

The 1700/01/26 Cascadia subduction zone Earthquake and Tsunami

Jason R. Patton
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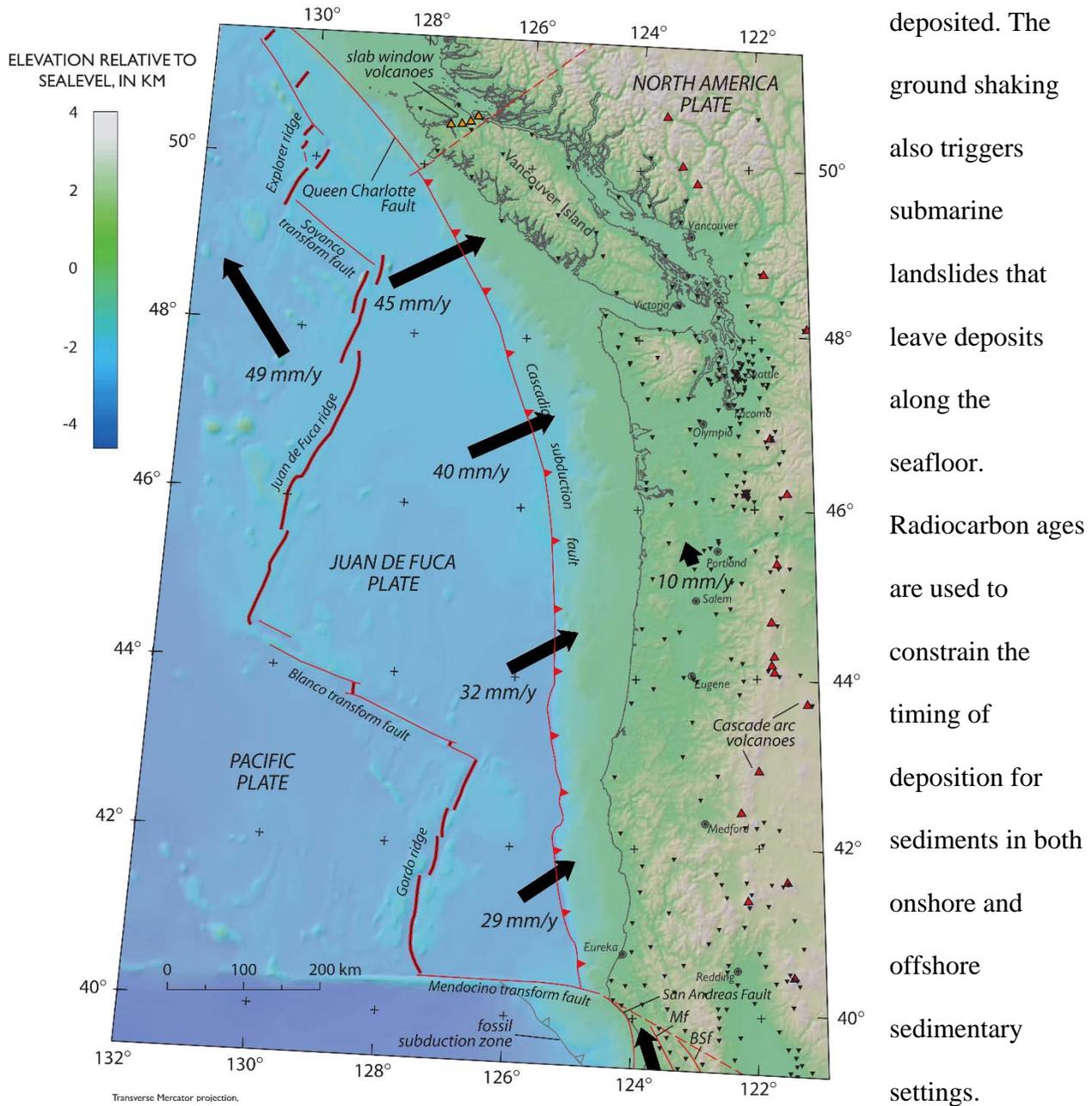
Abstract: Cascadia subduction zone earthquakes (CSZ) can generate strong ground shaking and deadly tsunamis. Geologists used sediment cores and stream bank exposures to find sedimentary evidence for these past subduction zone earthquakes along the CSZ. This sedimentary evidence is in the form of buried marsh deposits and tsunami deposits. Geologists used radiocarbon ages to determine the timing of many of these past earthquakes and tsunamis. Based on radiocarbon age control, these CSZ earthquakes recur every 240 to 540 years. Based on radiocarbon age control, the most recent earthquake occurred sometime between 1695 and 1720 A.D. Geologists and historians found evidence of a tsunami in Japan that, when compared to other possible sources of tsunamis in the Pacific Ocean, was most likely generated during a CSZ earthquake that happened on January 26, 1700.

Introduction: The Juan de Fuca oceanic plate subducts eastwardly beneath the continental crust of the North America plate to form the CSZ, at rates of 29- to 42-mm/year (McCroory et al., 2006; **Figure 1**). The last subduction zone earthquake was in January of 1700 (Atwater et al., 2005). Geologic evidence for this earthquake is found along the coast of Oregon, Washington, and California. There is also evidence, in Japan, of a tsunami triggered from this earthquake. Evidence for prior earthquakes is also found along the coast, as well as offshore in marine sediments. This evidence spans the past 7,500 years on land (Nelson et al., 2006) and ~10,000 years offshore (Goldfinger et al., 2012).

During earthquakes along the subduction zone, the ground deforms vertically and the ground shakes as seismic waves propagate through the Earth. This vertical deformation can place marsh deposits, once partly above tide where plants can grow, lower into the tidal zone where plants

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may not grow. The marsh deposits then get buried by mud. Biological microfossils found in the sediment can be used to infer the relative vertical position of the ground when the sediment was



deposited. The ground shaking also triggers submarine landslides that leave deposits along the seafloor. Radiocarbon ages are used to constrain the timing of deposition for sediments in both onshore and offshore sedimentary settings.

Figure 1. The CSZ fault is designated by a red line with triangles. Relative plate motions are shown as black arrows and the rates are labeled in mm/year. From McCrory et al. (2006).

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Methods: Geologists placed sediment cores along the coast in bays and estuaries along the entire subduction zone (Atwater et al., 2005; Nelson et al., 2006). These cores were placed to find buried marsh deposits. Microfossils are used in the marsh cores to interpret the sedimentary environment of the sediments that were deposited. Geologists also placed sediment cores in the deep sea offshore of the CSZ (Goldfinger et al., 2012). These cores were placed to find deposits of submarine landslides possibly triggered by earthquakes on the CSZ. Organic material is used for radiocarbon age control based on the radioactive half-life of ^{14}C for both types of studies.

Historians reviewed records of tsunamis in Japan. They focused on “orphan” tsunamis, tsunamis that did not have “parent” earthquakes (i.e. the earthquakes occurred elsewhere). Tsunami modelers then used subduction zones with records of past earthquakes that were of an age close to 1700 A.D. as a source for their tsunami models. They then modeled tsunami waves as they propagated across the Pacific Ocean to hit Japan. They then compared the tsunami model results with the records of tsunami inundation found by the historians (Atwater et al., 2005). They also compared historic tsunamis triggered elsewhere and compared their inundation in Japan with that of the 1700 A.D. orphan tsunami.

Results: Geologists found that there were marsh soils with overlying tidal mud (and sometimes tsunami sands) in many of the locations that they cored (Atwater, 1987; Atwater et al., 2005; Nelson et al., 2006). The stratigraphic contact between the marsh deposits and the overlying mud is sharp (less than 2 mm; Atwater and Hemphill-Haley, 1997). The marsh deposits had microfossils that were indicative of a high marsh environment (high in elevation compared to the tidal range). The mud had microfossils indicative of a tidal to sub-tidal environment (low in elevation compared to the tidal range). Radiocarbon age results span the past 7,500 years.

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Geologists found submarine landslide deposits, called turbidites, in the deep sea offshore of the CSZ. These turbidites are correlatable over spans of hundreds of kilometers. Radiocarbon ages from underneath the turbidites mostly match for each of the correlated turbidites. These radiocarbon ages span the past 10,000 years (Goldfinger et al., 2012).

Historians found documents in Japan with evidence of an orphan tsunami that hit Japan in January 1700 A.D. Tsunami modelers modeled tsunami waves from the different subduction zones in the Pacific Ocean and found that the CSZ could have generated a tsunami that matched the records found in Japan. Also, only the CSZ had an earthquake with a radiocarbon age that was close to the time of the orphan tsunami that hit in January of 1700 (Atwater et al., 2005).

Discussion: The geologists who studied the paleoseismology of the CSZ based on sediment cores discussed the different possible interpretations of their data (Atwater and Hemphill-Haley, 1997, Atwater et al., 2005). The buried soils could be created by cut and fill by tidal streams, deposition by storms or floods, and fluctuations in sea level. The buried soils generally have “less relief and more lateral continuity” (Atwater and Hemphill-Haley, 1997) than would be expected for the sediment stratigraphy of mud overlying marsh deposits found in the locations they studied. Modern channel erosion leave unconformities with larger relief than found in the locations they studied. Microfossils in the mud, combined with the fact that the buried soils are lower in elevation than the modern tidal range, support that these buried marsh deposits were probably not buried by storms nor floods. Fluctuations in sea level generally leave behind evidence of gradual sea level change, but the abruptness of the contact between the marsh deposits and the overlying mud suggest the change in environment occurred over a very short period of time (like during an earthquake). Nelson et al. (2006) correlated stratigraphic evidence along the Oregon and Washington coast to determine the range in timing for past earthquakes.

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Based upon the correlation of turbidites, and onshore records of past earthquakes, Goldfinger et al. (2012) conclude that, during the past 10,000 years, there are 19 earthquake triggered turbidites (seismoturbidites) in the northern margin offshore of Washington and 41 seismoturbidites in the southern margin offshore of southern Oregon. Goldfinger et al. (2012) discuss the alternative interpretations for their data and find that there are no other explanations that meet the criteria that they use (regional correlations, “confluence” test, etc.).

Atwater et al. (2005) consider other sources for the 1700 A.D. tsunami in Japan. Based upon the timing of past earthquakes, a subduction zone earthquake in Alaska is a candidate. However, the Good Friday earthquake of 1964 generated a tsunami that inundated Japan that was modest in size compared to the 1700 A.D. tsunami. Likewise, earthquakes in Kamchatka (1952) and Chile (1960) also produced tsunamis in Japan that were dissimilar from the 1700 A.D. tsunami. These evidences support the interpretation that the orphan tsunami of 1700 A.D. was generated by an earthquake along the CSZ.

Conclusion: Sediment coring along the Pacific Northwest, on land and at sea, allowed researchers (Atwater, 1987; Atwater and Hemphill-Haley, 1997; Atwater et al., 2005; Goldfinger et al., 2012) to find evidence of past earthquakes preserved in sediment stratigraphy. These geologists used radiocarbon age control to conclude that, for the past 10,000 years, the CSZ has earthquakes every ~240 years in the south (i.e. northern California and southern Oregon) and ~540 years in the north (i.e. Washington; Atwater and Hemphill-Haley, 1997; Nelson et al., 2006; Goldfinger et al., 2012). Historians and tsunami modelers used records of orphan tsunamis in Japan, records of past subduction zone earthquakes around the Pacific Ocean, and tsunami models to conclude that the most recent CSZ earthquake was on January 26, 1700 A.D.

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