Using tsunami deposits and modeling to study tsunami history and sources in Washington State, USA

Dr. Carrie Garrison-Laney
Washington Sea Grant/University of Washington, USA

Abstract

Washington State, on the Pacific coast of the United States, has many tsunami sources, including the Cascadia subduction zone, shallow faults that cross waterways, submarine and subaerial landslides, and distant source trans-Pacific tsunamis. However, Washington has had very few tsunamis in the last 150 years, and of those, only landslide and distant source tsunamis have been observed. Because of this, accurate assessments of future tsunami size and frequency must rely on the study of paleotsunami deposits and the modeling of tsunami flow and sediment transport. A tidal marsh at Discovery Bay, along the Strait of Juan de Fuca, is an ideal setting to study the history of tsunamis from various sources. There are at least nine distinct tsunami deposits spanning the last 2,500 years in the marsh deposits at Discovery Bay; and several thinner, less distinct deposits that may represent distant source tsunamis, such as the 1964 Great Alaska Earthquake tsunami, which flooded the site. The marsh contains a deposit inferred to be from the 1700 A.D. Cascadia earthquake, and some of the older deposits are likely from earlier Cascadia tsunamis. Tsunami deposits can be used to provide estimates of tsunami inundation extent, flow depths, and current velocities, which can be compared to output from tsunami inundation models. Tsunami deposits can also be used to study tsunami sources. A collaboration with Tohoku University modeling tsunami sediment transport using the characteristics of tsunami deposits will test various sources. There are a greater number of tsunami deposits at Discovery Bay than known tsunamis or earthquakes in the same timespan, so further study must be done to accurately assess the tsunami hazard in Discovery Bay and the Strait of Juan de Fuca.

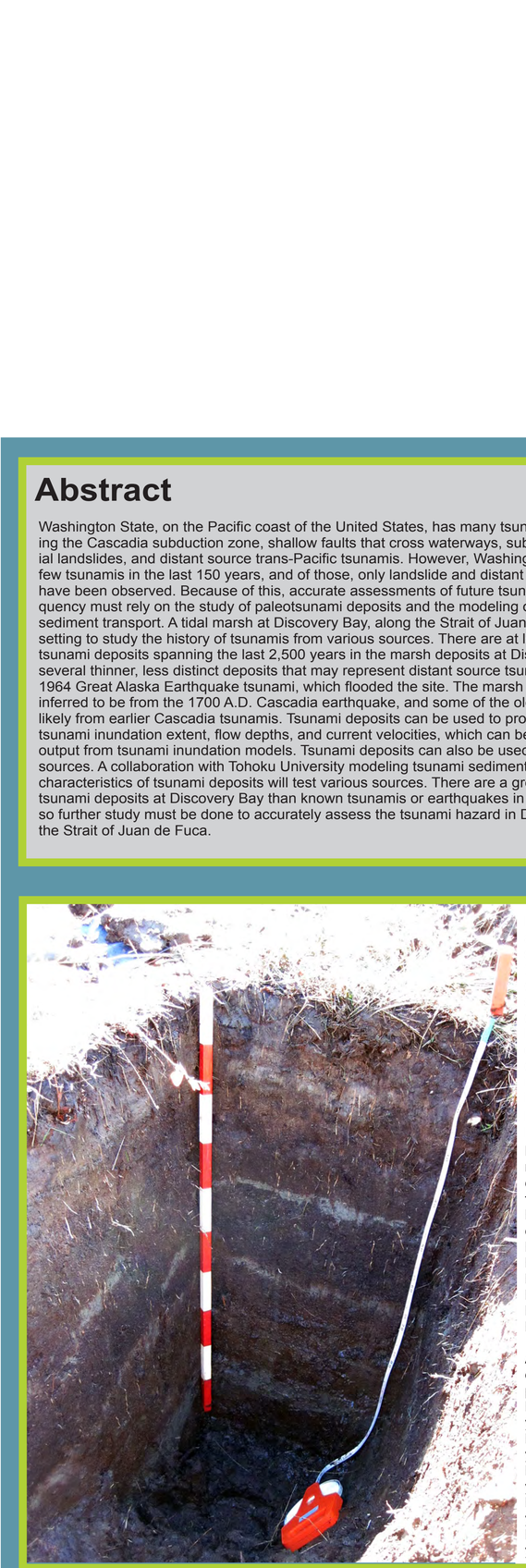

Figure 1 (right). Study area of the Cascadia subduction zone, and tectonic setting (insets). Earthquake sources in Washington (inset cross section). Discovery Bay tsunami deposit study site (green box) and nearby shallow faults in the North America plate shown on air photo.

Figure 2 (left). Tsunami deposits at Discovery Bay. Pictured, from top down:
Bed 1, AD 1700 Cascadia;
Bed 2 , 630-560 cal yr BP;
Bed 3, 1010-670 cal yr BP;
Bed 4, 1120-750 cal yr BP.

Additiona tsunami deposits below (not pictured):
Bed 5, 1290-1205 cal yr BP;
Bed 6, 1630-1275 cal yr BP;
Bed 7, 1710-1330 cal yr BP;
Bed 8, 2100-1400 cal yr BP;
Bed 9, 2750-2150 cal yr BP

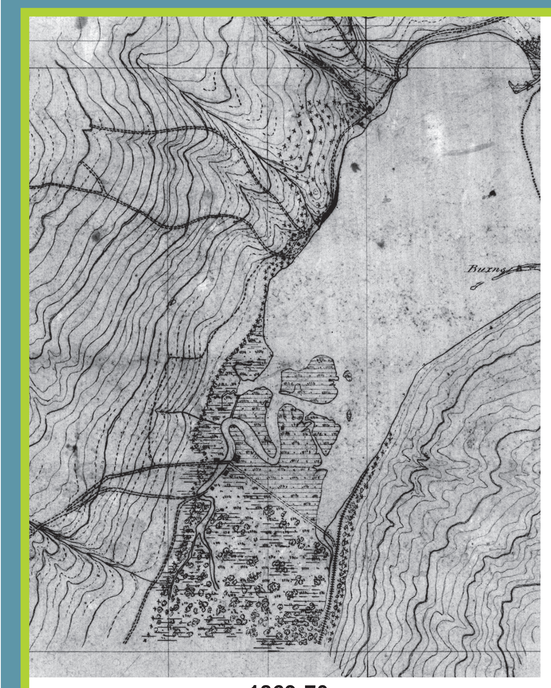

Figure 3. Discovery Bay study area from Figure 1. Historical map from 1869-1870 (left), and modern 2017 air photo (right), showing marsh area essntially unchanged over time. The modern marsh is an effective recorder of tsunami deposits, with an abundant sediment source, and a vegetated tidal marsh that traps tsunami sediemnts. Location of Pit site (Figure 2), and Bowman residence (Figure 8) shown on right.

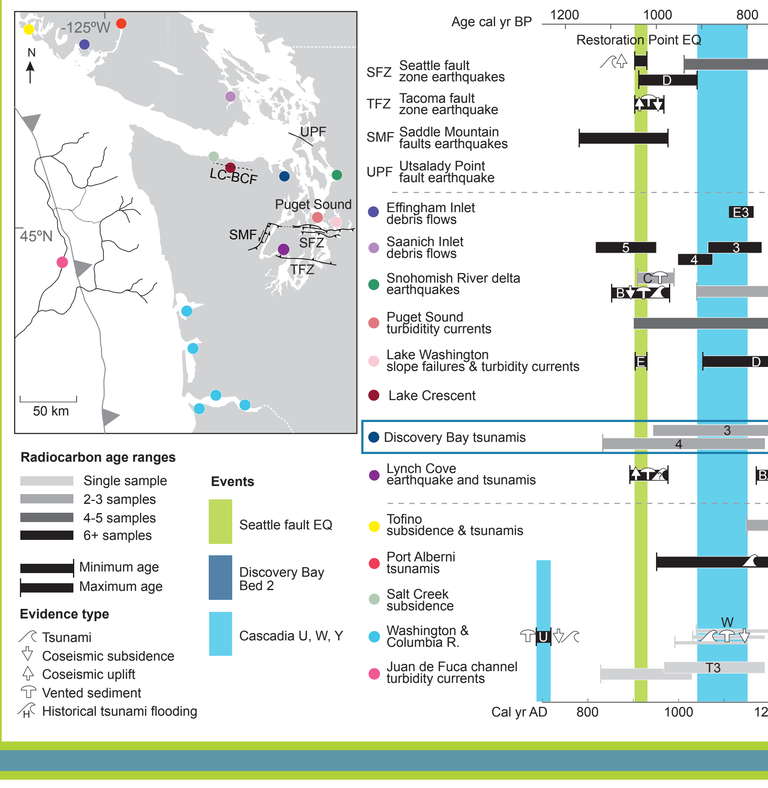

Figure 4 (left). Comparison of grouped radiocarbon ages for earthquakes from Puget Lowland crustal faults (top), slope failures (center), and evidence for Cascadia earthquakes, including coseismic subsidence and tsunamis (bottom). Colored dots on map correspond to colored dots next to place names on age plot. Symbols under "Evidence type" indicate type of evidence on age plot. Vertical shading shows the age of the Seattle fault Restoration Point earthquake (green); SW Washington estuaries Cascadia earthquakes Y, W, and U (light blue); and Discovery Bay bed 2 (dark blue). Age range bars are shaded to reflect the number of samples used to determine the range, and are bracketed as minimum or maximum ages where known. For locations of abbreviated crustal fault names, refer to Figure 1. Citations as follows: SFZ (Atwater and Moore, 1992; Bucknam et al., 1992; Atwater, 1999; Nelson et al., 2014); TFZ (Sherrod, 2001; Sherrod et al., 2004; Nelson et al., 2014); SMF (Witter et al., 2008; Blakely et al., 2009; Barnett et al., 2015); UPF (Johnson et al., 2004); Effingham Inlet (Enkin et al., 2013); Saanich Inlet (Blais-Stevens et al., 2011); Snohomish River delta (Bourgeois and Johnson, 2001); Puget Sound (Smith, 2012); Lake Washington (Karlin et al., 2004); Lake Crescent (Pollen, 2016); Discovery Bay (Garrison-Laney and Miller, 2017; Lynch Cove Garrison-Laney, 2017; Bucknam et al., 1992; Sherrod, 2001; Hemphill-Haley, 1996; Jovanelly and Moore, 2009; Martin and Bourgeois, 2012); Tofino (Clague and Bobrowsky, 1994); Port Alberni (Clague et al., 1994; Clague and Bobrowsky, 1994a; Clague and Bobrowsky, 1994b); Salt Creek (Hutchinson et al., 2013); SW Washington sites (Atwater and Hemphill-Haley, 1997; Atwater et al., 2003; Atwater and Griggs, 2012); Juan de Fuca Channel turbidites shown with reported maximum and adjusted age ranges (Goldfinger et al., 2012); historical tsunami flooding (Seattle Daily Times, 1964; Port Townsend Leader, 1964).

Cascadia 1700 A.D. Earthquake M_W ~9.0

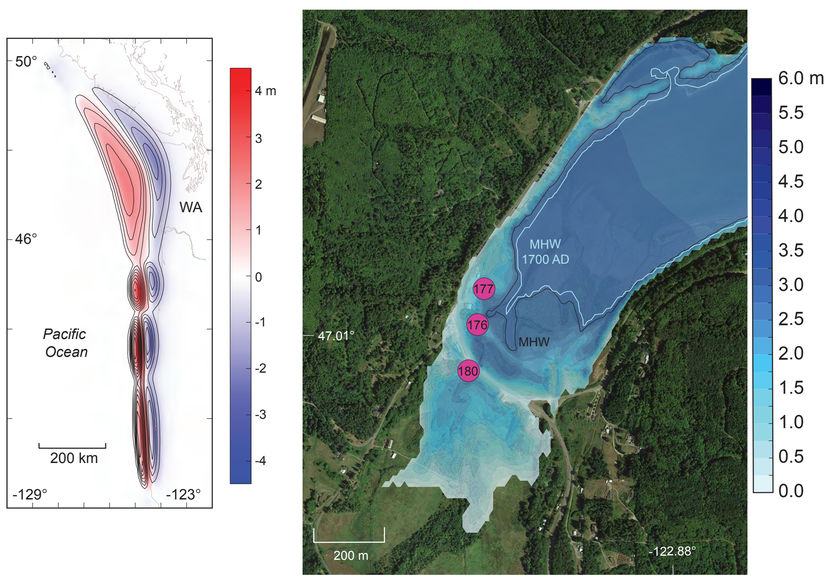

Figure 5. GeoClaw (LeVeque et al., 2011; Berger et al., 2011; Clawpack Development Team, 2015) tsunami simulation of inundation flood depths for the Cascadia subduction zone tsunami from 1700 A.D, using the Mw ~9.0 earthquake deformation shown on left. On the right, the pink circles show simulation gauge locations. Marker 177 shows location of the Pit in Figure 2. Deformation model by Gao, 2016, Figure 4.16c.

Alaska 1964 A.D. Earthquake M_W 9.2

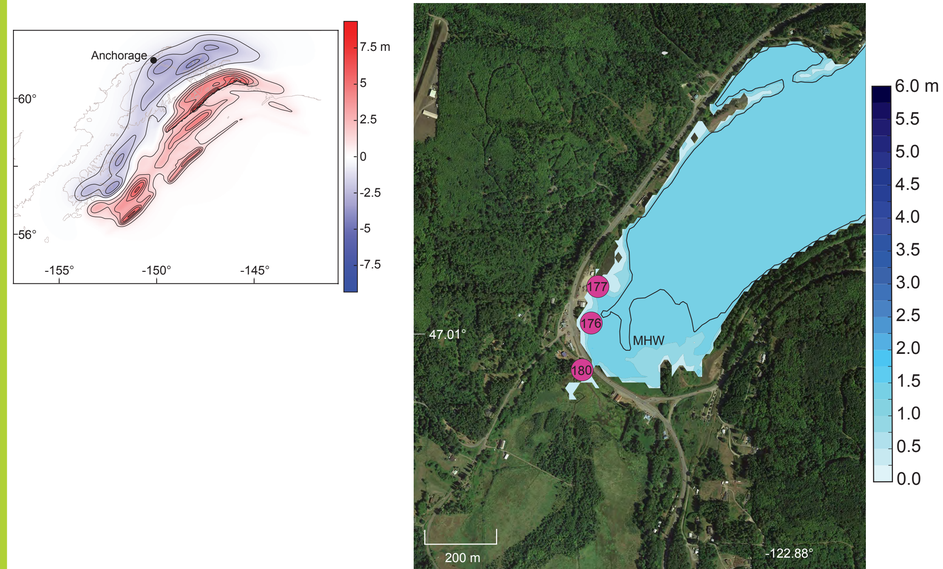

Figure 7. GeoClaw (LeVeque et al., 2011; Berger et al., 2011; Clawpack Development Team, 2015) tsunami simulation of inundation flood depths for the Alaska subduction zone tsunami from 1964 A.D, using the Mw 9.2 earthquake deformation shown on left. On the right, the pink circles show simulation gauge locations. Marker 177 shows location of the Pit in Figure 2. Marker 180 shows the location of the Bowman residence in Figure 8. Deformation model by Suleimani, 2011.

Figure 8. The Bowman residence at Discovery Bay (above in 2017) that flooded in 1964 by the Great Alaska tsunami. The historical account of flooding (Port Townsend newspaper account, right) describes two waves flooding the home. The first at about 2:30 a.m., the second at about 4:00 a.m.

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Tidal Wave Alerts Received By Various Agencies Here

Various agencies here received tidal wave alerts following the destructive Alaska earthquake Friday night, but as far as could be determined by the police and sheriff's departments there was no damage of consequence in this area.

Sheriff Robert L. Hansen said that when the warning of a possible tidal wave was received by his department he and deputies set about warning people known to be living in low areas near tidewater.

Hansen said the only definite report of inundation to come to his attention was from Mrs. Audrey Bowman, resident at the head of Discovery Bay, whose home was flooded by water which overflowed Salmon Creek.

Mrs. Bowman told the sheriff that the creek rose to a height about six feet above normal level and water flowed into her home. The first flood occurred at about 2:30 a.m. Saturday and receded about 20 minutes later. The water rose again at about 4 a.m. to the same depth as before and then receded for good.

Tidal action in Quilcene Bay caused log rafts to break up and workmen were busy over the weekend retrieving logs.

Observers noted a rapid change of tides. It was reported that a Japanese freighter at the Crown Zellerbach mills rose about six or seven feet due to the flood tide caused when the wave entered Puget Sound. The ship settled to its former level at the dockside about a half hour later.

Sheriff's officers and City police and fire departments stood by Friday night to give warning if needed. They were in constant radio and telephone contact with the Coast Guard, State Patrol and other agencies.

Red Cross In Drive to Raise Disaster Funds

The Red Cross here is participating in a drive to obtain contributions to aid in the relief of Alaskan earthquake victims, according to Jefferson County

Seattle fault 930-900 A.D. earthquake M_W = 7.3

Figure 6. GeoClaw (LeVeque et al., 2011; Berger et al., 2011; Clawpack Development Team, 2015) tsunami simulation of inundation flood depths for the Seattle fault tsunami from the 930-900 A.D. earthquake, using the M_W = 7.3 deformation shown on the left. Deformation model of Chamberlin et al., 2015, Table 1, Scenario A. The inudation does not reach sites with tsunami deposits at Discovery Bay, suggesting that the Seattle fault is not a likely source of tsunamis at Discovery Bay.

Figure 9. A collaboration with Anawat Suppasri using a tsunami sediment transport model developed at Tohoku University will model different tsunami sources using tsunami deposit characteristics. The deposit seen above at Discovery Bay may be from the 1964 Great Alaska tsunami, which caused flooding (Figure 8). This collaboration will help identify distant source tsunamis that have left deposits at Disccovery Bay, in addition to local sources, both Cascadia and crustal faults. White bar on the right is 10 cm.

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