Investigation Of Late Holocene Fault Displacement On The Southern Whidbey Island Fault Zone In The Northern Puget Lowland: Collaborative Research Between Humboldt State University and the U. S. Geological Survey, Earthquake Loss Reduction Products, Cascadia.

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Investigations Undertaken

The Puget lowland is traversed by east-west to southeast-northwest trending faults that accommodate north-south directed contraction. The primary faults that accommodate this contraction are, from south to north, the Tacoma fault, the Seattle fault, the Southern Whidbey Island fault zone, the Northern Whidbey Island fault zone and the Devils Mountain fault (Johnson et al., 1996, 1999; Brocher et al., 2001) (Figure 1). This research addresses the question of whether there is geologic evidence for late Holocene contraction across the Southern Whidbey Island fault zone where it crosses south central Whidbey Island (Figure 2).

Individual fault traces of the Southern Whidbey Island fault zone have been located using marine seismic data (Johnson et al., 1996). Three main fault strands cut across central Whidbey Island (Figure 2). The northern fault strand is the focus of this study because the northern fault strand is straddled by two coastal wetlands.

The objective of the study is to assess whether, in the late Holocene, the two coastal wetlands on either side of the northern fault strand of the Southern Whidbey Island fault zone have similar or different relative sea level histories. The Crockett marsh coastal wetland is ca. one km north of the northern fault strand, and the Hancock marsh coastal wetland is ca. 2 km south of the northern fault strand (Figure 2).

The two wetlands should have the identical relative sea level histories because they are close to each other (8 km apart). Any glacio-isostatic influence on relative sea level should be reflected identically in both wetlands. Furthermore, any tectonic influence on relative sea level resulting from strain accumulation and release on the underlying subduction zone similarly should result in identical relative sea level perturbations at both sites.

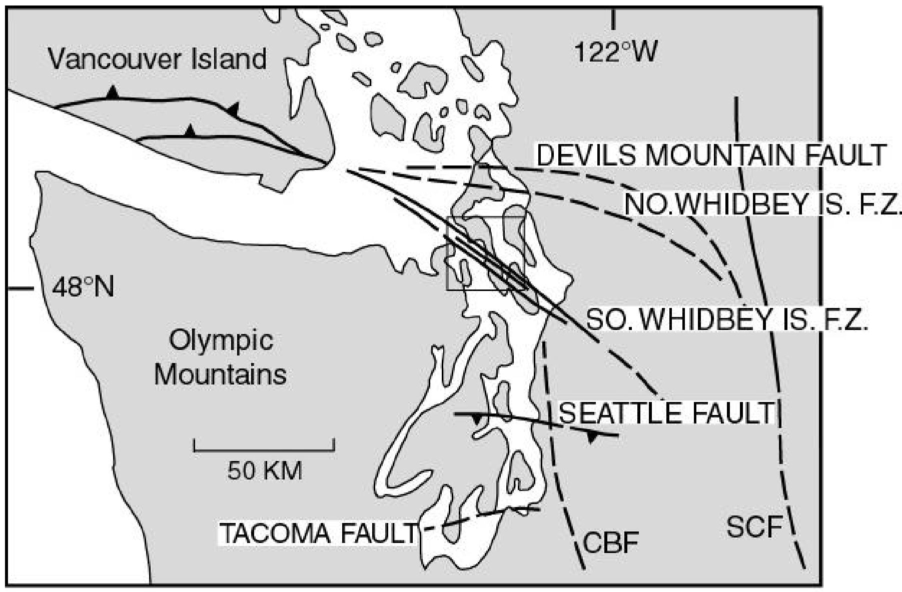

Figure 1. Location map of northwest Washington state and southern Vancouver Island showing location of faults in the Puget lowland that can accommodate north-south contraction. SCF, Straight Creek fault; CBF, Coast Range Boundary fault. Map is modified after Johnson et al. (1996).

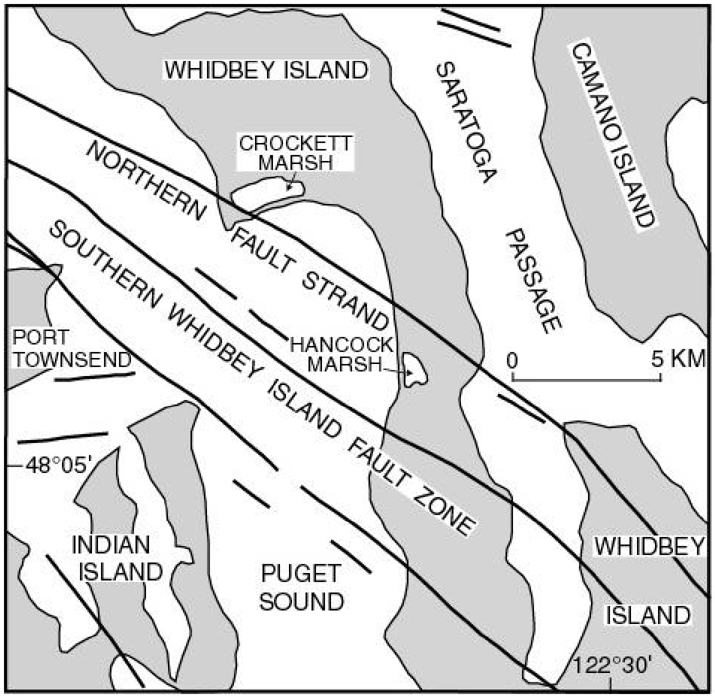

Figure 2. Tectonic map showing the three main fault traces of the Southern Whidbey Island fault zone. Map is adapted from Johnson et al. (1996). Crockett coastal marsh and Hancock coastal marsh straddle the trace of the northern strand of the Southern Whidbey Island fault zone.

The relative sea level histories of the two wetlands can serve as a test for late Holocene movement on the northern strand of the Southern Whidbey Island fault zone because the only event that could produce different relative sea level histories is vertical displacement on the northern strand of the Southern Whidbey Island fault zone. Therefore, if the relative sea level curves for the two marshes are not the same, then we infer that the north fault strand has moved in the late Holocene.

In order to determine the sea level histories at the two coastal wetlands, cores were taken in a transect across each wetland perpendicular to the barrier sand bar that separates the Puget Sound (Admiralty Bay) from the wetland. The core transects start at the barrier sand bar and proceed inland with cores every 50 m until the transect reaches the interior of the wetland where it merges with the dry upland (Figure 3).

Based on the coring program, a geologic cross section was constructed for Crockett marsh and Hancock marsh (Figure 3). At both marshes, the geologic configuration indicates relative sea level rise over time because the sand barrier has built upward and outward over the late Holocene (the caption to Figure 3 explains a minor exception in the case of Hancock marsh). As the barrier built upward and outward, a peat wetland aggraded behind the sand barrier (Figure 3).

In order to determine a relative sea level curve, paleo sea level index points must be identified in the geologic cross sections. The paleo sea level index points are at the contact of the peat with the underlying substrate (Figure 3). The underlying substrate is beach sand or a thin veneer of beach sand over Pleistocene glacial sediment. The contact is a paleo sea level point because the underlying sand has marine diatoms and the overlying peat has freshwater and brackish-water plant macrofossils. As a first approximation, this transition is indicative of the tidal level of mean higher high water (MHHW). More detailed biostratigraphic analysis of this contact is planned; such analysis will further refine the tidal level represented by the sand/peat contact.

The sea level curves (Figure 4) for the two marshes can be constructed because, for all sea level index points, the depth below the marsh surface is known. For selected index points, the time at which the point was at the threshold of mean higher high water is known through ^{14}C dating of plant macrofossils (seeds) in the peat immediately above the contact. Therefore, depth to contact, knowing the contact represents paleo MHHW and age of the contact allow construction of the two sea level curves. The "data points" for the sea level curves are rectangles (Figure 4). The height and width of the rectangles express the magnitude of the error in locating the data point on the relative sea level curve. The error in width is the range of the calibrated radiocarbon age based on the 2-sigma laboratory-reported age (Stuiver et al., 1998). The error in relative sea level height, represented by height of rectangle, is ± 0.5 m, which reflects uncertainty in the depth measurements and uncertainty in the determination that the contact is at MHHW. The latter error will be reevaluated through surveying relative to tidal level at both sites and through biostratigraphic analyses at the contact areas.

Results

The two relative sea level curves are not the same. Superposition of the Crockett and Hancock curves (Figure 4) shows that, for ages older than ca. 2,500 years, equivalent-age sea level index points at Crockett are stratigraphically higher than at Hancock. Also, there is a ca. 800-year interval of time (ca. 3,200 to 2,400 years before A.D. 1950) when the Crockett site shows no change in relative sea level whereas there is no period of time at Hancock when relative sea level is not rising. However, in the last ca. 2,500 to 2,000 years, the relative sea level curves appear to be similar within limits of sea level resolution.

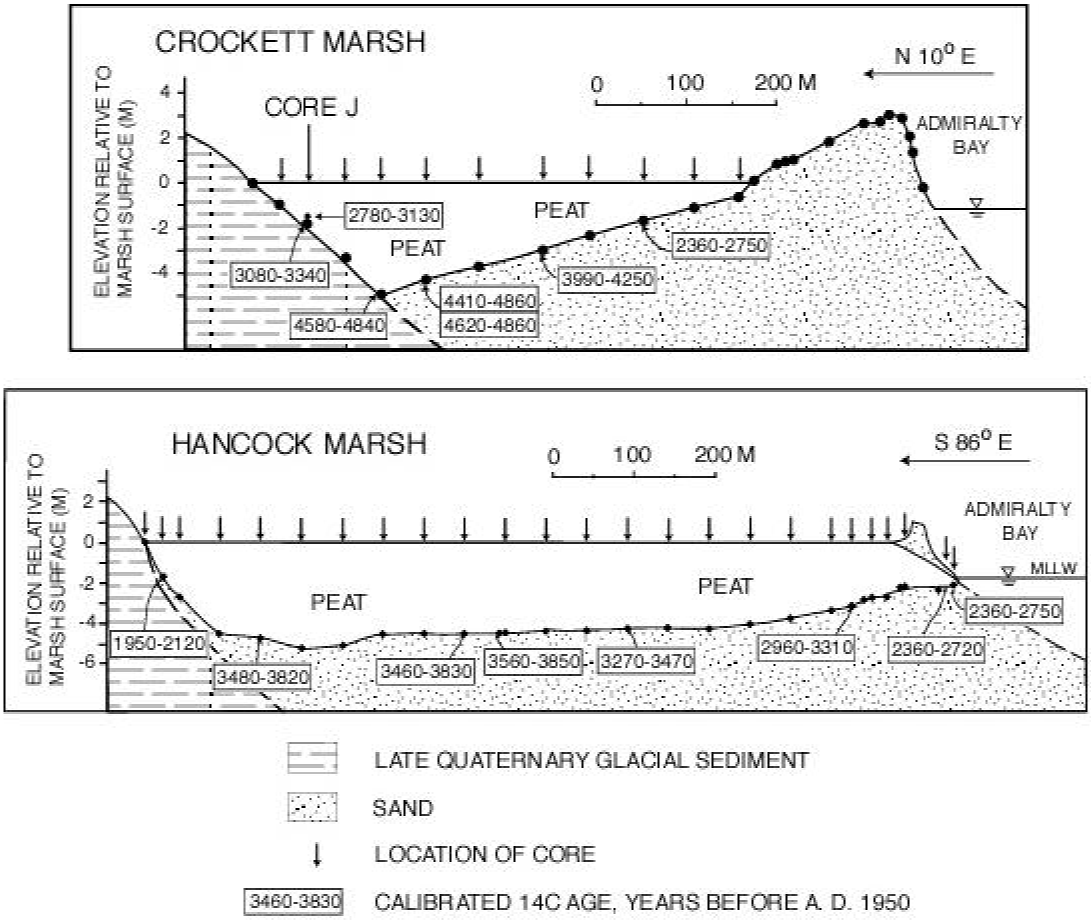

Figure 3. Geologic cross section of Crockett and Hancock coastal marshes. The cross sections are perpendicular to the barrier sand berm that separates Admiralty Bay from the peat lowland. The Hancock cross section differs from the cross section for Crockett marsh because at Hancock peat is exposed in the intertidal zone seaward of the sand barrier berm. The reason that peat is exposed in the intertidal zone and the sand barrier berm is underlain by peat is that the sand barrier first built upward and prograded seaward; then, while the sand barrier continued to built upward, the barrier started to retreat landward, eroding peat that had been previously deposited behind the barrier.

We infer that the explanation for the dissimilarity of relative sea level curves is vertical tectonic displacement on the northern strand of the Southern Whidbey Island fault zone in the late Holocene. Using the assumption that were it not for this displacement the sea level curves would be similar, we have vertically displaced the Crockett curve downward (bold dashed curve, Figure 5) so that equivalent-age sea level index points in the two curves are at the same stratigraphic elevation (Figure 5). This relocation of the Crockett curve creates a single sea level curve. This single sea level curve (gray shaded curve, Figure 5) characterizes both sites in the late Holocene if the Crockett site had not been tectonically uplifted relative to the Hancock site. By reconstructing one relative sea level curve, we are able to determine first, how much and in what sense vertical displacement occurred at Crockett versus Hancock when the sea level curves became divergent, and second, when the vertical tectonic displacement occurred. The amount of vertical displacement is 2.5 m ± 0.5 m up to north and the displacement occurred, within the resolution provided by the calibrated age ranges for the ^{14}C ages, about 2,900 to 3,350 years before A. D. 1950.

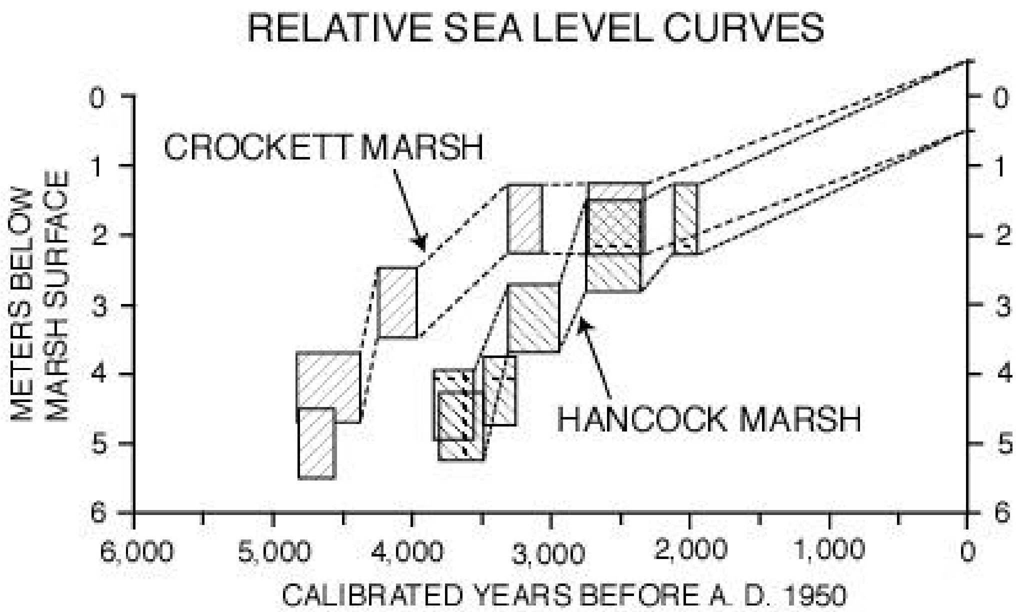

Figure 4. Relative sea level curves for Crockett and Hancock coastal marshes.

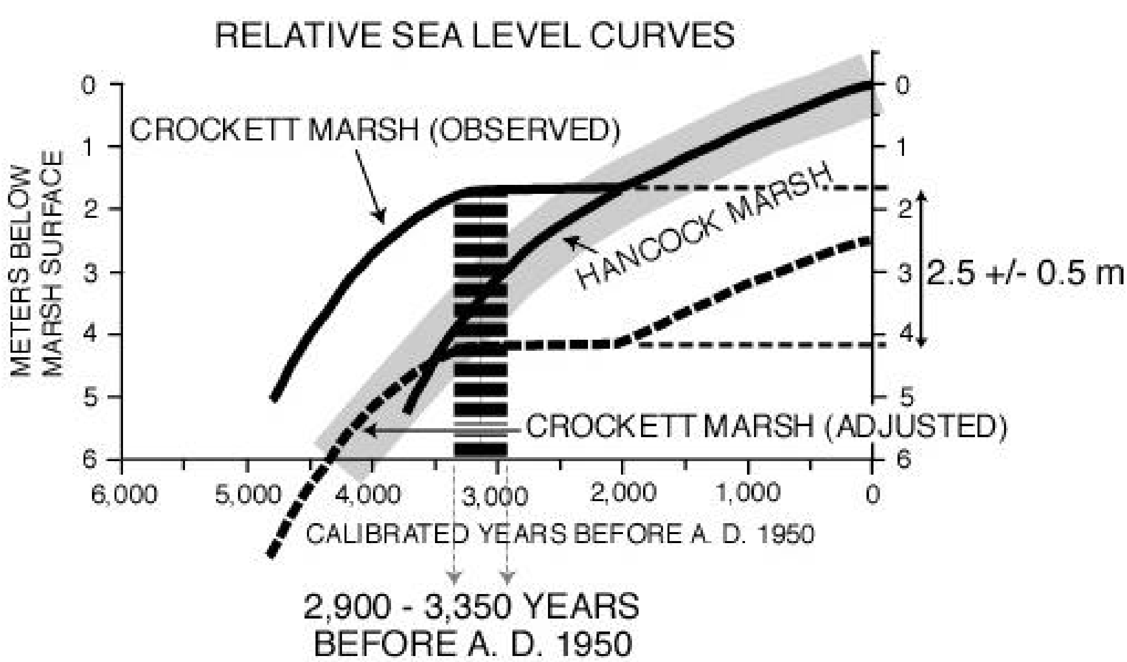

Figure 5. Combined relative sea level curves for Crockett and Hancock coastal marshes, showing a reconstruction of what a single sea level curve (broad shaded curve) would be for both sites if there

had been no crustal vertical displacement of Crockett versus Hancock marshes. In order to construct a single curve, the Crockett relative sea level curve had to be shifted down 2.5 ± 0.5 m. The magnitude of shift (2.5 ± 0.5 m) is the estimated vertical displacement on the north fault strand necessary to form two divergent sea level curves. The time of divergence is 2,900 to 3,350 years before A. D. 1950; this is the estimated time of the crustal earthquake that uplifted Crockett relative to Hancock marshes.

We tentatively conclude that there was coseismic displacement on the northern fault strand of the Southern Whidbey Island fault zone about 2,900 to 3,400 years ago and that vertical component of the fault displacement, 2.5 m ± 0.5 m, was up to the north. This project is ongoing. Work to be addressed in the next year includes paleoecologic investigation of the cores, using diatoms, to reconstruct paleo environment. Additional ^{14}C samples were collected in July 2001 and will be submitted for age determination. Surveying has been completed at the marshes and the core sites will be tied to tidal datum.

References

Brocher, T. M., Parsons, T., Blakely, R. J., Wells, R. E., and Fisher, M. A., 2001, New insights on crustal faults in the Puget Lowland, Washington, from the SHIPS, gravity and magnetic surveys, Seismological Research Letters, 72, 238

Johnson, S. Y., Potter, C. J., Armentrout, J. M., Miller, J. J., Finn, C., and Weaver, C. S., 1996, The southern Whidbey Island fault: an active structure in the Puget lowland, Washington, Geological Society of America Bulletin, 108, 334-354.

Johnson. S.Y., Dadisman, S.V., Mosher, D.C., Blakely, R.J., Childs, J.R., and Rhea, S.B., 1999, Neotectonics of the Devils Mountain fault and northern Whidbey Island fault, eastern Strait of Juan de Fuca and northern Puget Lowland, Washington: Seismological Research Letters, v. 70, p. 220.

Stuiver, M., Reimer, P. J., Bard, E., Beck, J. W., Burr, G. S., Hughen, K. A., Kromer, B., McCormac, G., Plicht, J. v. D., and Spurk, M., 1998, INTCAL98 radiocarbon age calibration, 24,000-0 cal BP: Radiocarbon, v. 40, p. 1041-1084.

Non-technical Summary

Imaging of deformed sediment within Puget Sound leads to the hypothesis that the northern strand of the Southern Whidbey Island fault zone has been active in the last 10,000 years. In order to test this hypothesis, we have focused study on two salt marshes that occur on either side of the trace of the northern strand of the Southern Whidbey Island fault. Our goal is to construct a history of the rise of sea level at the two sites and determine if this history is similar or different at these sites. If it is different, then different sea-level rise histories support the idea that the fault has moved, with one side going up relative to the other. Preliminary coring in the salt marshes and preliminary dating and stratigraphic study of salt marsh sediment suggest that the sea level histories are different at the two sites. We tentatively conclude that there was an earthquake on the northern fault of the Southern Whidbey Island fault zone about 2,900 to 3,400 years ago. The earthquake caused the salt marsh on the north side of the fault to abruptly rise approximately 2.5 m relative to the salt marsh on the south side of the fault.

Reports Published

Kelsey, H. M., and Sherrod, B. L., 2001, Test for late Holocene displacement on the Southern Whidbey Island fault zone, northern Puget lowland, Washington, Seismological Research Letters, v. 72, p. 253.

Availability of seismic, geodetic, or processed data

None available at present.