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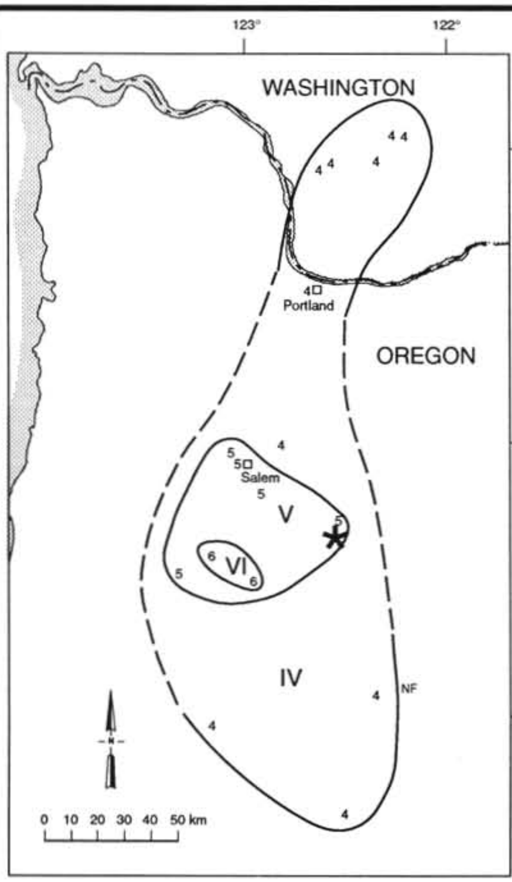

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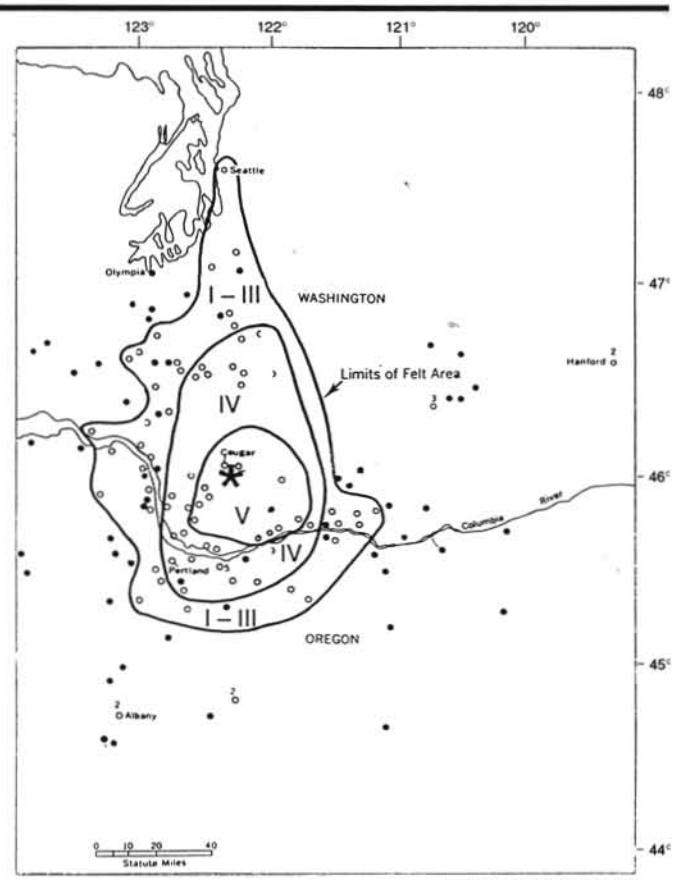

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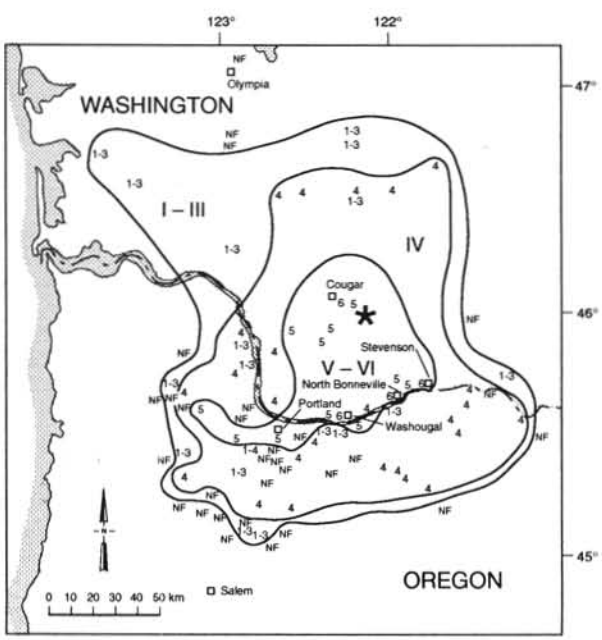

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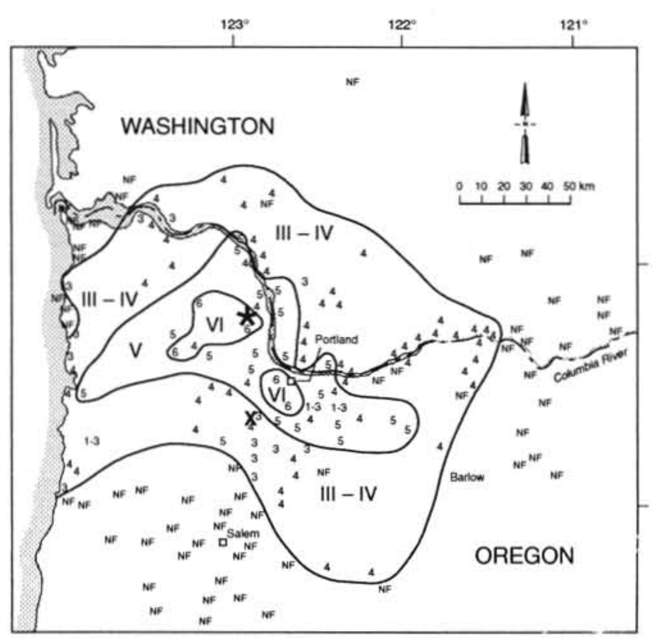

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Oregon Geology is designed to reach a wide spectrum of readers interested in the geology and mineral industry of Oregon. Manuscript contributions are invited on both technical and general-interest subjects relating to Oregon geology. Two copies of the manuscript should be submitted, typed double-spaced throughout (including references) and on one side of the paper only. If manuscript was prepared on common word-processing equipment (IBM compatible or Macintosh), a file copy on diskette should be submitted in place of one paper copy (from Macintosh systems, 3.5-inch high-density diskette only). Graphic illustrations should be camera-ready; photographs should be black-and-white glossies. All figures should be clearly marked, and all figure captions should be together on a separate sheet of paper.

The style to be followed is generally that of U.S. Geological Survey publications. (See the USGS manual *Suggestions to Authors*, 7th ed., 1991, or recent issues of *Oregon Geology*.) The bibliography should be limited to references cited. Authors are responsible for the accuracy of the bibliographic references. Names of reviewers should be included in the acknowledgments.

Authors will receive 20 complimentary copies of the issue containing their contribution. Manuscripts, news, notices, and meeting announcements should be sent to Beverly F. Vogt, Publications Manager, at the Portland office of the Oregon Department of Geology and Mineral Industries.

Cover illustration

Isoseismal maps for significant earthquakes in 1961 near Portland. "X" indicates additional epicentral locations as described in text. Related article about historical earthquakes in and around Portland begins on page 116.

OIL AND GAS NEWS

Drilling continues at Mist Gas Field

At the Mist Gas Field in Columbia County, Nahama and Weagant Energy Company of Bakersfield, California, continues the multiple-well drilling program that began during May. Longview Fibre 12A-33-75 (TD 2,475 ft) was completed as a successful gas well; Longview Fibre 12B-35-65 (TD 3,727 ft) is currently suspended; CFW 41-35-75 (TD 3,331 ft), Adams 31-34-75 RD (TD 3,419 ft), and CC 41-36-75 (TD 1,792 ft) were plugged and abandoned; CC 22B-19-65 is currently suspended at a total depth of 2,940 ft; and at LF 31-36-65, drilling operations are underway.

NWPA symposium approaching fast

Registration materials are still available for the Northwest Petroleum Association (NWPA) 10th annual symposium, which will be held September 26-28, 1993, at the Inn of the Seventh Mountain in Bend, Oregon. The symposium will include a field trip to the Newberry National Volcanic Monument. For further information, contact the NWPA, PO Box 6679, Portland, OR 97228-6679.

Mist Gas Field celebrated

During this summer, the Mist Gas Field, which was discovered in 1979 and has currently 17 productive wells and an underground natural gas storage facility, reached $100 million in revenues from natural-gas production. In recognition of this milestone, the Oregon Department of Geology and Mineral Industries, Northwest Natural Gas Company, Oregon Natural Gas Development Corporation, and Nahama and Weagant Energy Company held a celebration on September 11 at the field. The field is a successful endeavor between private industry, government, and public organizations, in which landowner rights and the environment are protected, while the natural gas generates tax and royalty revenues and provides employment and other direct benefits for residents of Columbia County.

Revised *Mist Gas Field Report* released

The *Mist Gas Field Report* is now available in its annually updated version. See the more detailed announcement on page 114 in this issue of *Oregon Geology*.

Recent permits

Permit no.	Operator, well, API number	Location	Status, proposed total depth (ft)
488	Nahama and Weagant Adams 14-31-74 36-009-00310	SE¼ sec. 31 T. 7 N., R. 4 W. Columbia County	Permit issued; 2,700.
489	Nahama and Weagant HNR 42-27-64 36-009-00311	NE¼ sec. 27 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,500.
490	Nahama and Weagant HNR 24-22-64 36-009-00312	SW¼ sec. 22 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,700.
491	Nahama and Weagant HNR 31-21-64 36-009-00313	NE¼ sec. 21 T. 6 N., R. 4 W. Columbia County	Permit issued; 2,100.
492	Nahama and Weagant CFW 23-33-74 36-009-00314	NW¼ sec. 33 T. 7 N., R. 4 W. Columbia County	Permit issued; 1,700.
493	Nahama and Weagant CC 24-19-65 36-009-00315	SW¼ sec. 19 T. 6 N., R. 5 W. Columbia County	Application; 3,000.

□

Field trip guide to Cascadia paleoseismic evidence along the northern Oregon coast: Evidence of subduction zone seismicity in the central Cascadia margin

Revised from Friends of the Pleistocene Field Trip Guide, 1993

by Curt D. Peterson, Mark E. Darienzo, Scott F. Burns, and William K. Burris, Department of Geology, Portland State University, Portland, Oregon 97207-0751, phone (503) 725-3022

SUMMARY

Broad pocket beaches, low marine terraces, and numerous small estuaries are characteristic features of the northern Oregon coast, the middle part of the Cascadia coastline that extends from British Columbia to northern California. Like the middle child, the northern Oregon coast provides the link between the northern and southern ends of the Cascadia margin. Perhaps less dramatic in relief but not in beauty, this central Cascadia coastline differs significantly from the jagged coastlines of northern Washington and southern Oregon/northern California. The apparent geologic quiescence of the northern Oregon coast does not reflect the catastrophic earthquakes that have struck the region in recent prehistoric time.

On this field trip, we explore the northern half of the Oregon coastline for geologic evidence of subduction zone seismicity. Such evidence includes multiple events of abrupt coastal subsidence, tsunami inundation, and shaking-induced liquefaction of unconsolidated sediments. The earthquake evidence is recorded in late Holocene tidal-basin deposits (300–5,000 years old) and in uplifted marine terrace deposits of late Pleistocene age (80,000–120,000 years old). A total of 16 field localities showing evidence of earthquake-induced subsidence, tsunami generation, liquefaction, and/or debris flows are discussed in this field trip guide (Figure 1).

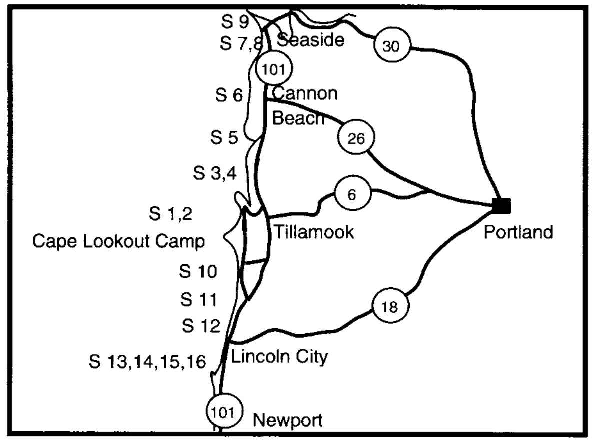


Figure 1. Regional highway map with field trip stops (S 1–16).

INTRODUCTION

The potential for great earthquakes in the Cascadia Subduction Zone (CSZ) (Figure 2), where the Juan de Fuca Plate is being subducted under the North American Plate, is one of the most controversial topics in Quaternary geology of the Pacific Northwest. In the last dozen years, expert opinions on the nature of seismicity along this margin have ranged from terminated subduction to aseismic subduction to the potential for great (M_W 9) subduction zone earthquakes (Heaton and Kanamori, 1984). Late Quaternary deposits of the central CSZ are reported to show evidence of episodic coastal subsidence and tsunami deposition (Figure 3) (Atwater, 1987; Darienzo and Peterson, 1990), coseismic sediment liquefaction (Peterson and Madin, 1992), and coseismic debris flows (Darienzo, 1991; Gallaway and others, 1992). However, the reported evidence of episodic coastal subsidence and associated tsunami deposition as been interpreted by some to possibly represent spit breaches, storm surges, or other aseismic mechanisms. In this field trip guide, we discuss field sites that discriminate between seismic and aseismic mechanisms causing episodic marsh burial. However, these sites must be viewed within the larger neotectonic context of the central Cascadia margin to evaluate their relevance to the paleoseismicity debate.

REGIONAL NEOTECTONIC FRAMEWORK

The central Cascadia margin, both offshore and onshore, is now known to be riddled with faults and folds in the upper North American Plate (Figure 4). Some faults possibly extend downward to the plate interface or even into the lower Juan de Fuca Plate (Goldfinger and others, 1992; Vern Kulm, Oregon State University, personal communication, 1993). Are these faults active, and if so,

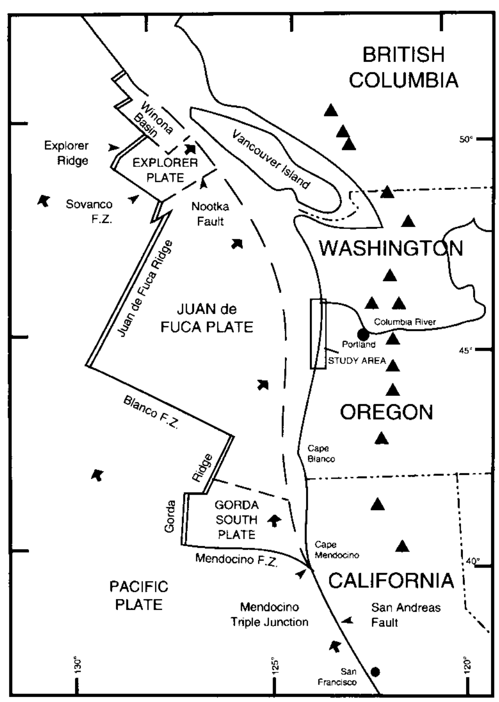


Figure 2. Tectonic framework of the Cascadia Margin and location of field trip area (plate motions indicated by bold arrows).

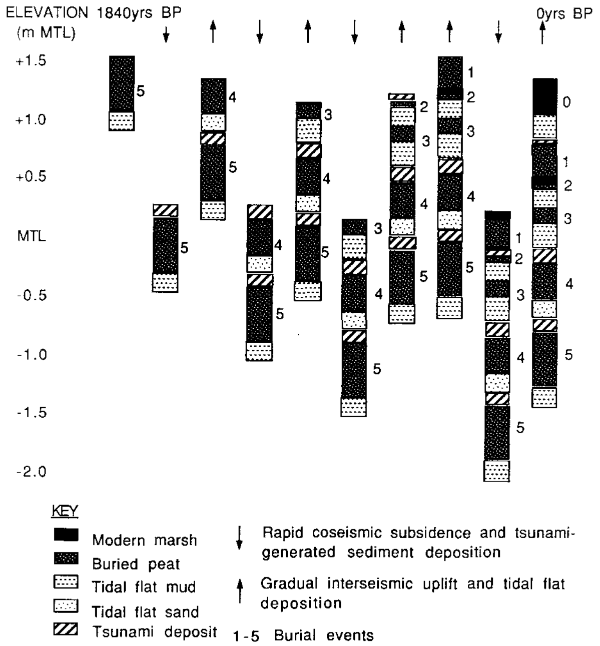


Figure 3. Stratigraphic stacking model of rapid coseismic subsidence followed by gradual sedimentation and post-seismic tectonic rebound that produced the upper 2.5 m of the stratigraphic record at Netarts Bay. The amount of subsidence is determined from estimates of modern and paleoenvironmental tidal elevations. After Darienzo and Peterson (1990).

what accounts for their combined lack of historic seismicity? How have these folds and faults affected the coastal stratigraphic record? The northern Oregon coastal terraces (late Pleistocene in age) show relatively less vertical deformation than do corresponding terraces from the southern and northern ends of the margin (Figure 5). We ascribe the larger rates of coastal inelastic deformation (faults and folds) in the southern Cascadia margin to its being closer to the deformation front, i.e., the leading edge of the North American Plate (Peterson and others, 1991). The larger rates of coastal inelastic deformation of the Cascadia margin in northern Washington might be due to its proximity to the margin bend, i.e., the bulge in the downgoing slab at the Olympic Pensinsula (Figure 2). A compensatory bulge in the downgoing slab at the margin bend might increase the width of the locked zone and its associated upper-plate deformation in the Olympic Peninsula (Crosson and Owens, 1987).

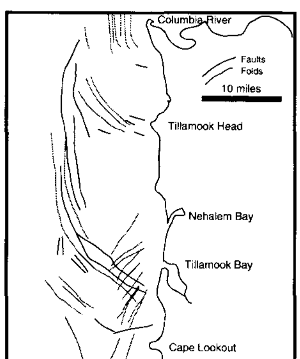


Figure 4. Coastal section of the offshore neotectonic map. Redrawn from Goldfinger and others (1992).

In addition to the inelastic deformation, there is the predicted component of cyclic elastic deformation associated with episodic

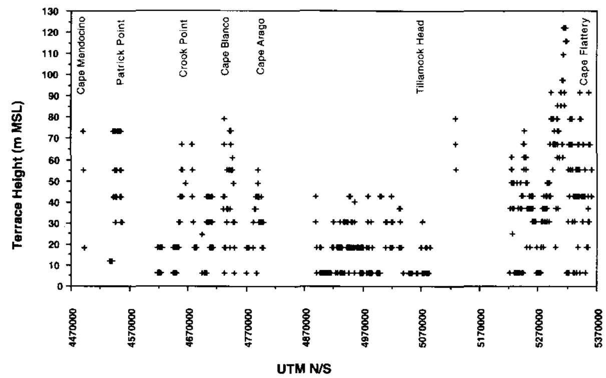


Figure 5. Plot of lowest-terrace surface elevation versus distance (UTM) along the Cascadia margin. From Peterson and others (1991).

dislocation of a strongly coupled megathrust (Heaton and Kanamori, 1984). Alternating conditions of aseismic coastal uplift and coseismic coastal subsidence are predicted for coastlines landward of a zero isobase of upper plate flexure (Figure 6). Preliminary maps of episodic coastal subsidence or continuous subsidence have been established from buried marsh records in late Holocene wetland deposits of the central Oregon coast (Briggs and Peterson, 1992). The initial results of this mapping suggest that the central Cascadia coastline converges with the predicted zero isobase of elastic flexure in central Oregon (Figure 7). The apparent coincidence of both diminished terrace deformation and the zero isobase of elastic deformation in the central Oregon coast might denote the landward limit of the locked zone (Peterson and Briggs, 1992). All of the marsh settings observed in this field trip (northern Oregon coast) should fall in the realm of elastic coseismic subsidence, if the assumptions above are valid.

Finally, direct evidence of earthquake rupture length, which is related to earthquake magnitude, has proven to be elusive in the central Cascadia margin. Because of the relatively poor precision

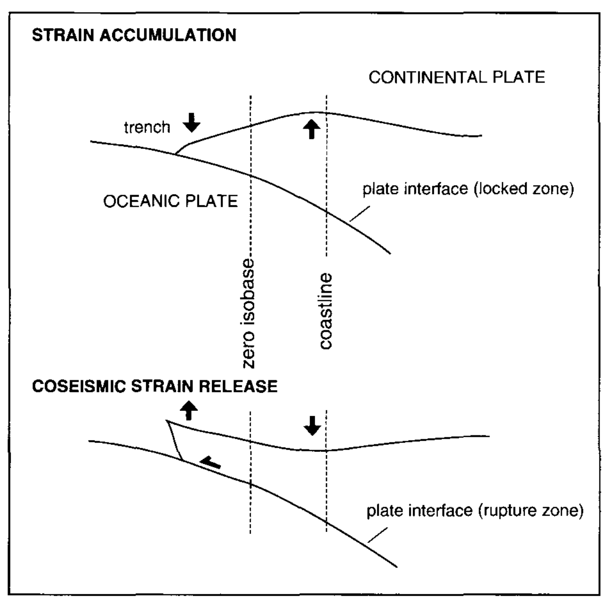


Figure 6. Simplified cross section of zero isobase, plate subduction, and deformation cycles. From Darienzo (1991).

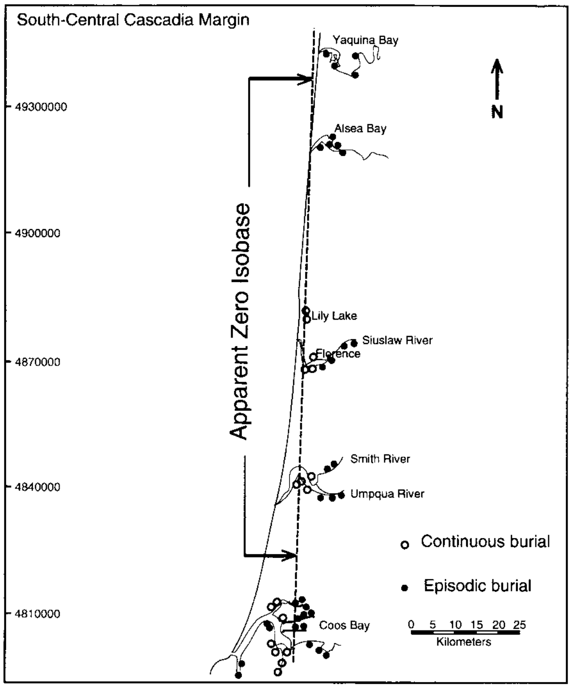


Figure 7. Map of core sites showing episodic burial (solid circles) and continuous burial (open circles) in central Oregon (unpublished map relating to Briggs and Peterson, 1992). Continuous burial cores are thought to lie on zero-isobase of upper plate flexure (see Figure 6).

of radiocarbon dating, it has not been possible to use that method to prove that the entire coast subsided at the same time in one catastrophic earthquake. Dendrochronology (tree ring dating) has successfully constrained the age of the last subsidence event(s) (approximately 300 years ago) in coastal wetlands of southern Washington (Yamaguchi and others, 1989).

What is required to test the model that large earthquakes affected many areas along the coast simultaneously (event synchroneity) is a unique stratigraphic record of coastal subsidence and corresponding tsunami inundation that can tie widely separated bays to distinct regional events (Figure 8) (Peterson and Darienzo, 1992). Such a record might exist in the northern Oregon coast, where the last five Cascadia Subduction Zone (CSZ) subsidence events apparently establish a unique regional sequence (Figure 9) (Darienzo, 1991). This sequence includes the following events:

- Event 1. Subsidence + tsunami at approximately 300 calendar years before present (Cal. Yr. BP).
- Event 2. Northward-decreasing subsidence + tsunami at approximately 800±200 radiocarbon years before present (RCYBP).
- Event 3. Subsidence + no tsunami (possible exception at Seaside) at approximately 1,100±200 RCYBP.
- Events 4 and 5. Each with subsidence + tsunami, both roughly in the range of 1,500–1,800 RCYBP.

If confirmed, this central Cascadia earthquake sequence might ultimately provide a link to bridge the paleoseismic records of the southern and northern regions of the Cascadia Subduction Zone.

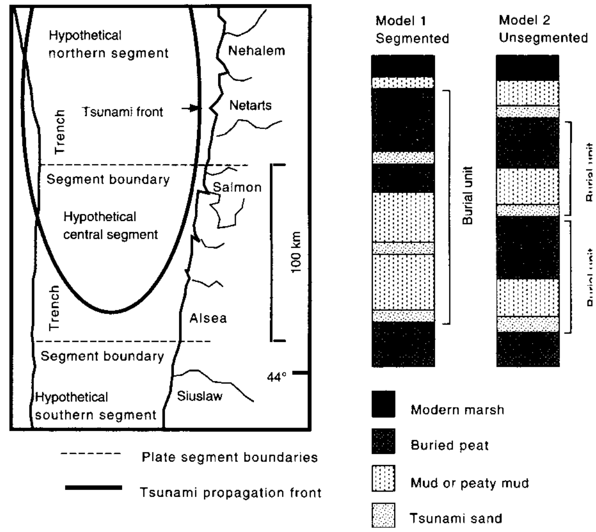


Figure 8. Two models of marsh development and tsunami deposition used to discriminate rupture segments in the northern Oregon coast. One-to-one correspondence between buried peat (coastal subsidence) and tsunami deposition at adjacent bays indicates event synchroneity between bays. From Peterson and Darienzo (1992).

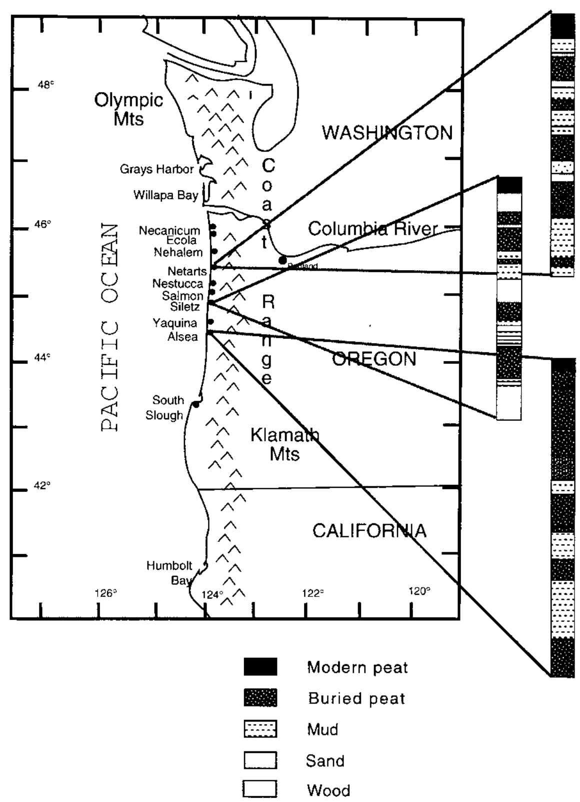


Figure 9. Representative stratigraphy of three sites (Netarts Bay, Siletz Bay, and Alsea River) on the northern Oregon coast. These sites record five coseismically buried peats (indicated by numbers next to stratigraphic column) in approximately the last 2,000 years, suggesting regional synchroneity of the events.

SITE DESCRIPTIONS

Warning: Oregon beaches are renowned for sneaker waves. While viewing these stops, please keep an eye on the ocean and your companions if you venture near the surf zone. Also, to minimize impact on rural coastal communities, park well off the roadside and keep to public access paths. Finally, Stops 1, 2, 8, 11, and 14 can be fully viewed only at low tide. Consult tide tables and plan your trip accordingly.

Stop 1. Netarts marsh, Netarts Bay

Location (Figure 10): Netarts Road about half a mile north of the Cape Lookout campground. Park on the side of the roadway. Walk out onto the bay marsh at a road culvert, about 150 ft north of the debris-flow chute. The modern debris-flow deposits extend out on the marsh about 150 ft west of the road culvert. Continue another 150 ft west, beyond the debris flow fan, to the cutbank of a small tidal channel to view the prehistoric marsh stratigraphy. **Requires low tide to see all outcrops.**

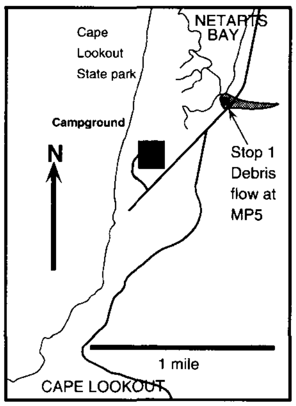


Figure 10. Location of Stop 1. MP = mile post.

Features: Type section of episodic coastal subsidence and tsunami deposition in the northern Oregon coast. Also, rapid recolonization of modern (aseismic) debris flow on marsh, confirming submergence mechanism of prehistoric peat burial.

Site description: Netarts Bay is a shallow lagoon bounded by Cape Meares and Cape Lookout (two basaltic headlands), a sand spit, and the Coast Range (Figures 1 and 11). We consider the Netarts Bay marsh stratigraphy to be the type section for paleoseismological evidence of Cascadia earthquakes in the last 3,000 years along the northern Oregon coast (Figure 12) (Darienzo, 1991). Buried peats are overlain by distinct tsunami sands and/or barren to rooted tidal flat muds. The development of the marsh stratigraphy over the last couple of thousand years, including the last five coseismic burial events, is a combination of tectonic and eustatic sea-level rise processes (Figure 3). The record of alternating uplift and coseismic subsidence (1–1.5 m [3–5 ft] of vertical deformation) is preserved by eustatic sea-level rise and sedimentation in the protected bay wetlands.

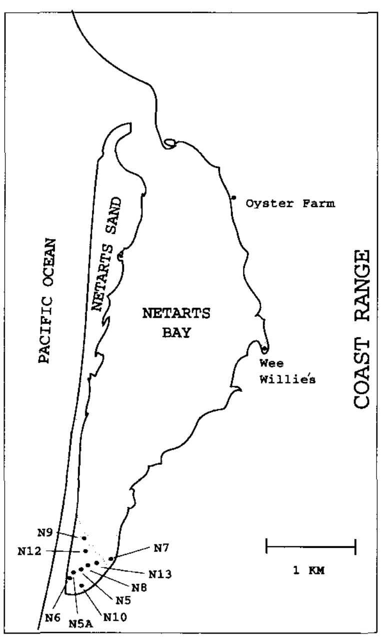


Figure 11. Sketch map of Netarts Bay showing core site locations.

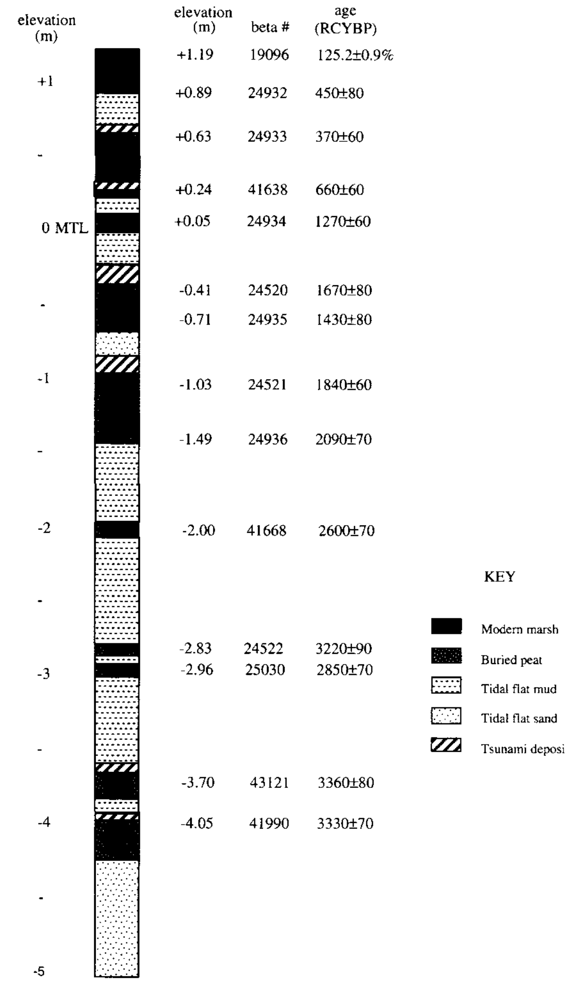


Figure 12. Generalized stratigraphy of buried peats and tsunami deposits with corresponding radiocarbon ages in Netarts Bay. Beta number is radiocarbon laboratory sample number.

In December 1990, a small debris flow (4 x 10^3 m^3 [141 x 10^3 ft^3] at the source) covered a 5 x 10^3 m^2 (54 x 10^3 ft^2) area of modern, transitional salt marsh (average elevation + 1.3 m [4 ft] mean sea level [MSL]) in the southeast margin of Netarts Bay (C.D. Peterson and others, unpublished data, 1991). The debris-flow sediments overlying the marsh include gravel, sand, and mud (1–50 cm [0.4–20 in.] in thickness) that fanned out onto the preexisting marsh surface (Figure 13). Salt marsh plants, dominated by *Deschampsia caespitosa*, rapidly recolonized the debris-flow deposit, completing dense vegetative cover within one year. The resulting marsh burial deposit is characterized by lateral discontinuity, chaotic internal structure, very poorly sorted sediments, and abundant plant shoots. In the absence of relative sea-level rise, this catastrophic burial process was unable to terminate marsh growth or yield any burial sequences characteristic of older (prehistoric) subsidence events at this site.

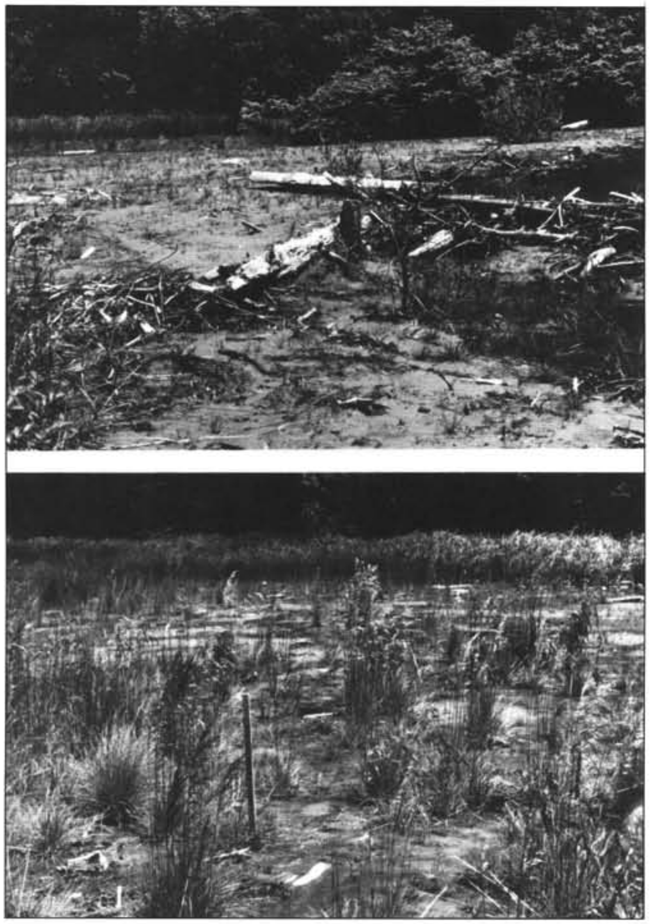


Figure 13. Photographs of debris flow on marsh at Stop 1, both taken six months after the marsh burial. Dense vegetative cover was complete within 12 months after burial by the debris flow.

Stop 2. Wee Willie's, Netarts Bay

Location (Figure 14): Netarts Road 3¼ mi north of Cape Lookout State Park campground entrance. Park near Wee Willie Restaurant. Walk out onto the small marsh and view buried peats/tree roots in tidal creek cutbanks. Continue southwest around a bay terrace point, about 300 ft from the parking lot, to the Pleistocene terrace deposits that front the bay shoreline. Continue about half a mile south along the exposed terrace deposits. **Requires low tide.**

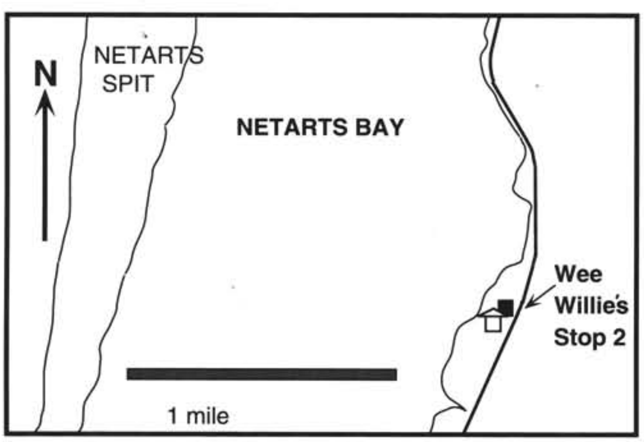


Figure 14. Location of Stop 2.

Features: Late Holocene record of coseismically buried peats and tsunami-deposited sands in marsh cores and cutbanks (Figure 15). Late Pleistocene analogs of abruptly buried peats in adjacent bay terrace deposits.

Site description: At the marsh at Wee Willie's (Figures 11 and 14), coseismically buried peats are visible in cutbanks and deeper cores. Protruding tree roots in the buried peats are indicators of forested wetlands and demonstrate past episodes of tectonic uplift above the reach of tidal range sedimentation. The prehistoric records of the last three CSZ subsidence events can be seen in the tidal creek cutbanks including Event 1 (buried peat and tsunami sand), Event 2 (tsunami sand in rooted mud), and Event 3 (buried peat but no tsunami deposit). At least six coseismic burial events have been documented in deeper cores of the site at Wee Willie's. The oldest dated peat is about 2,600 radiocarbon years before present (RCYBP). Sharp contacts between peats and overlying tsunami sands or bay muds correspond to equally abrupt changes from (1) fresh-water diatoms to brackish-water diatoms and/or (2) fossil *Juncus* rhizomes (high marsh) to *Triglochin* rhizomes (low marsh to colonizing tidal flat species). All of these paleotidal indicators point to episodic events of rapid marsh submergence. The lack of such records in some central Oregon marsh sites (Briggs and Peterson, 1992) rules out eustatic or regional sea-level changes as the mechanism responsible for the episodic submergence. The marsh burial events recorded in Netarts and other northern Oregon bays are the result of tectonic subsidence.

Late Pleistocene analogs to the buried marshes at Wee Willie's are found at many locations in marine terrace deposits of the central Oregon coast (Mulder, 1992). Perhaps the best exposed buried Pleistocene peats are those that occur in the youngest uplifted terrace deposits, assumed to be the Whisky Run terrace at about 80,000 years old (80 ka), that rim Netarts Bay (Figure 16). At least 11 subsidence events are recorded in continuous drill cores and exposed bay cliffs at this site (Figure 17). These sections are thought to represent about a 5,000-year period (maximum) of

Figure 15. Photograph of Friends of the Pleistocene field trip participants viewing cutbanks in small tidal creek of the marsh at Wee Willie's.

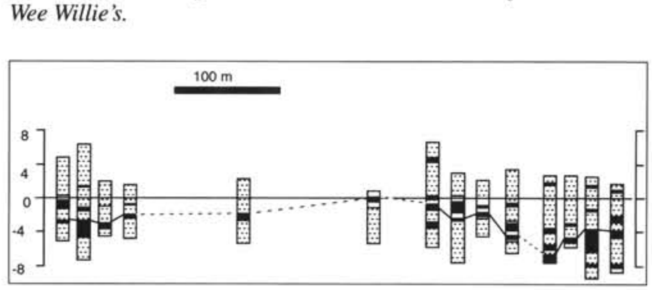


Figure 16. Cross section of buried peat horizons in late Pleistocene bay terrace deposits. From Mulder (1992).

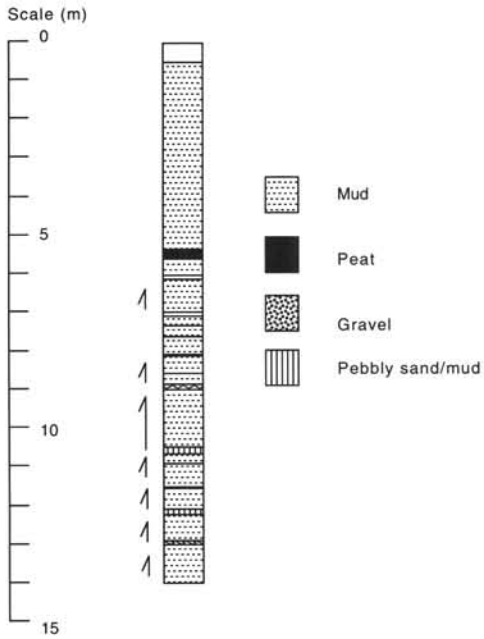


Figure 17. Core log from a drill site, located 1,600 ft (0.5 km) southeast of Wee Willie Restaurant, in late Pleistocene marine terraces. Black lines show buried peats, and arrows show grain-size fining-up trends associated with interseismic emergence. From Mulder (1992).

deposition, yielding an approximate average recurrence interval of not more than 500 years (Mulder, 1992). The terrace deposits also show subtle signs of liquefaction including muddy flow bands and small vertical dikes but no large-scale warping (folds) or vertical offsets (faults). The lack of substantial inelastic deformation of the terrace deposits here argues against the episodic subsidence originating from local faults (Figure 4). By contrast, local faults and folds are thought to dominate the coastal subsidence record in southern Oregon (Peterson and Briggs, 1992) and northernmost California (Clarke and Carver, 1991).

Stop 3. Cape Meares overlook

Location (Figure 18): Three Capes Highway, 12 mi east of Cape Meares. Park on the side of the roadway where the Tillamook Bay and spit can be viewed (Figure 19).

Features: Overview of Tillamook Bay to the north, including fringing bay marshes and major historic spit breach. Large landslide area is visible to the west, on the north side of Cape Meares.

Site description: Tillamook Bay has experienced some significant changes in historic time, including rapid sedimentation following the Tillamook burn, extensive dike construction for pasturage, and a major spit breach from 1952 to 1956 (Glenn, 1978). However, these historic changes are small by comparison to the late Holocene subsidence events that flooded all of the tidal marshes surrounding the bay. Evidence of episodic events of abrupt sea-level rise (1–2 m [3–6 ft] subsidence) is recorded by bay muds overlying supratidal peats in wetland deposits at the north, south, and west ends of the bay (Figure 20). There are also late Pleistocene buried peats exposed in sea-cliff terrace deposits just north of Cape Meares (see Stop 4 below). As with Netarts Bay, the late Pleistocene Tillamook estuary extended much farther seaward than does the present bay.

The major historic spit breach (1952) at the south end of the Tillamook Bay spit (Figure 20) left no geologic evidence of submergence or catastrophic flooding in adjacent marshes. The lack of marsh response to this historic spit breach is significant in view of the size of the breach prior to artificial closure by the U.S. Army Corps of Engineers in 1956. Based on these observations and similar ones in Alsea Bay (Peterson and Darienzo, 1992), we conclude that prehistoric spit breaches are unlikely candidates for the mechanism(s) of episodic marsh termination and burial recorded in the larger Cascadia tidal basins.

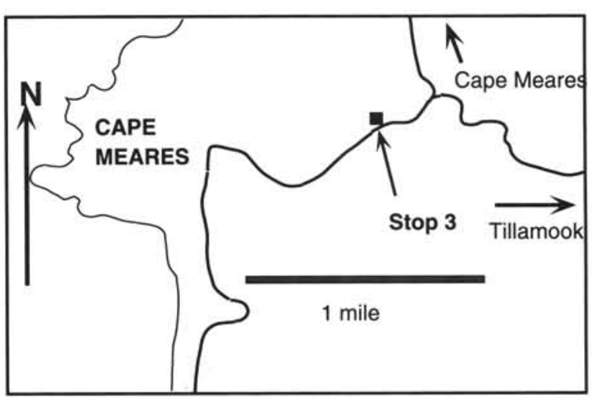


Figure 18. Location of Stop 3.

Figure 19. Overview of Tillamook Bay, view to the north, showing bay spit.

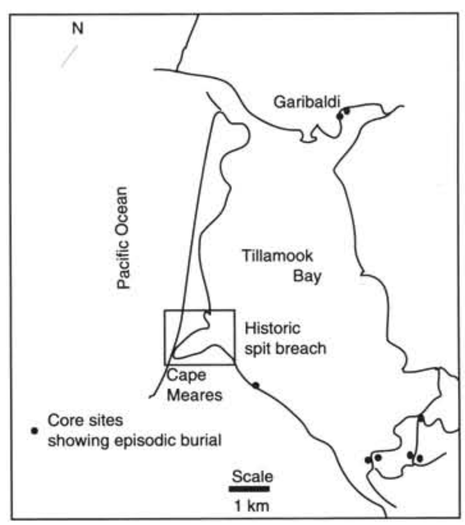


Figure 20. Map of Tillamook Bay, including marsh core sites recording prehistoric subsidence events. Core sites at Garibaldi show thin tsunami deposits over prehistoric buried peats. The historic breach of the southern end of the Tillamook Bay spit is shown (box). Adjacent marsh sites show no evidence of submergence from the spit breach.

Stop 4. Cape Meares beach

Location (Figure 21): Beach access in the Cape Meares village. Park off the roadway, and please do not block the residents' driveways. Walk out onto the beach and head south ⅓ to 1 mi along the sea cliffs.

Features: Late Pleistocene peats, liquefaction, and colluvium in marine (bay) terrace deposits (Figure 22).

Site description: At least three buried peat horizons can be traced in late Pleistocene estuarine deposits in the sea cliffs south of the town of Cape Meares. The buried peats generally show sharp upper contacts with bay muds, indicating abrupt subsidence (Mulder, 1992). Small clastic dikes and abundant muddy-flow features demonstrate sediment liquefaction. Are these liquefaction features of coseismic origin, or were they produced by debris-flow loading? Toward the southern end of the exposed Pleistocene section, the bay deposits are buried under colluvium derived from the Cape Meares ridge.

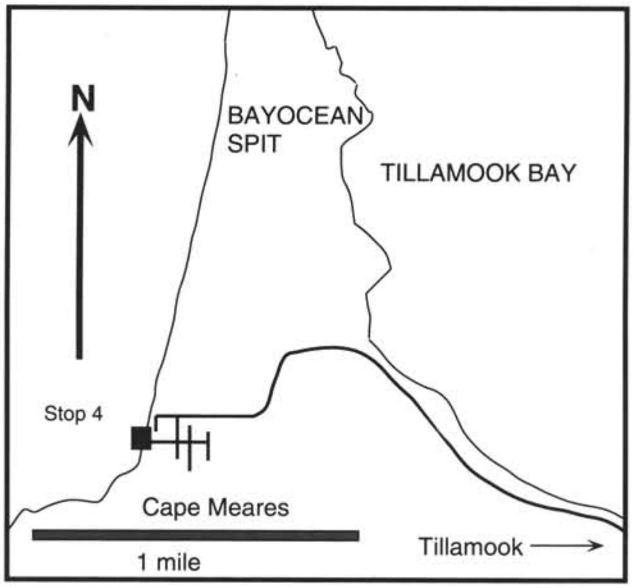


Figure 21. Location of Stop 4.

Stop 5. Short Sands, Cove Beach, Arch Cape, Arcadia, Indian Beach

Location (Figure 23): Low terrace sea cliffs along Highway 101, between the Cape Falcon (south) and Tillamook Head (north) headlands.

Features: Evidence of episodically buried peaty horizons in late Pleistocene terrace deposits from Cape Falcon to Tillamook Head.

Site description: Unlike the present coastline, the late Pleistocene coast of northern Oregon had extensive barrier lagoons. These lagoons have left records of episodically buried peaty horizons at many sites (Mulder, 1992) that are not associated with fault-controlled river valleys or faults mapped offshore (Goldfinger and others, 1992). For example, episodically buried peaty horizons in late Pleistocene barrier lagoon deposits are found at many sites between Cape Falcon and Tillamook Head. Although outcrop exposure is not continuous, there is no evidence to suggest that the buried peat horizons are restricted to local structures (faults or fold axes). Furthermore, long-term vertical deformation of the lowest late Pleistocene terrace surface (assumed 80 ka in age) in this area is negligible, e.g., about 10 m (33 ft) elevation change over the distance of 10 km (6 mi) (Mulder, 1992). The late Pleistocene subsidence events recorded here, as in other sites of the northernmost Oregon coast, appear to be located in the zone of elastic deformation, landward of the locked zone.

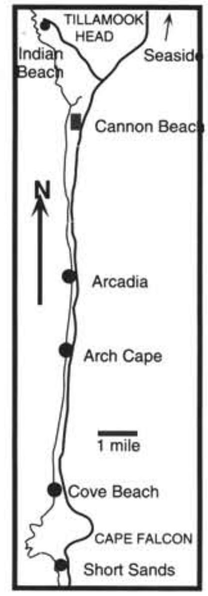


Figure 23. Locations of Stop 5.

Stop 6. Cannon Beach

Location (Figure 24): Ecola wetlands adjacent to Ecola Creek near downtown Cannon Beach. Park near the public rest rooms adjacent to the city park and walk out onto the marsh between the roadways and the waste water treatment ponds.

Features: Examine cores and shallow pits (1 m [3 ft] depth) in wetlands for evidence of the last two prehistoric events of tsunami overtopping of the Cannon Beach barrier spit.

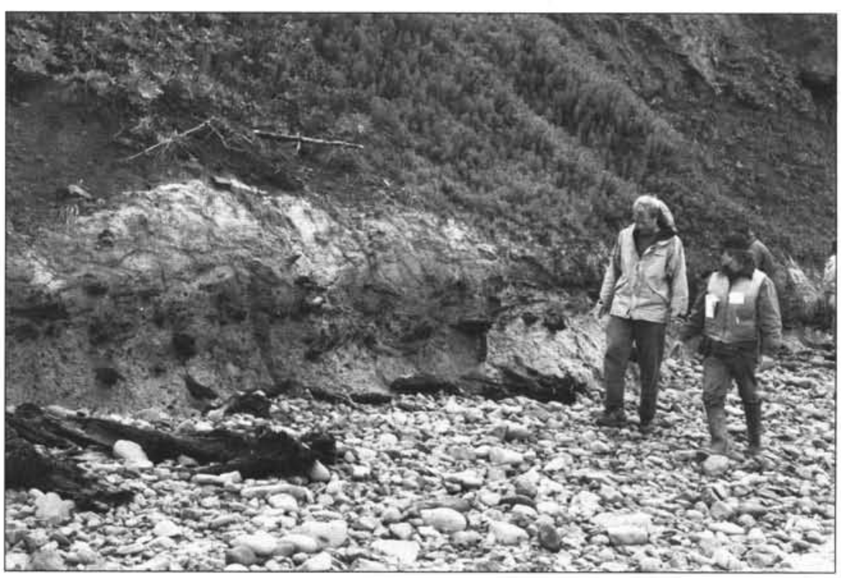


Figure 22. Photograph of bay terrace deposits exposed in sea cliffs south of the village of Cape Meares.

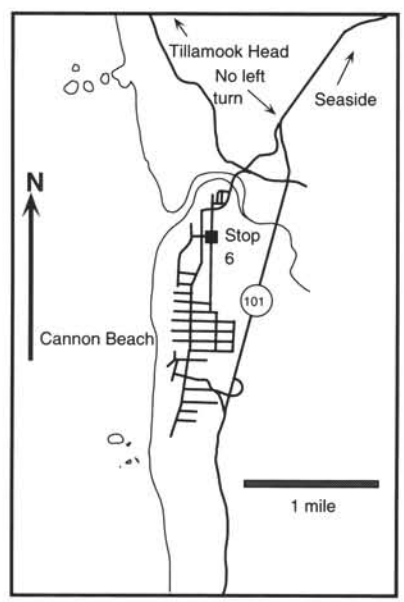


Figure 24. Location of Stop 6.

Site description: The Ecola Creek wetland area behind downtown Cannon Beach (Figure 25) is the first site to yield unequivocal geologic evidence of Cascadia tsunami runup heights at the ocean shoreline (Gallaway and others, 1992). As many as eight buried peats and/or tsunami deposits are recorded in about 3,000 radiocarbon years of deposition in the Ecola Creek wetlands (Figure 26). The uppermost buried peat (younger than 380±60 RCYBP) is associated with a tsunami, whereas the second youngest tsunami (younger than about 1,000 years in age) is located within a peat, i.e., no subsidence.

Figure 25. Photograph of Friends of the Pleistocene field trip participants in the Ecola Creek wetlands, facing towards the source of the prehistoric tsunami sands (downtown Cannon Beach area) that blanketed the wetlands.

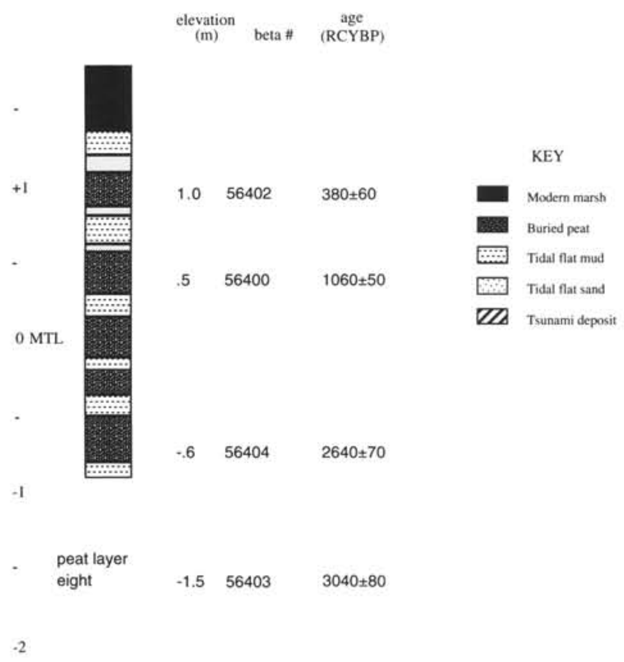


Figure 26. Core log of buried peats from core site northeast of Ecola Creek bend. This log shows thin tsunami sands at the top of uppermost buried peat (38±060 RCYBP) and on the top and bottom of a debris-flow deposit (less than 1,200±60 RCYBP, assumed less than 1,000 RCYBP by correlation to other cores [Gallaway and others, 1992]). A total of eight buried peats are found at this core site (oldest is 3,040±80 RCYBP). The top five peats/tsunami layers (shown in this figure) might be correlative with the last five regional dislocation events (Figure 9). Beta number is radiocarbon laboratory sample number.

We interpret these tsunami deposits to represent Events 1 and 2 of the five CSZ subsidence events mentioned above. Tsunami-deposit isopach maps indicate that these paleotsunamis entered the wetlands both via the Ecola Creek mouth and by overtopping the southern end of the Cannon Beach spit (Figure 27). Backshore-foredune transitions in the Cannon Beach spit and in many other spits of the Cascadia margin exceed + 5 m (16 ft) MSL (Petit, 1991), yielding CSZ tsunami runup heights of at least 6 m (20 ft) above MSL at Cannon Beach (Figure 28).

The prehistoric CSZ tsunami Event 2 is of particular interest for two reasons. This Cascadia tsunami appears to have propagated well beyond the area of corresponding coastal subsidence in central Oregon (Darienzo, 1991). In addition, it bounds a debris-flow deposit in the northwest corner of the Ecola Creek wetlands (Gallaway and others, 1992). To our knowledge, this is the first debris flow to be tied directly to a megathrust dislocation event in the Cascadia margin. Two and possibly three sand layers from the Event 2 tsunami are associated with the deposition of the debris flow on the wetland surface adjacent to a ravine (Figure 25). The separation of the tsunami layers by the debris-flow sediments confirms multiple wave trains of the Event 2 tsunami. Multiple trains of tsunami waves (two to three) for the Event 2 tsunami are also implied by alternating sand and organic detritus layers at other Ecola Creek wetland sites.

Unlike the prehistoric Cascadia tsunamis, the significant flooding from the historic 1964 Alaskan tsunami was limited to the Ecola Creek mouth area. The preexisting Ecola Creek bridge at the north end of Cannon Beach was removed from its footings and carried about 150 m (500 ft) up the Ecola Creek channel by that tsunami (Terry Swagert, Cannon Beach resident, personal communication, 1992). No historic tsunami deposits have been identified in the Ecola

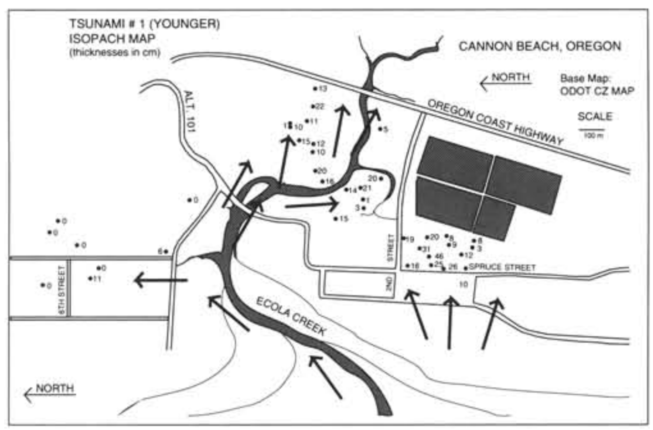


Figure 27. Isopach map of youngest prehistoric tsunami (300 Cal. Year BP) deposit thickness at Cannon Beach. Maximum deposit thickness at south end of Cannon Beach spit indicates spit overtopping as well as surge propagation up the Ecola Creek channel. Arrows show direction of tsunami movement.

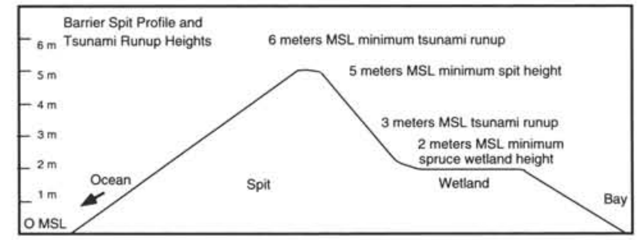


Figure 28. Generalized diagram of tsunami overtopping spit of assumed elevation (+5 m MSL). Estimated minimum runup height of CSZ tsunamis at Cannon Beach ocean shoreline is +6 m MSL (Gallaway and others, 1992).

Creek wetlands except for small remnants of the destroyed bridge that were found immediately adjacent to the Ecola Creek channel. The wetland areas of tsunami inundation and deposition for the last two prehistoric Cascadia tsunamis are at least ten times larger than that for the 1964 Alaskan tsunami in the Ecola Creek wetlands.

Stop 7. Seaside overview at Tillamook Head

Location (Figure 29): Take the beach access route off Highway 101 at the south end of Seaside to drive west to the Tillamook Head overlook. Park along the roadway or hike out to the sea cliff above the Seaside cove for a broad overview of the south end of the Clatsop spit area.

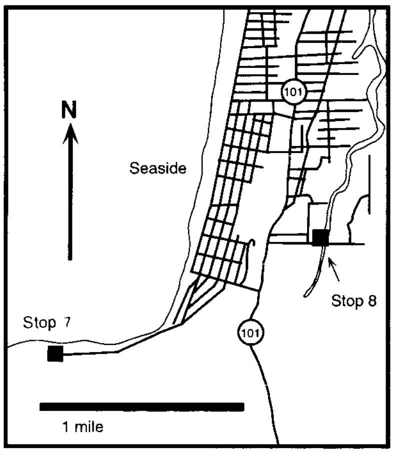


Figure 29. Locations of Stops 7 and 8.

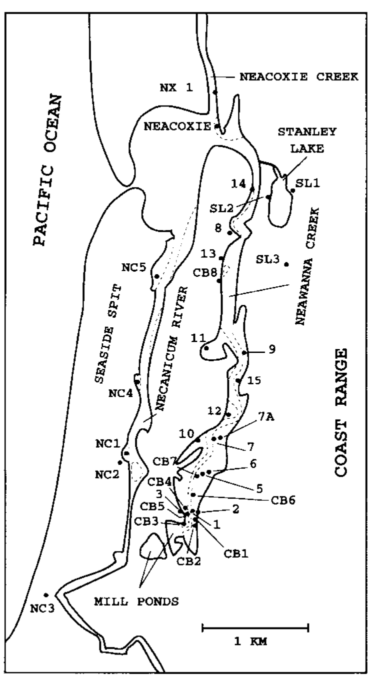


Figure 30. General map of Seaside area, showing location of cores taken and cutbanks (CB) examined.

Features: Beach cobble ridges, Necanicum and Neawanna River morphology, and probable historic tsunami deposits in Necanicum River.

Site description: The Seaside area is developed on Clatsop Spit, which extends south to Tillamook Head and north to the Columbia River. Gravel beach ridges and dunes prograded westward, due to diminished rates of eustatic sea-level rise during late Holocene time (Rankin, 1983). The source of the gravels, which range up to cobble size, is the Tillamook Head basalt. Gravel beach ridges are separated by small, linear valleys that contain the Necanicum River, Neawanna Creek, and Stanley Lake wetlands (Figure 30).

The marshes of the Necanicum River valley contain two distinct sand layers sandwiched between rooted muds within 1 m (3 ft) depth (Figure 31) (Darienzo and others, 1993). The sands can be traced over 2 km (1.2 mi) from core site NC2 to NC5 (Figure 30). Radiocarbon dates and historic artifacts indicate that the anomalous sand layers are historic. Neither layer is associated with abruptly buried peats, further distinguishing them from prehistoric Cascadia tsunamis. However, historic tsunamis are known to have surged into Necanicum Bay. Walls of water 3 m (10 ft) high and 1.2 m (4 ft) high, respectively, are reported to have traveled up the Necanicum River as a result of tsunamis produced by the 1964 and 1946 Alaskan and Aleutian earthquakes. Sand from the 1964 tsunami was deposited on the Highway 101 bridge, where it crosses the Neawanna Creek (Neal Maine, Seaside Public Schools, personal communication, 1992). There is no evidence that the historic Alaskan tsunamis left any sandy deposits in the Neawanna Creek wetlands behind Seaside.

The young Necanicum River valley has no prehistoric marsh deposits; thus we have no record of paleotsunami inundation along Seaside's ocean frontage areas. However, geologic evidence of prehistoric tsunami inundation landward of Seaside is well preserved in the Neawanna and Stanley Lake wetlands (see Stop 8 below).

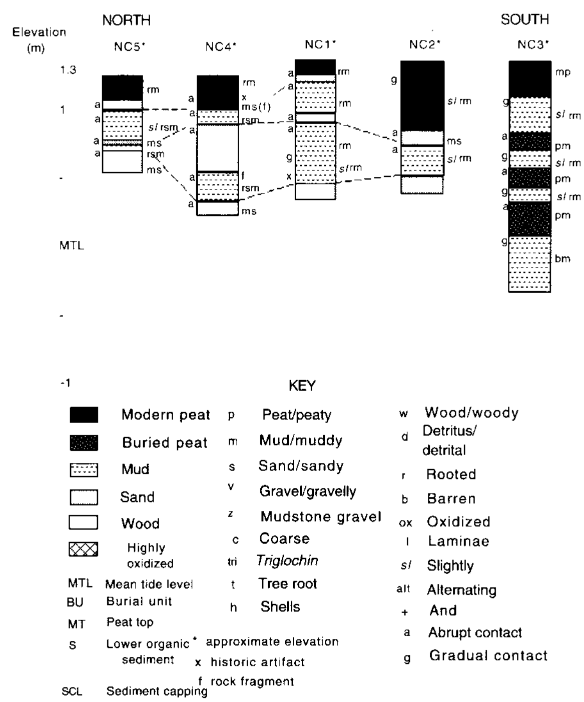


Figure 31. Stratigraphy of historic sand layers (probable 1946 and 1964 Alaskan tsunami deposits) in Necanicum River.

Stop 8. Neawanna cutbank

Location (Figure 29): At the south end of Seaside, turn off Highway 101 to travel east on S Ave. about ⅓ mi to the bridge crossing over Neawanna Creek. Park and walk north, out onto the marsh, or along the cutbank on the east side of the Neawanna tidal creek. **Requires low tide.**

Features: Coseismically buried peats, tsunami-deposited sand, and debris-flow deposits.

Site description: The upper reaches of the Neawanna tidal channel contain evidence for six coseismic burial events in the last 2,200 RCYBP. The coseismic subsidence events are denoted by abruptly buried peats, tsunami sands, and some debris-flow deposits (Darienzo, 1991) (Figure 32). Tree roots protruding from peaty horizons in the cutbanks indicate that some of the paleowetlands here were forested prior to coseismic subsidence and burial.

The debris-flow deposits overlying the buried peats are characterized by chaotic structure and poorly sorted clay and gravel. The gravel contains rounded mudstone fragments that are easily crushed between the fingers. One debris-flow deposit (20–30 cm [8–12 in.] thick) can be traced in the cutbank over a distance of 80 m (260 ft) between core sites CB5 and CB6, where it gives way to sand at CB6 (Figure 30). Debris-flow deposits are not found downstream of core site 7, confirming an upland/upstream source. Additional work is needed to constrain the relative timing of the debris-flow deposits with respect to tsunami inundation. However, beach sand is mixed in with some of the muddy gravel deposits, suggesting the potential for codeposition from tsunami and debris-flow sources.

The sandy tsunami deposits in the Neawanna core sites pinch out (from 26 to 0 cm [100 in.] thickness) with distance down the tidal

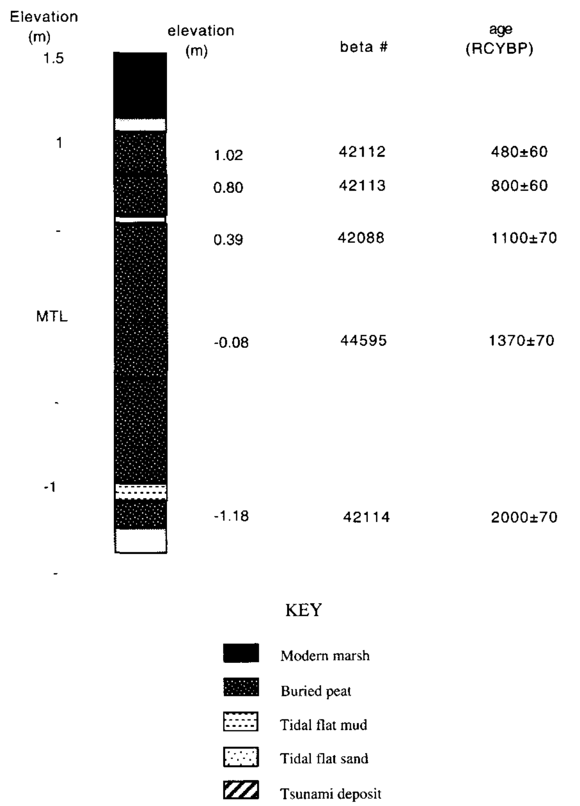


Figure 32. Stratigraphy and radiocarbon ages of buried peats from core site 2 along the upper reaches of the Neawanna. Beta number is radiocarbon laboratory sample number.

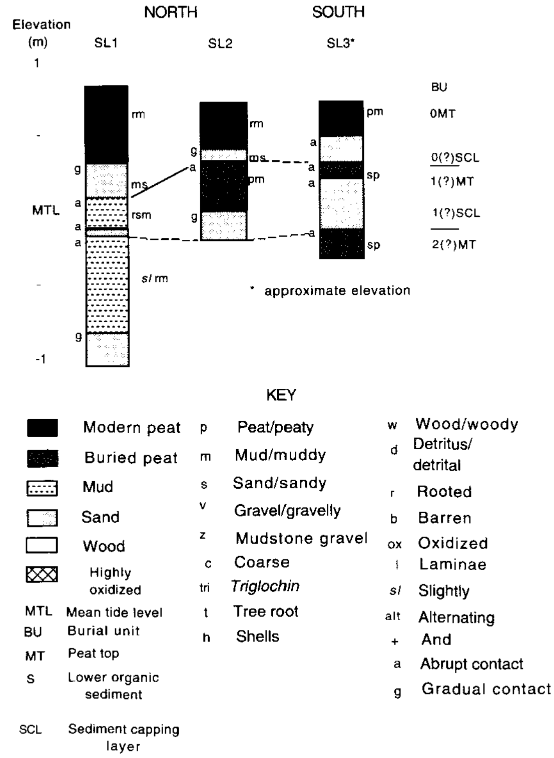


Figure 33. Stratigraphy of representative cores in the Stanley Lake area.

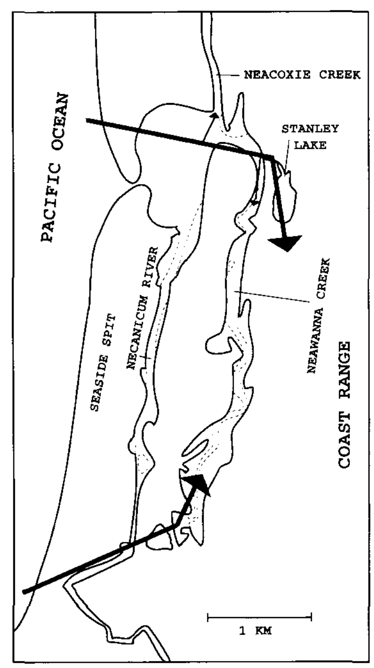


Figure 34. Arrows show probable directions of movement of the tsunami surges for the last two Cascadia earthquakes. The thicker arrows depict the main surge corridors and the thinner arrows other possible corridors.

channel (to the north). A northward propagation of the tsunami surge here is also supported by the sand mineralogy, indicating a beach sand supply from the west, as opposed to a river sand supply from upstream or downstream. The beach sands are discriminated from river sands on the basis of heavy mineralogy and relative grain rounding (Darienzo and others, 1993). The paleotsunamis that deposited beach sands in marshes of the upper Neawanna tidal channel are interpreted to have surged through or over the spit at the south end of Seaside.

However, even thicker paleotsunami deposits are found in the Stanley Lake area, northeast of Seaside (Figure 33). The sand layers range from 4 to 68 cm (1.5–27 in.) in thickness and contain from 75 to 100 percent beach sand components. The uppermost sand layer(s) in Stanley Lake was (were) deposited within the last 800 years RCYBP, suggesting deposition from one or both of the last two Cascadia tsunamis. The lack of an intervening peat might reflect scouring by the last paleotsunami (CSZ Event 1), but this hypothesis will require AMS radiocarbon dating for confirmation. The mineralogy and thickness of the tsunami sands here indicate that the tsunami surges breached the ridge between the Necanicum bay mouth and the Stanley Lake valley before dissipating with distance south along the Stanley Lake valley. At the south end of the Stanley Lake valley, the CSZ Event 1 and Event 2 tsunamis are separated by a peaty horizon. The patterns of Cascadia tsunami propagation in the Seaside area are complex (Figure 34), with surges crossing gravel ridges at low points and dissipating in intervening lowland valleys between the gravel ridges.

Stop 9. Youngs Bay, Columbia River

Location (Figure 35): Drive north toward Warrenton, but head east on Oregon Coast Highway 101 alternate (old Hwy 101) toward Astoria. Park at the west end of the bridge and walk north out on a dike road to view tidal creek cutbanks in the northeast corner of the small marsh.

Features: Marsh cutbank and/or shallow cores show evidence of two paleotsunami deposits about 10 km (6 mi) upriver of the Columbia River mouth.

Site description: This marsh site is located at the west side of Youngs Bay, between Warrenton and Astoria, in the lower Columbia River estuary. There has been much speculation about Cascadia tsunami runup in the Columbia River. The 1964 Alaskan tsunami is reported to have nearly topped dikes along the Warrenton shoreline that were 3 m (10 ft) high. The two paleotsunami deposits recorded at this site clearly indicate sufficient tsunami runup to overtop high marsh settings some 15 km (9 mi) from the mouth. However, the Columbia River tidal inlet has been substantially altered in historic time. Numerical tsunami modeling will likely be required to evaluate the importance of historic inlet changes in controlling potential runups of future Cascadia tsunamis.

A general core log for the shallow marsh stratigraphy at this site is shown in Figure 36. The upper tsunami layer is associated with

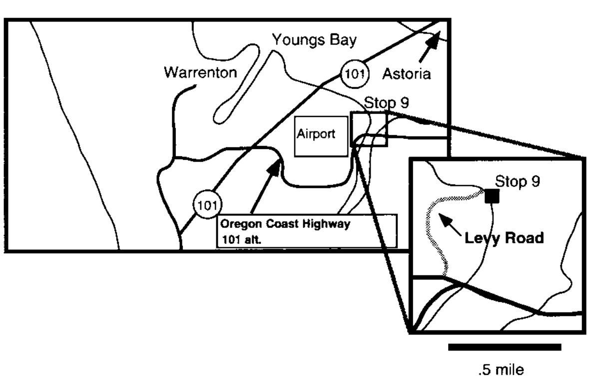


Figure 35. Location of Stop 9.

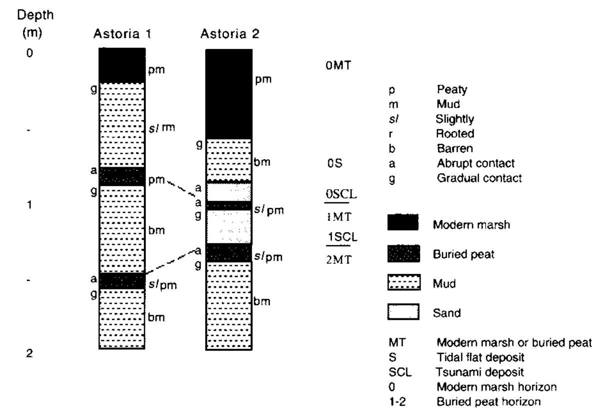


Figure 36. Stratigraphy of last two Cascadia tsunamis (Events 1 and 2) in Youngs Bay-Warrenton area of lower Columbia River.

marsh burial and is presumed to be CSZ Event 1, at about 300 years ago. The lower tsunami layer is not associated with coastal subsidence and is tentatively correlated with CSZ Event 2. These deposits have yet to be radiocarbon dated. It is interesting to note that at this site the tsunami layer associated with local subsidence is thinner than the tsunami layer not associated with local coastal subsidence. This site possibly extends the propagation distance of the CSZ tsunami Event 2 at least 100 km (62 mi) beyond the area of observed coastal subsidence in central Oregon (Peterson and Darienzo, 1992).

Stop 10. Nestucca Bay marsh

Location (Figure 37): Highway 101 bridge area over Nestucca River as it enters Nestucca River valley between Woods and Pacific City. The prehistoric wetlands are now pasture lands. River banks have been diked, so marsh stratigraphic examination requires coring or shallow pits in the pastures. **Permission for access to the pasture lands is required from the owners.**

Features: Coseismically buried peats and tsunami-deposited sands. This site has the largest number of buried peats (12) reported to date for the central Cascadia margin.

Site description: Nestucca Bay is fed by the Nestucca and Little Nestucca Rivers and is separated from the Pacific Ocean by a long sand spit (Figures 1 and 38). There are very few natural marshes in the area due to the extensive diking of wetlands for grazing of dairy cattle. Nevertheless, coseismically buried peats were identified beneath pasture soils along both rivers (Figure 38) (Darienzo, 1991). The strongest evidence for coseismic peat burial with tsunami deposition is at the Nestucca Duck sites, which record CSZ Event 1, about 300 years in age (Figure 38). However, thin tsunami layers (1 cm [0.4 in.] thick) that are associated with several buried peat horizons have been traced upriver to the Hurliman 4 site and to sites along the lower reaches of the little Nestucca channel (Figure 38).

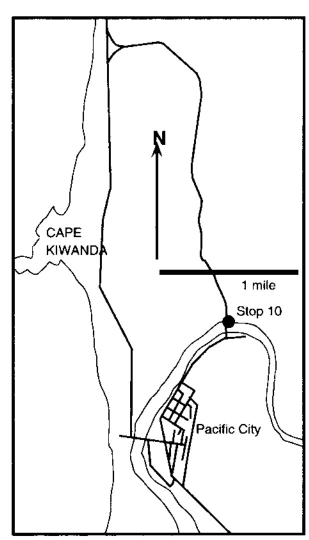


Figure 37. Location of Stop 10.

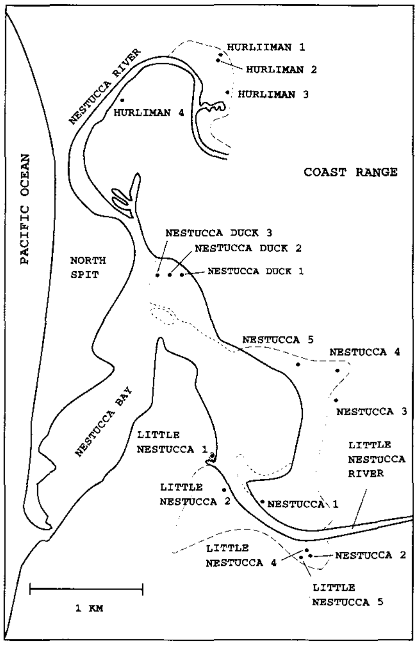


Figure 38. General map of Nestucca Bay with core site locations. The areas outlined with the wide dashed lines are pasture land and short dashed lines tidal marshes.

The deepest paleoseismological core taken in the Pacific Northwest was from the Hurliman 2 core site (Figure 39). Some 12 burial events were identified in 13 m (43 ft) of core depth at that site. The deepest buried peat yielded a radiocarbon age of approximately 5,700 RCYBP. The average recurrence interval of the upper six burial events is similar to that calculated for the lower six burial events, i.e., about 400–500 years. The average long-term recurrence interval for this central Cascadia site (12 buried peats in 5,700 years) is somewhat shorter than that estimated from offshore turbidites, i.e., 500–600 years, based on 13 turbidites in the last 6,700 years) (Adams, 1990).

Stop 11. Neskowin

Location (Figure 40): Walk the beach south of Neskowin in winter for evidence of standing forest stumps in the surf zone. **Requires low tide.**

Features: Late Holocene forest developed on wave-cut platform that is now in the surf zone.

Site description: A forest of tree stumps (more than 100 in number) is occasionally exposed in the surf zone immediately south of the town of Neskowin (Figure 41). This forest likely corresponds to one of several buried wetland horizons in the Neskowin River valley behind the beach. A radiocarbon age of one standing stump in the forest is approximately 2,000 RCYBP (C.D. Peterson and B. Paul, unpublished data, 1990). This forest is located on a Holocene wave-cut platform that was initially cut below sea level. It then emerged above sea level to grow the forest, then submerged below sea level, where it now stands in the surf zone. Abrupt subsidence and burial by beach sands are thought to have preserved the forest in its present sea-level position. The recognition of similar surf zone forests on the Oregon coast (1983–1985) helped focus the attention of some of these authors on late Holocene sea-level changes in the central Cascadia margin.

The Oregon coast consists of segments of sandy beaches, called littoral cells, that are separated by headlands or other barriers. Movement of sand up and down the coast is generally confined to each cell, with the headlands or other barriers inhibiting transport of sand from

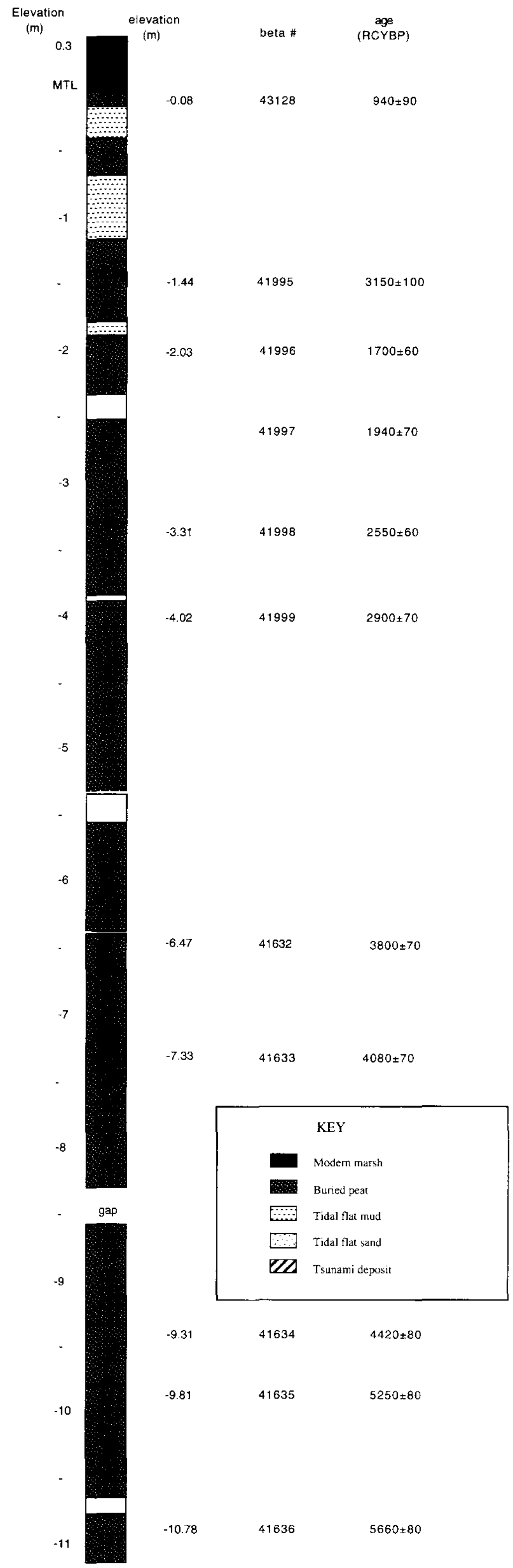


Figure 39. Radiocarbon ages of buried peats from Hurliman 2 and Little Nestucca 5. Beta number is radiocarbon laboratory sample number.

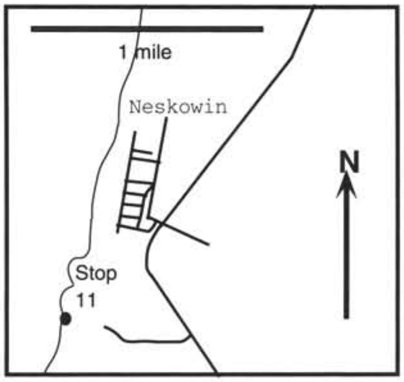


Figure 40. Location of Stop 11.

Figure 41. Photograph of large stumps developed on late Holocene wave-cut platform now in the surf zone. Age of one tree is about 2,000 RCYBP.

one cell to another. Progradational beaches north of Neskowin contrast sharply with widespread shoreline retreat in the Lincoln City cell to the south. The two cells differ in sand supply, even though the adjacent cells are similar in size, river drainage-basin area, and predicted rate of uplift (Goldfinger and others, 1992). We hypothesize that sand is excavated from bluffs in the Lincoln City cell and bypassed around Cascade Head to supply the Neskowin-Pacific City cell. Such a process could be accelerated during periods of beach and sea cliff erosion following coseismic subsidence.

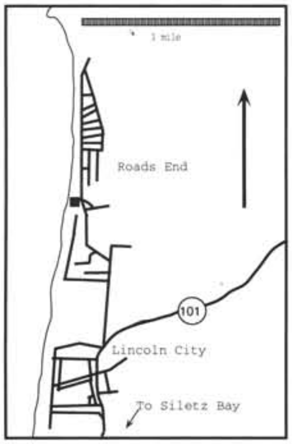


Figure 42. Location of Stop 12.

Stop 12. Roads End Beach Wayside

Location (Figure 42): At the north end of Lincoln City find Roads End intersection with Highway 101 (McDonalds Restaurant on opposite side of intersection). Take road north to the Roads End Beach Wayside parking lot. Walk down the path to the beach and head south 300 ft to view the late Pleistocene sea cliffs.

Features: Coseismic liquefaction features (convolute bedding) in late Pleistocene marine-terrace deposits.

Site description: The late Pleistocene terraces (assumed 80 ka in age) contain highly convoluted heavy-mineral layers that were originally deposited in planar foreshore beds (Figure 43). These convoluted beds are associated with clastic dikes, sills, and vent-collapse structures in many of the Oregon marine terrace deposits (Peterson and Madin, 1992). The tops of the convoluted beds at this site are eroded, proving the liquefaction to have occurred during the period of marine terrace deposition and not during the subsequent 80,000 years (Figure 44). Higher up in the section, some transitional backshore to eolian dune sands show a second liquefaction event. Some sites in the Lincoln City terraces show as many as three distinct liquefaction events that occurred during the period of deposition, near the end of that marine transgression.

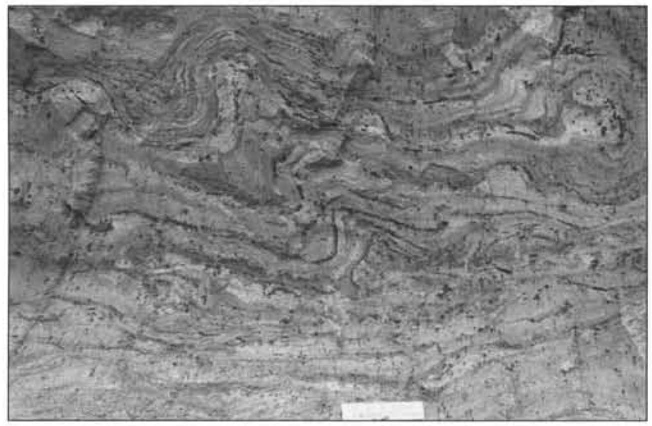


Figure 43. Photograph of highly convoluted beds in marine terrace deposits.

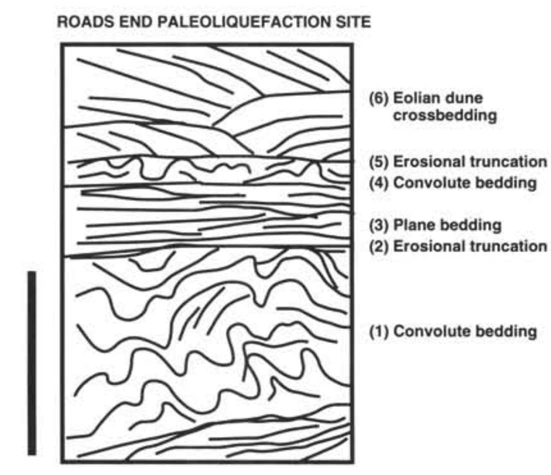


Figure 44. Convoluted foreshore deposits (liquefaction) are truncated by overlying planar beds. A second liquefaction event is represented by smaller scale convolute beds in overlying dune deposits. Liquefaction in dune deposits generally corresponds to permeability caps under interdune pond sediments. High pore pressure allowed localized liquefaction above the water table.

Stop 13. Salishan Spit, Siletz Bay

Location (Figure 45): Stop at the office of Salishan Lease Holders, Inc., on the west side of Highway 101, opposite Salishan Lodge. With permission, drive out to the Siletz Bay spit. Park at the north end of the Golf course and walk east on a dirt access road to about half the length of the fairway. Leave the road and walk north 300 ft through trees and/or brush to wetland areas.

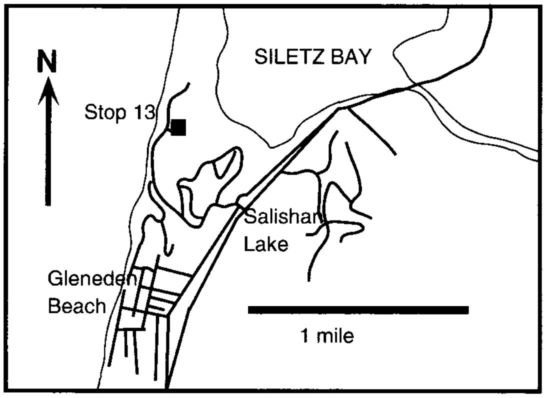


Figure 45. Location of Stop 13.

Features: Coseismically buried peats and tsunami-deposited sands.

Site description: Siletz Bay is separated from the Pacific Ocean by a spit that now contains an artificially stabilized foredune and numerous residences (Figures 1 and 46). Six coseismically buried peats with overlying tsunami deposits up to 25 cm (10 in.) thick are identified in marsh deposits along the spit and across the bay in the Millport Slough area (Darienzo, 1991) (Figures 46 and 47). The Salishan House site at the southern end of the spit contains particularly well-developed buried peats and overlying tsunami sands.

This is an example of one of our tsunami sensitive sites. The tsunami sands on the spit are derived directly from the beach (spit overtopping) except for the fifth buried peat, which shows a significant river sand component. Since the bay deposits adjacent to the spit are predominantly of river sand mineralogy (Peterson and others, 1984), a tsunami that propagated up the bay would deposit a mixed (beach/river) sand mineralogy. The overtopping of the spit by three of the last four paleotsunamis substantiates estimates of tsunami runup (+ 6 m [20 ft] MSL) predicted from the Cannon Beach sites discussed above. Additional work is needed here to establish the age of the topmost tsunami layer, which is contaminated by young roots descending from the modern wetlands.

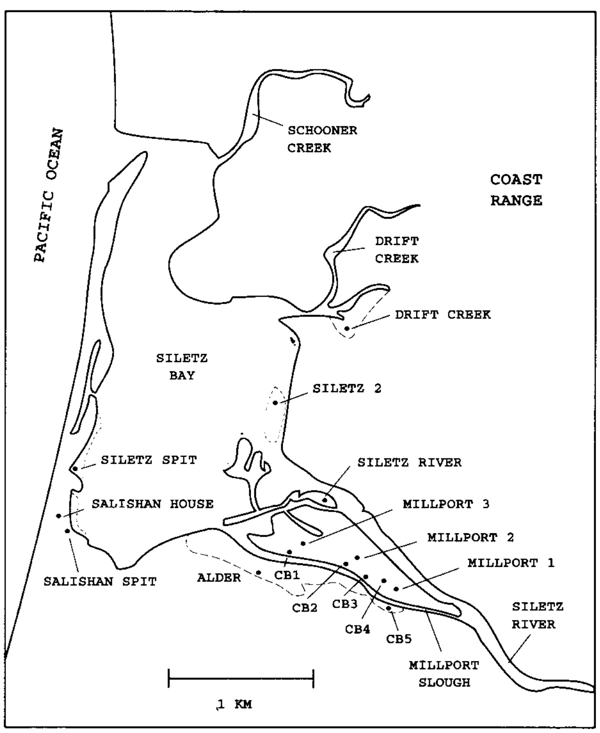


Figure 46. General map of Siletz Bay showing core site locations. Dashed lines show cored marsh areas.

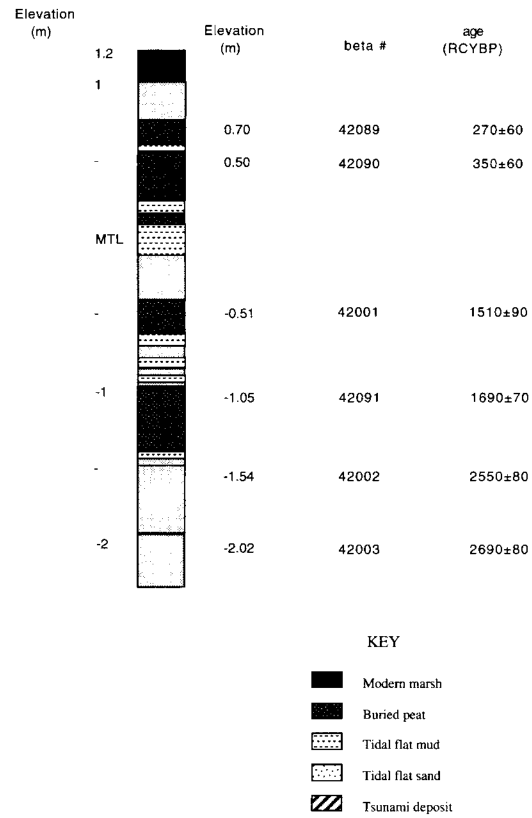


Figure 47. Radiocarbon ages of buried peats from Salishan House. Beta number is radiocarbon laboratory sample number.

Stop 14. Millport Slough, Siltez Bay

Location (Figure 48): Turn east off Highway 101 at Alder Road, immediately north of Salishan Lodge. Take the road to a small bridge over a tidal channel (Millport Slough). Explore cutbanks southeast of the Millport Slough bridge to find one to three buried wetland horizons. **Requires low tide.**

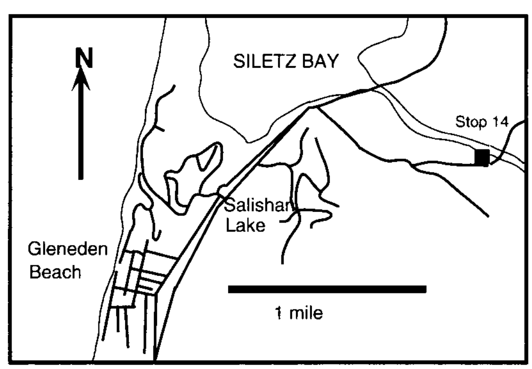


Figure 48. Location of Stop 14.

Features: Several buried wetlands in tidal creek cutbanks; additional buried peats and tsunami deposits in deeper cores.

Site description: This distal marsh site (Figure 46) is located well upriver of the bay mouth and ocean shoreline. It shows evidence of multiple uplift and subsidence cycles (Figure 49). Sufficient sediment supply during aseismic uplift cycles permitted the development of forested wetlands prior to subsequent subsidence events. Tsunami layers directly overlying buried peats are thin and discontinuous this far up the bay, but they do occur locally above the fourth, fifth, and seventh buried peats (Figure 49).

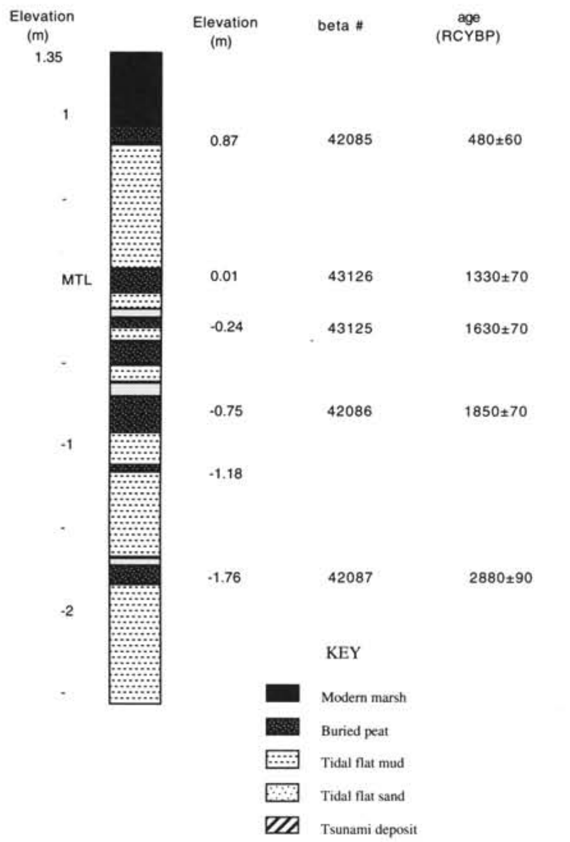


Figure 49. Radiocarbon ages of buried peats from Millport Slough. Beta number is radiocarbon laboratory sample number.

Stops 15 and 16. Gleneden and Lincoln Beaches

Location (Figure 50): Here we describe two separate late Pleistocene liquefaction sites. The Gleneden site is easily accessed from the Gleneden Beach Wayside, about 1 mi west of Highway 101. Walk down the beach access trail and continue north (30–650 ft) to view the sea cliffs. The Lincoln Beach site can be accessed by a long beach walk, or with permission from the Sea and Sand Trailer Park owners. From the Trailer Park, just north of Lincoln Beach, walk north (160 ft) to view the sea cliff deposits.

Features: Coseismic liquefaction features (flames, sills, and dikes) in late Pleistocene marine terrace deposits.

Site description: At the Gleneden Beach Wayside site are well-exposed examples of injection flames and lateral sills in late Pleistocene beach and dune deposits (assumed age 80 ka). The largest flame structure (> 1 m [3 ft] in height) at this site is located under a slight overhang at a distance of about 100–150 m (300–500 ft) north from the beach access path. The smaller clastic sills throughout the outcrop (Figure 51) are representative of liquefaction evidence at many late Pleistocene coastal terrace sites in Oregon and Washington (Peterson and Madin, 1992). The sills are identified by injection terminations of primary bedding at both upper and lower sill contacts (Figure 52).

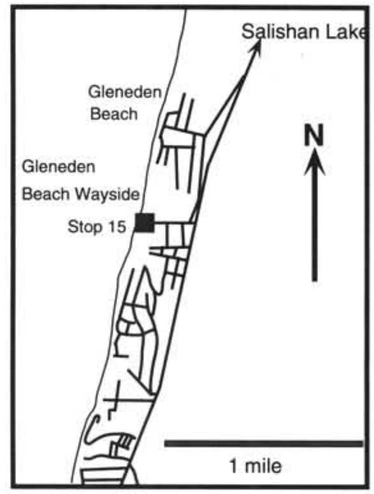


Figure 50. Location of Stop 15; Stop 16, not shown, is located on the beach 2 mi south of Stop 15.

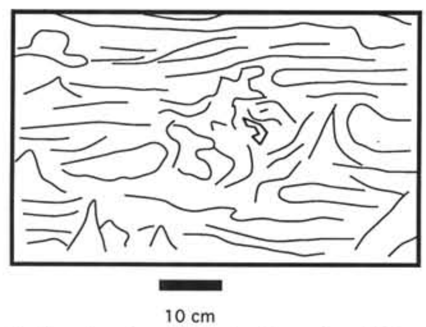
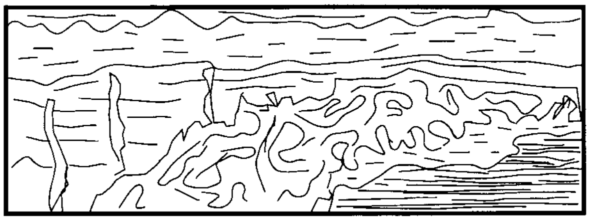


Figure 51. Line drawing of clastic sills and small flame structures in coarse backshore sands from a late Pleistocene marine terrace deposit at the Gleneden Beach site.

Figure 52. Photograph of clastic sills in backshore beach deposits of late Pleistocene marine terrace.

The liquefaction features at the Sea and Sand Trailer Park site include large-scale vertical and horizontal injections that have dismembered horizontal peats in muddy deposits (10–15 m [30–50 ft] outcrop length). These deposits are thought to represent a back-berm lagoonal setting, as evidenced by the basal channel contacts in beach/barrier deposits. The sand injections actually represent two different episodes of coseismic liquefaction. The initial injection event(s) occurred during the period of deposition



1 m

Figure 53. Line drawing of late Pleistocene lagoonal deposits showing two episodes of coseismic liquefaction at Lincoln Beach Trailer Park. Thin peaty layers in the section are dismembered by vertical and horizontal sand injections. These severely disturbed beds underlie an undeformed silty layer (< 0.5–1 m [2–3 ft] thick) that caps the section. Thin vertical cracks are filled with unweathered sand that is much younger (no iron staining) than the weathered lagoonal deposits.

of the section (about 80 ka) followed by subsequent weathering of the deposits. A second set of thin vertical cracks (50-cm [20-in.] spacing) cut the weathered deposits, and these cracks are filled with unweathered sands (possibly Holocene? in age), suggesting a more recent event of injection(s) (Figure 53).

ACKNOWLEDGMENTS

Support for the research that has been conducted at many of these field trip stops has been provided by Oregon Sea Grant College Program, National Earthquake Hazards Reduction Program, National Science Foundation, Oregon Department of Geology and Mineral Industries, Federal Emergency Management Agency, and the Clatsop County Sheriff's Office.

REFERENCES CITED

Adams, J., 1990, Paleoseismicity of the Cascadia subduction zone: Evidence from turbidites off the Oregon-Washington margin: Tectonics, v. 9, p. 569–583.

Atwater, B.F., 1987, Evidence for great Holocene earthquakes along the outer coast of Washington State: Science, v. 236, p. 942–944.

Briggs, G.G., and Peterson, C.D., 1992, Neotectonics of the south-central Oregon coast as recorded by late Holocene paleosubsidence of marsh systems [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 910.

Clarke, S.H., and Carver, G.A., 1991, Late Holocene tectonics and paleoseismicity, southern Cascadia subduction zone: Science, v. 255, p. 188–192.

Crosson, R.S., and Owens, T.J., 1987, Slab geometry of the Cascadia subduction zone beneath Washington from earthquake hypocenters and teleseismic converted waves: Geophysical Research Letters, v. 14, p. 824–827.

Darienzo, M.E., 1991, Late Holocene paleoseismicity along the northern Oregon coast: Portland, Oreg., Portland State University doctoral dissertation, 167 p.

Darienzo, M.E., Craig, S., Peterson, C., Watkins, A., Wienke, D., Wieting, A., and Doyle, A., 1993, Extent of tsunami sand deposits landward of the Seaside Spit, Clatsop County, Oregon: Final Report to Clatsop County Sheriff's Office, Clatsop County, Oregon, 21 p.

Darienzo, M.E., and Peterson, C.D., 1990, Episodic tectonic subsidence of late Holocene salt marsh sequences in Netarts Bay, Oregon, central Cascadia margin, U.S.A: Tectonics, v. 9, p. 1–22.

Gallaway, J.P., Watkins, A.M., Peterson, C.D., Craig, S.C., and McLeod, B.L., 1992, Study of tsunami inundation of Ecola Creek wetlands and spit, Cannon Beach, Oregon: Final Report to Clatsop County Sheriff's Office, Clatsop County, Oregon, 21 p.

Glenn, J.L., 1978, Sediment sources and Holocene sedimentation history in Tillamook Bay, Oregon: Data and preliminary interpretations: U.S. Geological Survey Open-File Report 78–680, 64 p.

Goldfinger, C., Kulm, L.D., Yeats, R.S., Mitchell, C., Weldon, R., II, Peterson, C., Darienzo, M., Grant, W., and Priest, G.R., 1992, Neotectonic map of the Oregon continental margin and adjacent abyssal plain: Oregon Department of Geology and Mineral Industries Open-File Report O–92–4, 17 p., 2 plates.

Heaton, T.H., and Kanamori, H., 1984, Seismic potential associated with subduction in the northwestern United States: Seismological Society of America Bulletin, v. 74, p. 933–941.

Mulder, R.A., 1992, Regional tectonic deformation of the northern Oregon coast as recorded by Pleistocene marine terraces: Portland, Oreg., Portland State University master's thesis, 96 p.

Peterson, C.D., and Briggs, G.G., 1992, Response of coastal depositional systems to tectonic strain cycles in the Cascadia subduction of the U.S. Pacific Northwest: International Geological Congress, 29th, Kyoto, Japan.

Peterson, C.D., and Darienzo, M.E., 1992, Discrimination of climatic, oceanic, and tectonic mechanisms of cyclic marsh burial from Alsea Bay, Oregon, U.S.A: U.S. Geological Survey Open-File Report 91–441–C, 53 p.

Peterson, C.D., Darienzo, M.E., Pettit, D.J., Jackson, P., and Rosenfeld, C., 1991, Littoral cell development in the convergent Cascadia margin of the Pacific Northwest, U.S.A, *in* Osborne, R., ed., From shoreline to the abyss. Contributions in marine geology in honor of F.P. Shepard: SEPM Special Publication 46, p. 17–34.

Peterson, C.D., and Madin, I.P., 1992, Variation in form and scale of paleoliquefaction structures in late Pleistocene deposits of the central Cascadia margin [abs.]: Geological Society of America Abstracts with Programs, v. 24, no. 5, p. 74.

Peterson, C.D., Scheidegger, K.F., Niem, W., and Komar, P.D., 1984, Sediment composition and hydrography in six high-gradient estuaries of the northwestern United States: Journal of Sedimentary Petrology, v. 54, p. 086–097.

Petit, D.J., 1991, Distribution of sand within selected littoral cells of the Pacific Northwest: Portland, Oreg., Portland State University master's thesis, 249 p.

Rankin, D.K., 1983, Holocene geologic history of Clatsop Plains foredune ridge complex: Portland, Oreg., Portland State University master's thesis, 176 p.

Yamaguchi, D.K., Woodhouse, C.A., and Reid, M.S., 1989, Tree-ring evidence for synchronous rapid submergence of the southwestern Washington coast 300 years B.P. [abstract]: Eos, v. 70, no 43, p. 1332. □

DOGAMI releases publication updates

Three new releases of the Oregon Department of Geology and Mineral Industries (DOGAMI) represent updates of earlier publications: the annual report and map of the Mist Gas Field, the database of mineral localities, and the directory of mineral producers in the state.

Mist Gas Field Report
Open-File Report O–93–1

The Mist Gas Field Report is now available with all activity and changes for the year 1992. The report includes (1) the Mist Gas Field Map, showing location, status, and depth of all wells, and (2) the listing of production figures from the initial production in 1979 through the end of 1992, showing well names, revenue generated, pressures, annual and cumulative production, and other data. The new Mist Gas Field Report is DOGAMI Open-File Report O–93–1 and sells for $8.

Mineral Information Layer for Oregon (MILOC)
Open-File Report O–93–8

MILOC is a database in dBase III+ format that can be imported into computerized geographic information systems or used with a personal computer as a stand-alone, county-by-county database. For use as a mineral-data layer, each site is located by both latitude/longitude and Universal Transverse Mercator (UTM) coordinates.

The database provides information on nearly 8,000 mineral occurrences, prospects, and mines in Oregon. Records on individual sites include a great variety of data on location, commodity, geology, descriptions of mine workings, and many other subjects. The updated version has been made more user-friendly and, in response to input from users, contains some changes in the structure of the records.

The database comes as a set of two 1.2-megabyte (5¼-inch, high-density) diskettes in MS-DOS format and sells for $25. Owners of the first edition may exchange their original diskettes for the new ones at the reduced price of $15.

Directory of Mineral Producers in Oregon
Open-File Report O–93–9

The *Directory of Mineral Producers* was derived from a Departmental computer listing originally designed for internal use. Its updated version includes approximately 1,000 production sites operated by about 550 mineral producers and includes more exploration companies than the earlier version.

The 56-page directory contains two tables: Table 1 is arranged alphabetically by commodity and operator, covering over 30 commodities—from "Abrasives" to "Zeolite"—and listing producers with addresses and township/range designations of their operating sites. Table 2 is arranged alphabetically by county and commodity, showing in abbreviated form which commodities are produced by whom in a given county. The price for the new directory, Open-File Report O–93–9, is $8.

The new reports are now available over the counter, by mail, FAX, or phone from the Nature of Oregon Information Center, Suite 177, State Office Building, 800 NE Oregon Street #5, Portland, Oregon 97232-2109, phone (503) 731-4444, FAX (503) 731-4066; and the DOGAMI field offices in Baker City: 1831 First Street, Baker City, OR 97814, phone (503) 523-3133, FAX (503) 523-9088; and Grants Pass: 5375 Monument Drive, Grants Pass, OR 97526, phone (503) 476-2496, FAX (503) 474-3158. Orders may be charged to Visa or Mastercard. Orders under $50 require prepayment except for credit-card orders. □

Position Announcements
Oregon Department of Geology and Mineral Industries

Geotechnical Engineer/Seismic Hazard Geologist/Engineering Geologist

The Oregon Department of Geology and Mineral Industries seeking to hire a geologist, engineering geologist, or geotechnical engineer to participate in seismic hazard studies. The minimum qualifications are a master's degree in geology, engineering geology, geotechnical engineering, or geophysics. Duties will include geologic mapping, geologic computer modeling, shallow seismic reflection profiling and other detailed geophysical surveys, fault trenching, paleoliquefaction studies, design, contracting, and execution of drilling and cone penetrometer programs, and other tasks necessary to identify earthquake sources and map the geologic component of earthquake hazard in western Oregon urban areas. In addition to the minimum educational requirements, applicants should have significant experience in two or more of the specific areas listed above. Excellent written and oral communication skills, particularly with nontechnical audiences and media, are essential. Applicants with significant mathematics, engineering, and computer background will be more competitive. This position will commence in late 1993 or early 1994, and the position is guaranteed through July 30, 1995, with the possibility of continuation beyond that date. Salary is commensurate with experience; negotiations will start at $2,606 per month, with an excellent benefit package. This position will be stationed in Portland, Oregon. Field work in the Willamette Valley and along the Oregon coast will be required. Interested applicants should send a resume and cover letter to Ian Madin, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street # 28, Portland, OR 97232. Resumes will be accepted until October 1, 1993. After that date, necessary application materials and an explanation of the hiring process will be provided to applicants.

Minerals Economist

The Oregon Department of Geology and Mineral Industries is seeking to hire a minerals economist to participate in data collection, data analysis, and communication regarding the economics of mineral production in the state with attention to demand for aggregate and other mineral commodities.

Duties will include developing data and models for mineral production in Oregon, participating in select mineral economic issues in parts of Oregon, completing an annual list of Oregon mineral producers, and developing new reports of selected case studies of mineral production in various parts of the state.

Minimum qualifications include proficiency in statistics, excellent communication skills, excellent interpersonal qualities under a variety of conditions, and training in economics. Experience in mineral economic analysis and computer skills are desirable. Applicants with significant qualifications in these categories will be the most competitive.

This position will begin in early 1994 and is guaranteed through June 1995, with the possibility of continuation beyond that date. Salary is commensurate with experience.

The position is stationed in Portland, Oregon. Travel throughout Oregon will be required.

Interested applicants should send a resume and cover letter to Don Hull, Oregon Department of Geology and Mineral Industries, 800 NE Oregon Street # 28, Portland, OR 97232. Resumes will be accepted until November 15, 1993. After that date, necessary application materials and an explanation of the hiring process will be provided to applicants.

Reclamationist

The Oregon Department of Geology and Mineral Industries Mined Land Reclamation program will soon have a position opening for a reclamationist.

The reclamationist conducts field inspections of proposed and active mining operations, produces site compliance reports, calculates reclamation bonds, and participates in technical reviews as part of an interdisciplinary team.

Qualifications for a reclamationist typically include at least a bachelor's degree with a major in environmental, biological, or physical science, or in engineering and at least one year of experience in reclamation, environmental coordination, or engineering. Preference is given for experience in mining.

Anyone sending a resume will receive a formal announcement of the job opening at the time the position officially opens. Expected hiring is January 1994. Starting salary range is $2,606–$2,871 per month plus excellent benefits.

If you are interested, please send a resume and cover letter to Department of Geology and Mineral Industries, Attn: Recruiting, 1536 Queen Avenue SE, Albany, OR 97321.

An Equal Opportunity Employer

Historical earthquakes in and around Portland, Oregon

by Jacqueline D.J. Bott and Ivan G. Wong, Woodward-Clyde Federal Services, 500 12th Street, Suite 100, Oakland, California 94607

ABSTRACT

A reevaluation of all known moderate-sized earthquakes in the Portland area has revealed that at least 17 events of Richter magnitude (M_L) 4 and larger have occurred in historic time; six events have been M_L 5 and greater. These observations indicate that the Portland region is the most seismically active area in Oregon. Based on the historical record, recurrence estimates suggest that a M_L 5.5 and larger earthquake will occur about every 100 to 150 years and a M_L 6 and larger earthquake every 300 to 350 years. A crustal earthquake of M_L 6 or greater could generate a greater level of ground shaking in the Portland metropolitan area than could a moment magnitude (M_W) 8+ event on the Cascadia subduction zone and thus needs to be considered in seismic hazard evaluations of the region.

INTRODUCTION

Fewpeople realize that the region centered on the city of Portland is possibly the most seismically active area within the state of Oregon. The Richter magnitude (M_L; see Table 1) 5.6 Scotts Mills earthquake of March 25, 1993 (Figure 1), which shook most of western Oregon and southwestern Washington, is the largest event known to have occurred in northwestern Oregon and attests to the earthquake potential of the region. The absence of larger events in the historical record, however, has led to the general belief that larger events cannot occur. Recent recognition of the potential for a great earthquake (moment magnitude [M_W] 8+) rupturing the Cascadia subduction zone has also accelerated research into investigating crustal faults, which are the sources of the earthquakes occurring in the Portland region. Seismic monitoring of earthquakes in northern Oregon since 1980 has led to an improved understanding of seismogenic sources and the rate of earthquake occurrence in the region.

In this study, we have reviewed the earthquake history of the Portland region and reevaluated all events of approximate M_L 4 and greater that have occurred since the first recorded earthquake in 1846. Specifically, estimates of the magnitudes of these moderate-sized earthquakes were based on the size of their felt areas (i.e., areas in which the earthquake was reported as having been felt by people)—particularly, of course, those earthquakes that occurred prior to adequate seismographic coverage and thus do not have instrumentally determined values. After these reevaluated events have been incorporated into the historical record, the earthquake recurrence for the Portland region can be estimated. Such information is critical for the estimation of average recurrence intervals of earthquakes larger than the largest ever observed, e.g., M_L 6 and greater, and hence for the assessment of seismic hazards.

EARTHQUAKE DETECTION

How do we learn about earthquake occurrences? Historical earthquake records can generally be divided into records of the pre-instrumental period and the instrumental period. In the absence of adequate seismographic coverage, the detection of earthquakes is generally based on direct observations and felt reports. The results are strongly dependent on population density and distribution, and the study region, typical of much of the western United States, was sparsely populated in the 1800s. Thus the detection of pre-instrumental earthquakes shows varying degrees of completeness.

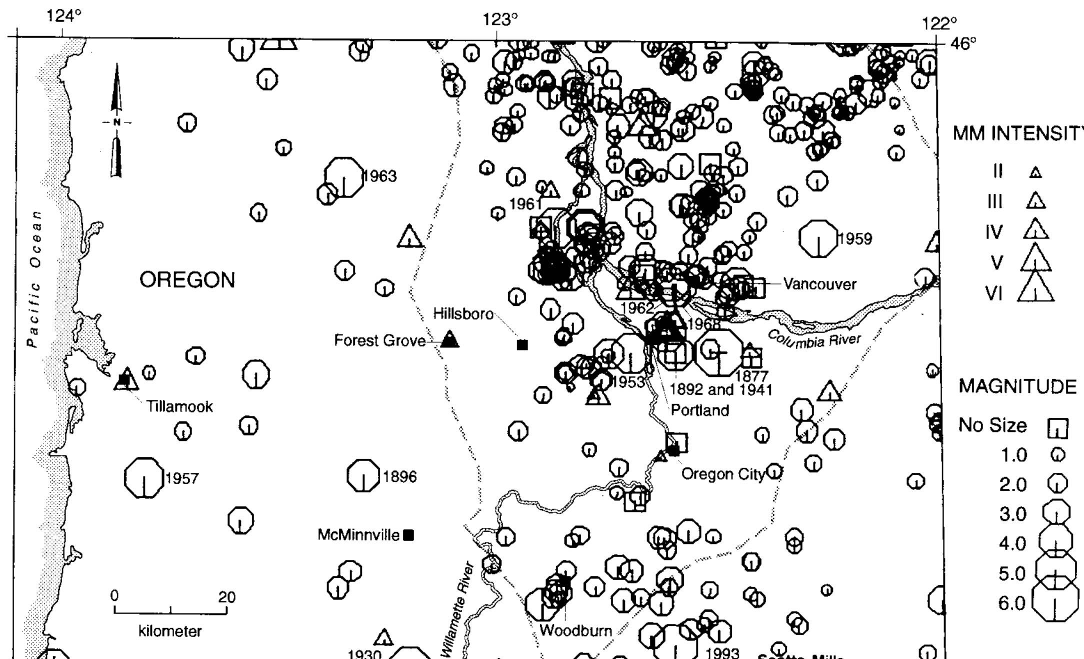


Figure 1. Historical seismicity of northwestern Oregon and portions of southwestern Washington during the period from 1846 to the present. In this study, the Portland region coincides with the Portland fold belt province as defined by Unruh and others (1993), and its boundaries are shown by the dashed line.

Table 1. *Types of earthquake magnitudes*

Symbol	Description
M_L	Richter (local) magnitude
M_S	Magnitude derived from recorded surface waves
m_b	Magnitude derived from recorded body waves
M_D	Magnitude derived from recorded duration of earthquake
M_W	Moment magnitude, derived from seismic moment
M	Unspecified magnitude

An evaluation of the population growth in the Portland region shows gradual increase up to 1940 in all counties except Multnomah (Oregon) and Pierce (Washington). Despite this slow growth, however, many widely distributed towns were established in or near the Willamette Valley and along the Columbia River as early as the 1850s. For example, Portland was first settled in the mid-1840s. Similarly, Salem was established in 1844, Hillsboro in 1845, Forest Grove in 1850, Eugene in 1852, McMinnville in 1853, and Tillamook in 1866 (Figure 1). Newspapers in the region, which are a major source of documentation, began publishing soon after the establishment of the major towns. Based on this relatively early settlement in the region, we estimate that the pre-instrumental historical record is complete for earthquakes of M_L 5 and larger since about 1850.

Although seismograph stations were established as early as 1906 in Seattle and 1944 in Corvallis, adequate seismographic coverage of the Portland region did not begin until 1980, when the University of Washington expanded its regional network into northwestern Oregon. Prior to this time, few stations operated in Oregon. Two of the most important seismograph stations, although at considerable distance from Portland, were the Blue Mountains Observatory in northeastern Oregon and the Longmire station in southwestern Washington. The latter was operated as part of the Worldwide Standardized Seismographic Network in addition to the Corvallis station. Based on this evolution of seismographic coverage, the historical record is complete at small magnitude levels (M_L 2.5 and greater) only since 1980.

SIGNIFICANT EARTHQUAKES

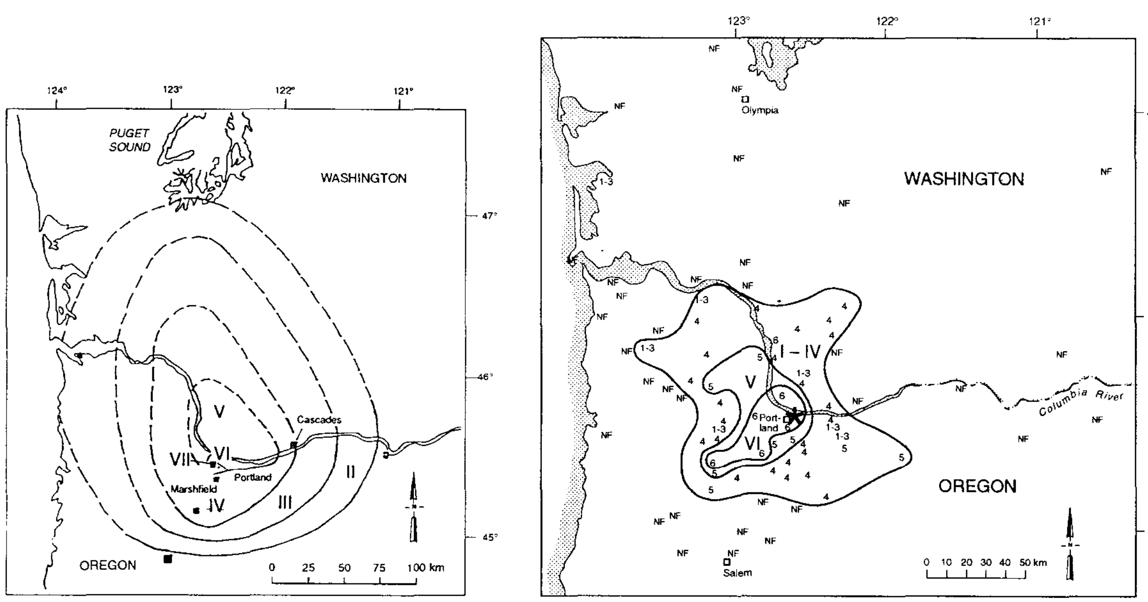
Introduction

In historical times, 17 earthquakes of estimated M_L 4 and greater are known to have occurred within the Portland region (Figure 1). These events, their felt effects and felt areas are described in the following discussion. Available isoseismal maps including ones developed in this study for the earthquakes in 1941, 1961 (August 18, September 17, and November 6), and 1963 were evaluated.

On the basis of several empirical relationships between felt areas of various intensities and M_L developed by Toppozada (1975) for California and western Nevada, we have attempted to estimate the magnitudes of the significant historical earthquakes in the Portland region. We believe that these relationships are applicable to both western Oregon and Washington because the crustal attenuation in both regions appears to be comparable to California. For example, the attenuation factor, Q_0, is about 150 in much of California and approximately 200 in northwestern Oregon and southwestern Washington (Singh and Herrmann, 1983). When we use the well-constrained felt areas of the 1962 Portland and the 1981 Elk Lake earthquakes for calibration, the Toppozada (1975) relationships appear to estimate the actual magnitudes quite well.

1877 earthquake

The earliest known significant historical earthquake in the Portland region occurred on October 12, 1877 (Figure 1). Two events are actually reported for this day, one at about 9 a.m. PST and one at 1:53 p.m. PST (Berg and Baker, 1963). There appears to be some confusion in the various anecdotal sources as to which event had a maximum intensity of Modified Mercalli (MM) VII (see Table 2 for description of MM intensity scale). Research by Thenhaus (1978) uncovered the fact that a smaller event of maximum intensity MM III occurred at 9 a.m. and was probably located near Cascades, Washington, because it was not reported as felt elsewhere. The second earthquake, at 1:53 p.m., occurred near Portland, where it caused chimneys to break (MM VII). It was also felt in a number of towns around Portland (e.g., Marshfield) and as far north as Puget Sound (Figure 2). Based on the isoseismal map developed by Thenhaus (1978), the total felt area is estimated to be 41,250 km^2.



12 October 1877 M_L 4¾ | 29 December 1941 M_L 4½

Figure 2. Isoseismal maps for the 1877 and 1941 earthquakes. Asterisk indicates instrumentally determined epicenter.

Table 2. *Abridged Modified Mercalli (MM) intensity scale. Equivalent Rossi-Forel (RF) intensities in parentheses.*

I	Not felt except by a few under especially favorable circumstances. (RF I).
II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (RF I to II).
III	Felt quite noticeably indoors, especially on upper floor of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (RF III).
IV	Felt indoors by many, outdoors by few during the day. Some awakened at night. Dishes, windows, door disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (RF IV to V).
V	Felt by nearly everyone, many awakened. Some dishes, windows, and other fragile objects broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (RF V to VI).
VI	Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight. (RF VI to VII).
VII	Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-Ebuilt ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars. (RF VIII).
VIII	Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel wall thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water levels. Persons driving cars disturbed. (RF VIII + to IX).
IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings; with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (RF IX +).
X	Some well-built structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks. (RF X).
XI	Few, if any, [masonry] structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.
XII	Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

Averaging the estimated magnitudes from the various felt area relationships indicates that the 1877 earthquake probably was about a M_L 5¼ event (Table 3). For comparison, the M_L 5.5 Portland earthquake of 1962 was felt in Seattle with an intensity of MM IV, whereas the 1877 earthquake was felt only in the southern Puget Sound with an intensity of MM II. The less severe damage reported for the 1877 earthquake supports the conclusion that the 1877 earthquake had a smaller magnitude than the 1962 event.

1892 earthquake

At 8:30 p.m. PST on February 3, 1892, a "severe" earthquake (MM VI) (Townley and Allen, 1939) caused brick buildings to sway and windows to rattle in Portland, terrifying people inside (Holden, 1898) (Figure 1). The motion was reported as lasting 30 seconds and as being the most severe shock ever felt in Portland, although this is puzzling, given the observations of the 1877 event. As far as is known, no major damage occurred. In Astoria, the earthquake lasted 3 seconds, causing houses to shake. It was felt as a light shock as far west as the Yaquina Head lighthouse on the Oregon coast. The earthquake was felt over an area of more than 26,000 km^2 (Coffman and others, 1982), although no known isoseismal map has been developed. Based on this felt area, a poorly constrained value of a M_L 5 is estimated (Table 3).

1896 earthquake

The inhabitants of McMinnville were awakened at 3:17 a.m. PST on April 2, 1896, by an earthquake of maximum intensity MM VI, accompanied by a loud rumbling noise and followed by two or three distinct shocks in rapid succession (Townley and Allen, 1939). The earthquake was felt in Portland at about 3:20 a.m. PST as a single shock of brief duration and was also felt as far south as Salem. The earthquake was felt over an area of about 2,600 km^2 (Coffman and others, 1982) and is thought to have occurred close to McMinnville (Figure 1), which was the location of the greatest felt intensity (Berg and Baker, 1963). We estimate a M_L 4 for this earthquake, because we believe the felt area may be somewhat underestimated (Table 3).

1930 earthquake

On July 19, 1930, at 6:38 p.m. PST, an earthquake of intensity MM V–VI (Coffman and others, 1982) occurred near Perrydale, Oregon, a town about 20 km northwest of Salem (Figure 1). Plaster cracked and windows rattled at McCoy (Neumann and Bodle, 1932), and the roadbed was cracked 0.8 km west of Perrydale. A smaller foreshock occurred in the same area on July 8 at 12:30 p.m. PST but with a maximum intensity of only MM III. Although no felt area has been estimated for the larger earthquake, reports of localized damage indicate a magnitude of at least M_L 4 (Table 3).

1941 earthquake

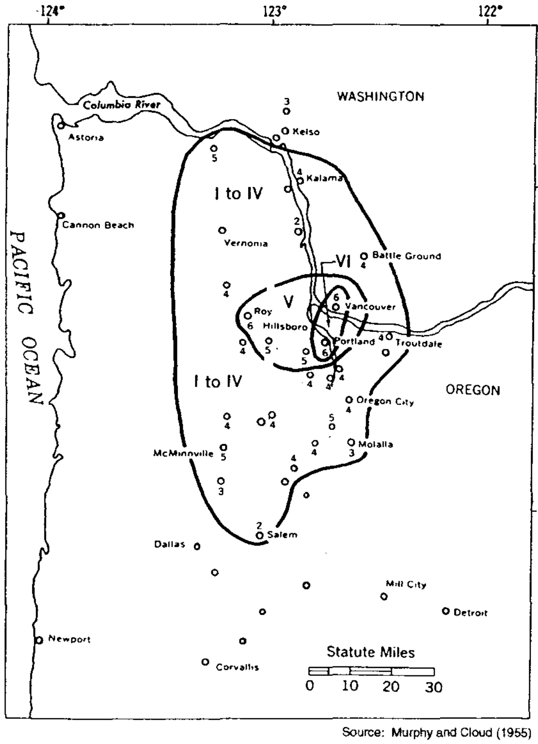
A strong earthquake was felt by most residents of Portland on December 29, 1941, at 10:37 a.m. PST (Figure 2). Small objects were displaced, and some trees and bushes were shaken (Neumann, 1943). Display windows shattered, and plaster cracked in Hillsboro and Sherwood. The earthquake caused chimneys to crack, vases to overturn, trees to shake and a school bell to ring in Yamhill, frightening many people (Neumann, 1943). Intensity MM VI effects were also felt in Vancouver and Woodland, Washington, where plaster cracked, vases overturned, and small objects moved. The felt area is estimated to be about 9,000 km^2, although this value is not well constrained. The epicenter is assigned to the Portland area, the location of the maximum intensity (Figure 1). Based on the size of the felt area, the earthquake appears to be about M_L 4½ (Table 3).

1953 earthquake

Coffman and others (1982) report that an earthquake of intensity MM VI occurred in northwest Oregon on December 15, 1953, and was felt over an area of about 8,000 km^2 (Figures 1 and 3). Slight damage was sustained in Portland and Roy, Oregon, and in Vancouver, Washington. The earthquake occurred sometime just before 8:32 p.m. PST on December 15, the time the earthquake was instrumentally recorded in Corvallis. In Portland, it was generally felt, frightening many people, cracking plaster, and causing objects and dishes to fall (Murphy and Cloud, 1955). Murphy and Cloud (1955) report one cracked chimney, slight damage to a tile fireplace, and cracks at the juncture between a one-story building and the abutting apartments. The location of this event is well constrained by the isoseismal map (Figure 3), which shows the maximum intensity within a small zone between Vancouver and Portland. Calculations of magnitude from the felt area suggest this earthquake to be about M_L 4½ (Table 3).

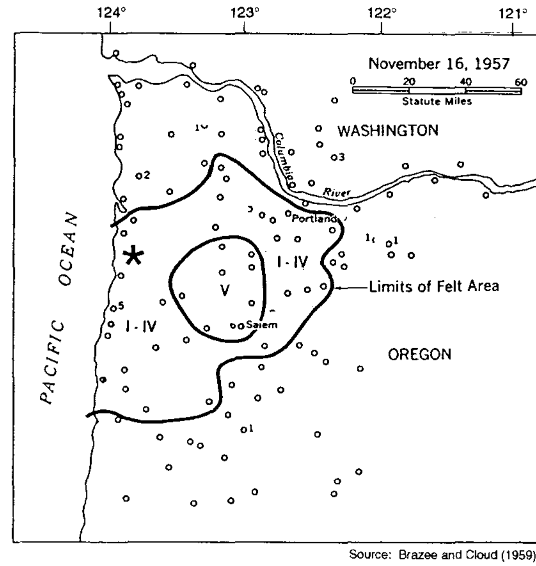
1957 earthquake

On November 16, 1957, at 10:00 p.m. PST, an earthquake shook the area just northwest of Salem (Brazee and Cloud, 1959) (Figure 4). The instrumental (i.e., instrumentally determined) location reported in Coffman and others (1982) lies about 80 km northwest of Salem, 60 km further west than the felt epicenter would suggest (Figure 1). This large discrepancy may be due to a



15 December 1953 M_L 4½

Figure 3. Isoseismal map for the 1953 earthquake.



16 November 1957 M_L 4½

Figure 4. Isoseismal maps for the 1957 earthquake. Asterisk indicates instrumentally determined epicenter.

bias in the population distribution or site-response effects in the Willamette Valley area around Salem. Similarly, strong ground shaking occurred in the Salem area in the recent Scotts Mills earthquake, as typified by the damage to the State Capitol building, although the epicenter lay about 32 km to the east. Most people in Salem were frightened by the 1957 earthquake, where the highest intensity is reported (MM VI) (Figure 4). However, only slight damage, consisting of cracked walls and plaster, was reported in the western part of Salem (Brazee and Cloud, 1959). Momentary power outages were reported, including a television blackout. Some people felt a single sharp, blast-like jolt, while others said the vibrations lasted for several seconds. The magnitude, based on the felt area of 13,600 km^2 assumed for this event (Figure 4), is estimated to be about M_L 4½ (Table 3).

August 18, 1961, earthquake

At 8:46 p.m. PST, on August 18, 1961, a maximum intensity MM VI earthquake was felt in and around the towns of Lebanon and Albany south of Salem (cover illustration). This earthquake was felt over an area of 18,300 km^2 from southwest Lane County in Oregon to Cowlitz County in Washington. The instrumental location is approximately 40 km northeast of the location of the maximum intensity (cover illustration), where chimneys toppled, windows broke, traffic lights and signs fell, and plaster cracked. The instrumental (i.e., instrumentally determined) magnitude assigned to this earthquake is M 4.5 (unspecified magnitude scale) by Cal Tech in Pasadena, California, and a coda duration magnitude (M_D) 3.9 as measured at the Longmire station (T. Yelin, U.S. Geological Survey, personal communication, 1993). The available data show a large felt area trending north-south, but the east-west extent is difficult to constrain. The magnitude of the event from limited felt information suggests a M_L 4½ (Table 3).

September 15/17, 1961, earthquakes

Two moderate earthquakes occurred on September 15 and 17, 1962, approximately in the same vicinity near Siouxon Peak in southwestern Washington. The maximum intensities and felt areas are MM VI and 22,000 km^2, and MM VI and 24,300 km^2, respectively (cover illustration and Table 3). The first event occurred at 7:25 p.m. PST near Cougar, Washington, in Gifford Pinchot National Forest. The event was felt by and frightened many people, and the shock lasted 20 seconds. Small objects were overturned, and hanging objects swung east-west (Lander and Cloud, 1963). Several aftershocks that were felt followed the first event.

The September 17 earthquake, the larger of the two events, occurred at 7:56 a.m. PST. Instrumental magnitudes for the two principal earthquakes on September 15 and 17 are M_L 4.8 and M_L 5.1, respectively, determined from the Wood-Anderson seismograph operated by the University of California at Berkeley (UCB) in Arcata, California (Grant and Weaver, 1986) (Table 3). The epicenter of the larger event was southeast of Cougar (cover illustration), where the shaking lasted 20 seconds, and most observers felt it and heard moderate earthquake noises. A house shifted 2.5 cm on its foundations in North Bonneville, Washington. In Stevenson, Washington, there was slight damage to chimneys, cement foundations cracked, a woodstove moved 15 cm, and plate glass "rippled like a flag" (Lander and Cloud, 1963). In Latourell, Oregon, some cracks were found in a heavy cement basement foundation. Booming noises were heard at Yale Dam and Washougal, Washington. Grant and Weaver (1986) suggest that this earthquake occurred within the Mount St. Helens seismic zone.

November 6, 1961, earthquake

At 5:29 p.m. PST on November 6, 1961, an earthquake was widely felt over an area of 23,000 km^2 in northwest Oregon and southwest Washington (cover illustration). There is some uncertainty in the instrumental location of this earthquake. However, an aftershock of maximum intensity MM V on November 7 at 1:30 p.m. was felt principally in the Portland area, where china clinked, pictures tilted, and a television set slid across the floor. The location of the aftershock suggests that the main shock may have occurred closer to Portland than the instrumental locations would indicate (cover illustration and Figure 1).

During the main shock, minor cracking of plaster appeared to be the principal damage (Lander and Cloud, 1963). Some people reported that this event was the sharpest shock felt in Portland since the body-wave magnitude (m_b) 7.1 earthquake of April 13, 1949, that was centered around Olympia, caused $25 million in damage, and killed eight people. The 1961 earthquake caused a brick chimney to fall, plaster to crack, interior lights to break, door frames to jam, and a water fountain in Portland to spring a leak (Lander and Cloud, 1963). Groceries were thrown from shelves in a grocery store, and windows rippled. People reported noises from several directions. In nearby Glenwood, Washington County, the earthquake was felt by all in the community. Concrete foundation blocks broke, loud rumbling noises like a truck passing by were heard, and a porch roof under repair fell down (Lander and Cloud, 1963).

A magnitude of M_D 4.5 has been estimated from the Longmire station (T. Yelin, U.S. Geological Survey, personal communication, 1993); however, Grant and Weaver (1986) note that Longmire magnitudes tend to overestimate the actual value by several tenths of a magnitude unit. Based on the felt area, we estimate a M_L 5 for the 1961 event (Table 3).

1962 earthquake

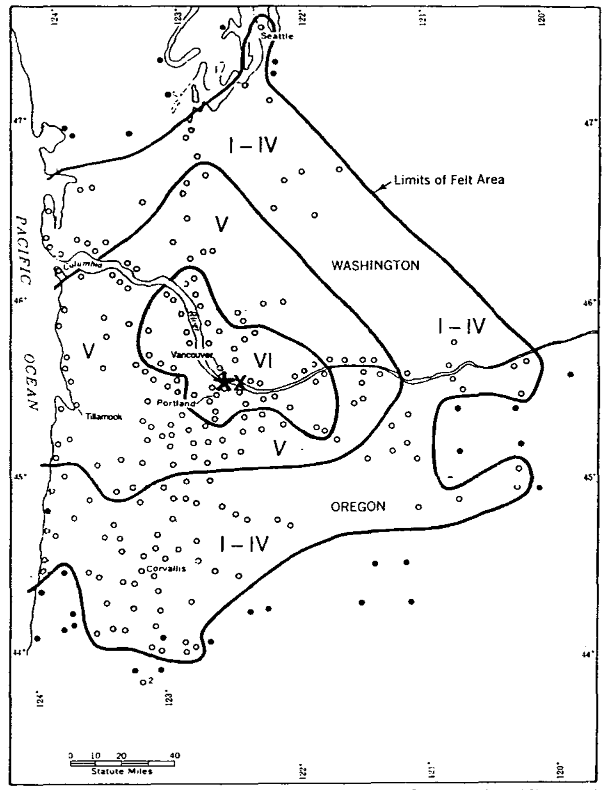
Until the recent Scotts Mills earthquake, the largest event in historical times in the Portland region occurred at 7:36 p.m. PST on November 5, 1962, with a maximum intensity of MM VII (Coffman and others, 1982) (Figure 1). Numerous chimneys cracked or fell down, windows broke, and plaster cracked in Portland (Dehlinger and Berg, 1962). Six light fixtures fell in a grocery store, and the newsroom located on the fourth floor of the *Journal* Building sustained cracks (Lander and Cloud, 1964). No damage to utilities occurred, but the upsurge of telephone use after the earthquake caused a temporary disruption of service in some areas. A crack 7 m long and 4 cm wide appeared on a road between Tillamook and Oceanside, Oregon (Lander and Cloud, 1964). In Vancouver, Washington, a large chandelier fell, and a jail elevator was put out of service. Numerous aftershocks occurred, but none were large enough to be felt in Portland.

The magnitude of this earthquake has been variously estimated as M 4¾ (UCB-Berkeley, probably M_L), M_L 5 (Dehlinger and others, 1963), M_L 5½ (UCB-Arcata), and more recently as M_D 4.9 and M_L 5.2 (Yelin, 1990) and M_W 5.2 (Yelin and Patton, 1991) (Table 3). It was felt over a wide area (estimated as 52,400 km^2 from Coffman and others [1982] and 70,000 km^2 in this study) (Figure 5). Our magnitude estimate based on the felt area is M_L 5½ (Table 3). Peak ground accelerations of 0.076 *g* (vertical) and 0.103 *g and 0.096 g (horizontal) were measured at a the U.S. Coast and Geodetic Survey strong motion seismograph in the former State Office Building in downtown Portland (Dehlinger and others, 1963). Dehlinger and others (1963) located this event at a depth of 15–20 km, although this value is not well constrained.*

In a more recent study of earthquakes in the Portland area, Yelin and Patton (1991) relocated this event to 15 km northeast of downtown Portland, just east of the original epicentral location of Dehlinger and others (1963), and to a depth of 16 km (Figure 5).

1963 earthquake

At 6:36 p.m. PST on December 26, 1963, an earthquake was felt with a maximum intensity of MM VI in northwestern Oregon (von Hake and Cloud, 1965). This earthquake was felt over an area of only 10,700 km^2 (Figure 6), and damage was slight. Plaster cracked in a few places, and books and pictures fell in North Plains and Timber, Oregon, and Toutle, Washington. In Tillamook, Oregon, a car swayed and went to the opposite side of the highway before being controlled. The isoseismal map for this earthquake (Figure 6) is not well constrained due to differing intensity reports in closely spaced



Source: Lander and Cloud (1964)

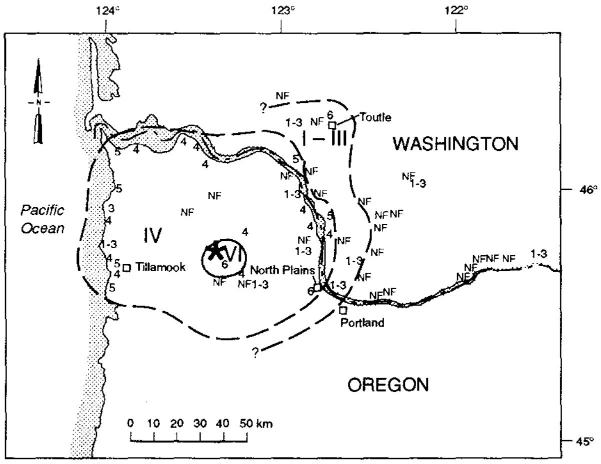
5 November 1962 M_L 5.5

Figure 5. Isoseismal map for the 1962 earthquake. Asterisk indicates instrumentally determined epicenter.

locations—possibly an indication that varied site conditions played a major role in ground motions. The instrumental location, however, agrees well with the area of maximum intensities northwest of Portland (Figures 1 and 6). A magnitude of M_D 4.1 (Longmire) and m_b 4.5 (NOAA) have been instrumentally determined (Table 3). The calculated magnitude from the felt area is M_L 4½.

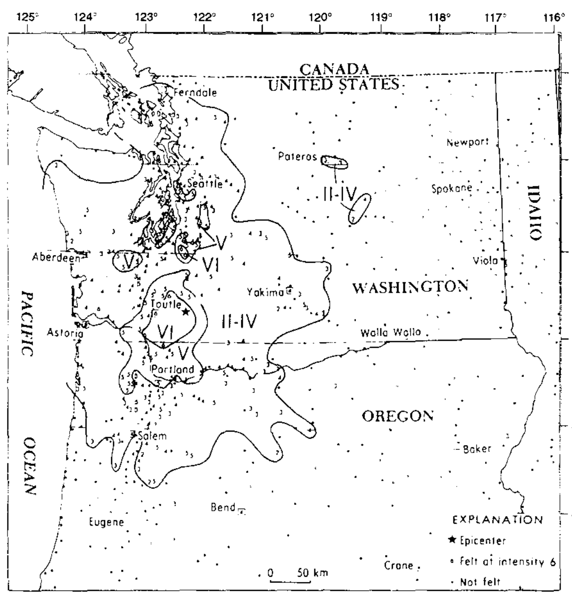
1981 earthquake

The 1981 Elk Lake, Washington, earthquake, the largest known earthquake associated with the St. Helens seismic zone, occurred at 10:09 p.m. PST on February 13, 1981. The earthquake, with magnitudes m_b 5.1, M_S (surface-wave magnitude) 4.8, M_L 5.5, and M_D 5.2 (Stover, 1984), was felt over an area of 104,000 km^2 (Figure 7 and Table 3). Maximum intensities of MM VI were felt around the epicentral region. Damage was reported as foundation and plaster cracks, overturned furniture, broken glasses and dishes, and a few cracked windows. In Ariel, the sidewalk cracked and in Graham, seiches (earthquake-generated waves) occurred in lakes and swimming pools, and chimneys were cracked (Stover, 1984). In Kidd Valley, pottery was broken and 300 maps fell to the floor in the Antique Shed store (Stover, 1984). The main shock was preceded nine months earlier by a swarm of earthquakes that occurred over a two-month period (Grant and others, 1984). The locations of about 1,000 aftershocks delineate a north-northwest-trending, right-lateral, strike-slip fault zone, 6 km long, 3 km wide, and extending from 5 to 12 km in depth (Grant and others, 1984). At least six aftershocks of M_L 2.9 to 3.6 were felt in Kidd Valley, 13 km east of Toutle, that night and the following day. The largest aftershock was felt as far south as Vancouver.



27 December 1963 M_D 5.0

Figure 6. Isoseismal map for the 1963 earthquake. Asterisk indicates instrumentally determined epicenter.



13 February 1981 M_L 5.5

Figure 7. Isoseismal map for the 1981 earthquake.

Other significant earthquakes

Portland has been the site of several smaller earthquakes of interest. One earthquake occurred on January 27, 1968, at 12:28 a.m. PST, in the Portland area. This was the first large event since the damaging November 5, 1962, earthquake (Heinrichs and Pietrafesa, 1968). Heinrichs and Pietrafesa (1968) estimate the magnitude to be M_L 3.7 and the depth of focus to be at 20 to 24 km. Their epicenter places this earthquake south of the Columbia River in the eastern Portland area (Figure 1).

Another earthquake occurred on May 13, 1968, at 10:52 a.m. PST, and its epicenter is located between northeast Portland and the Columbia River. The instrumentally determined value of M_L 3.8 for the event is from the Blue Mountains Observatory. The focal depth is thought to be around 4–12 km (Couch and others, 1968), although it is not well constrained due to lack of adequate seismographic coverage. A maximum intensity of MM IV was felt in Portland. The earthquake caused windows to rattle and hanging objects to swing, but no damage was reported. This earthquake occurred in the vicinity of the November 5, 1962, and the January 27, 1968, events (Figure 1).

Other moderate-sized earthquakes in the Portland region include the following:

- A MM V on August 4, 1959, 21 km northeast of Portland (Figure 1), which was felt over an area of 1,570 km^2. In Portland, the event caused swaying motion, and a few objects were displaced (Eppley and Cloud, 1961). Based on the felt area, the magnitude for this earthquake, estimated to be M_L 4.7 by the Canadian seismographic network, appears to be significantly overestimated.
- A m_b 4.6 event on March 7, 1963, which occurred west of Salem but was felt from Portland to Eugene (von Hake and Cloud, 1965). Damage was limited to slightly cracked plaster and broken dishes in Salem.
- A M_D 3.5 (Longmire) earthquake on January 26, 1964, near Merrill Lake, Washington (von Hake and Cloud, 1966). The event was felt over an area of 5,000 km^2 but only made windows and dishes rattle.
- A M_D 4.1 (Longmire) (MM V) event on October 1, 1964, 9 km east of Cougar (von Hake and Cloud, 1966). Many people were awakened in Portland, and windows and doors rattled.
- A m_b 4.3 (MM V) event on November 30, 1968, in Lewis County, Washington, that was felt over an area of 2,600 km^2 (Coffman and Cloud, 1970).

EARTHQUAKE RECURRENCE

The recurrence or frequency of occurrence for earthquakes in a given magnitude range in a specific region can be estimated on the basis of the Gutenberg-Richter relationship developed for that region. We have estimated this relationship for the Portland region, using our revised historical earthquake record and following the maximum-likelihood procedure developed by Weichert (1980). The earthquake record was corrected for incompleteness, and dependent events (foreshocks and aftershocks) were deleted. All event magnitudes were converted to equivalent M_L values.

Assuming the usual form of the Gutenberg-Richter relationship of $\log N = a-bM$, the recurrence parameters of b and a of 0.84±0.07 and 2.55, respectively, were estimated for the Portland region. This recurrence results in a return period for earthquakes of M_L 6 and greater of about 325 years, with the uncertainty in this value being at least several decades. For M_L 5.5 and greater, the return period of 100 to 150 years is consistent with the occurrence of the 1962 Portland and 1993 Scotts Mills earthquakes in the 150-year historical period. For M_L 6.5 and greater earthquakes, the return period is estimated to be approximately 800–900 years.

CONCLUSIONS

In the relatively brief historical record for northwestern Oregon and southwestern Washington, a large number of moderate-sized earthquakes up to M_L 5.6 have shaken the Portland region and sometimes caused damage. In view of the tectonic and geologic setting of the Portland region astride the Cascadia subduction zone, however, the occurrence of earthquakes as large as M_L 6½ or larger, which have not been experienced in historic times, also seems quite possible. The historical record suggests that such events may occur in the Portland region every few hundred years. It would seem prudent that residents as well as the engineering community and government agencies take the proper steps to mitigate the hazards that will be posed by such probably damaging earthquakes.

Table 3. *Significant historical earthquakes in the Portland region, showing areas for three MM intensity zones* ($A_{I\text{-}V\text{-}VI}$), *magnitudes calculated from each area* (M_{A_I}, *etc.*), *average* (M_{ave}), *and best estimate* (M_{FA}) *magnitudes. Recording source abbreviations: UCB = University of California-Berkeley; UW = University of Washington; NOAA = National Oceanic and Atmospheric Administration*

Earthquake	Maximum intensity	A_I (km^2)	A_V (km^2)	A_{VI} (km^2)	M_{A_I}	M_{A_V}	$M_{A_{VI}}$	M_{ave}	M_{FA}	Instrumental magnitude (recording station or source)
October 12, 1877	VII	41,250	2,875	125	5.2	4.6	4.3	4.7	5¼	—
February 3, 1892	V-VI	26,000	—	—	4.9	—	—	—	5	—
April 2, 1896	V	2,600	—	—	3.3	—	—	—	4	—
July 19, 1930	V-VI	—	—	—	—	—	—	—	4	—
December 29, 1941	VI	9,300*	2,143	803	4.2	4.5	5.0	4.6	4½	—
December 15, 1953	VI	10,000	1,782	341	4.3	4.4	4.7	4.5	4½	—
November 16, 1957	VI	13,600	2,476	—	4.5	4.6	—	4.55	4½	—
August 18, 1961	VI	18,300	—	—	4.6	—	—	4.6	4½	M 4.5 (Pasadena); M_D 3.9 (Longmire).
September 15, 1961	VI	22,000	3,213	—	4.8	4.7	—	4.75	4¾	M_L 4.8 (UCB-Arcata).
September 17, 1961	VI	24,300	5,125	—	4.8	4.9	—	4.85	5	M_L 5.1 (UCB-Arcata).
November 6, 1961	VI	23,000	5,656	919	4.8	5.0	5.1	5.0	5	M_D 4.5 (Longmire).
November 5, 1962	VII	70,000	29,403	6,790	5.4	5.7	5.8	5.6	5½	M_W 5.2 (Yelin and Patton, 1991); M_L 5.0 (Dehlinger and others, 1963); M_L 5.5 (UCB-Arcata).
December 26, 1963	VI	10,700	—	—	4.3	—	—	4.65	4½	M_D 4.1 (Longmire); m_b 4.5 (NOAA).
February 14, 1981	VI	104,000	15,800	1,900	5.8	5.4	5.3	5.5	5½	M_L 5.5, M_D 5.2 (UW); M_S 4.8 , m_b 5.1 (Stover, 1984).

*Felt area estimate not well constrained

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REFERENCES

Berg, J.W., and Baker, C.D., 1963, Oregon earthquakes, 1841–1958: Seismological Society of America Bulletin, v. 53, p. 95–108.

Brazee, R.J., and Cloud, W.K., 1959, United States earthquakes 1957: U.S. Department of Commerce, 108 p.

Coffman, J.L., and Cloud, W.K., 1970, United States earthquakes 1968: U.S. Department of Commerce, 111 p.

Coffman, J.L., Von Hake, C.A., and Stover, C.W., 1982, Earthquake history of the United States: National Oceanic and Atmospheric Administration and U.S. Geological Survey, Publication 41–1, with supplement, 208 p.

Couch, R.W., Johnson, S., and Gallagher, J., 1968, The Portland earthquake of May 13, 1968, and earthquake energy release in the Portland area: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 30, no. 10, p. 185–204.

Dehlinger, P., and Berg, J.W., Jr., 1962, The Portland earthquake of November 5, 1962: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 24, no. 11, p. 185–188.

Dehlinger, P., Bowen, R.G., Chiburis, E.F., and Westphal, W.H., 1963, Investigations of the earthquake of November 5, 1962, north of Portland: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 25, no. 4, p. 53–68.

Eppley, R.A., and Cloud, W.K., 1961, United States Earthquakes, 1959: U.S. Department of Commerce, 115 p.

Grant, W.C., and Weaver, C.S., 1986, Earthquakes near Swift Reservoir, Washington, 1958–1963: Seismicity along the southern St. Helens seismic zone: Seismological Society of America Bulletin, v. 76, p. 1573–1587.

Grant, W.C., Weaver, C.S., and Zollweg, J.E., 1984, The 14 February 1981 Elk Lake, Washington, earthquake sequence: Seismological Society of America Bulletin, v. 74, p. 1289–1309.

Heinrichs, D.F., and Pietrafesa, L.J., 1968, The Portland earthquake of January 27, 1968: Oregon Department of Geology and Mineral Industries, Ore Bin, v. 30, no. 2, p. 37–40.

Holden, E.S., 1898, A catalogue of earthquakes on the Pacific Coast, 1769 to 1897: Smithsonian Miscellaneous Collections, no. 1087, p. 24–27, 31–253.

Lander, J.F., and Cloud, W.K., 1963, United States earthquakes 1961: U.S. Department of Commerce, 106 p.

———1964, United States earthquakes 1962: U.S. Department of Commerce, 114 p.

Murphy, L.M., and Cloud, W.K., 1955, United States earthquakes 1953: U.S. Department of Commerce, 51 p.

Neumann, F., 1943, United States earthquakes, 1941: U.S. Department of Commerce, 69 p.

Neumann, F., and Bodle, R.R., 1932, United States earthquakes 1930: U.S. Department of Commerce, 25 p.

Singh, S., and Herrmann, R.B., 1983, Regionalization of crustal coda Q in the continental U.S.: Journal of Geophysical Research, v. 88, p. 527–538.

Stover, C.W., 1984, United States Earthquakes 1981: U.S. Department of Commerce, 123 p.

Thenhaus, P.C., 1978, A study of the October 12, 1877, Oregon earthquakes: U.S. Geological Survey Open-File Report 78–234, 14 p.

Toppozada, T.R., 1975, Earthquake magnitude as a function of intensity data in California and western Nevada: Seismological Society of America Bulletin, v. 65, p. 1223–1238.

Townley, S.D., and Allen, M.W., 1939, Descriptive catalog of earthquakes of the Pacific Coast of the United States, 1769–1928: Seismological Society of America Bulletin, v. 29, p. 1–297.

Unruh, J.R., Wong, I.G., Bott, J.D.J., Silva, W.J., and Lettis, W.R., 1993, Seismotectonic evaluation Scoggins Dam, Tualatin Project: Unpublished report prepared for U.S. Bureau of Reclamation.

Von Hake, C.A., and Cloud, W.K., 1965, United States earthquakes, 1963: U.S. Department of Commerce, 69 p.

———1966, United States earthquakes 1964: U.S. Department of Commerce, 91 p.

Weichert, D.H., 1980, Estimation of the earthquake recurrence parameters for unequal observation periods for different magnitudes: Seismological Society of America Bulletin, v. 70, p. 1337–1346.

Yelin, T.S., 1990, A revised catalog of earthquakes in Washington State and northern Oregon, 1960–1969, with comments on spatial and temporal seismicity patterns, 1960–1990: Unpublished manuscript.

Yelin, T.S., and Patton, H.J., 1991, Seismotectonics of the Portland, Oregon, region: Seismological Society of America Bulletin, v. 81, p. 109–130. □

To our readers

Because of the length of the articles, this issue has been expanded from the usual 24 pages to 28 pages. As a result, we shall publish one of our later issues with 20 pages. *—ed.*

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