in the history of the United States.

Robert Wesson, chief of the Office of Earthquakes, Volcanoes, and Engineering at the USGS National Center in Reston, Virginia, said the basis for selection of the 15 earthquakes is a combination of magnitude, damage, and casualties.

Earthquakes are measured in two basic ways: magnitude and intensity. Magnitude is an instrumental measure of the amount of energy released by an earthquake, as indicated by ground motion. Magnitude scales theoretically have no upper limit. The Modified Mercalli Scale (MMS) of intensity, using Roman numerals, is based on human judgment of the amount of damage and effects caused by earthquakes and ranges from I (not felt) to XII (almost total destruction of human-made structures).

The 15 most significant earthquakes in U.S. history, listed in order of the time of their occurrence, are as follows:

1. Cape Ann, Massachusetts, November 18, 1755. Estimated magnitude 6.0, maximum MMS intensity VIII. It was centered in the Atlantic 200 mi east of Cape Ann and was felt over 400,000 mi^2, from Nova Scotia south to Chesapeake Bay and from Lake George, N.Y., east into the Atlantic. Damage was heaviest on Cape Ann and in Boston, with about 100 chimneys destroyed.

2. New Madrid, Missouri, seismic zone, 1811-1812. In the most violent series of earthquakes in U.S. history, three earthquakes (in this list counted as one) hit the New Madrid seismic zone in southeastern Missouri and northeastern Arkansas on December 16, 1811, and January 23 and February 7, 1812, at estimated magnitudes of 8.4 to 8.7 and maximum MMS intensities of XI. Damage and casualties were not great because the area was sparsely populated, but the earthquakes were felt over the entire United States east of the Mississippi River and probably far to the west. The earthquakes caused extensive changes in the surface of the land.

3. Virgin Islands, November 18, 1867. Estimated magnitude 7.5, maximum MMS intensity VIII. It was felt from the Dominican Republic to the Leeward Islands. Property damage occurred in the Virgin Islands and Puerto Rico, some caused by 20-ft sea waves triggered by the earthquake.

4. Charleston, South Carolina, August 31, 1886. Estimated magnitude 6.6, maximum MMS intensity X. It killed 60 people. Most buildings in the Charleston area were damaged or destroyed, with losses of $20 million. It was felt in New York City, Boston, Milwaukee, Havana, and Ontario.

5. Charleston, Missouri, October 31, 1895. Estimated magnitude 6.2, maximum MMS intensity IX. It was near the junction of the Mississippi and Ohio Rivers and was the strongest shock in the New Madrid seismic zone since the three great earthquakes in 1811-1812. It was felt over 1 million square miles in 23 states and Canada, caused considerable damage, and created a four-acre lake near Charleston.

6. San Francisco, California, April 18, 1906. Estimated magnitude 8.3, maximum MMS intensity XI. Although known as the San Francisco earthquake, the 1906 shock actually ruptured the San Andreas fault along a 270-mi-long segment from San Benito County north to Humboldt County. Fault slip was up to 21 ft in Marin County. Damage was estimated at more than $24 million, directly from the earthquake and from the fires that followed in San Francisco. The death toll from the earthquake and fires was more than 700 persons.

7. Mona Passage, Puerto Rico, October 11, 1918. Estimated magnitude 7.5, maximum MMS intensity IX. It was one of the most violent recorded on Puerto Rico and was followed by a tsunami that drowned many people. The death toll was 116, and damage was estimated at $4 million.

8. Long Beach, California, March 10, 1933. Although the magnitude was only 6.2, and the maximum MMS intensity was VIII, this earthquake was one of the most destructive in the United States because it was in a heavily settled area, with many poorly constructed buildings, including schools. About 115 people were killed, and hundreds more were injured. Damage was estimated at $40 million. The earthquake led to stricter construction codes in California to mitigate earthquake damage.

9. Olympia, Washington, April 13, 1949. Magnitude 7.1, maximum MMS intensity VIII. This earthquake caused heavy damage in Washington and Oregon. Eight people were killed, and many others were injured. The earthquake was felt eastward to western Montana and south to Cape Blanco, Oregon.

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