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Geologic Evidence of Historic and Prehistoric Tsunami Inundation at Seaside, Oregon

Brooke K. Fiedorowicz
Portland State University

THESIS APPROVAL

The abstract and thesis of Brooke K. Fiedorowicz for the Master of Science in Geology presented June 5, 1997, and accepted by the thesis committee and the department.

COMMITTEE APPROVALS: [redacted]

Curt D. Peterson, Chair

[redacted]

Richard E. Thoms

[redacted]

Ansel G. Johnson

[redacted]

Daniel M. Johnson
Representative of the Office of Graduate Studies

DEPARTMENTAL APPROVAL: [redacted]

Marvin H. Beeson, Chair
Department of Geology

* *

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Abstract

An abstract of the thesis of Brooke K. Fiedorowicz for the Master of Science in Geology presented June 5, 1997.

Title: Geologic Evidence of Historic and Prehistoric Tsunami Inundation at Seaside, Oregon

Over the past decade, research conducted along the Cascadia subduction zone coast established evidence for coseismic subsidence, liquefaction, and nearfield tsunami deposition. Seaside is a low lying northern Oregon coastal city potentially at risk for nearfield tsunami inundation from a Cascadia earthquake. The 1964 Alaskan farfield tsunami impacted Seaside, and deposits from that event serve as a model for interpreting prehistoric tsunami deposits in the Seaside area.

A reconnaissance subsurface study of potential tsunami inundation sites was performed by trenching and gouge coring in the coastal wetlands along the Necanicum River, Neacoxie Creek, drainage to the east of Neacoxie Creek, Stanley Lake, and Neawanna Creek. A total of 278 core sites were logged for shallow lithologic stratigraphy and contact relations.

To establish tsunami depositional trends from the 1964 farfield event, 71 observation sites, 62 core logs, two grids, and eight trenches were evaluated. Wave amplification occurred in the Necanicum River/estuary mouth and north of 12th Avenue, south of the G Street bridge crossing Neacoxie Creek, and south of the HWY.

101 bridge crossing Neawanna Creek. These areas contain anomalously thick sand deposits compared to the deposits along the Necanicum River and Neawanna Creek where the wave attenuated, depositing a sand layer thinning up stream.

Neawanna Creek wetlands contain most of the preserved 1700 AD earthquake subsidence horizons and sand layers. Within the Seaside wetlands, 90 core sites contain the 1700 AD subsidence horizon. No subsided peaty horizons were observed west of Neawanna Creek. At the Mill Creek/Stanley Lake area, the 1700 AD tsunami deposition is minimal to non-existent. In the southernmost Neawanna wetlands, 1700 AD tsunami deposits are restricted to a narrow zone southeast of the Mill Ponds and north of S Avenue bridge.

Overland inundation of the 1700 AD tsunami, interpreted from core records, did not reach the central Neawanna wetlands (<1.5 km east of the present coastline) and crossed a narrow cobble ridge entering the Neawanna wetlands from a southern Necanicum channel.

GEOLOGIC EVIDENCE OF HISTORIC AND PREHISTORIC TSUNAMI INUNDATION AT SEASIDE, OREGON.

by

BROOKE K. FIEDOROWICZ

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The road to a completed master's thesis is a long, arduous process with many people involved. Oregon Department of Geology and Mineral Industries (DOGAMI) intergovernmental agreement contract #4110002 administered by George Priest and the Office of Naval Research, U. S. government prime contract #N600014-96-1-0893 administered by the Oregon Graduate Institute supported the research for this thesis. However, without the reasoning, assistance, and push from my primary advisor, Curt Peterson, the actual thesis process would still be continuing. He also took the time to understand a midwesterner and introduce her to the way of the waves.

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Introduction

Subduction zone earthquakes (Mw 8-9) along the Pacific Northwest region of North America (Figure 1) result from the dislocation of the Cascadia megathrust between the subducting Juan de Fuca oceanic plate and the overriding North American continental plate (Heaton and Kanamori, 1984). Coseismic uplift or subsidence of the ocean floor during a megathrust earthquake produces a vertical displacement of the water column, resulting in tsunami propagation (Atwater, 1987; Darienzo and Peterson, 1990). The Cascadia subduction zone extends from southern British Columbia to northern California, making the adjacent Pacific coast and major population centers susceptible to severe earthquakes and potentially disastrous tsunami.

Seaside, Oregon, a northern Oregon coastal community (Figure 2), has the potential to be substantially impacted by a megathrust earthquake and subsequent tsunami. The elevation of Seaside ranges from four meters at the ocean waterfront to eight meters at the base of the foothills, which bounds the beach plain to the east. The population vastly increases from the 6,000 permanent residents to 60,000 tourists during peak summer weekends. Many hotels and tourist accommodations are set near beachfront property.

Seaside suffered significant damage from a farfield tsunami (March 27, 1964) that was generated by a subduction zone earthquake focused near northern Prince William Sound, Alaska (NAS, 1971,1972; Griffin, 1984). Seaside's city council estimated $46,000 worth of damage (at 1964 costs) to the city's property along the Necanicum

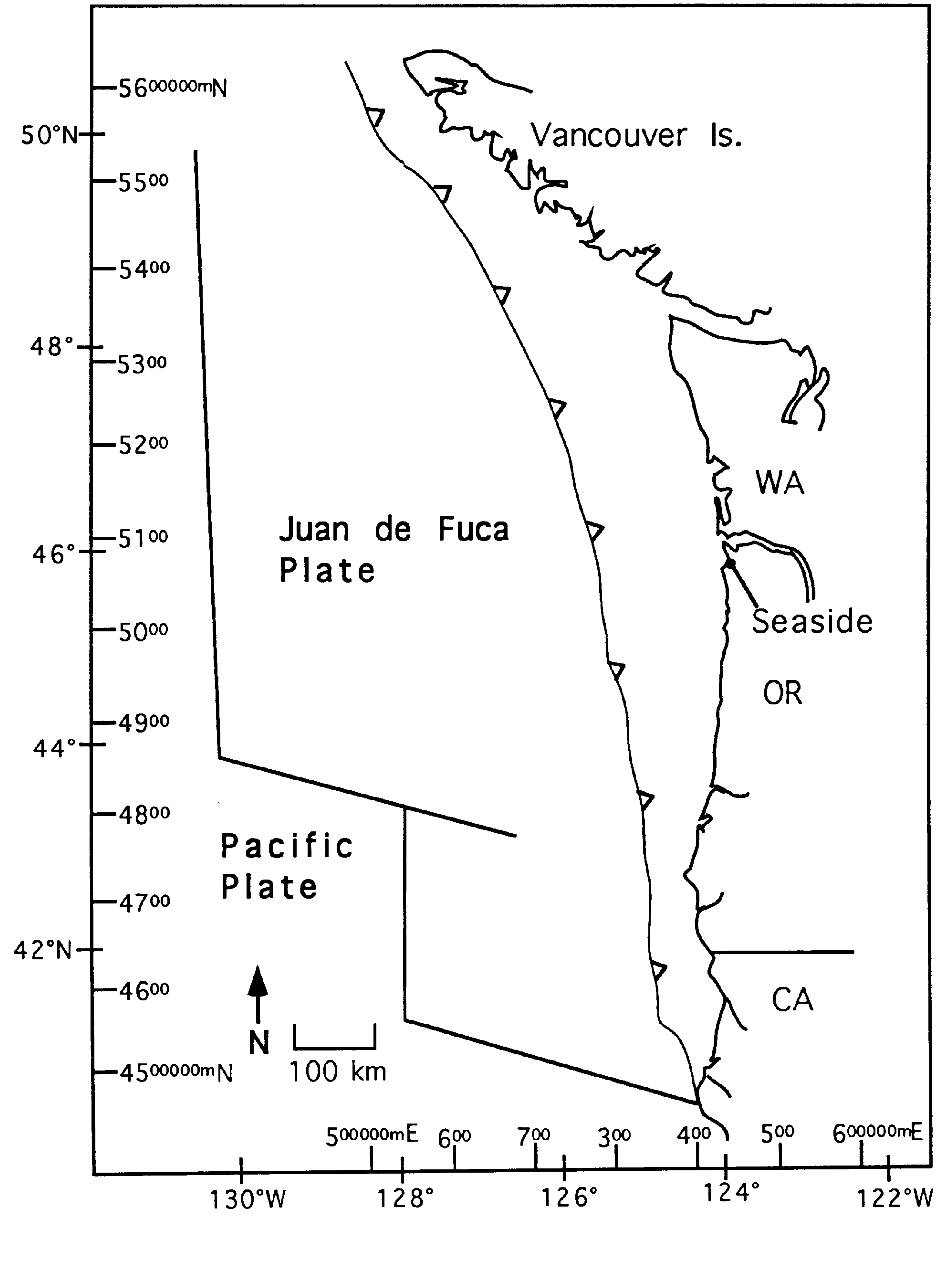


Figure 1. Cascadia subduction zone and plate configuration. Triangles on the solid line represents the trench between the descending oceanic plates and the over-riding North American plate. Straight line segments west of the trench represent the spreading ridge and transform faults.

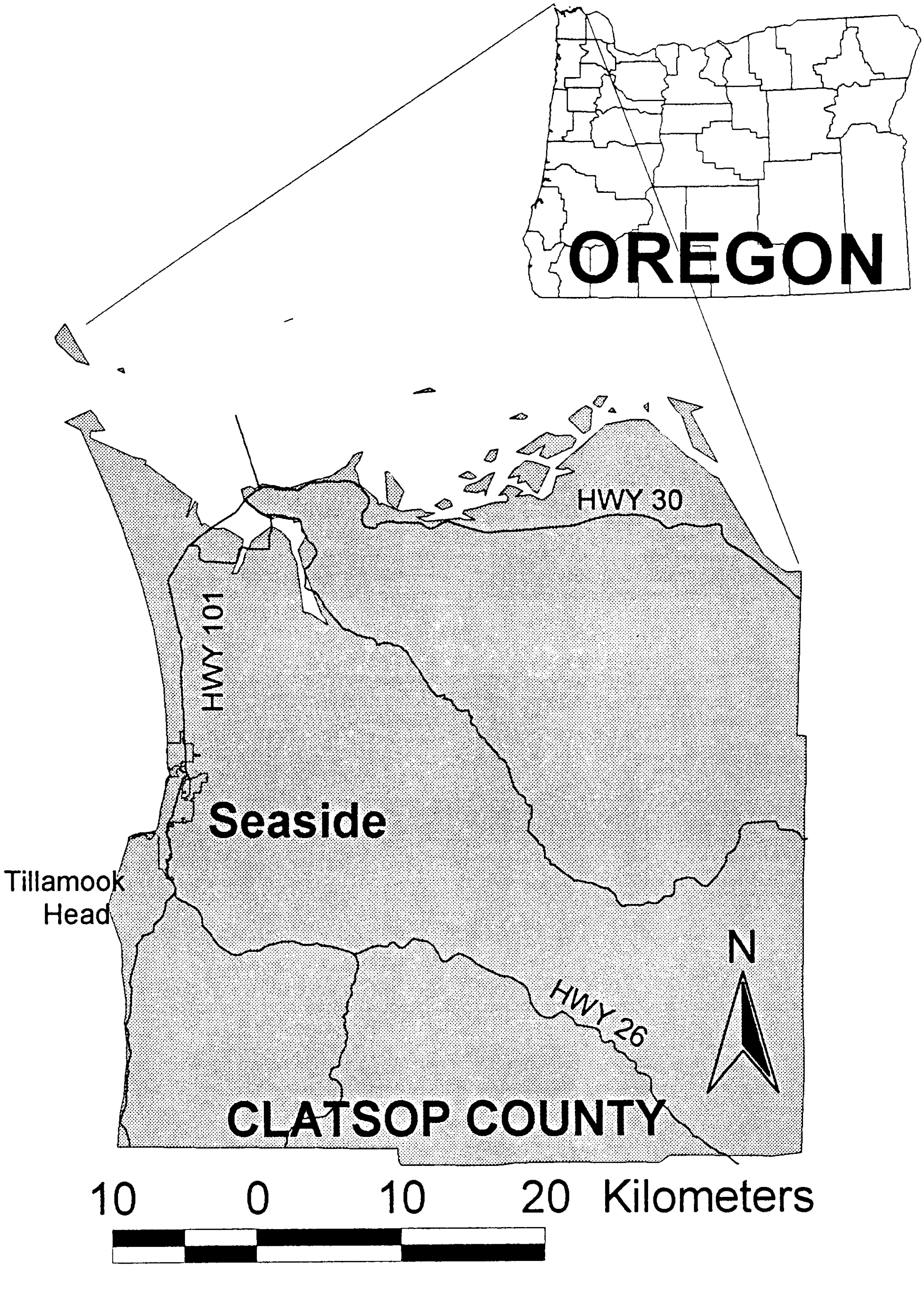


Figure 2. Study area location of Seaside, Oregon.

River, Venice Beach, and shoreline (*Seaside Signal*, April 2, 1964), and $235,000 damage to private property along the Necanicum and Neawanna channels (Lander and others, 1993). Exceptional tsunami damage at Seaside relative to other coastal Oregon communities might have resulted from local amplification, as reported for Port Alberni, British Columbia and Crescent City, California (Griffin, 1984; Lander and others, 1993; Clague and others, 1994).

Nearfield paleotsunami evidence has been found in the coastal wetlands of Seaside (Darienzo, 1991; Darienzo and others, 1993). Evidence for nearfield paleotsunami inundation in Seaside and other backbarrier tidal wetland sites in northern Oregon consists of thin sand layers located between underlying muddy peats and overlying rooted muds. A three step process produces this peat and sand combination. First, coseismic subsidence occurs, associated with dislocation of the megathrust. Second, the tsunami wave washes over the wetlands and deposits the entrained sand. Finally, intertidal mud, then peat covers the deposited sand.

Several computer models have been developed to predict possible runup from a nearfield (Cascadia) tsunami inundating the Seaside area (Whitmore, 1993; Myers, 1994). Geologic evidence of nearfield tsunami inundation is needed to verify and calibrate these computer simulations.

Increasing government and public attention is now being focused on mitigation of potential tsunami runup in the Pacific Northwest coast. The Department of Oregon Geology and Mineral Industries (DOGAMI) has produced coarse-scale inundation maps of the entire Oregon coast (Priest, 1995). Myers (in progress) is creating new computer models for both Cascadia subduction zone tsunami and the 1964 Alaskan tsunami runup in Seaside and adjacent coastal areas. Several coastal towns are developing tsunami evacuation routes (Visher, 1995).

This study focuses on the geologic evidence of tsunami inundation in Seaside, Oregon. Specifically, historic 1964 and prehistoric 1700 AD events are analyzed. Results presented in this study include logs of shallow cores taken throughout the coastal wetlands of Seaside that record evidence of deposition from historic and prehistoric tsunami. Analysis of these cores includes the determination of lithostratigraphy, sedimentary structures, radiocarbon age, and microfossil paleotidal indicators. The results of these analyses are used to map nearfield paleotsunami inundation in the Seaside wetlands. The inundation maps also address potential mechanisms of maximum inundation, for example, channel surge or barrier overtopping in Seaside.

Background

Tsunami Generation in Subduction Zones

Interactions between the Pacific plate and the continental plates surrounding it cause the entire Pacific rim to be tectonically active. Two results of this tectonism are volcanoes and earthquakes. Earthquakes in excess of Mw 8 (called great earthquakes) may result in a large vertical displacement of water generated by sudden uplift or subsidence of the ocean floor and/or sudden coseismic subsidence of adjacent coastal land (Lander and others, 1993; Ingmanson and Wallace, 1995). Coseismic subsidence occurs from the release of convergent tectonic strain accumulated in the coastal margin of the continental plate. When the oceanic plate slips under the continental plate during a coseismic dislocation of the megathrust, the strain is released by 1) regional subsidence landward of the zero-isobase, 2) regional uplift seaward of the zero-isobase, and 3) local uplift or subsidence associated with faulting in the upper plates (Plafker, 1972; Heaton and Hartzell, 1987; Barnett, 1997).

Once vertically displaced, the water attempts to regain equilibrium by forming long-period surge waves. These waves, called tsunami, are defined as shallow-water gravity waves traveling at a velocity, v, proportional to the square root of water depth, d, and gravitational constant, g, ($v = \sqrt{gd}$). Tsunami may have periods ranging from 6 to 60+ minutes and are capable of traveling across ocean basins and propagating along coastal margins. Amplitudes of the waves may range from a few centimeters to over 30 m depending upon the amount of vertical displacement caused by the generating event and the depth of water. Depending on near-shore bathymetry and wave momentum, the runup height of the waves on coastal land commonly exceeds the wave amplitude, and a tsunami's impact on coastal regions will be locally greater in some areas than in others (Lander and others, 1993; Myers, 1994).

Tsunami are relatively rare events, occurring on average once per year somewhere in the Pacific basin. Most of these events are small enough that they can only be distinguished from normal tides by tide gauges. Tsunami large enough to damage coastal towns occur about once every ten years somewhere on the Pacific margin. With settlement along coastal areas increasing, the frequency and amount of damage from tsunami is likely to rise. (Lander and others, 1993)

Cascadia Margin Neotectonics

Over the past decade, the Cascadia subduction zone has been recognized as a potential source of great undersea earthquakes. The geologic records of these great earthquakes, which include shaking induced liquefaction, tsunami, and subsidence, have been studied by many investigators (Heaton and Kanamori, 1984; Clague and Bobrowsky, 1994; Atwater and others, 1995; Charland and Priest, 1995, Satake and others, 1996). The megathrust earthquakes produced along the Cascadia subduction zone, which extends 1200 km from southern British Columbia to northern California, result from the subduction of the Juan de Fuca oceanic plate below the North American continental plate (Figure 1). The active Cascade volcanoes provide evidence that subduction continues below the North American plate (Wilson, 1989). Subduction occurs at an estimated rate of 4 cm/yr. (Heaton and Hartzell, 1987). Interplate earthquakes produced at the Cascadia subduction zone are so proximal to the coast that delay times, and therefore warning times, between earthquake and tsunami may be only 15-20 minutes, as opposed to farfield events with travel times of hours (Atwater and others, 1995). The Cascadia subduction zone was first identified by T. Atwater in 1970, but it was not until 1987 that B. Atwater reported evidence for coseismic subsidence and associated tsunami inundation at several southwestern Washington coastal bays.

Geologic records of paleoseismicity in the Cascadia subduction zone indicate that great earthquakes are rare events. The most recent great earthquake occurred about 1700 AD (Atwater and others, 1995). Dendrochronological records from drowned trees in the coastal wetlands of the Cascadia margin (Yamaguchi and others, 1989; Jacoby and others, 1992), and farfield tsunami runup records in Japan (Satake and others, 1996) support this estimated age of the last Cascadia event. Older geologic records suggest that recurrence intervals for Cascadia events are on the order of 200 to 600 years (Darienzo and others, 1993; Atwater and others, 1995). Peterson and others (1991) and Darienzo and Peterson (1995) estimate a 10-20 percent chance that a great earthquake producing a tsunami will occur in the next 50 years.

Historic Records of Subduction Zone Generated Tsunami

Heaton and Hartzell (1987) indicate many similarities between the Cascadia subduction zone and other subduction zones around the world, particularly those at southwestern Japan, Columbia, and southern Chile. These locations contain young oceanic lithosphere prone to large, shallow, thrust earthquakes. Large local tsunami have occurred in areas roughly analogous to the Cascadia subduction zone. Earthquakes in Japan in 1944 (Mw 8.1) and 1946 (Mw 8.1) generated local tsunami with maximum runup heights of 7.5 and 6.0 m, respectively. Columbia and northern Equador experienced an earthquake-generated tsunami in 1906 which caused extensive damage along the coastal areas. The Chilean earthquake in 1960 produced one of the largest tsunami in historic times, with damage caused not only locally but in Japan and Hawaii as well. Local runup for the Chilean earthquake reached a maximum of 20 m. However, coastal areas close to the epicenter experienced runup heights less than ten meters (Heaton and Hartzell, 1987).

Finally, runup in the Prince William Sound area for the 1964 Alaskan earthquake was 9-12 m above the prevailing low tide. The Patton Bay fault, located at the southern end of Prince William Sound, uplifted crustal blocks relative to sea level. A western block was upthrown eight meters above an eastern block. Corresponding tilting of Prince William Sound to the northwest created local amplification and seiching in fjords. Both the local faulting and local amplification substantially increased local runup above regional heights. (NAS, 1972)

Pacific Northwest Impacts

Several studies investigating coseismic subsidence and tsunami deposits have been done throughout the Pacific coast, extending the length of the Cascadia subduction zone. Atwater (1987) first introduced evidence for great subduction earthquakes in the coastal marshes of Willapa Bay, southwestern Washington where sandy layers cover three buried lowlands which are sand free deposits. These sand sheets become thinner and finer grained landward, suggesting a bayward source rather than stream flooding.

Clague and Bobrowsky (1994) describe sand deposits within peats and muds in tidal marshes on Vancouver Island, British Columbia, Canada. These areas contain both historic and prehistoric tsunami deposits. Distinguishing characteristics of these sand layers include sharp upper and lower contacts, massive sand and silty sand, and detrital wood and plant debris. Some of the prehistoric deposits imply much larger events than the 1964 Alaskan event. (Clague and Bobrowsky, 1994)

In Oregon, Peterson and others (1993) produced a field trip guide for the central Cascadia margin involving sites of paleotsunami deposits in Siletz Bay, Nestucca Bay, Netarts Bay, Cannon Beach, Seaside, and Youngs Bay (Columbia River). Netarts Bay core sections contain Cascadia earthquake evidence dating back to 3 Ka in the form of buried peats with overlying sand. The stratigraphy is considered the type section for paleoseismological evidence in the northern Oregon coast (Peterson and others, 1993). Peterson and Priest (1995) completed a reconnaissance investigation of the tidal marshes along Yaquina Bay for paleotsunami evidence. Peterson and others (1996) completed an extensive study producing a tsunami hazard map and explanation of the

Siletz Bay area. Peterson and Gallaway (in progress) have determined prehistoric nearfield tsunami inundation at Cannon Beach, Oregon.

1964 Alaskan Tsunami Impacts in Pacific Northwestern Region

Since no written record exists for prehistoric events such as the 1700 AD, studies and records of more recent tsunami events become especially significant. The current historical record for the Pacific coast consists only of farfield tsunami (Charland and Priest, 1995), chiefly the 1964 tsunami caused by a Mw 9.2 earthquake centered in the northern Prince William Sound of Alaska (NAS, 1971; Lander and others, 1993; Clague and Bobrowsky, 1994). This distal earthquake produced a Pacific wide tsunami which reached the shores of Antarctica (NAS, 1972). The most damaging inundation along the U. S. coast occurred in areas of Alaska and Crescent City, California. Landslides in Anchorage, caused the majority of the damage in Alaska, but most fatalities resulted from the tsunami runup. Out of the 115 people killed in Alaska, 106 deaths were tsunami related (NAS, 1972).

This earthquake generated tsunami of March 27, 1964 devastated the waterfront in Crescent City, California. Eye-witnesses reported surge crests of at least six meters in height. Between midnight and 2 AM on March 27th, four separate wave surges occurred. The waves carried logs and cars several hundred meters inland. The surges damaged numerous buildings along the harbor waterfront and along exposed beach ridges to the south of town. A total of 29 city blocks were hit, 289 homes and businesses damaged or destroyed, and 11 people killed. Repair costs exceeded $16 million in 1964 (Griffin, 1984).

The tsunami waves from the 1964 Alaskan earthquake crashed upon the shores of Seaside with little to no warning. According to the April 2, 1964, edition of the *Seaside Signal*, estimates of the wave height were three meters. The majority of the bridges crossing the Necanicum River suffered severe damage, and the already condemned 4th Avenue bridge was completely washed out. The waves threw automobiles against houses, a home shifted off its foundation, and appliances and furniture shifted about. Even the SP&S railroad trestle crossing near the mouth of Neawanna Creek lost all supporting pilings when the water raged past. Fortunately, no deaths or major injuries occurred.

Study Area

Seaside is a northern Oregon coastal community of roughly 6,000 permanent residents, located in Clatsop County just north of Tillamook Head and south of Astoria and the Columbia River mouth (Figure 2). The study area involves the coastal wetlands in the Seaside area including the Necanicum River, Neawanna Creek, Neacoxie Creek, and Stanley Lake (Figure 3). These wetlands extend as much as 1.5 kilometers inland from the present ocean shoreline.

Significant local amplification of the 1964 tsunami waves occurred at Port Alberni, British Columbia, Crescent City, California, and Seaside, Oregon. The entire Oregon coast felt the effects of tsunami impacts, however, Seaside received significant damage in the bay mouth areas. The physiography of Tillamook Head, the Columbia

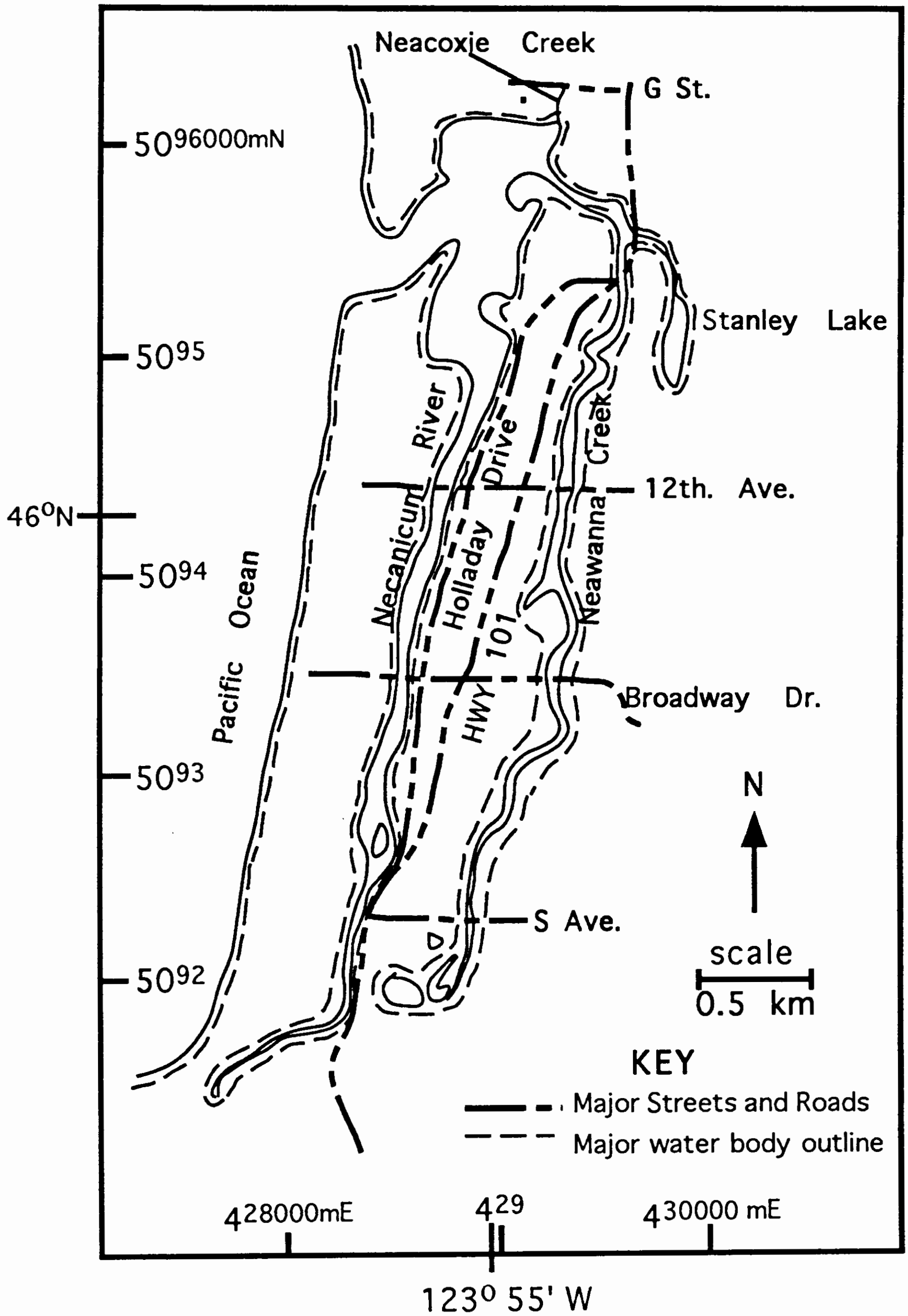


Figure 3. Seaside coastal wetlands.

River ebb delta-shoal, and the construction of the Necanicum bay mouth could have contributed to the local amplification of the 1964 tsunami in Seaside (Myers, 1994; Myers, personal communication, 1996). Lewis and Clark sketch maps (Thwaites, 1905), native American midden sites, and cobble ridges in Seaside all help establish the morphology of the coast that was affected by late-prehistoric tsunami. Lewis and Clark completed the first maps of Seaside during their expedition west in 1805-1806 (Thwaites, 1905). However, their sketch map (Figure 4) does not show Neawanna Creek, and the Necanicum River has apparently changed morphology during the last 200 years. Also, at the time of the Lewis and Clark expedition, native Americans lived along the beaches in Seaside (Thwaites, 1905). Connolly (1992; 1995) and Phebus and Drucker (1979) have done extensive anthropological studies on three native American midden sites in Seaside. They believe that at one time there was an embayment near the southern end of Seaside. All three midden sites, Avenue Q, Par-tee, and the Palmrose (Figure 5), contain bay clam shells not found in the Necanicum River near these sites in Seaside today.

Rankin (1983) examined the processes of the prograding dunes of northern coastal Clatsop County and the cobble ridges of Seaside. The N-S trending cobble ridges of Seaside have aligned the interdune valleys containing Neawanna Creek and the Necanicum River. The primary sources of the clasts are from both Tillamook Head and the Necanicum River. Storm waves deposited the cobbles as parallel beach ridges. Knowing the locations and trends of these ridges provides a better understanding of the

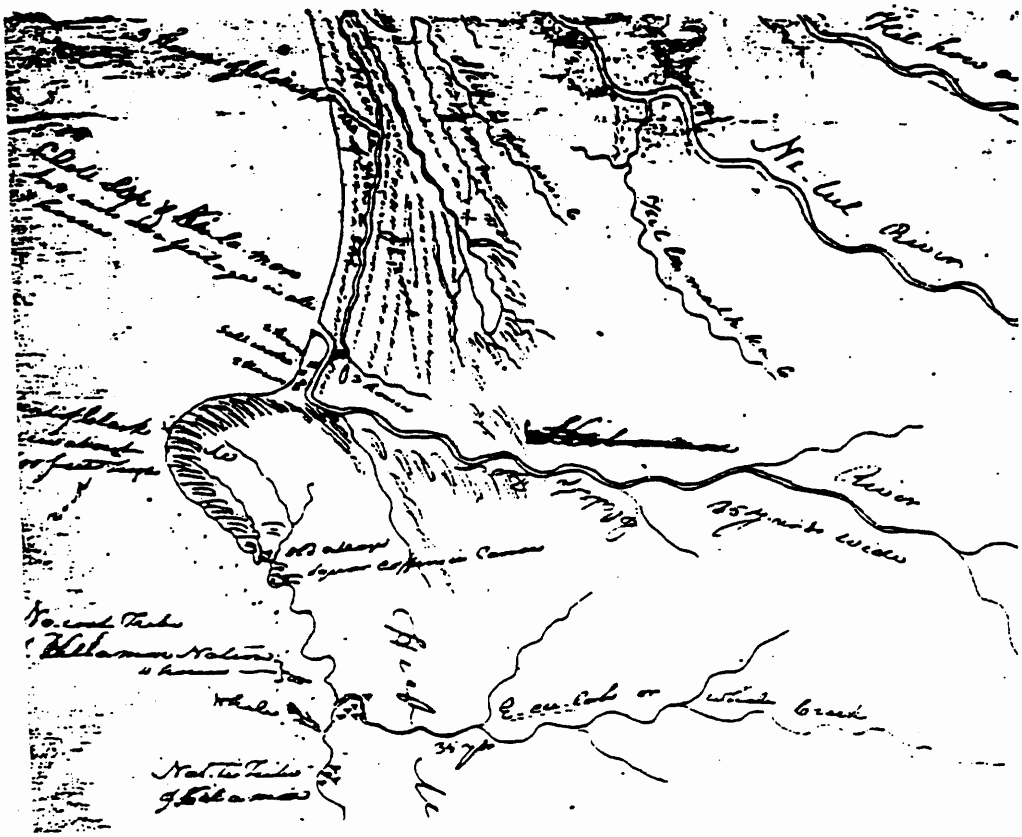


Figure 4. Lewis and Clark sketch map of the Seaside area, expedition of 1805-1806 (Thwaites, 1905).

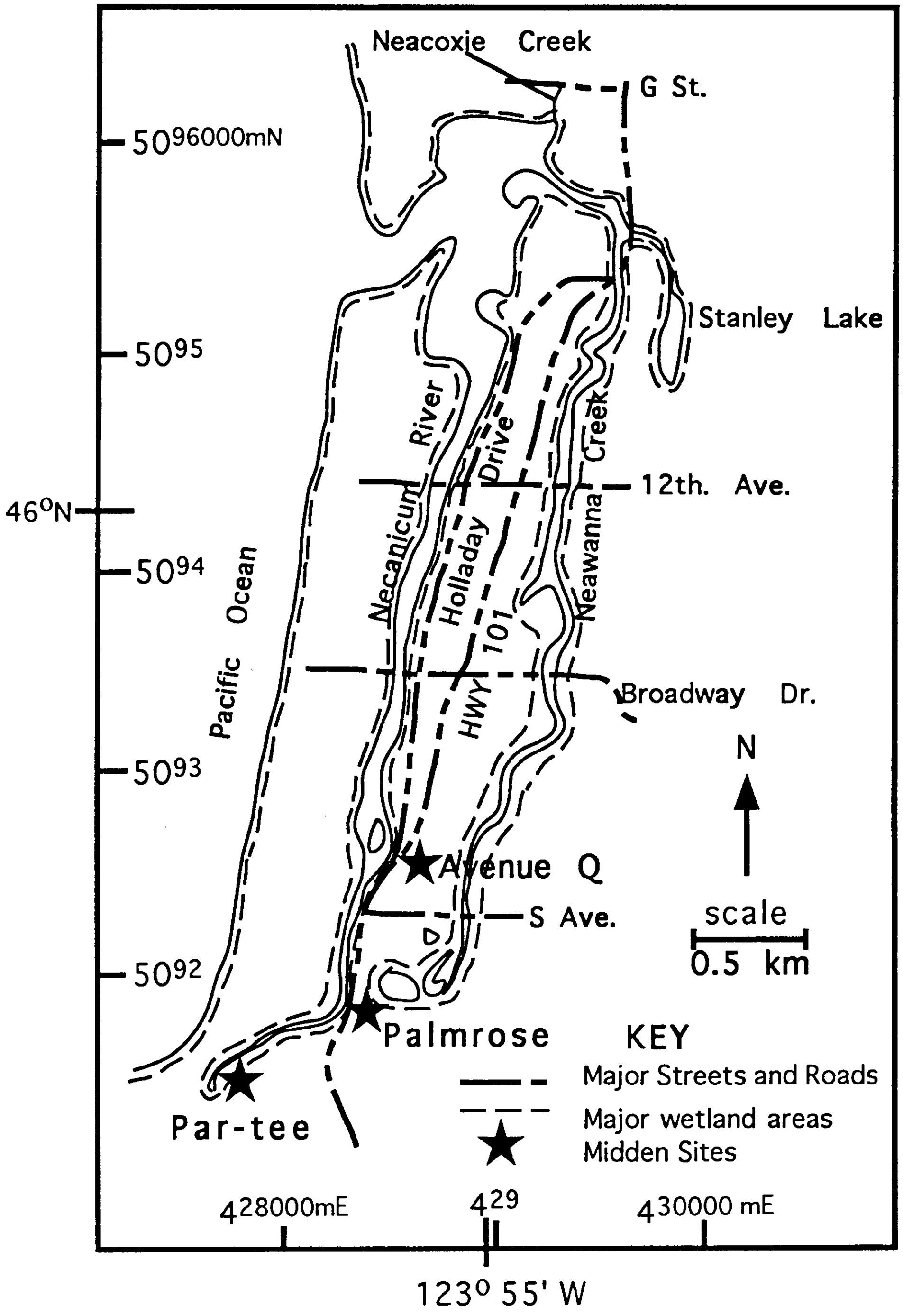


Figure 5. Three native American midden sites located in the Seaside area.

morphology of the Seaside coastline in prehistoric times.

Darienzo (1991) and Darienzo and others (1993) completed a preliminary tsunami study in the Seaside area. Evidence for the prehistoric tsunami was found primarily in the wetlands of Neawanna Creek and Stanley Lake. This study follows the work of Darienzo, including much additional coring at and between Darienzo's reported core sites. Some radiocarbon dates and interpretations reported by Darienzo are included under the Results section of this study and are cited where used.

Methods

Coastal wetlands of Seaside, Oregon, consist of the Necanicum River, Neawanna Creek, Neacoxie Creek, and Stanley Lake. These low lying areas represent protected environments with high potential to preserve evidence of coseismic subsidence and tsunami inundation. Extensive reconnaissance coring of these back barrier sites involved obtaining samples from up to three meters in depth with gouge cores (25 mm diameter, 1 m length core barrel, plus additional 1 m extensions). Pound cores (aluminum 7.5 cm diameter tube cut to desired length, pounded into the ground by sledge hammer, and pulled out by hand winch) yielded generally undisturbed sections for radiocarbon and diatom analysis. All cores were logged at one centimeter intervals for sediment lithology, special characteristics such as grading and laminations, and contact relationships. Visual estimates of organic content define mud and peat lithologies according to the standards given by Briggs, 1994 (Table 1). Sand layers are of significant interest, and when found are examined for sorting, grading, and abruptness of contacts above and below. Sand layers deposited by a tsunami should display characteristics of rapid deposition, such as sharp basal contacts and fining upward sequences (Darienzo and Peterson, 1990; Darienzo, 1991; Clague and Bobrowsky, 1994; and Atwater and others, 1995). Examination of contact relationships distinguishes between changes in depositional environment caused by coseismic subsidence, uplift, or gradual submergence. Sharp contacts (< 0.5 cm) between peat and the overlying mud can result from abrupt subsidence. Gradual contacts (>0.5 cm), such as a muddy peat grading upward into a peaty mud, indicate slowly changing depositional environments. However, minor coseismic subsidence (<1.0 m) occurring in dilute-brackish settings creates a gradual lithologic contact. Coseismic subsidence under such settings can be confirmed by sharp contacts between brackish and freshwater diatoms, which respond quickly to changes in environmental salinity (Barnett, 1997; Peterson and others, 1997). Intruded contacts show irregular lithologic interfaces, for example between sand and mud or peat. These contacts produced by sand fluidization and injection can result from coseismic liquefaction.

Table 1. Visual Estimation of Organic Material

Lithology	% Organics	Marsh Environment
peat	> 80%	very high marsh or forest
muddy peat	80 - 50%	high marsh
peaty mud	50 - 10 %	transitional marsh
rooted mud	10 - 5%	colonizing marsh
mud	< 5%	barren tidal flat

Locations of initial cores taken in this study were selected to confirm the work by Darienzo (1991) and Darienzo and others (1993). Aerial photos, topographic maps, and orthophoto maps were used to identify additional wetland sites for examination by coring, trenching, and cutbank examination.

Core locations were field plotted on orthophoto contour base maps (scale 1:1200) (Wegner, 1973). Some core positions, particularly those sites in extreme tree and brush cover were located with a Garmin GPS 45 XL (GPS = Global Positioning System) personal navigator connected to a real-time differential receiver, tuned to the Fort Stevens Coast Guard beacon. Accuracy of core site positions from both the large scale orthophotos and the real-time differential GPS is 3-10 m. All core locations are given both as UTM and NAD 1927 State Plane coordinates, and the program CORPSCON v.4.11 created by the US Army Topographic Engineering Center (TEC) was used to convert these coordinates.

Core locations along the upper Neawanna and Neacoxie Creeks contain very dense sand deposits which required an Australian sand auger (43 cm length, 7 cm diameter cylinder with a 1m length handle) to penetrate, allowing the identification of sediments below.

Radiocarbon samples were collected from trenches or pound cores, allowing for an undisturbed stratigraphic section. Ideal samples for radiocarbon dating included small sticks and spruce or pine cones in contact with the target tsunami sand layers. Less ideal samples included peaty sections several centimeters in thickness below the target tsunami sand layers. The ^{14}C samples were collected, labeled, and sealed in plastic bags. Sample preparation included: 1) washing the sample with deionized water, 2) removing noticeable root-hairs from the woody fragments, 3) drying, weighing, and packaging the sample in aluminum foil, and 4) sending them to a commercial laboratory (Beta Analytic, Inc.) for ^{14}C dating analysis. This company treated the samples with an acid/alkali/acid pretreatment, removed any additional root-hairs, and analyzed for radiocarbon. Standard radiocarbon testing was done along with the $^{12}C/^{13}C$ isotopic ratio analysis. Seven locations provided eight bulk and two Accelerator Mass Spectrometer (AMS) samples (Table 2). Darienzo (1991) and Darienzo and others (1993) radiocarbon results were also helpful in this study.

Table 2. Radiocarbon Samples and Core Locations

Location	Core Number	Sample Location (within section)
Stanley Lake (SSS)	879	55-65 cm
	879	54 cm
Neawanna Creek (SSW)	716	54 cm
	716	81 cm
	729	84 cm
	823	74 cm
	831	83 cm
	832	43 cm
	832	90 cm
Necanicum River (SSN)	884	71-80 cm

Diatom samples reveal the abundance of fresh, brackish, and marine diatoms present in a restricted deposit interval. The samples analyzed in this study were taken directly from above and below the subsided contact (± 1 cm). Darienzo (1991) outlined the diatom taxa analysis and sample preparation. This process involved:

1. Placing a small portion of sample (<5 g) in a beaker with 25 ml of deionized water.

2. Organic fragments are removed by adding 20 ml of 30% H_2O_2 solution, and the samples are placed under a fume hood for 24 hours.

3. Sand fractions are removed by sieving the sample with a no. 230 sieve (63 μm).

4. The sample is allowed to settle for 0.5 hours and then a 5 ml sub-sample is taken.

5. One drop of the sub-sample is placed onto a clean glass slide and is diluted with 2 drops of deionized water.

6. The glass slide is placed on a hot plate at 50° C until the sample is dry.

7. A drop of Preservaslide (resin dissolved in Xylene) is placed on the glass slide and covered with a cover slip. Slides are stored in a horizontal position.

E. T. "Chip" Barnett completed the diatom sample analyses for this study (Table 3). The relative abundances of marine, brackish, and freshwater diatoms above and below the contacts were evaluated semi-quantitatively (Barnett, 1997). The results are used to establish whether the area was inundated with sea water following apparent subsidence.

To calibrate interpretations of the prehistoric tsunami deposits, several localities of 1964 tsunami deposits were investigated in detail. Forty two core sites (including 5 from Darienzo's study in 1993) were investigated along the banks of the Necanicum River from the mouth to the golf course to verify attenuation of tsunami deposit thickness upstream (Darienzo and others, 1993). Core grids, taken at 25 meter intervals, aided in clearly defining the extent and characteristics of the sand deposit from the 1964 event in different depositional settings. Grid areas chosen are:

Neacoxie Creek from mouth to G Street (Gearhart) and three locations along the upper Neawanna Creek between 12th Avenue bridge and HWY. 101 bridge. The three grid areas show amplification or attenuation of the sand thickness from the 1964 event over small 0.1-0.5 km distances.

Table 3. Diatom Samples Analyzed

Location	Core Number	Sample Location (depth in section)
Stanley Lake (SSS)	879	50-54 cm
		54-57 cm
Neawanna Creek (SSW)	831	82 cm
		84 cm
Necanicum River (SSN)	827	288 cm

In addition to gouge core data for the 1964 event, profile trenches (dug by shovel with the sediment profile face cleaned by a putty knife) provided better exposures of the characteristics of a particular depositional layer. A north-south face and an east-west face were sketched. These trenches, on the average of 50 cm width by 50 cm depth, provided a better three-dimensional view than the traditional gouge core.

Since the 1964 event occurred only 30 years ago, eye-witness accounts provide additional valuable information on water level runup and associated sediment deposition. Interviewing and recording of the eye-witness accounts were primarily done by Thomas Horning, Seaside resident and local geologist. Additional interviews were conducted by this author.

Mapping of cobble ridges which indicate paleoshoreline "beach ridge" positions was completed to aid in understanding the general paleogeography of Seaside. Observations of surface cobble deposits were made and placed on the 1:1200 orthophoto base maps of Seaside. The Clatsop Plains study by Rankin (1983) was also used in establishing the general location of the cobble ridges in Seaside.

Finally, ground penetrating radar (GPR) was used to investigate the nature of the subsurface deposits between prominent cobble ridges, where dense sand or shallow water table prevented gouge coring or sand augering. All GPR lines were directed by Harry Jol (University of Wisconsin - Eau Claire Geography Department) and Sandy Vanderburgh (University of the Fraser Valley - Abbotsford Department of Geography). Seaside High School athletic practice fields were chosen as one of the GPR study sites and three lines were run: one north-south and two east-west. In 1994, three GPR lines were run at the Seaside Golf Course, along a portion of the first fairway (Jol and others, 1996). All GPR lines were done at one meter step intervals and the reflection mode was set at 400 volts.

Results

In the following results section, the tsunami deposit investigations are described for the corresponding tributaries in the following order: the Necanicum River, Neacoxie Creek, drainage to east of Neacoxie Creek, Stanley Lake, and Neawanna Creek (Figure 6). All core logs, trenches, and observation locations are displayed in a series of large scale maps including topographic contours. Figure 6 is a small scale reference figure for the larger-scale maps. Observation locations and descriptions are found in Appendix A. Appendix B contains all gouge core locations and descriptions. The gouge core field logs are contained within Appendix C. All radiocarbon dates including those from Darienzo and the beta identification numbers are in Appendix D. All grid core descriptions and locations and logs are found in Appendix E and F, respectively. Ground penetrating radar profiles of Seaside High School and Seaside golf course are presented as plates in the back pocket.

Both the 1964 and the prehistoric events contain tsunami-deposited sand layers (TSL). Historic (1964) TSL are identified by their shallow depth from surface, clean, quartz-rich sand, and typically sharp lower contacts. No subsidence occurred at Seaside because of the distal origin of the 1964 earthquake. Therefore, the 1964 sand layer should be found within a continuous lithologic unit, such as a mud or peaty deposit. This runup event was observed to have produced sand deposits at various known localities, therefore these sand layers will be referred to as the 1964 event.

Figure 6. Coastal wetlands of Seaside studied for historic and prehistoric tsunami evidence. Boxes indicate large scale maps referred to in text. SSN=Necanicum River, SSW=Neawanna Creek, SSXa= Drainage to the east of Neacoxie Creek.

The prehistoric tsunami-deposited sand layers (TSL) are located between underlying muddy peats and overlying rooted muds. This combination describes the sequence of events which are believed to occur following a megathrust earthquake: subsidence, tsunami inundation, and slow rebuilding of a colonizing (low) marsh to a very high marsh or forest setting. Some sandy layers at peat-mud contacts do not contain the correct subsidence stratigraphy or contact relations, so these sand layers might not be interpreted as tsunami deposits. These sands are referred to as sand capping layers (SCL). Further interpretations of TSL and SCL are provided in context of regional distribution in the discussion section.

Necanicum River (SSN)

Location

The N-S trending Necanicum River is located in the western portion of Seaside between the Pacific Ocean and Neawanna Creek. This study area extends five kilometers through western Seaside to its mouth. The eastern boundary of the Necanicum River wetlands is composed of cobble ridges, while the western side is defined by cobble ridges and the prograding beach system. The cove/golf course area (Ave. U, west) covers the southern extent of the Necanicum River study area.

1964 Event

Observations

Bridges crossing the Necanicum River suffered the greatest damage from the 1964 tsunami runup, although areas along the river were also flooded and inundated by drift debris. Between the Necanicum River and Holladay Drive (to the NE of SSN) surge levels reached one foot above the dune/cobble ridge elevation of 6.1 and 5.9 m (20 and 19.5 ft.) (SSN 668 and 669), respectively. Just to the immediate northwest of the 12th Avenue bridge, SSN 667 had drift debris at 3.5 m (11.5+ ft.). The 12th Avenue bridge crossing the Necanicum River indicated a surge level running just below the bridge at 4.4 m (14.5 ft.) (SSN 666). Observation sites and core locations for the Necanicum River mouth to 12th Avenue bridge are shown in Figure 7. The 4th Avenue bridge, already condemned, was completely destroyed by the surge up the Necanicum River. Observations immediately north of the Broadway Drive bridge noted that the water levels were at or just above present elevation along the Necanicum River banks (SSN 661-665). The Broadway Drive turnaround on the promenade received logs jammed into the public restrooms (SSB 640), and surge splash marks were observed at SSB 641. Observations and core locations for 12th Avenue to Broadway Drive are shown in Figure 8. Site SSN 660 on the Avenue A bridge contained drift debris at 3.8 m (12.5 ft.). A 3.8 m water mark was noted at SSN 659, 3.4 m (11.0 ft.) at SSN 657, and 3.6 m (11.8 ft.) at SSN 656 all of which are immediately to the northeast of Avenue G bridge (near the intersection of Ave. N and South Downing Dr.). Observation sites and core locations from Broadway Drive to the islands (Ave. S) are shown in Figure 9. Along the southern promenade, SSB 645 (near Ave. T) and SSB 646 (near the cove, west of West Point Rd.) had water levels at 4.9 m (16.0 ft.). At the Seaside Golf Course near the 9th hole green, two debris marks were noted at 2.9 and 2.3 m (9.5 and 7.5 ft.) (SSN 653). Finally, SSN 654 (near the

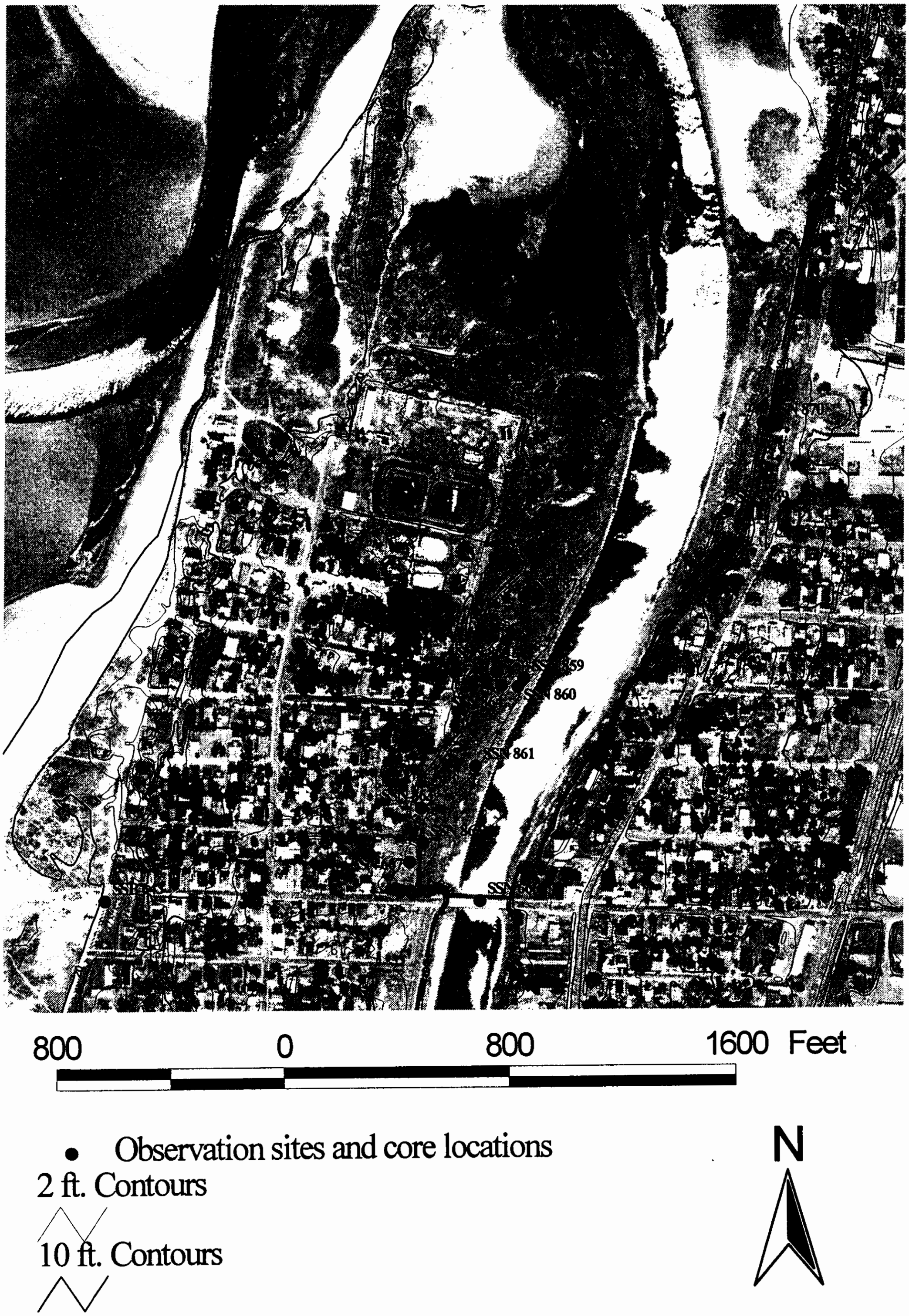


Figure 7. Observation sites and core locations from the Necanicum River mouth to 12th Ave. bridge.

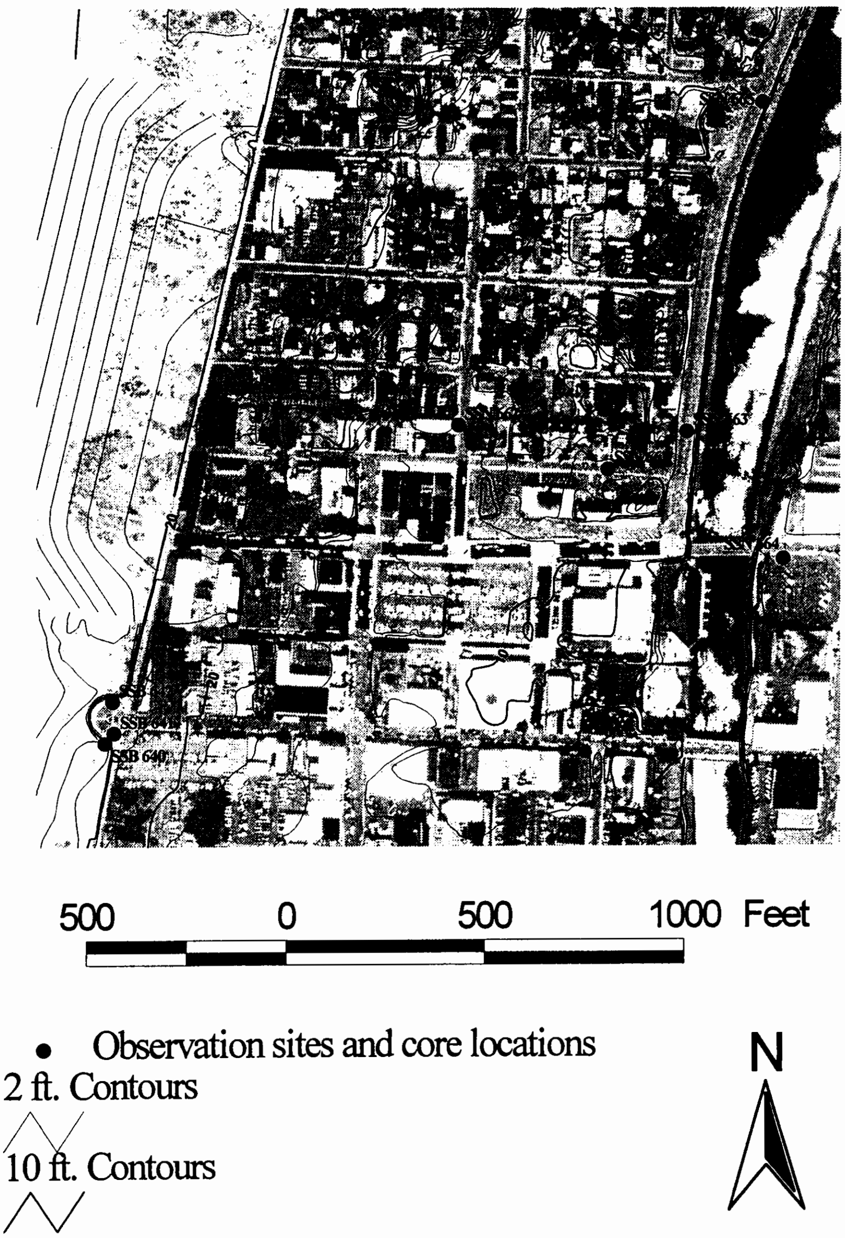


Figure 8. Observation sites and core locations for the Necanicum River from 12th Ave. to Broadway Dr.

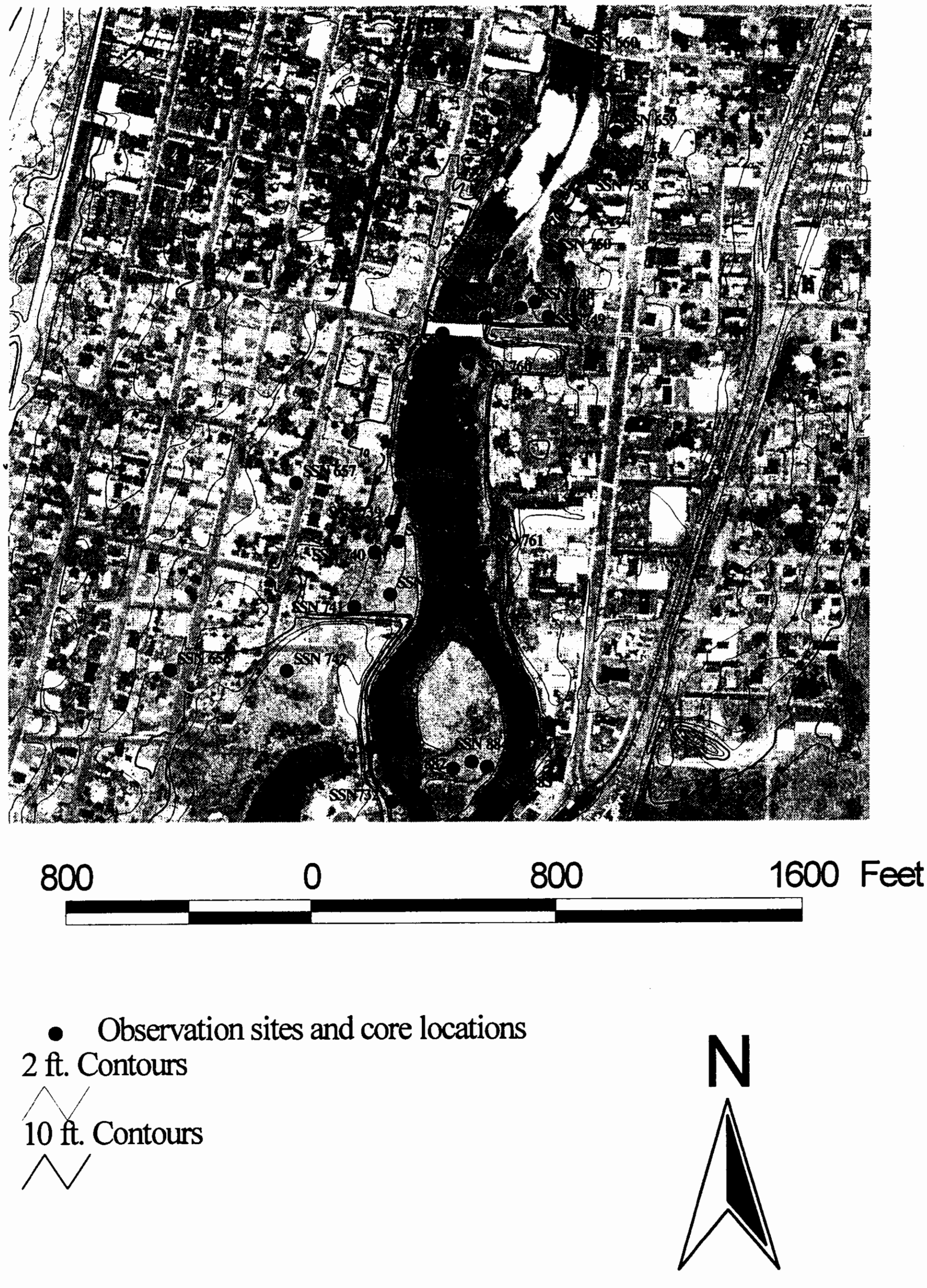


Figure 9. Observation sites and core locations for the Necanicum River from Broadway Dr. to the islands (Ave. S).

8th hole green) indicated debris at 2.9 m (9.5 ft.). Observation sites and core locations from the islands (Ave. S) to the Seaside golf course (Ave. U) including the cove are shown in Figure 10.

Gouge Coring

The 37 cores taken throughout the Necanicum River coastal wetlands will be described from the northern extent to the southernmost extent. Maximum penetration of 300 cm occurred at SSN 827 near the cove, but along the river 240 cm was the maximum depth reached. The average penetration was 100 cm, although, cobble ridges or dense sand limited the core interval to shallower depths in some areas.

Necanicum River mouth to 12th Avenue (Figure 7)

Near the mouth of the Necanicum River, SSN 871, 870, and 863 document the 1964 event within the northwestern bank (Figure 11). These cores contain a fairly thick clean sand (10-20 cm thick) in sharp lower contact with the underlying thin layer of peat or mud at a depth of 27-30 cm. This thick layer represents deposition from the 1964 tsunami.

Broadway Drive to the islands (Ave. S) (Figure 9)

Core sites SSN 759,750,747, and 737 all contain thinner 1964 sand layers than to the north. These cores have a thin sand layer (averaging 5 cm thick) in the 10 to 20 cm depth interval within a muddy peat or peaty mud (Figure 12). The southern extent of the Necanicum River indicates a tsunami sand layer (Figure 13) thinning with increasing distance upriver. Sites SSN 731, 882, and 884 are located relatively close to each other. Site SSN 731 does not contain shallow sand laminations or layers, indicating no

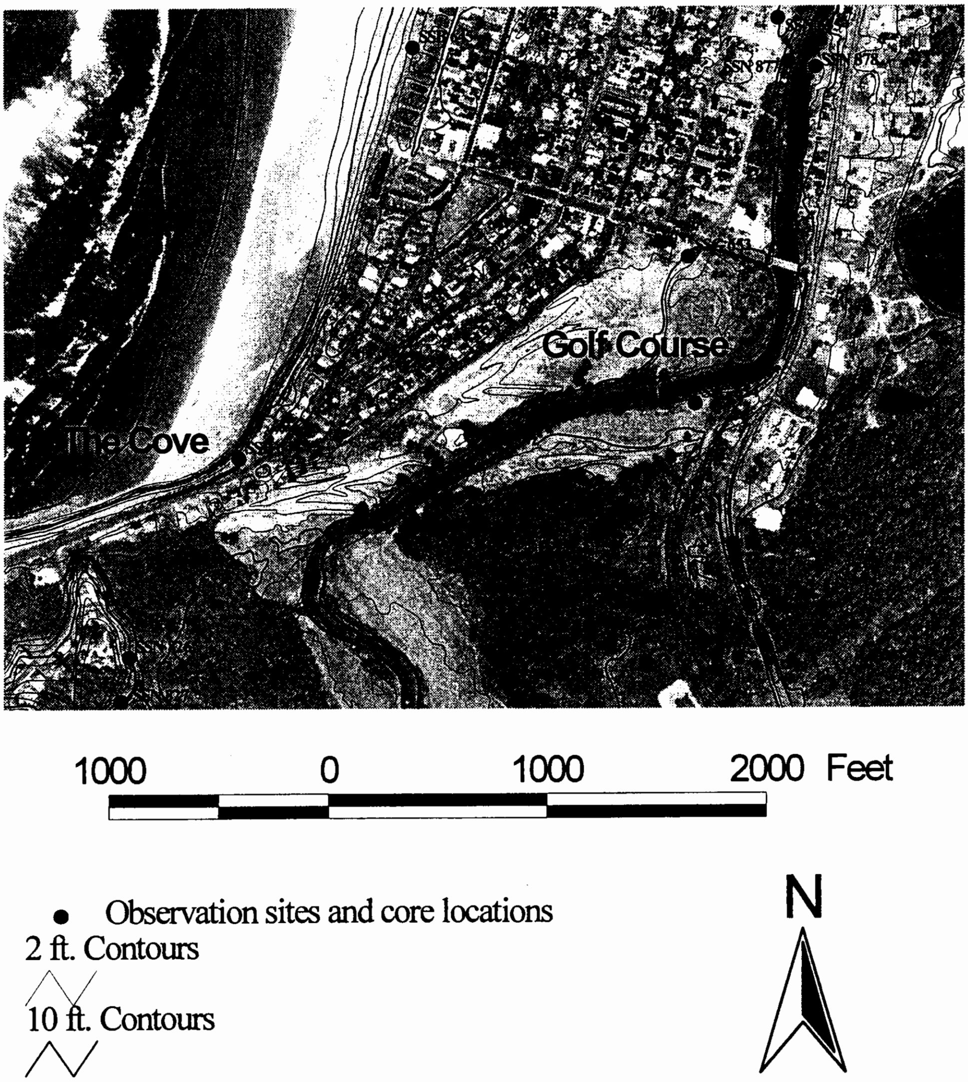


Figure 10. Observation sites and core locations for the Necanicum River from Necanicum Islands (Ave. S) to the cove/golf course (Ave. U).

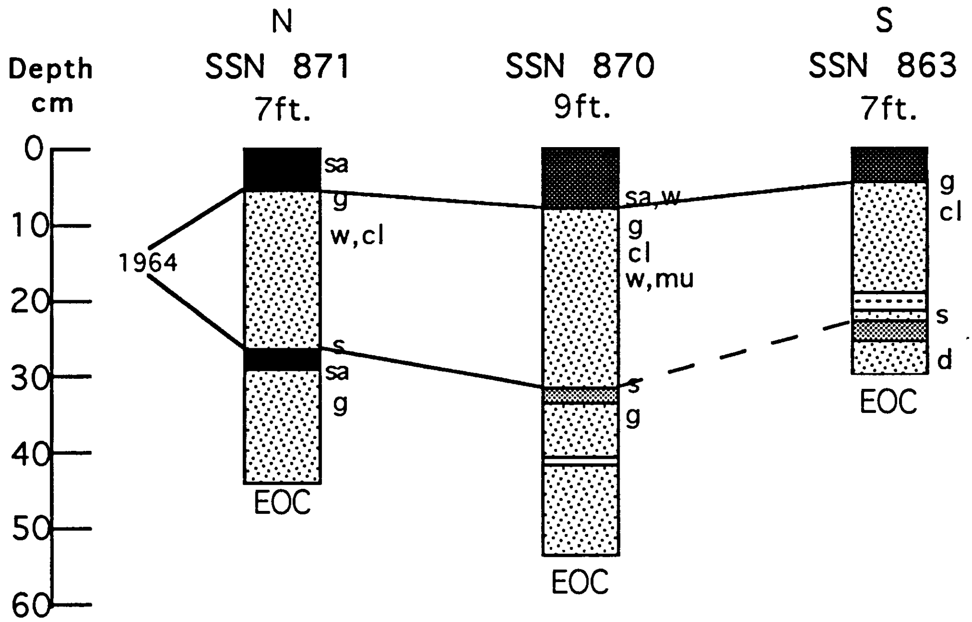


Figure 11. Northern Necanicum River cores SSN 871, 870, 863; showing a 1964 sand deposit. Gouge cores include present marsh surface elevation in feet.

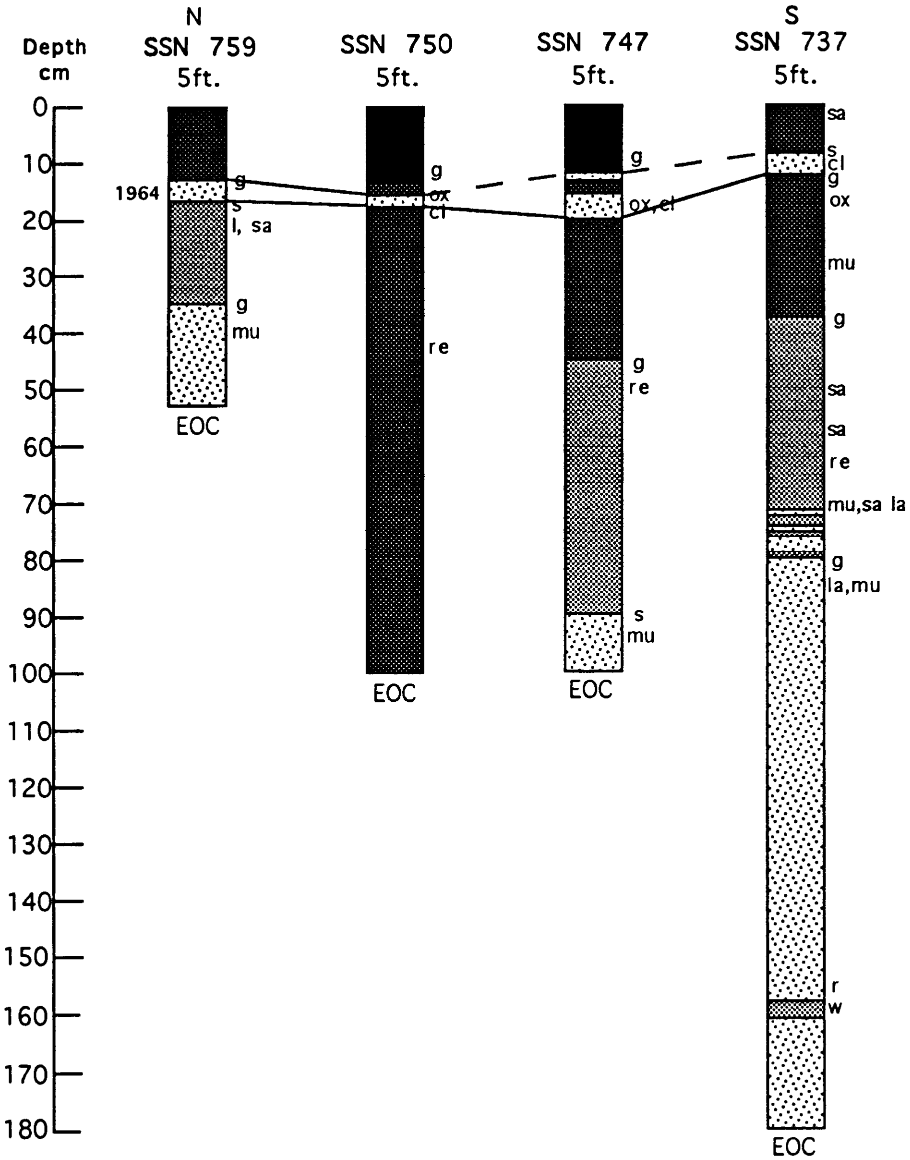


Figure 12. Central Necanicum River cores SSN 759, 750, 747, 737; showing a 1964 deposit.

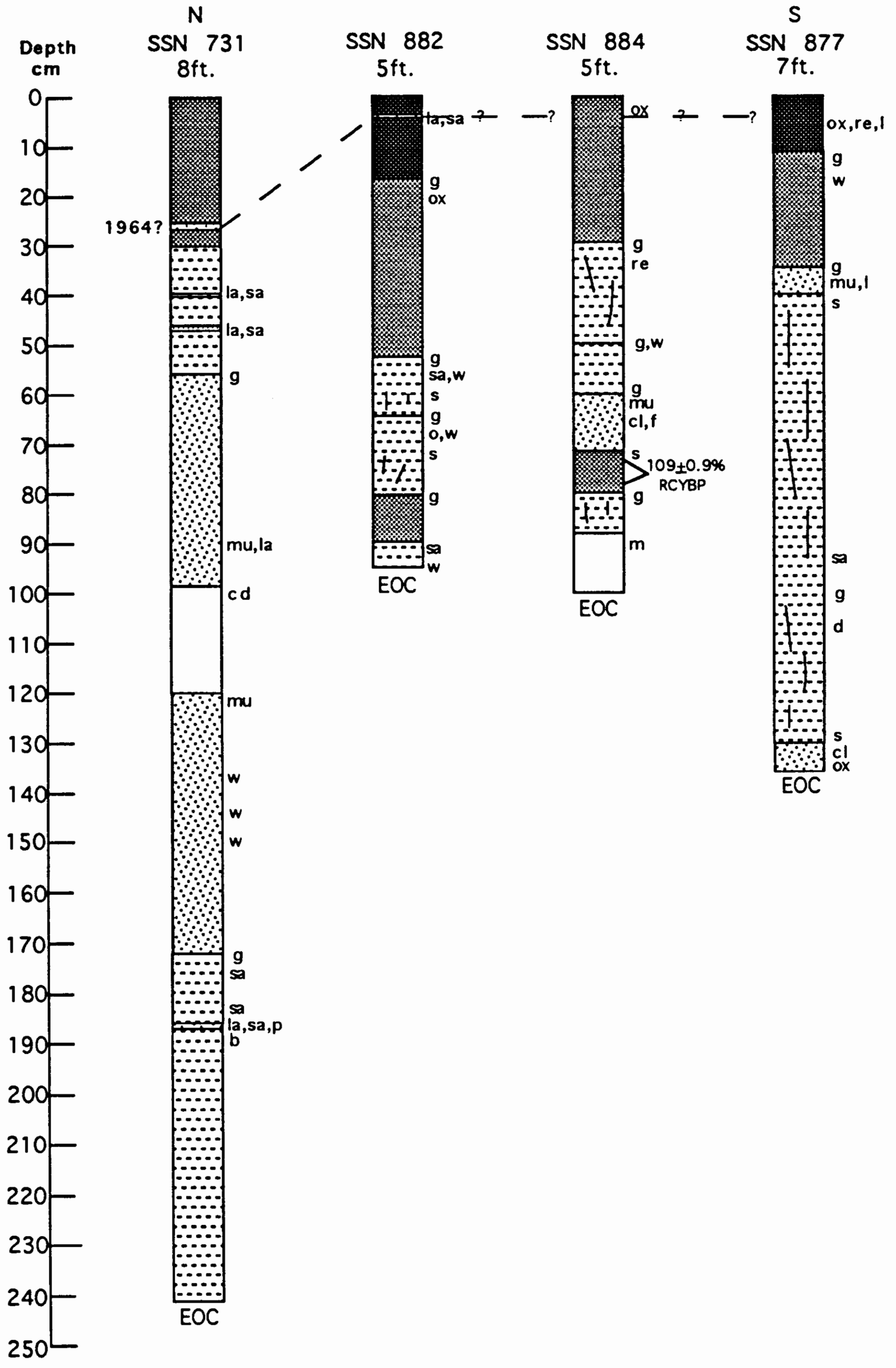


Figure 13. Southern Necanicum River cores SSN 731, 882, 884, and 877; showing the thinning of the 1964 deposit.

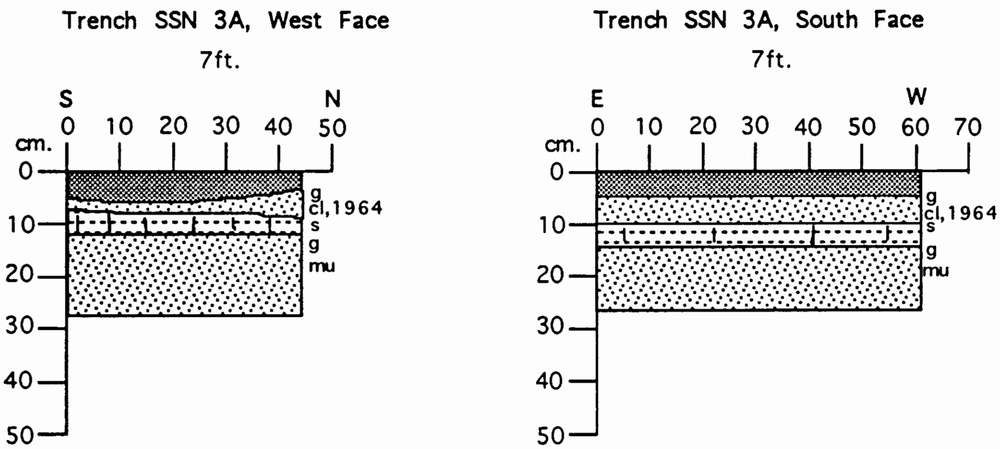
sand deposition from the 1964 event. However, SSN 882 on the central Necanicum River islands contains a sand lamination at five centimeters depth, which could very well have been deposited by the 1964 tsunami.

The islands (Ave. S) to Seaside golf course (Figure 10)

Immediately south of the old Hospital near Avenue S, no sand layers or laminations occur at shallow depths in SSN 877 (Figure 13). The stratigraphies of these cores do not match very well, but it is evident that further upriver, the shallow 1964 sand layer completely disappears.

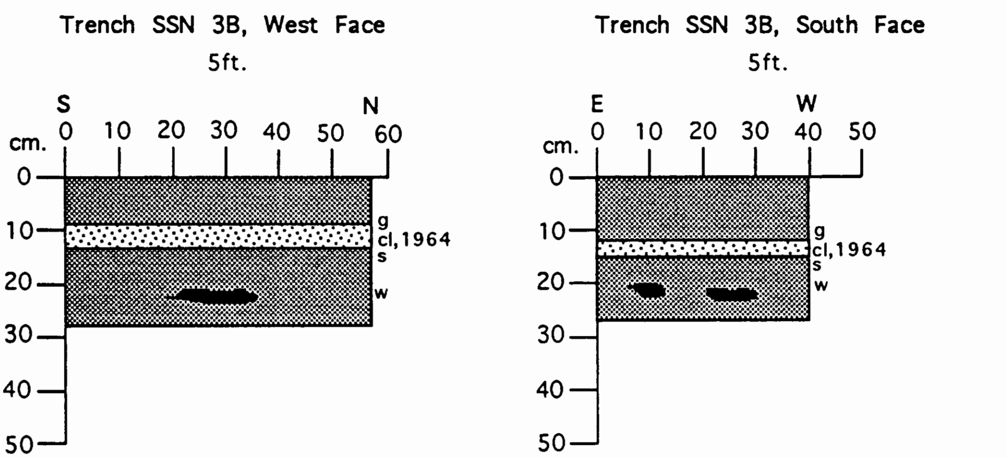
Trenching

Three trenches, 3A-C, were taken at sites along the Necanicum River. The northernmost trench, 3A, is located at gouge core site SSN 864. This trench contains a similar stratigraphy to the core log of SSN 864 (Figure 14). A clean sand layer with a lower sharp contact with a rooted mud is located between the 5-10 cm interval. The sand layer is an example of the 1964 tsunami sand deposit. Trench 3B is centrally located on the Necanicum River at gouge core site SSN 748. Again, both the trench and core log contain similar stratigraphies (Figure 15). Site SSN 748 indicates two thin (2 cm thick) clean sand layers at ten and 18 cm, where as the trench in both west and southern faces indicate one continuous sand layer at 9-13 cm. The two sand layers observed within the core might represent two surges of the 1964 tsunami. Finally, to the south, trench 3C is located at SSN 732 (Figure 16). The stratigraphy between the core log and the trench differ. Trench 3C does not contain any shallow sand layers and



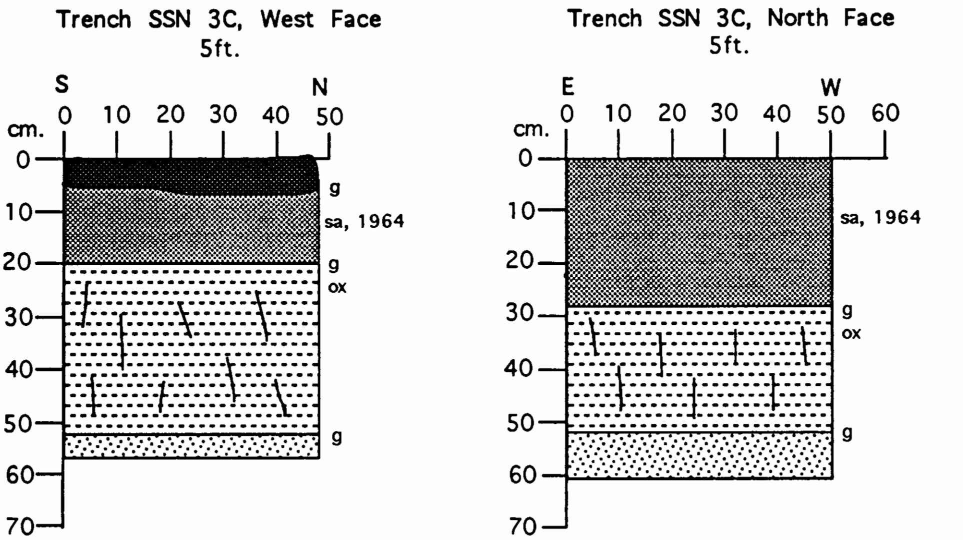
West Face	South Face
0-4 cm, peaty mud, lower gradational contact.	0-5 cm, peaty mud, lower gradational contact.
4-9 cm, sand, clean, sharp lower contact, 1964.	5-10 cm, sand, clean, sharp lower contact, 1964.
9-12 cm, rooted mud, lower gradational contact.	10-14 cm, rooted mud, lower gradational contact.
12-27 cm, sand, muddy.	14-27 cm, sand, muddy.

Figure 14. Northern Necanicum River trench 3A (core site SSN 864).



West Face	South Face
0-9 cm, peaty mud, gradational lower contact.	0-12 cm, peaty mud, gradational lower contact.
9-13 cm, sand, clean, sharp lower contact,1964.	12-15 cm, sand, clean, sharp lower contact,1964.
13-27 cm, peaty mud, detrital wood fragment @ 21-24 cm.	15-27 cm, peaty mud, detrital wood fragments @ 20-25 cm.

Figure 15. Central Necanicum River trench 3B (core site SSN 748).



0-7 cm, muddy peat, hint of sand @ 12 cm, lower gradational contact (1964).

7-20 cm, peaty mud, gradational lower contact.

20-52 cm, rooted mud, oxidized, lower gradational contact.

52-56 cm, sand.

0-28 cm, peaty mud, hint of sand @ 13 cm, gradational lower contact (1964).

28-52 cm, rooted mud, oxidized, lower gradational contact.

52-60 cm, sand.

Figure 16. Southern Necanicum River trench 3C (core site SSN 732).

does have a peaty mud overlying a rooted mud. Site SSN 732 has a peaty mud with three isolated sand layers at 38-50 cm, however no shallow sand layers are evident. Trench 3C contains a sandy section within the peaty mud at 13 cm, a possible indicator of the 1964 tsunami.

Diatom Analysis

A diatom sample taken from SSN 827 at 288 cm (Figure 10) would determine whether there was any marine influence within a continuous core of muddy peat at this site. This sample was difficult to evaluate due to a lack of sufficient diatom valves for counting. No definite influence of marine or freshwater, based on diatoms, could be determined for this sample.

Radiocarbon Samples

A possible buried horizon was identified on the island of the central Necanicum River at SSN 884. A peat sample obtained from 71-80 cm yielded 109.0±0.9% RCYBP as an age. This young date does not argue for a prehistoric buried interval from the 1700 AD Cascadia earthquake within the Necanicum River wetlands.

Summary

The Necanicum River contains many water level and runup observations from the 1964 tsunami event. Sites reported to have been impacted by flooding, debris and/or sand deposits were examined by gouge core or trenches to establish the resulting stratigraphic records from the observed runup. There is strong evidence for the 1964 tsunami deposits throughout the north to north-central wetlands of the Necanicum River. Three general trends are evident in the Necanicum River wetlands for the 1964 event: 1) shallow sand layer thickness decreases to the south, and the deposits eventually become non-existent in the area near the old hospital (Ave. S), 2) some deposits contain more than one sand layer or an interfingering of sand and mud shallow in the cores, indicating more than one surge depositing the sand, and 3) as distance from the mouth of the Necanicum River increases, the lithology of the sand layers reflects the local sand supply, the sand being more angular and containing less quartz and more rock fragments.

Prehistoric Events

No laterally-continuous buried peat horizons were observed in the Necanicum River wetlands. The only possible buried horizon occurs at SSN 884, however, due to the young radiocarbon date (109.0±0.9% RCYBP) at 71-80 cm within this core no further analysis of this site was undertaken.

Neacoxie Creek (SSX)

Location

Neacoxie Creek, to the north of Seaside, runs N-S and its mouth opens into the Necanicum estuary. A 7.3 m (24 ft.) tree and grass vegetated sand dune containing an underlying cobble layer bounds the eastern side of Neacoxie Creek. The western boundary of Neacoxie Creek is confined by low lying sand dunes. G Street bridge in Gearhart bounds the northern extent of the Neacoxie Creek study area. Tides influence the water level of the creek, throughout its length in the study area.

1964 Event

Observations

Observations made by eye-witnesses in 1964 indicated that G Street (road fill over culvert) substantially slowed the surge up Neawanna Creek (Figure 17). Driftwood and logs jammed the culvert, and some logs and sand were thrown onto the G Street pavement (SSX 650). Home owners reported sand deposits along the east bank and G Street crossing the Neacoxie Creek (T. Horning, personal communication, 1996). Large diameter drift logs were washed up against and on top of G Street. Homes on the western bank of Neacoxie Creek experienced flooding, marking a water level at 3.8 m (12.5 ft.) (SSX 648). In one case, a woodshed moved westward roughly 24.4 m (80 ft.) (SSX 652).

Gouge Coring

In the marsh surrounding Neacoxie Creek, ten gouge cores were taken (Figure 17). The average core depth was 65 cm, and no cores penetrated deeper than one meter. Extremely dense, thick sands underlie the upper muddy sand or peaty mud deposits on either side of Neacoxie Creek. Subsidence horizons or sand layers indicative of prehistoric deposits were not present in the Neacoxie Creek wetlands. However, shallow in the section, clean, fine-grained, occasionally fining upward sand layers were identified, indicating sand deposited from the 1964 tsunami.

On the east bank of Neacoxie Creek, SSX 754 and 770 show a thick, clean sand becoming muddy down section (Figure 18). The SSX 754 sand layer has a sharp lower

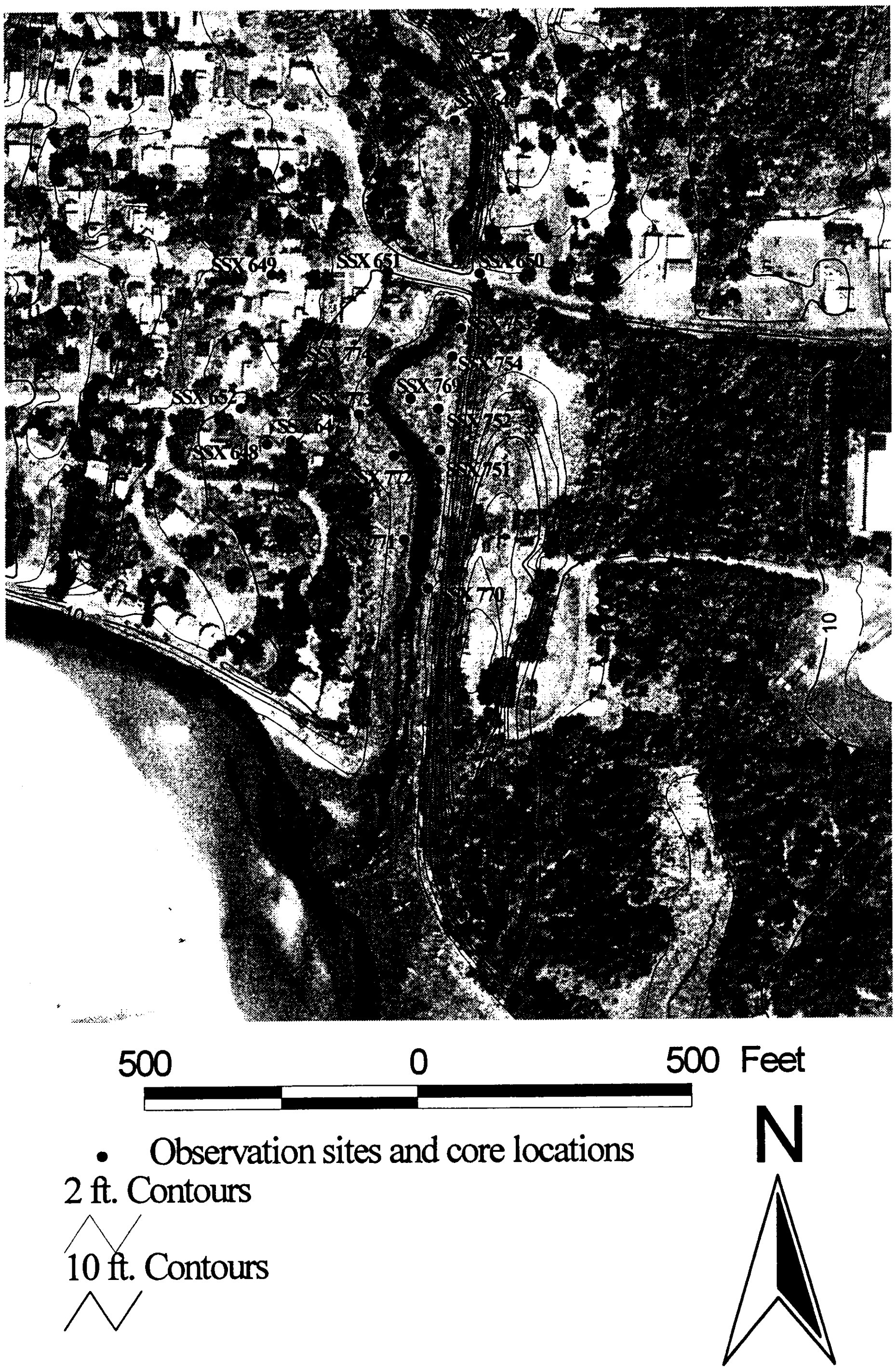


Figure 17. Neacoxie Creek observation sites and core locations.

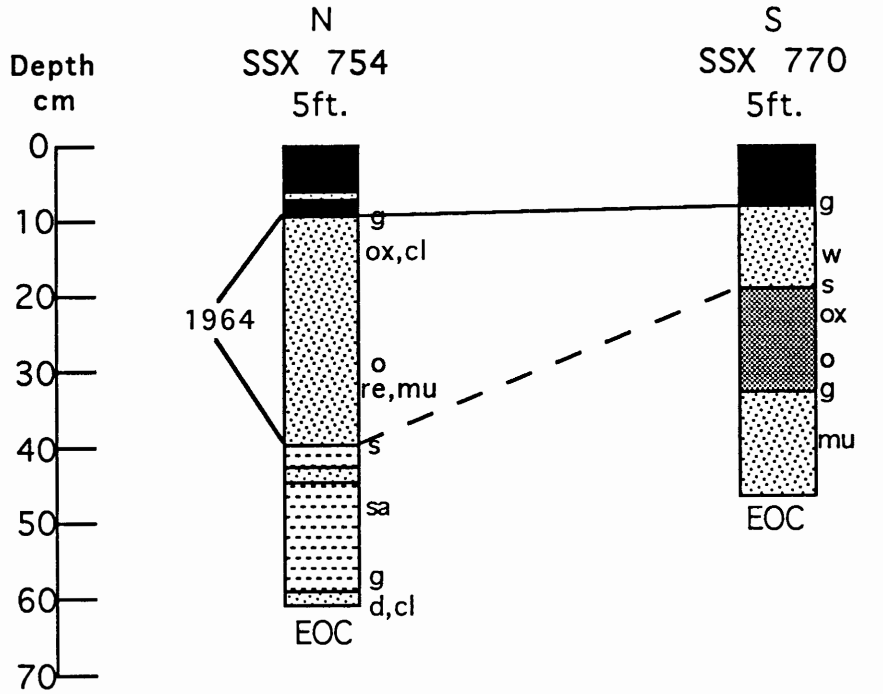


Figure 18. Neacoxie Creek east bank cores SSX 754 and 770.

contact with rooted mud from 9-40 cm depth, and an overlying thinner sand layer at seven centimeters. To the south, SSX 770 shows ten centimeter thick sand layers. The west bank of Neacoxie Creek (Figure 19) comprises gouge cores SSX 772-774, which all have clean sand laminations shallow in the section at 10-20 cm and thick sandy to muddy sand layers deep in the section. However, to the south, SSX 771 contains a thicker, clean sand layer from 9-18 cm with a sharp lower contact.

Grid coring

To obtain a clearer understanding of the tsunami depositional processes at Neacoxie Creek in 1964, 28 cores were incorporated in a 25 m grid with the main grid lines running roughly N-S (see methods). Logged grid core locations for Neacoxie Creek are found in Figure 20. Due to urbanization or meanders of the Neacoxie Creek channel, some grid sites could not be cored. Maximum gouge core penetration was 100 cm at SSX XVIII, and the average core depth reached was 72 cm.

Shallow 1964 sand deposits of the Neacoxie Creek east bank differed from those of the west bank. The east bank contains thick sand deposits, shallow in the section, at the north portion of the grid near the G Street. This is evident in grid core SSX III, having a 18 cm thick sand layer with a sharp lower contact. These thick deposits taper in the central reaches, evident in grid cores VII-X. Grid cores VII-X have shallow sand layers from 3 to 13 cm in thickness with mud laminations. Grid core XI, to the south of VII-X, thickens toward the mouth of Neacoxie Creek. This sand deposit ranges from 3 to 31 cm from the present surface, and it has a sharp lower contact with

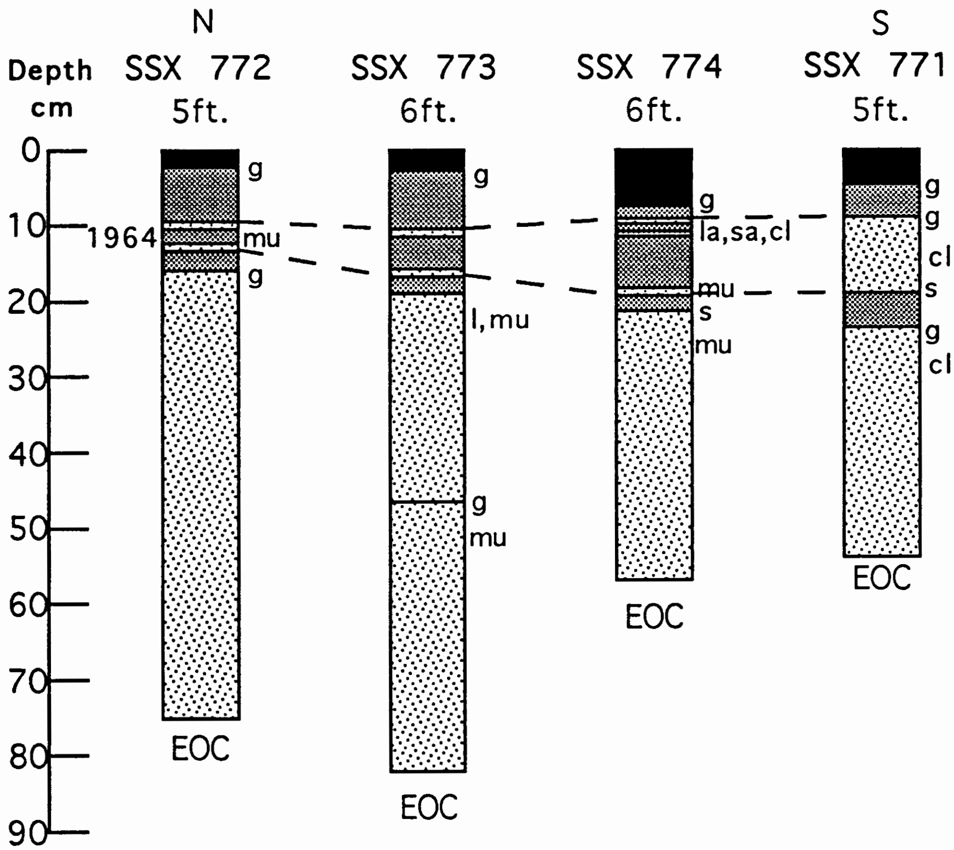


Figure 19. Neacoxie Creek west bank cores SSX 771-774.

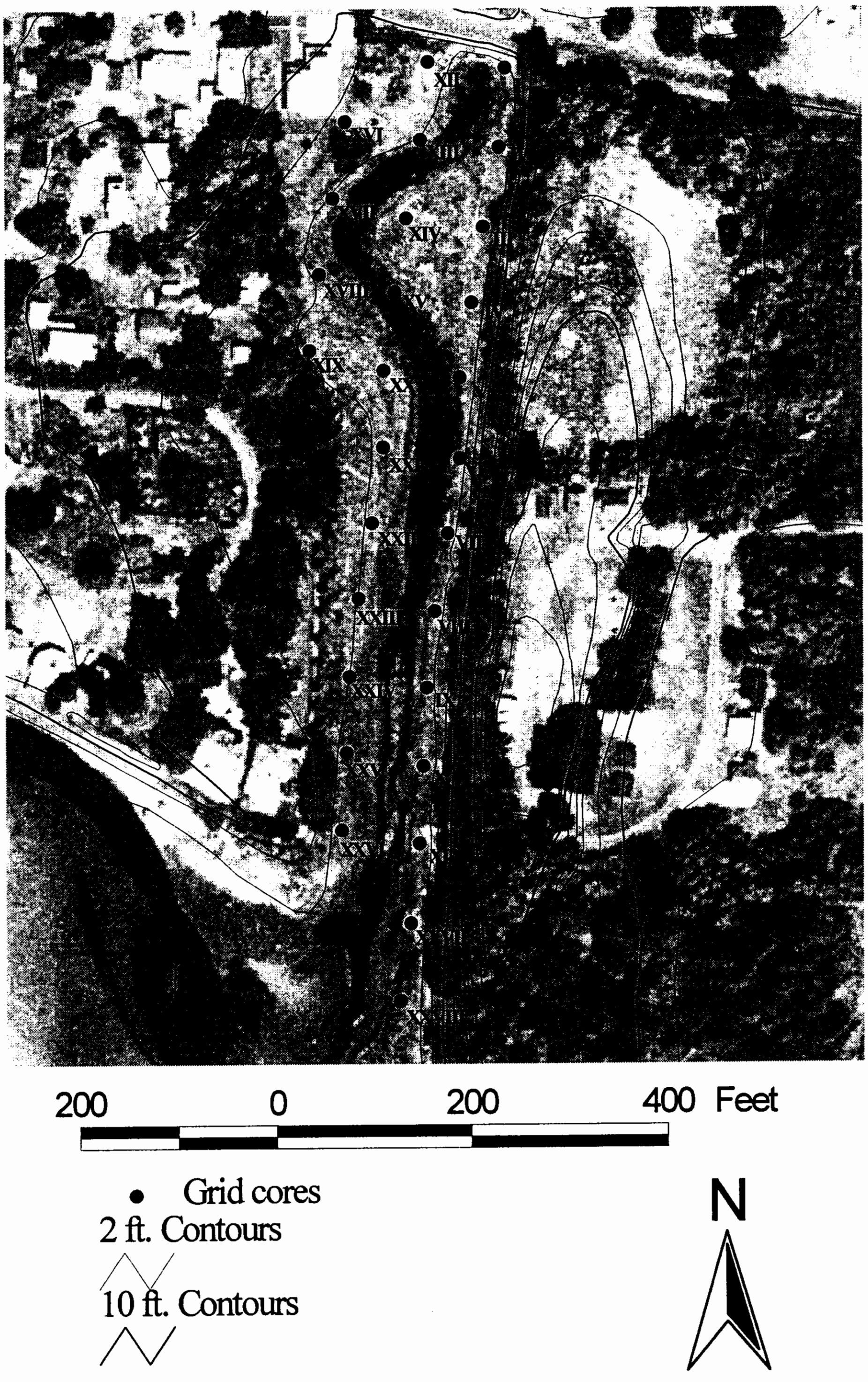


Figure 20. Neacoxie Creek grid core locations.

a peaty mud. However, XXVII and XXVIII grid cores south of XI show another thinning trend. Sand thickness varies from 12 cm in XXVII to six centimeters in XXVIII. Figure 21 shows the N-S grid section discussed for the Neacoxie Creek east bank. Grid cores on the western bank of Neacoxie Creek show a differing stratigraphy from the eastern bank. Cores to the north contain sand with interlayers of mud (about 1 cm thickness). In Grid core XIII, five mud interlayers of roughly one centimeter in thickness are contained within a sand layer ranging from 7 to 25 cm from present surface. Cores XX-XXII show interlayers of sand, mud and peaty mud ranging from about 8-50 cm. Peaty mud dominates the upper section along with some sand layers in grid core XX. Sand and mud layers dominate the upper section of XXI, and this core contains a combination of sand and peaty mud layers. The southernmost two cores, XXV and XXVI, contain sand layers very shallow in the section (from 10-20 cm) with confining muddy peat above and below the sand. Figure 22 shows the N-S section of the Neacoxie Creek western bank stratigraphy.

East-west cross-sections across the creek channel show differences in 1964 sand thickness from one bank to the other. To the north, cores III and XVIII are very similar in stratigraphy, especially in the upper 30 cm of section (Figure 23). Central Neacoxie Creek shows similar stratigraphy between east and west banks. Cores VI and XXI both have a shallow, clean sand layer with a lower sharp contact with a peaty mud, however, XXI contains more interlayering of mud and sand (Figure 24). Finally, farther south, cores X and XXVI have similar stratigraphies as well (Figure 25).

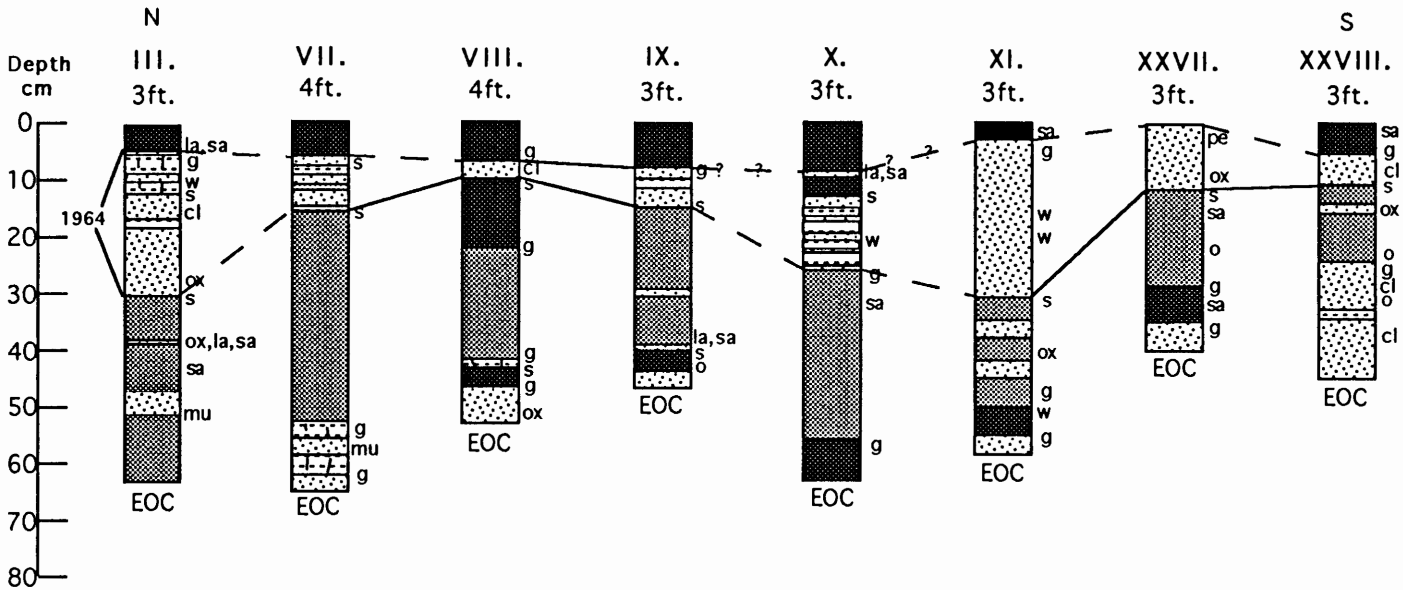


Figure 21. Neacoxie Creek east bank N-S grid cross-section (SSX III, VII, VIII, IX, X, IX, XXVII, and XXVIII).

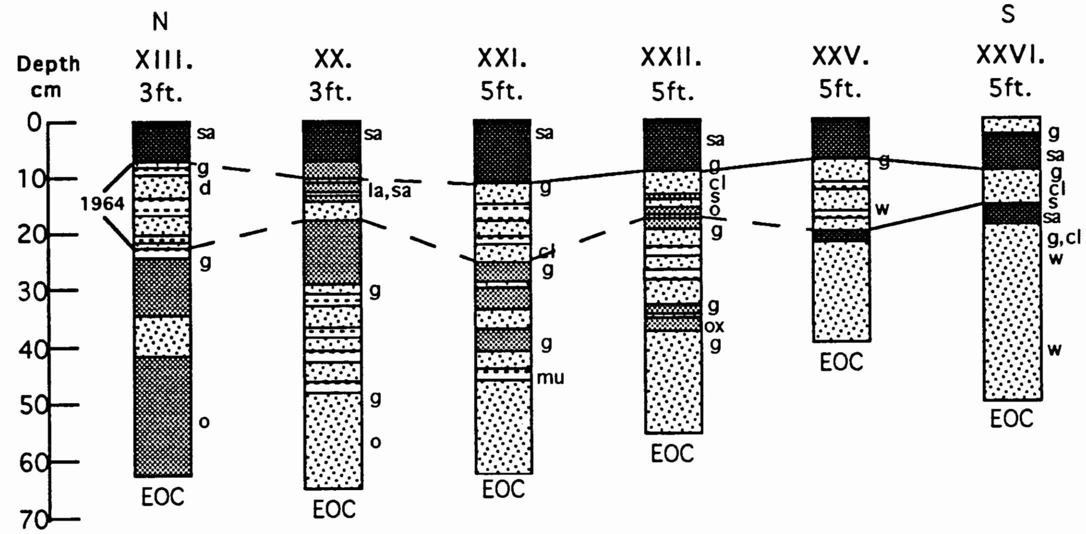


Figure 22. Neacoxie Creek west bank grid cores (SSX XIII, XX, XXI, XXII, XXV, XXVI)

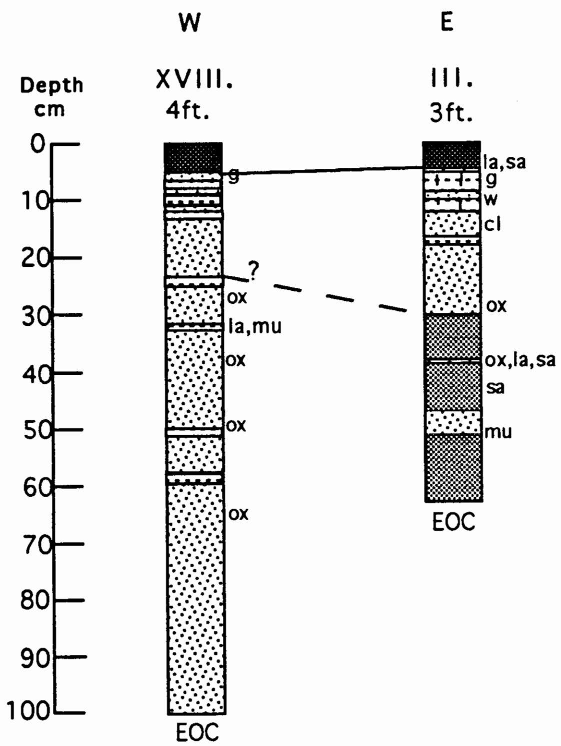


Figure 23. Neacoxie Creek E-W cross-sections, northern cores (SSX III and XVIII).

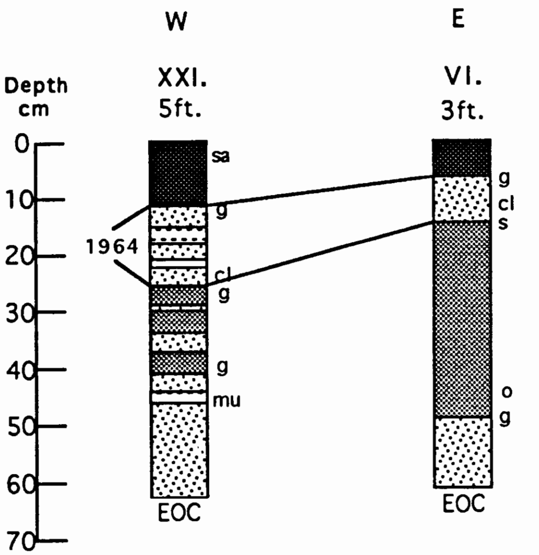


Figure 24. Neacoxie Creek E-W cross-section, central cores (SSX VI and XXI).

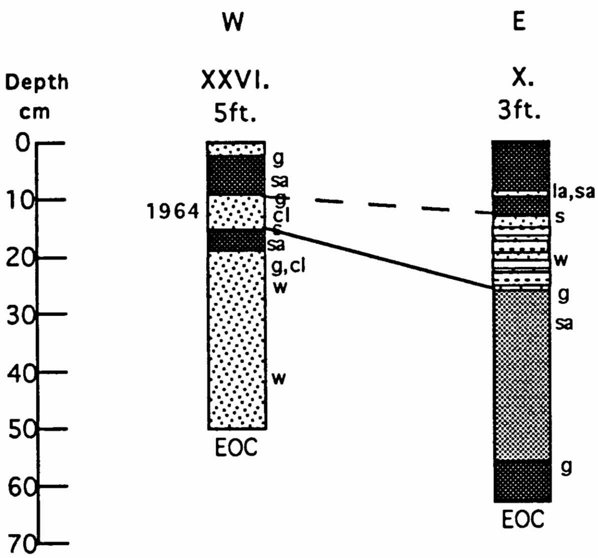


Figure 25. Neacoxie Creek E-W cross-section, southern cores (SSX X and XXVI).

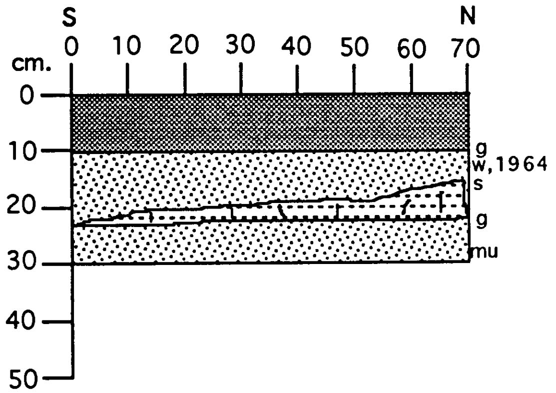
However, the eastern core (X) has more interlayers of sand and mud.

Two general trends are apparent from the close-spaced grid coring. Firstly, multiple surges are represented by thin mud layers separating the sand layers. For example, two mud layers are found within the sand deposits (SSX XXV, XXI, XIII, III, VII), yielding three apparent surge events. Grid site SSX III shows a thinning of sand layers from bottom (thickest) to top (thinnest). However, vertical trends in surge-sand layer thickness are variable in other sites showing sand layer separation by mud laminations. The second general trend of the 1964 sand layer is that it thins from the mouth of Neacoxie Creek to the middle reaches of the N-S grid area, and it then thickens immediately south of G Street.

Trenching

Additional subsurface investigations, using trenching, completed the study of the 1964 tsunami deposition along the banks of Neacoxie Creek. Two trenches, SSX 2A and 2B, were dug along the east bank of Neacoxie Creek. The northern most trench, SSX 2A (Figure 26), is located at gouge core site SSX 754, and it shows a very shallow section of sand underlain by rooted mud and overlain by peaty mud. Total depth of the trench extends to 30 cm. The upper sand layer, from 10-25 cm, has a sharp lower contact. The upper contact contains detrital wood fragments which grade into a peaty mud. The west face shows a thickening of the sand layer to the south over 70 cm, however, the south face indicates a uniform layer of consistent thickness.

Trench SSX 2A, West Face
5ft.



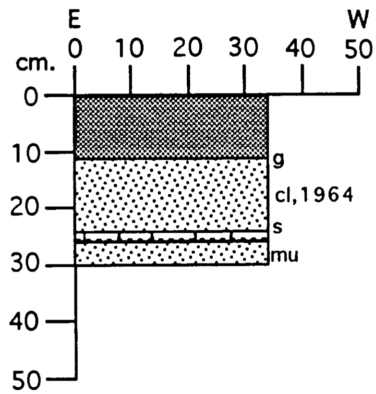
0-10 cm, peaty mud, gradational lower contact.

10-18 cm, sand, detrital wood fragments, sharp lower contact,1964.

18-23 cm, rooted mud, gradational lower contact.

23-30 cm, muddy sand.

Trench SSX 2A, South Face
5ft.



0-11 cm, peaty mud, gradational lower contact.

11-25 cm, sand, clean, sharp lower contact,1964.

25-26 cm, rooted mud.

26-30 cm, muddy sand.

Figure 26. Neacoxie Creek trench 2A (core site SSX 754).

Trench site SSX 2B, dug at grid core site SSX X (Figure 27), shows a peaty mud, sand, and rooted mud sequence from top to bottom of the trench. The clean sand layer, fairly uniform in thickness, has a lower irregular (not intruded) contact and an upper gradational contact. In both faces, there is no evidence of clastic dike or sill intrusion.

Prehistoric Events?

Weak subsidence horizons are located in five grid cores (SSX VIII, IX, X, XI, and XXVII) on the eastern bank of Neawanna Creek (Figure 21). The upper contact of the subsided muddy peat ranges from 29-55 cm in depth. Site SSX IX has a SCL (lamination); however, the remainder of the cores mentioned do not contain any SCL or TSL above the peat.

Drainage to the East of Neacoxie Creek (SSXa)

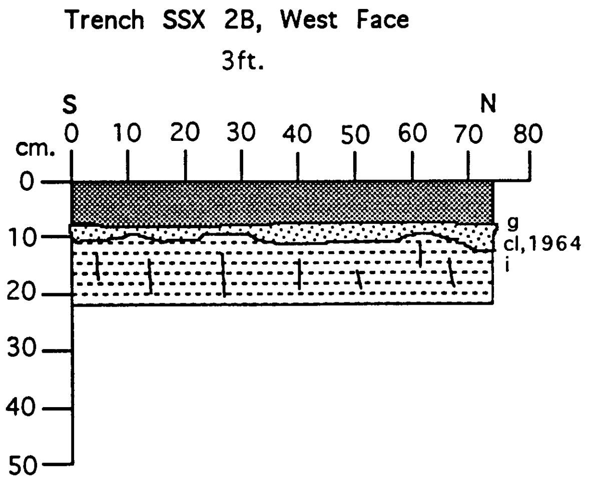
Location

This unnamed drainage directly east of Neacoxie Creek (Figure 28) is bounded to the west by a 7.3 m (24 ft.) sand dune (the eastern boundary of Neacoxie Creek). The northern and eastern limits of the drainage gradually increase in elevation with increasing distance from the creek axis. The drainage mouth, 243 m west of HWY. 101, empties into the Necanicum estuary.

1964 Event

Observations

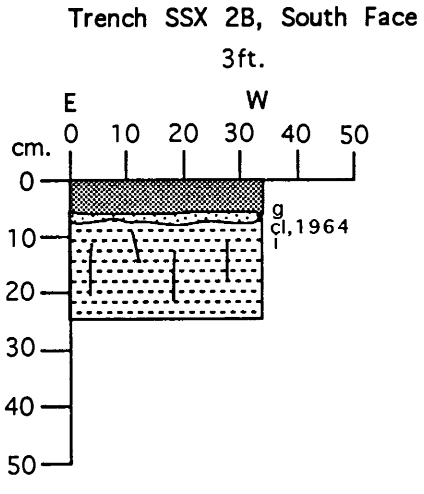
There were no direct observations of the 1964 surge impacts within this drainage, however extensive surge impacts are noted for the opposite bank on the southern side of the Necanicum estuary (Figure 28). Specifically, runup reached 4.1 m (13.5 ft.),



0-8 cm, peaty mud, gradational lower contact.

8-9 cm, sand, clean, irregular lower contact,1964.

9-21 cm, rooted mud.



0-6 cm, peaty mud, gradational lower contact.

6-8 cm, sand, clean, irregular lower contact,1964.

8-25 cm, rooted mud.

Figure 27. Neacoxie Creek trench 2B (grid core site SSX X).

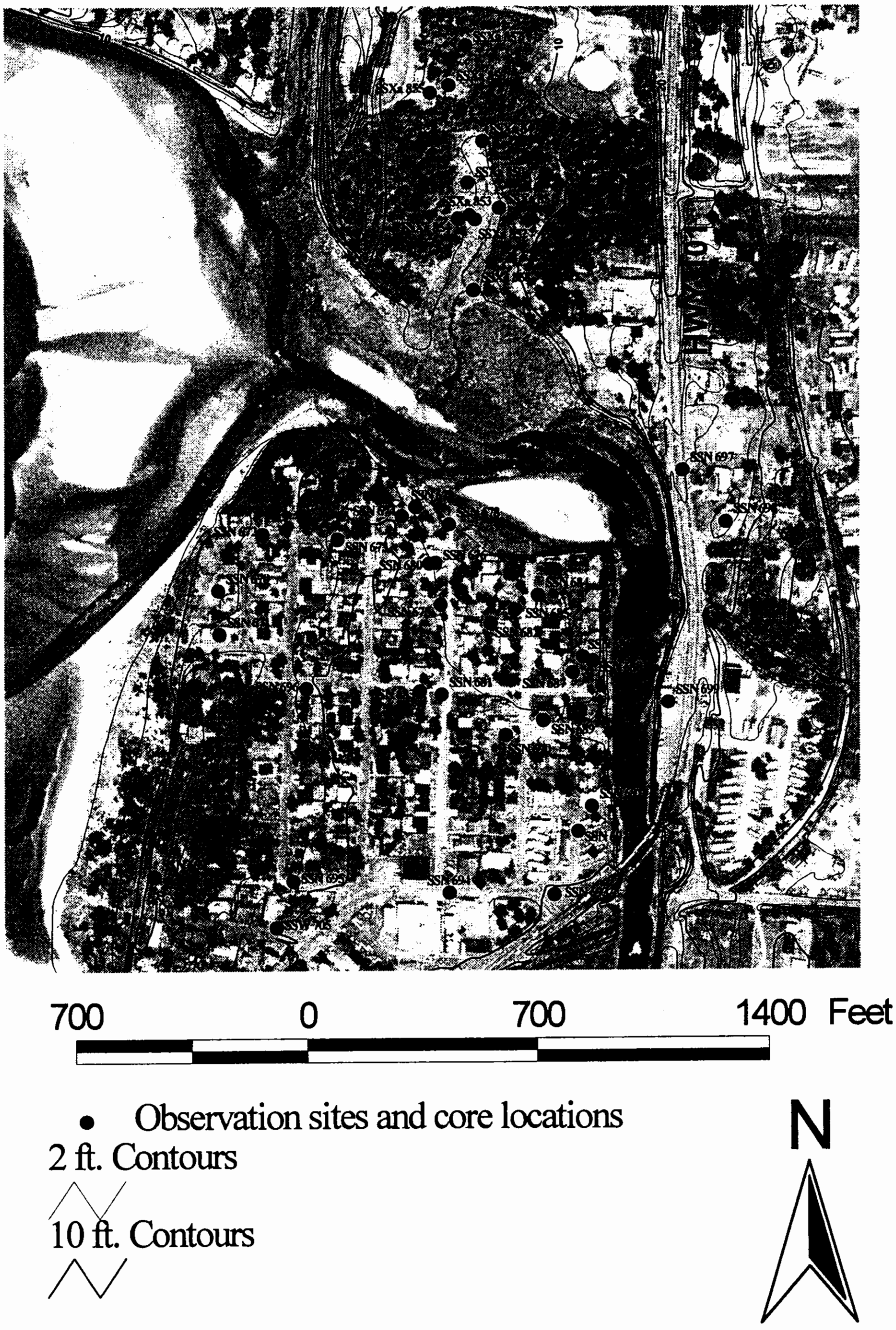


Figure 28. Drainage to east of Neacoxie Creek and Venice Park observation and core sites.

with cars and drift logs being moved 10's to 100's of meters. Thick sand deposits were deposited in Venice Park (Figure 29) and also (16 cm thick at SSW 722) were deposited on the tidal marsh/shoreline immediately downstream from the HWY. 101 bridge (T. Horning, personal communication, 1996).

Gouge Coring

Ten gouge cores, SSXa 849-857, were logged in this drainage. Deep penetration was not a problem in some cored sections with maximum penetration reaching up to 120 cm. All cores except for SSXa 857 (furthest core north) contained sand layers or traces of sand shallow in the section from 0-50 cm. Both core sites SSXa 855 and 856 contained sand layers 0.5 centimeters thick within a peaty mud at 7 and 11 cm, respectively. Figure 30 shows core sections of SSXa 853 and 855-856.

Trenching

Trench SSXa 4A was dug at gouge core location SSXa 850. Both the west and south faces were sketched and described in detail (Figure 31). Interfingering of sand and mud occurred between 20 and 33 cm. Further down section, muddy peat and sand surrounded mud inclusions. Although this view is fairly detailed, the general lithology matches that of what was logged in gouge core SSXa 850. The apparent clastic sill intrusions demonstrate liquefaction of the underlying sand layers.

1700 AD Event

Gouge Coring

Five of the cores taken to document the 1964 event (SSXa 850, 854-856) included deeper buried peaty horizons with sand bodies (Figure 32). Sites SSXa 850,

Figure 29. House located on 26th and Pine in Venice Park area. 1964 Tsunami drift log with sand sheet 10-15 cm thick. Behind the log the sand deposit increases to roughly 20-30 cm. Photographer: Bettie Hanson.

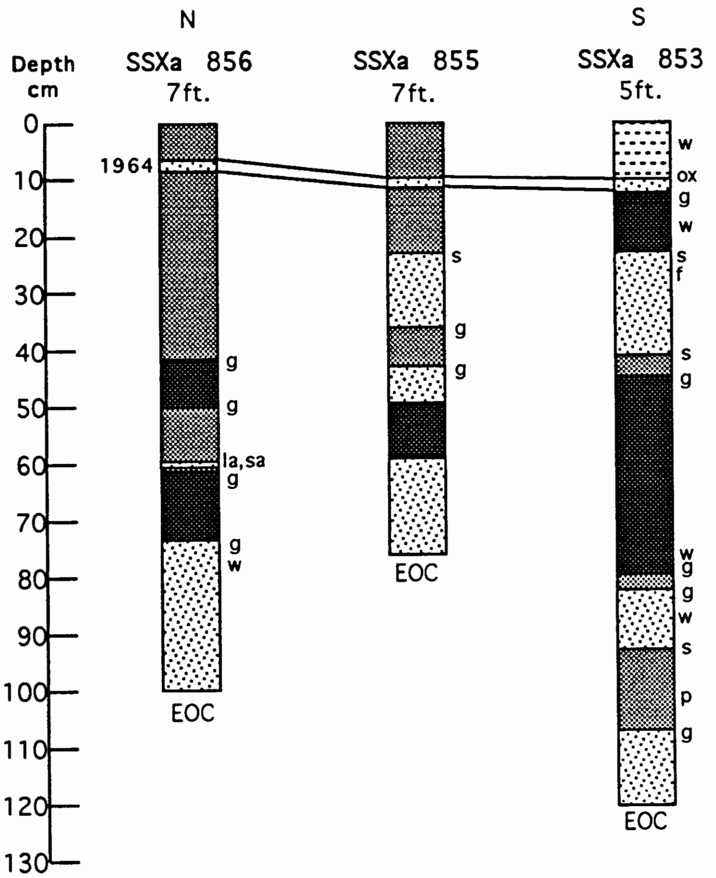
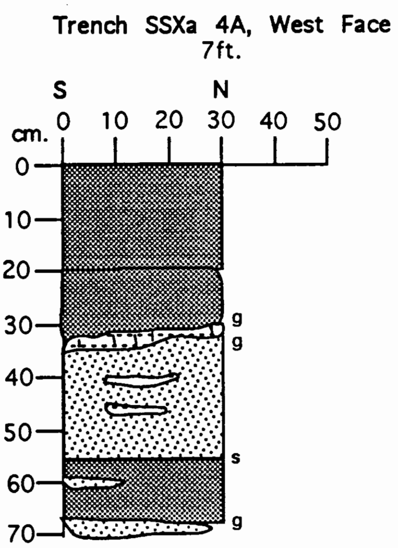


Figure 30. Drainage to east of Neacoxie Creek, cores SSXa 853, 855-856.



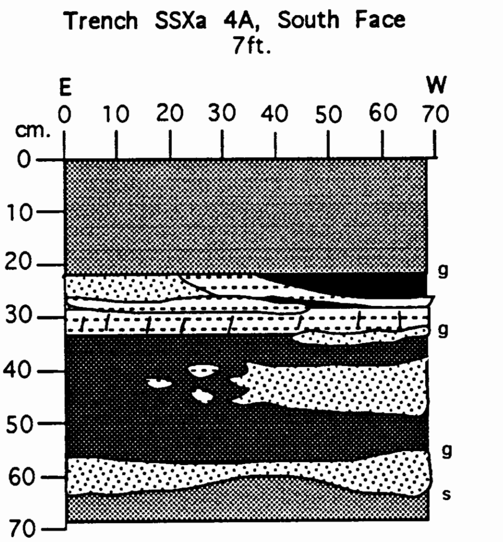
0-30cm, peaty mud, gradational lower contact.

30-33 cm, rooted mud, gradational lower contact.

34-57 cm, sand, mud inclusions, sharp lower contact.

57-68 peaty mud, sand inclusions, gradational lower contact.

68-70 cm, sand.



0-22 cm, peaty mud, gradational lower contact.

22-30 cm, peat, sand, and mud fingers.

30-33 cm, rooted mud, lower gradational contact.

33-56 cm, muddy peat, sand inclusions, lower gradational contact.

56-64 cm, sand, lower sharp contact.

64-68 cm, peaty mud.

Figure 31. Drainage to east of Neacoxie Creek, trench 4A (core site SSXa 850).

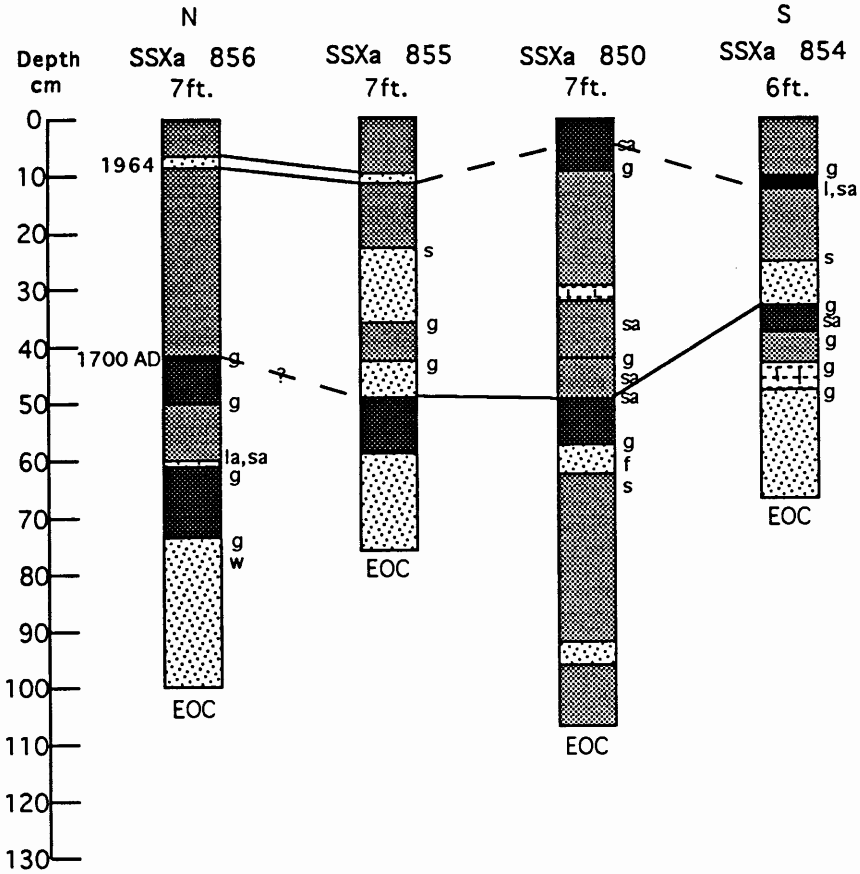


Figure 32. Drainage to east of Neacoxie Creek, prehistoric horizons?

854-856 show a sand layer or lamination (SCL) with a lower primarily sharp to gradual contact with a buried peat to muddy peat at 32-60 cm deep. Site SSX 856 contains two possible buried peaty layers also below the 1964 event. Site SSXa 850 indicates a reversed stratigraphy with the fining upward sand underlying the buried peat and a trace of sand above the muddy peat. Generally, these cores lack the expected sequence of sand layers between a peaty layer and an overlying mud. The placements of the deeper sand layers (pre-1964) are inconsistent and discontinuous between core sites.

Stanley Lake (SSS)

Location

Stanley Lake is located just south of the Seaside/Gearhart Airport at the northeast corner of the study area. The western boundary of this N-S trending lake is confined by a cobble ridge, and the eastern boundary gradually increases in elevation to eventually meet the foothills of the Coast Range. The southern extent of the Stanley Lake study area is just south of the intersection of 4th Street and 12th Avenue. Tide gates regulated the water flux of Stanley Lake until mid-summer 1996. Stanley Lake now connects with the Necanicum Estuary to the north by Mill Creek. Gouge core and observation sites are located in Figure 33.

1964 Event

Observations

There are no reports of 1964 surges reaching the Stanley Lake area. However, runup reached up to 4.7 m (15.5 ft.) and drift logs were reported from the Mill Creek mouth and east banks of the Necanicum estuary (Figure 28) (T. Horning, personal

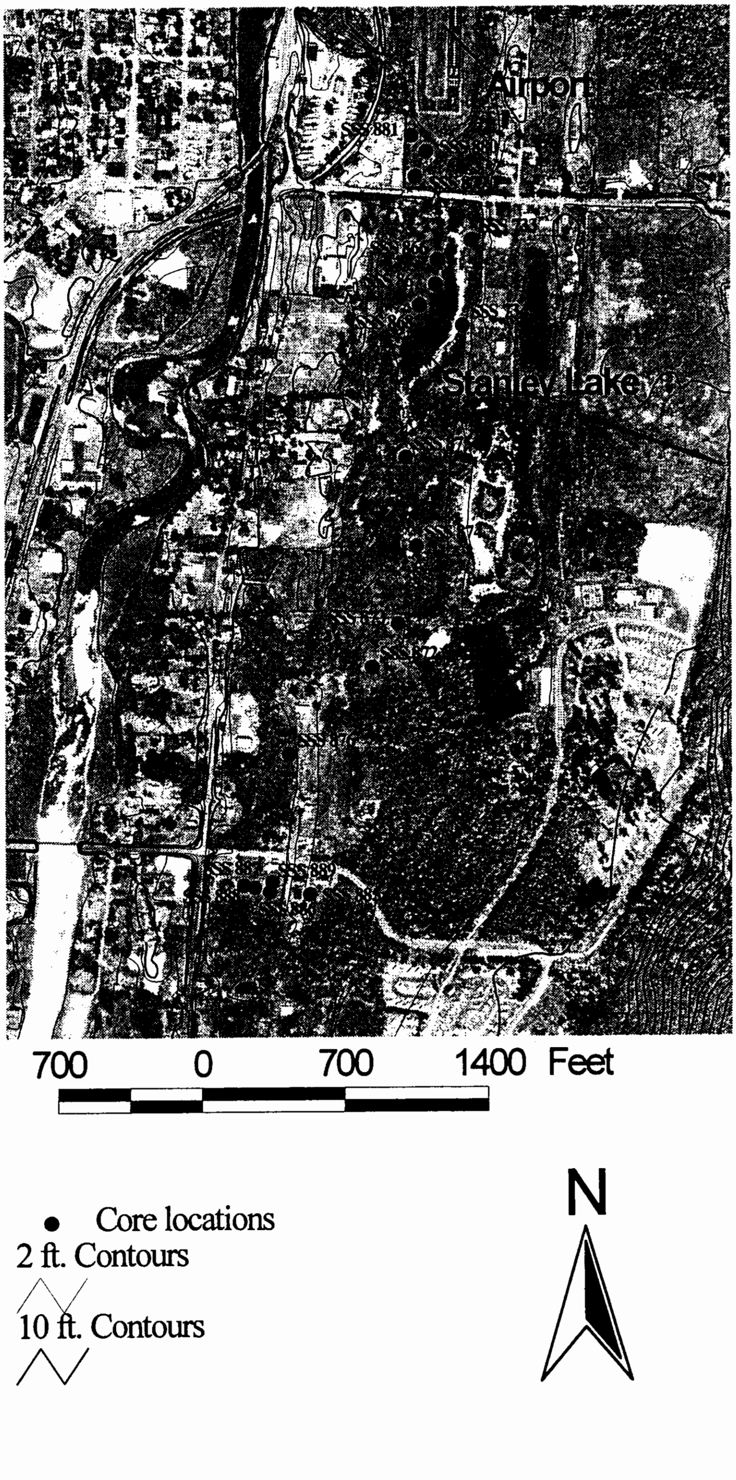


Figure 33. Stanley Lake core locations.

communication, 1996).

1700 AD Event

Gouge Coring

Coring at Stanley Lake was difficult due to a high water table causing portions of the cores to be unrecoverable. Eight gouge cores were taken in the immediate area surrounding Stanley Lake. Core SSS 733 reached maximum penetration for the area of 250 cm. However, the average core depth reached about 150 cm.

On the east side of Stanley Lake, SSS 733 and 734 display differing stratigraphies (Figure 34). Site SSS 734 indicates a sand layer (SCL) with a lower sharp contact at 88 cm with a muddy peat. The sand deposit is 13 cm thick with an overlying thick deposit of peaty mud.

Remaining core samples were taken on the western side of Stanley Lake. Immediately to the southwest of the Seaside/Gearhart Airport, three cores were taken, SSS 879-881 (Figure 35). All three cores have sand layers (TSL) overlying peaty mud or muddy peat. Rooted mud overlies the sand layers. Lower in the sections of these cores, variable deposits of sand and underlying cobbles inhibit further gouge core penetration. The sandy muddy peat to peaty mud contacts averaged 62 cm in depth from the surface. Cores taken at the south end of the airport runway showed extensive evidence of fluidization including clastic sand dikes and sills. Therefore, these cores were not logged for paleotsunami evidence.

Gouge cores, SSS 866-868 (Figure 36), were taken along the western edge of

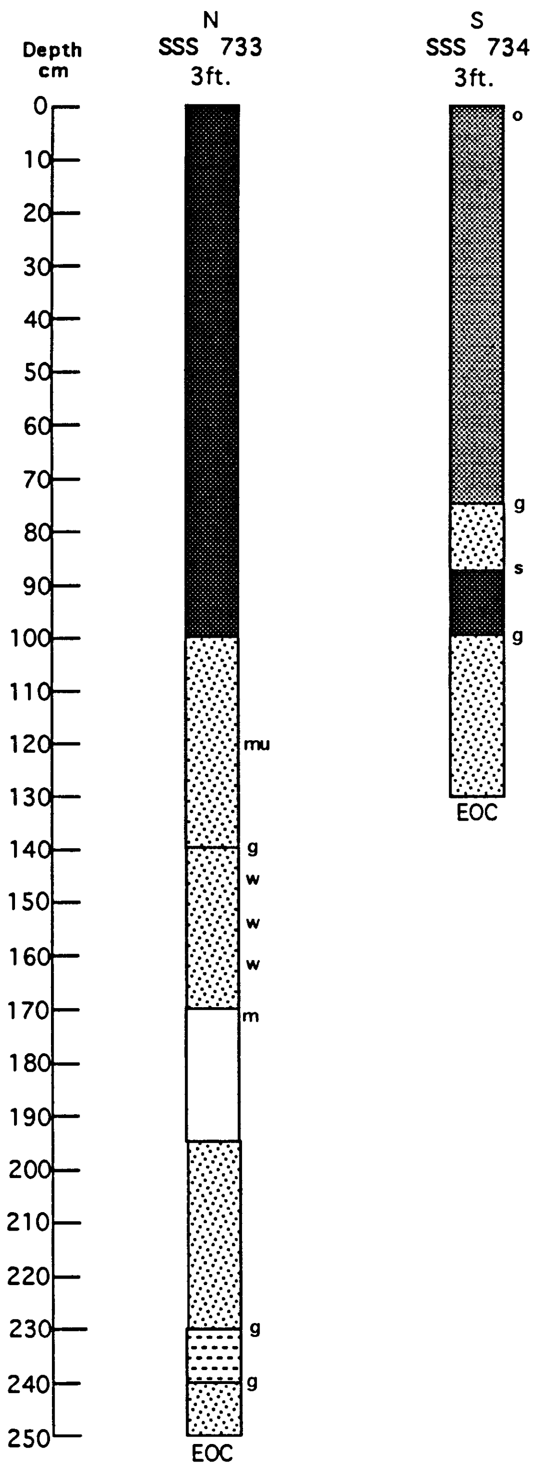


Figure 34. Stanley Lake cores SSS 733 and 734.

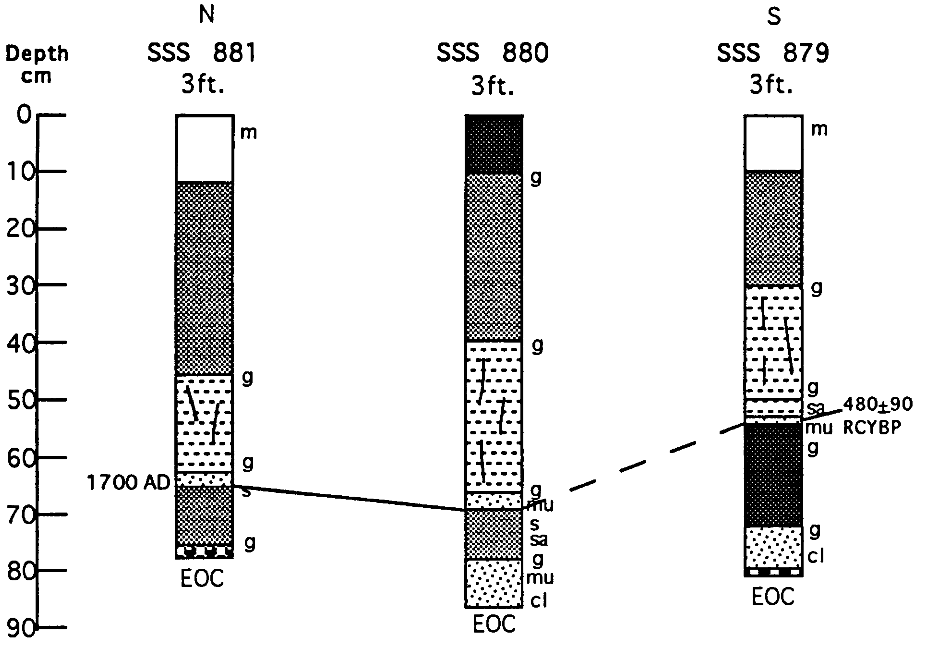


Figure 35. Stanley Lake cores SSS 879-881.

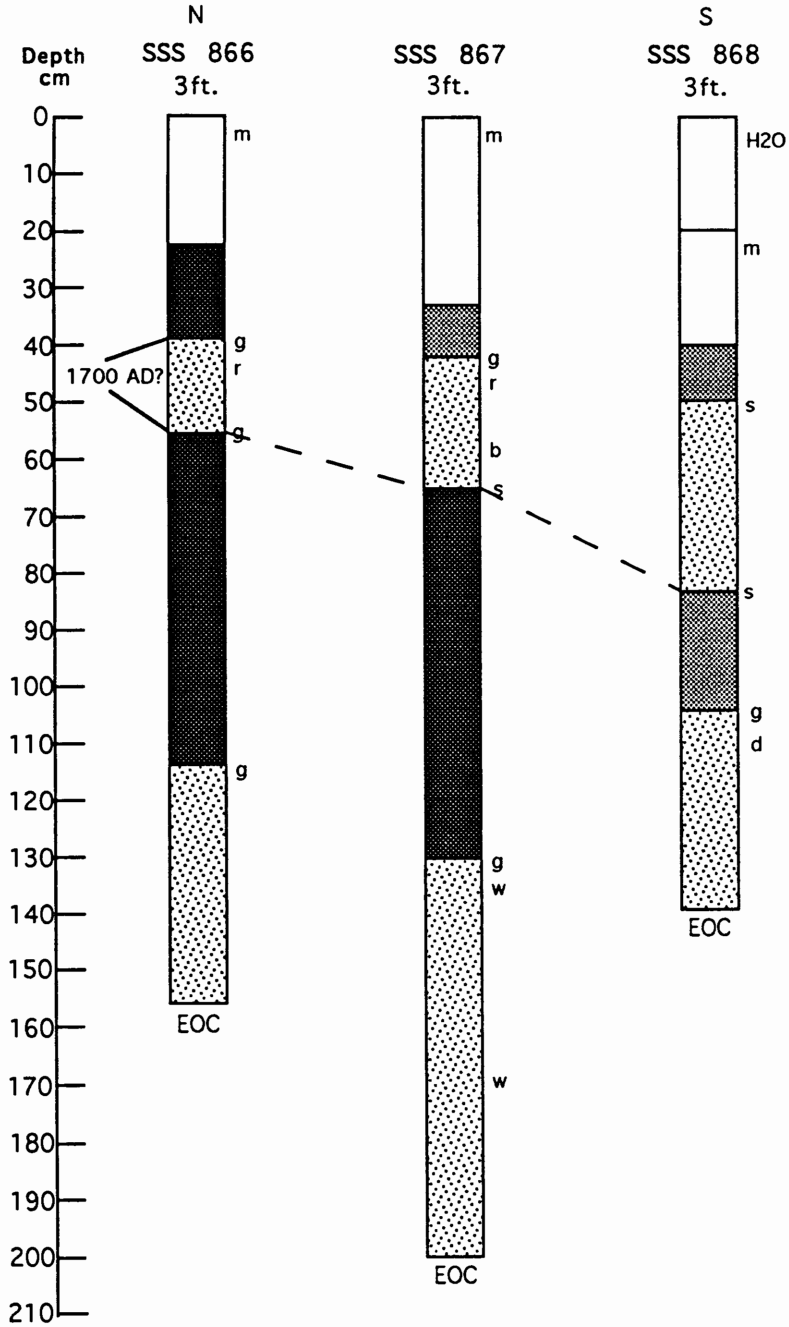


Figure 36. Stanley Lake cores SSS 866-868.

Stanley Lake. All three cores show a continuous sand horizon thickening to the south. However, a muddy peat encloses this sand layer, so a correspondence to abrupt subsidence cannot be established. Sand layers thicken from 17 cm at SSS 866 to 33 cm at SSS 868. These cores end in a fairly dense sand, no cobbles or gravel were encountered.

Further south, cores SSS 872-876 indicate a decreasing sand thickness to the south again within a peaty mud or muddy peat (Figure 37). At SSS 875, this four centimeter sand layer (at 46 cm) is slightly muddy. Site SSS 874 (at 44 cm) contains a sand layer of 0.5 centimeters within a muddy peat. In SSS 873 and 872, there is no sand present 40-50 cm in depth from the surface, although, a sand layer is evident within the interval of 140-150 cm of both cores. In both SSS 872 and 873, the cores show very similar stratigraphy. South of SSS 872, SSS 876 shows a sand layer within a peaty mud. This sand fines upward and has a sharp lower contact. Due to a lack of a distinct buried peaty unit and corresponding subsidence contact, it is not known what the relative stratigraphic ages are of the anomalous sand layers.

Farther south, SSS 887-889, the sand is not found within a consistent horizon (Figure 38). Some contacts are gradual while others are sharp, some contain basal sand while others do not, and some sand deposits are associated with organics and detrital wood fragments. There is little to no similarity in sand layer depth, thickness or stratigraphic sequences between these cores.

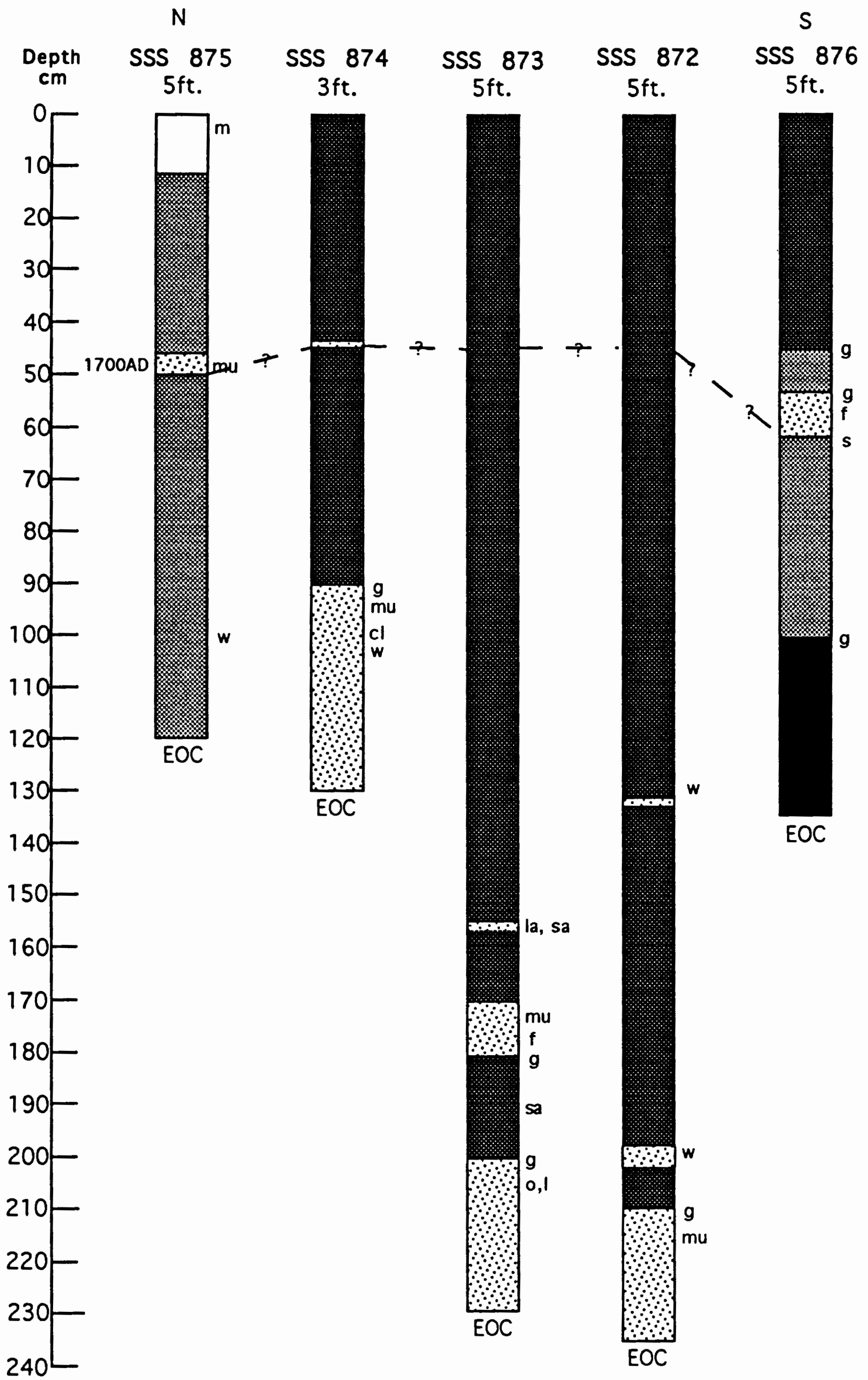


Figure 37. Stanley Lake cores SSS 872-876.

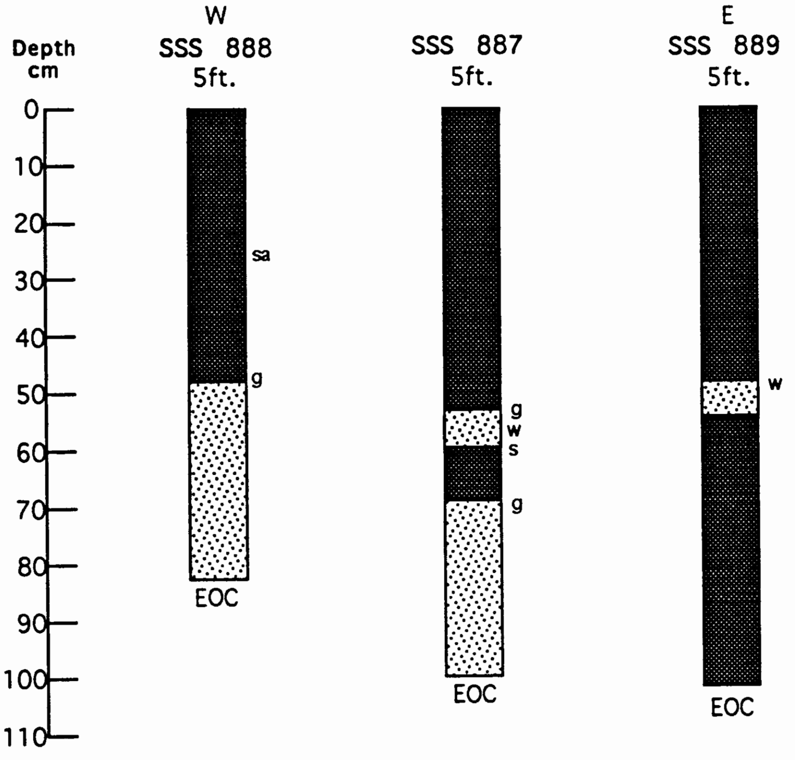


Figure 38. Stanley Lake cores SSS 887-889.

Radiocarbon Samples

Two radiocarbon samples taken from SSS 879 were analyzed. Both peat samples were retrieved by pound core. SSS 879 at 55-65 cm returned a date of 910 ±70 RCYBP. This sample contained a relatively thick peaty section, so the old date was suspect. Therefore, an additional, more confined peat sample was collected directly below the sand contact at 54 cm for AMS dating. This sample produced a new date of 480 ±90 RCYBP. This age is not inconsistent for a pre-event peat surface developed prior to the 1700 AD subsided event.

Diatom Analysis

Site SSS 879 showed a contact between a muddy peat and an overlying sand layer at 54 cm. A sample for diatom analysis was taken below the contact at 56 cm. This sample showed a considerable freshwater diatom influence with such species as *Eunotia pectinalis* and *Navicula radiosa*. The sample from above the contact showed a change to a brackish to marine diatom influence. Marine diatoms include *Cocconeis scutellum* and *Thalassiosira pacifica*, and brackish diatoms were dominated by *Synedra fasciculata*. The diatom data confirm an abrupt event of paleosubsidence from high marsh to low marsh recorded at the 0.5 meter depth interval (E. Barnett, personal communication, 1997).

Neawanna Creek (SSW)

Location

Neawanna Creek, which roughly trends N-S, is directly east of the Necanicum River, and its mouth empties directly into the Necanicum Estuary. The Neawanna wetlands extend along the eastern lowlands of Seaside. The narrow wetlands are relatively contiguous from the north (HWY. 101 bridge) to the south totaling a distance of about four kilometers. Eastern boundaries are formed at alluvial slopes of terraces at the base of the Coast Range foothills. The western boundaries of the Neawanna wetlands run parallel to cobble beach ridges along most of the tidal creek. Tidal influence in the modern creek diminishes from north to south, with beaver dams constricting freshwater runoff at the southernmost end of the wetlands.

1964 Event

Observations

Observations of the 1964 tsunami impacts along the Neawanna Creek include sites SSW 700-711. Site SSW 705 indicated live fish deposited in a field with a water mark at 3.4 m (11 ft.). No flooding occurred in the area near SSW 706. Sites SSW 700 and 701, along the northeastern bank of Neawanna Creek, had water marks of 3.0 m (10 ft.) from the tsunami waves, flush with one home owner's yard. On the western bank, SSW 702 indicated a water mark at 3.2 m (10.5 ft.). At SSW 703 and 704, a sand layer and water mark at 2 and 2.3 m (6.5 and 7.5 ft.) respectively were observed. At these localities standing waves in prolonged surges were observed as water flooded over a point bar marsh at an elevation of 3 m. The next day the site was observed to contain sand deposits overlying flattened grass leaning up river (J. Spillman, personal communication, 1996). Figure 39 shows observation sites and core locations for Neawanna Creek from its mouth to 12th Avenue. Site SSW 707 indicated a water mark at 1.8-1.5 m (6-5 ft.), immediately southeast of 12th Avenue bridge. However,

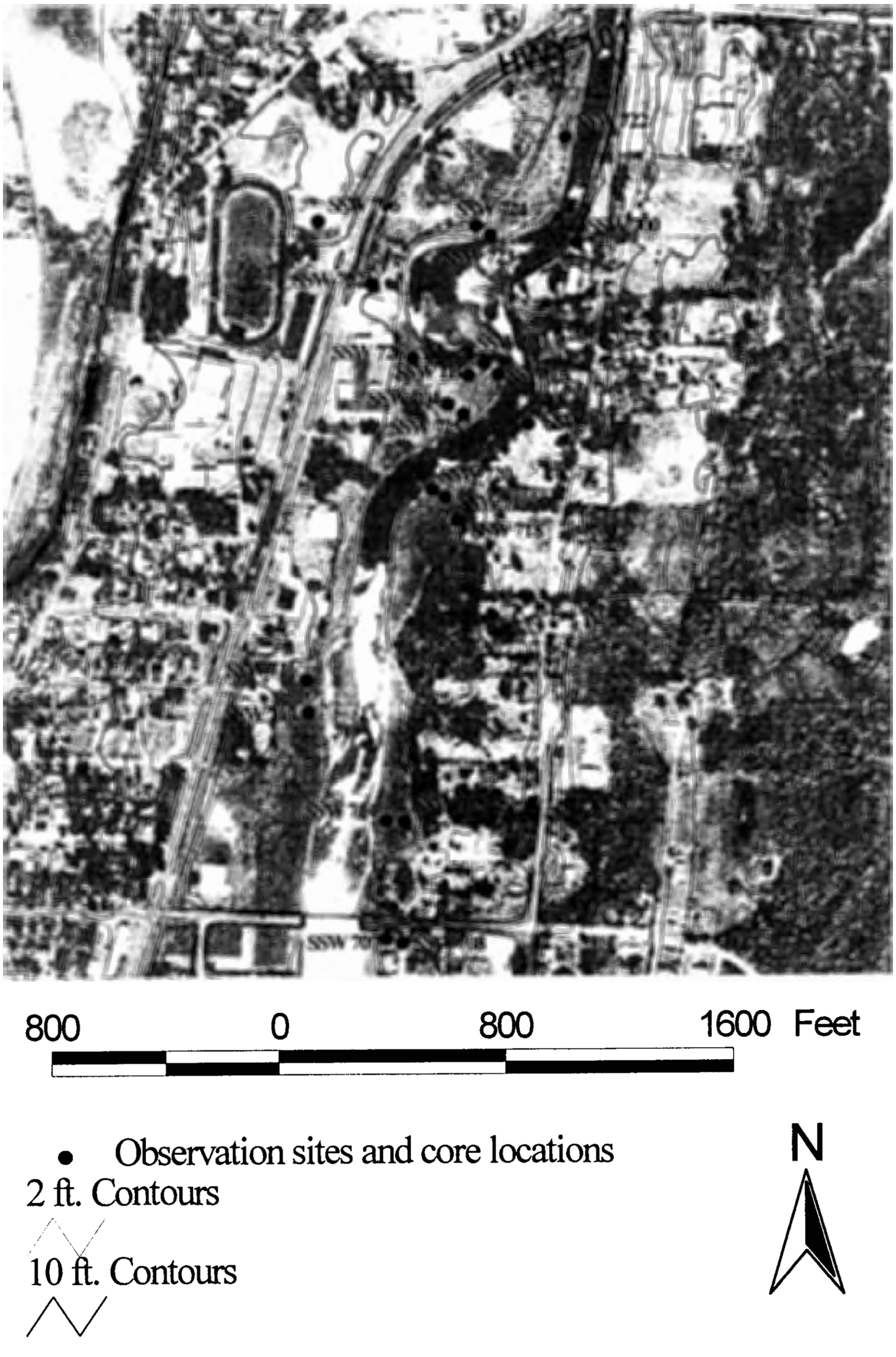


Figure 39. Neawanna Creek observation and core locations between its mouth and 12th Ave.

SSW 708 was not affected by flooding (2nd Street).

Remaining observations to the south (SSW 709-711) indicated that no flooding occurred at these locations. Figure 40 shows Neawanna Creek observations and core locations from 12th Avenue to south of Broadway Drive bridge.

Gouge Coring

The search for shallow 1964 sand deposits involved sixteen cores taken along the Neawanna Creek coastal wetland. Farthest to the north, cores SSW 722, 723, 725 and 726 show a distinct, thinning, 1964 sand sequence (Figure 41). SSW 722 contains a 15 cm thick sand layer overlying rooted mud. At SSW 723, the sequence is similar; however, there are mud and sand laminations at 11 and 17 cm. At SSW 726, sand thins to eight centimeters with a muddy sand layer at 11 cm. Further south, SSW 725 contains a five centimeter thick muddy sand. All lower sand to rooted mud contacts are sharp for this area. Cores SSW 718-720 contain 1964 sand layers or laminations within either rooted mud or peaty mud sections (Figure 42). Just to the northwest of the Broadway Drive bridge crossing Neawanna Creek, SSW 757 and 756 indicate shallow sand layers with sharp lower contacts with muddy peat. To the southwest of Broadway Drive bridge, SSW 763 contains a sand lamination at four centimeters within a muddy peat. These core logs are represented in Figure 43. Finally, cores SSW 803-808 contain a shallow, typically clean, sand horizon (Figure 44). Figure 45 contains observation sites and core locations from south of Broadway Drive to S Avenue. The stratigraphies of these cores are fairly complex and may

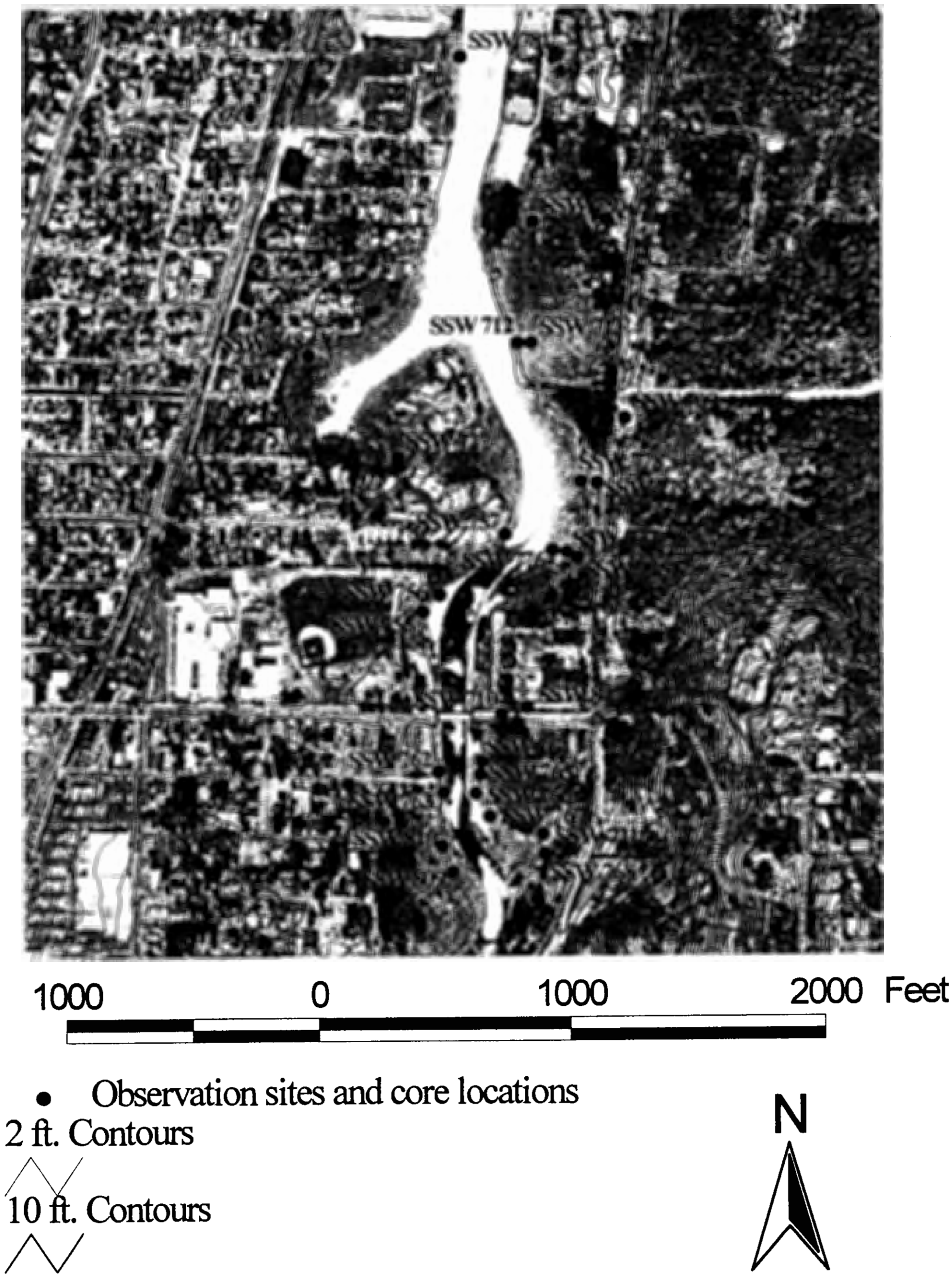


Figure 40. Neawanna Creek observation sites and core locations for 12th Ave. to south of the Broadway Dr. bridge.

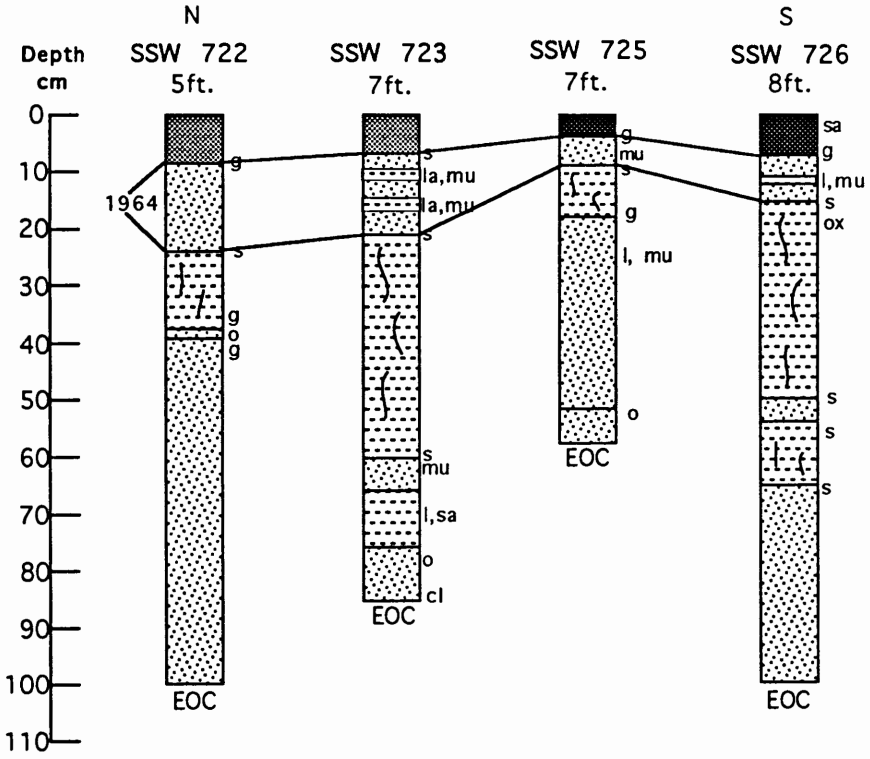


Figure 41. Neawanna Creek cores SSW 722, 723, 725, and 726.

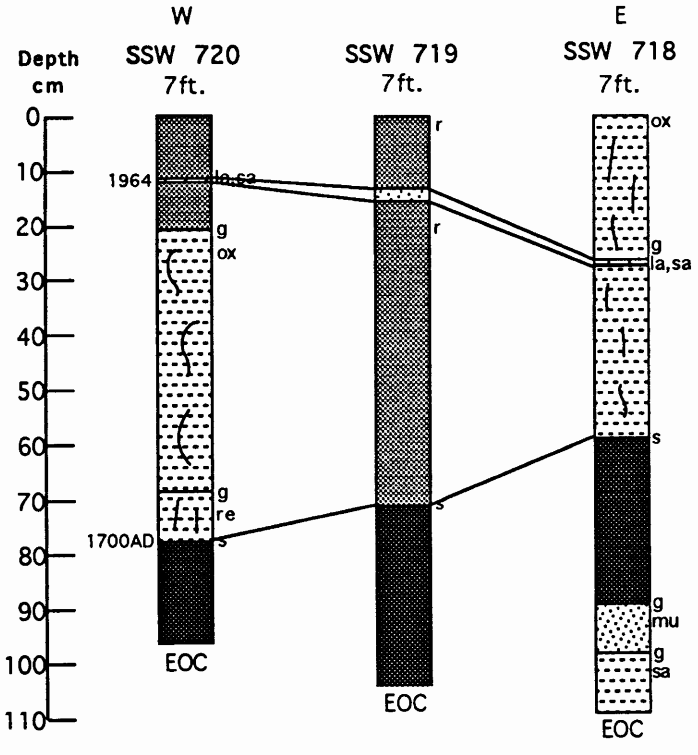


Figure 42. Neawanna Creek cores SSW 718-720.

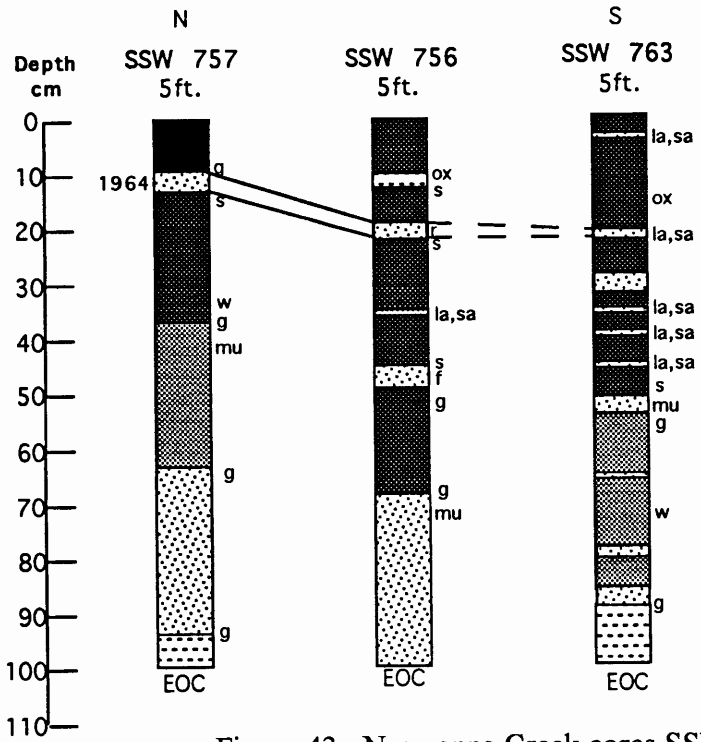


Figure 43. Neawanna Creek cores SSW 757, 756, 763.

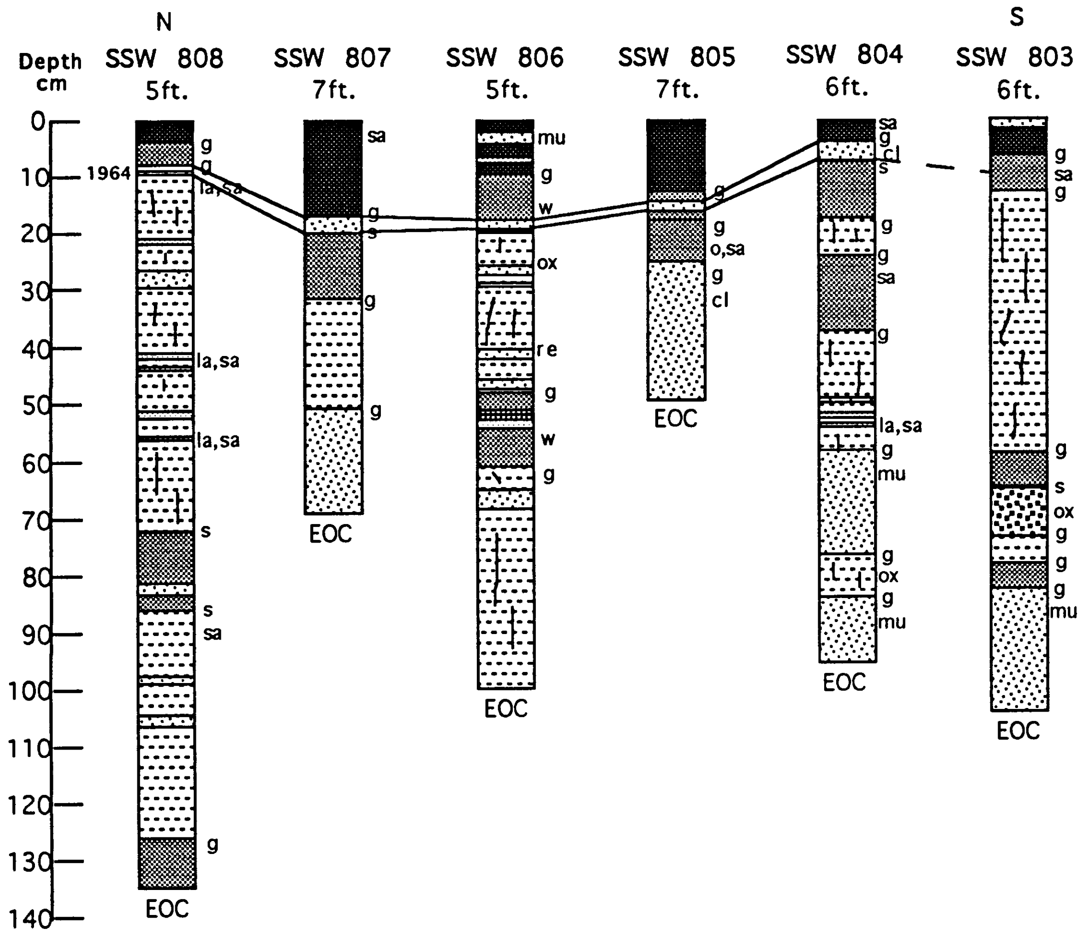


Figure 44. Neawanna Creek cores SSW 803-808.

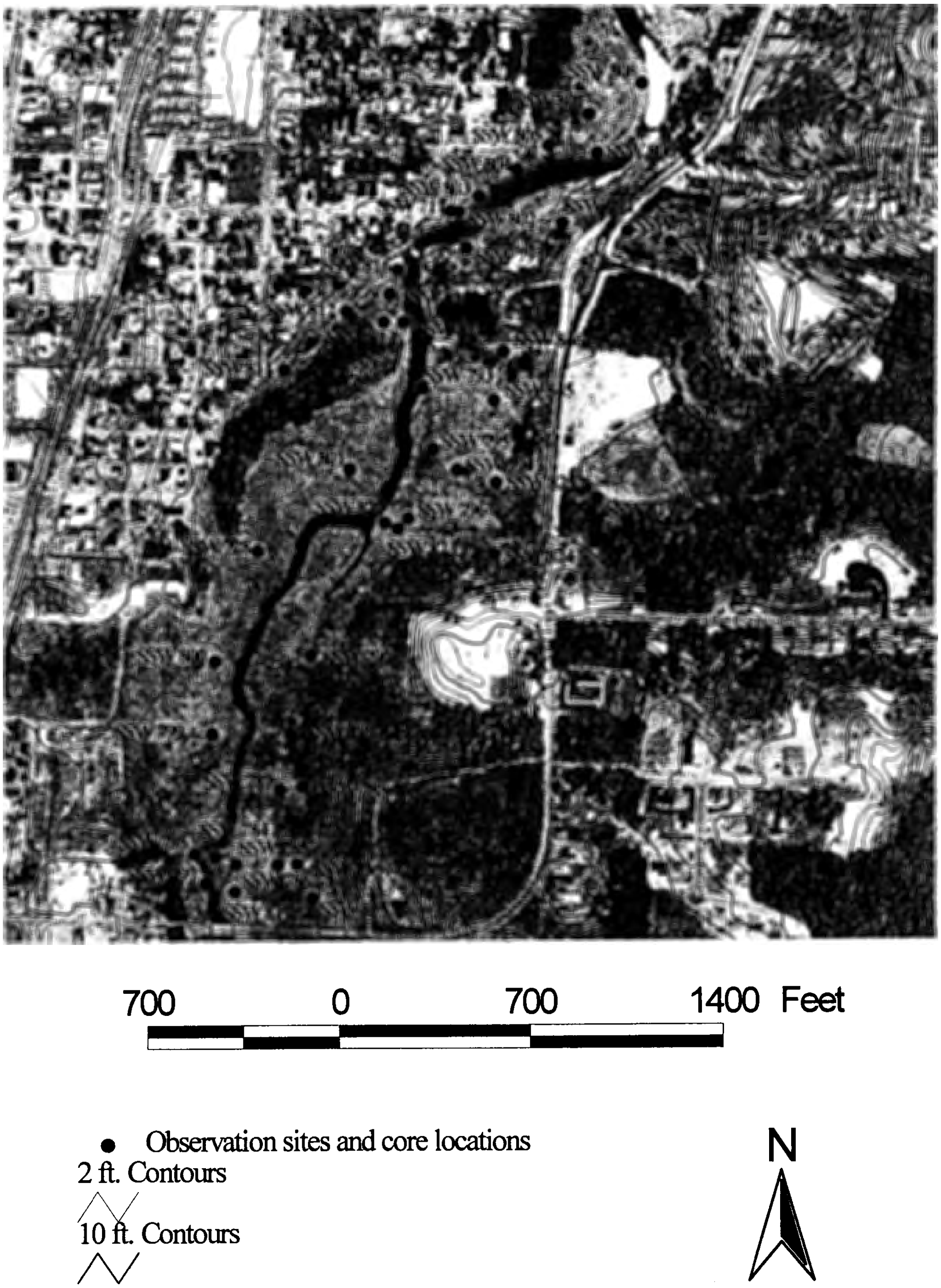


Figure 45. Neawanna Creek observation sites and core locations from south of Broadway Dr. to S Ave.

indicate disturbance caused by urbanization.

Grid Coring

A total of 30 gouge cores were taken at three localities along the lower Neawanna Creek (Figure 46). These areas were affected by the 1964 tsunami, evidenced by direct observations (see above Observation section). Of the northernmost cores, SSW I-V, VIII and X show shallow sand layers fading in and out of the section (Figure 47). An E-W cross-section of cores XIII, XIV, XVI, and XVIII in the central grid show a sand layer which thins landward of Neawanna Creek (Figure 48). However, a relatively thick sand layer is present in SSW XVI.

A N-S cross-section from XXVIII, XXVII, XXVI, and XXIX on the southeastern grid contains fine sand laminations from the 1964 event at 8 and 13 cm which grade to a thicker single sand layer (1 cm at 4-5 cm depth), to shallow sand traces, and then to no sand being present (Figure 49). The E-W cross-section of XXVIII, XXII, and XXI shows thinning of sand laminations landward (Figure 50). The westernmost cores (closer to the creek) contain two sand laminations, indicating two possible surges.

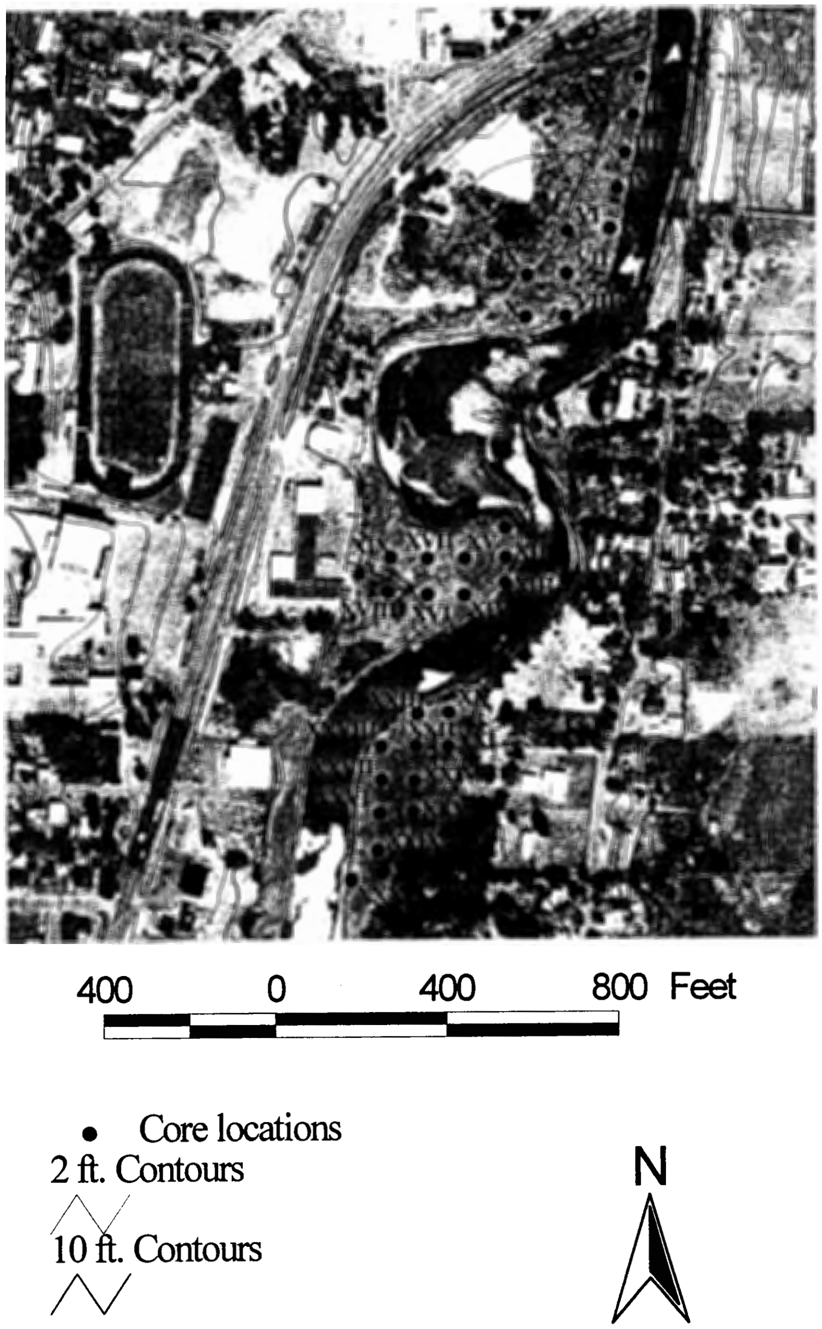


Figure 46. Neawanna Creek grid location map.

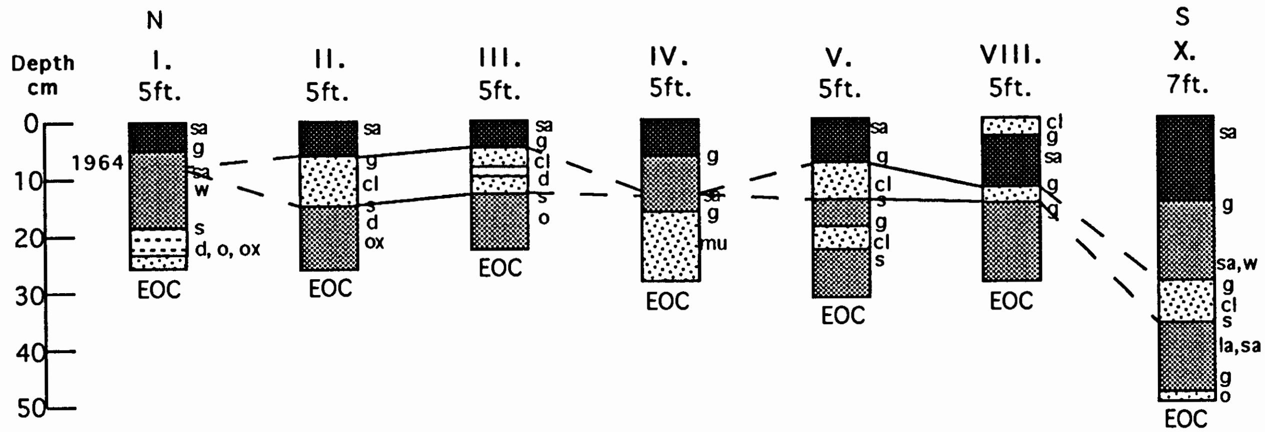


Figure 47. SSW grid cores I-V, VIII, and X.

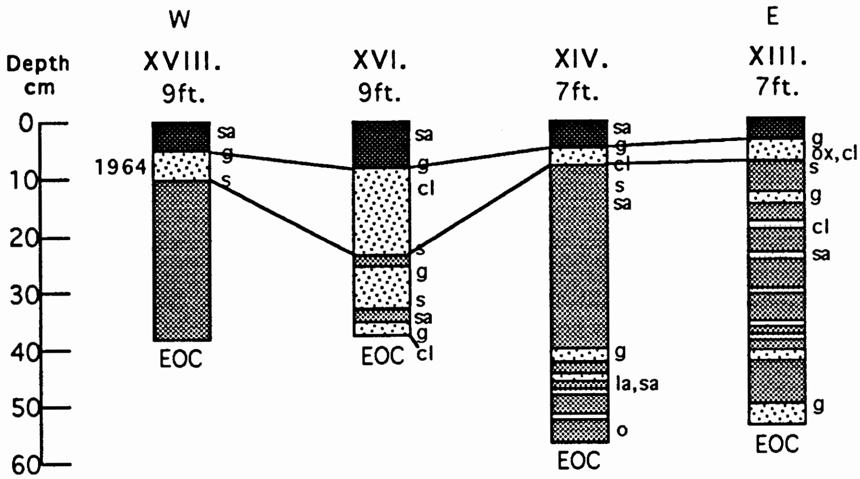


Figure 48. E-W cross-section of the central SSW grid cores XIII, XIV, XVI, and XVIII.

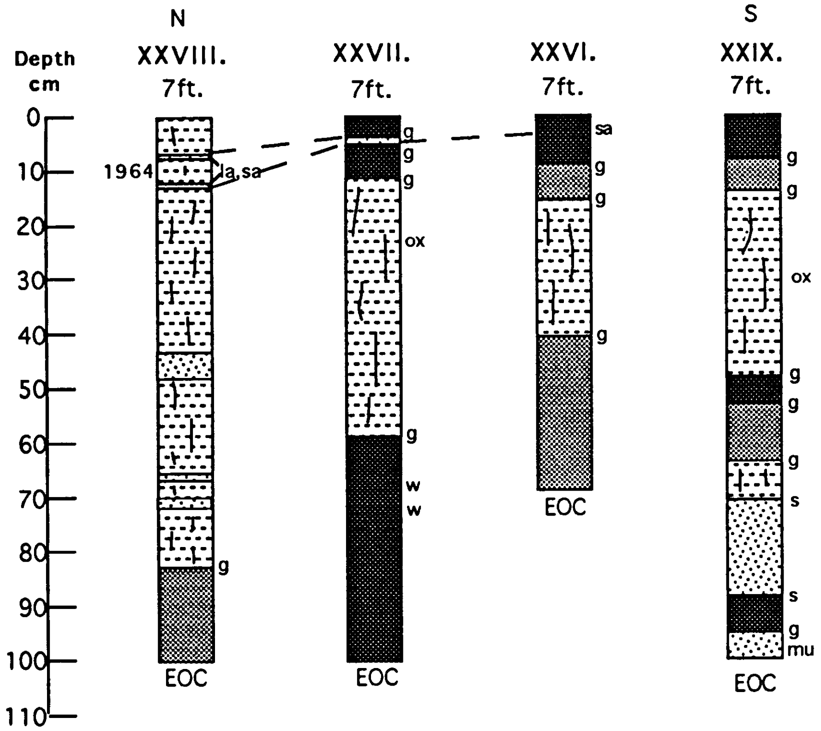


Figure 49. Southern SSW N-S grid cores XXVIII, XXVII, XXVI, and XXIX.

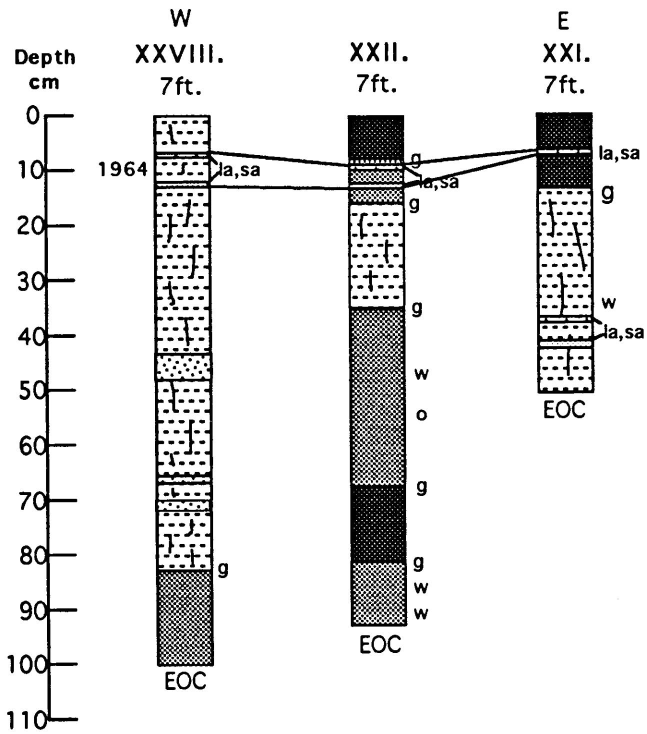


Figure 50. Southern SSW E-W grid cores XXVIII, XXII, and XXI.

Trenching

Two trenches, SSW 1A and 1B, were dug on the point bar near the mouth of Neawanna Creek. Trench SSW 1A shows the 1964 sand layer 7-13 cm in depth with a sharp lower contact above a peaty mud (Figure 51). Above the sand is a debris cap of organic detritus at seven centimeters of 1-3 cm in thickness.

Trench SSW 1B contains similar stratigraphy (Figure 52) showing the 1964 sand layer in sharp contact with an underlying peaty mud. However, overlying the sand is a sandy peat layer and underlying the peaty mud is a muddy sand.

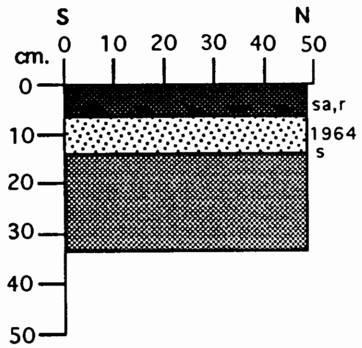
These trenches show a greater resolution of the shallow 1964 sand horizon compared to the limited view of the gouge cores. The sand layers observed in the trenches do not show evidence of internal mud laminations. Careful examination failed to confirm paleoflow directions from bent grass (flop-overs). Apparently, oxidation processes in the shallow soil decayed the plant macrofossils buried by the sand. Finally, there were no intruded contacts or fluidized features (clastic sills or dikes) observed in the trench exposures.

Prehistoric Events

The wetland shallow stratigraphy of Neawanna Creek is complex and variable over relatively short distances (10's to 100's of meters). Only about one half of the cores record subsidence contacts and many of the core sites contain multiple sand layers with intruded contacts. The core sites are grouped into four localities for a detailed discussion below. These localities are the Necanicum estuary confluence to

Trench SSW 1A, West Face

7ft.



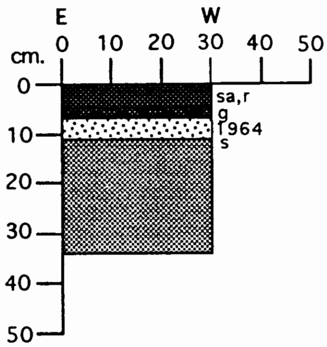
0-7 cm, sandy muddy peat (rooted), debris cap of detrital organics at 7 cm.

7-13 cm, sand, sharp lower contact, 1964.

13-34 cm, peaty mud.

Trench SSW 1A, South Face

7ft.



0-5 cm, sandy muddy peat (rooted), lower gradational contact.

5-7 cm, debris cap of detrital organics.

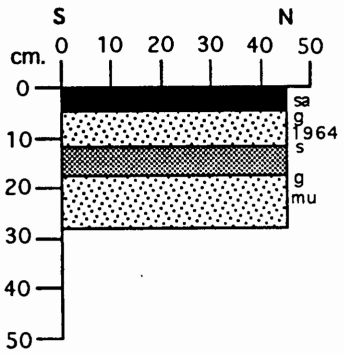
7-11 cm, sand, sharp lower contact, 1964.

11-34 cm, peaty mud.

Figure 51. Neawanna Creek trench 1A.

Trench SSW 1B, West Face

7ft.



0-5 cm, sandy peat, slight organic cap at 5 cm, gradational lower contact.

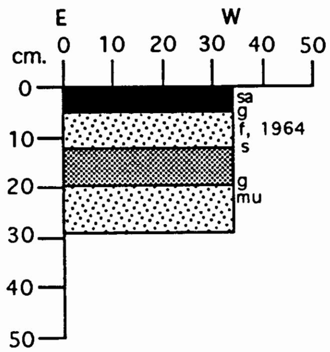
5-12 cm, sand, sharp lower contact, 1964.

12-18 cm, peaty mud, gradational lower contact.

12-28 cm, muddy sand, becomes sandier down section.

Trench SSW 1B, South Face

7ft.



0-5 cm, sandy peat, gradational lower contact.

5-12 cm, sand, fining up, sharp lower contact, 1964.

12-20 cm, peaty mud, gradational lower contact.

20-29 cm, muddy sand, becomes sandier down section.

Figure 52. Neawanna Creek trench 1B.

Avenue, 12th Avenue to south of Broadway Drive, south of Broadway Drive to S Avenue, and S Avenue to the southernmost Mill Ponds.

Neawanna Confluence to 12th Avenue (Figure 39)

Around the proximity of the 12th Avenue bridge, five cores indicate subsidence. SSW 720, 716, 717, 714, and 781 have a subsidence contact at roughly 77 cm from the surface (Figure 53). These cores have a muddy peat or peat sharply in contact with an overlying sand or rooted mud ranging from 67 to 88 cm depth within subsurface. The sand layer in both 716 and 717 is one centimeter in thickness. There is minor peaty mud development with an overlying thin sand layer at 56 cm in SSW 781.

12th Avenue to south of Broadway Drive (Figure 40)

Northeast of the Broadway Drive bridge, the core lithologies become irregular. SSW 712 has a thin mud layer between the peaty mud and the sand layer. In SSW 778 and 779, the stratigraphy has a rooted mud with an overlying sand layer. The contacts of the sand are intruded and the lower contacts occur at 60 and 55 cm for SSW 778 and 779 respectively. If these intruded sands within these cores are of coseismic origin, then a younger buried peat surface (1700 AD) must lie above them (Figure 54). Evidence of paleosubsidence from the 1700 AD event is absent from many cores in the Neawanna wetlands.

Near the Broadway Drive bridge, SSW 847, 762 and 766 show a buried horizon at 58 to 62 cm (Figure 55). All three cores have an overlying sand deposit (SCL) ranging from 2 to 4 centimeters thick. Site SSW 766 has a poorly developed muddy peat of only two centimeters in thickness.

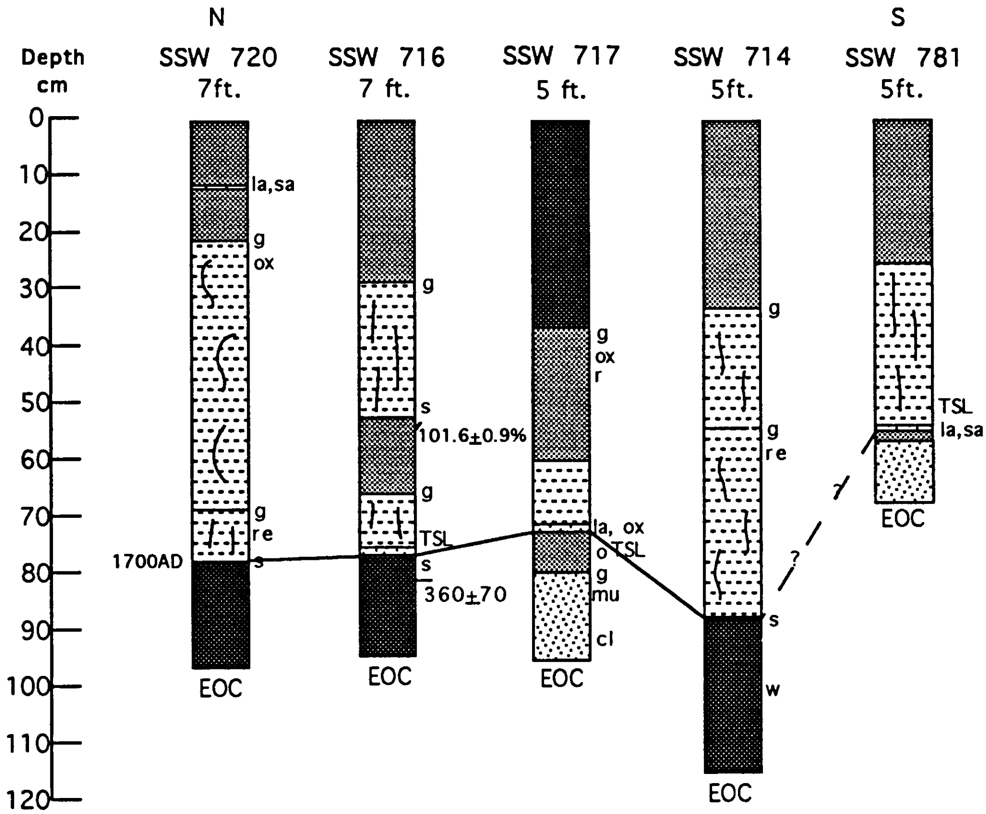


Figure 53. Neawanna Creek cores SSW 720, 716, 717, 714, and 781.

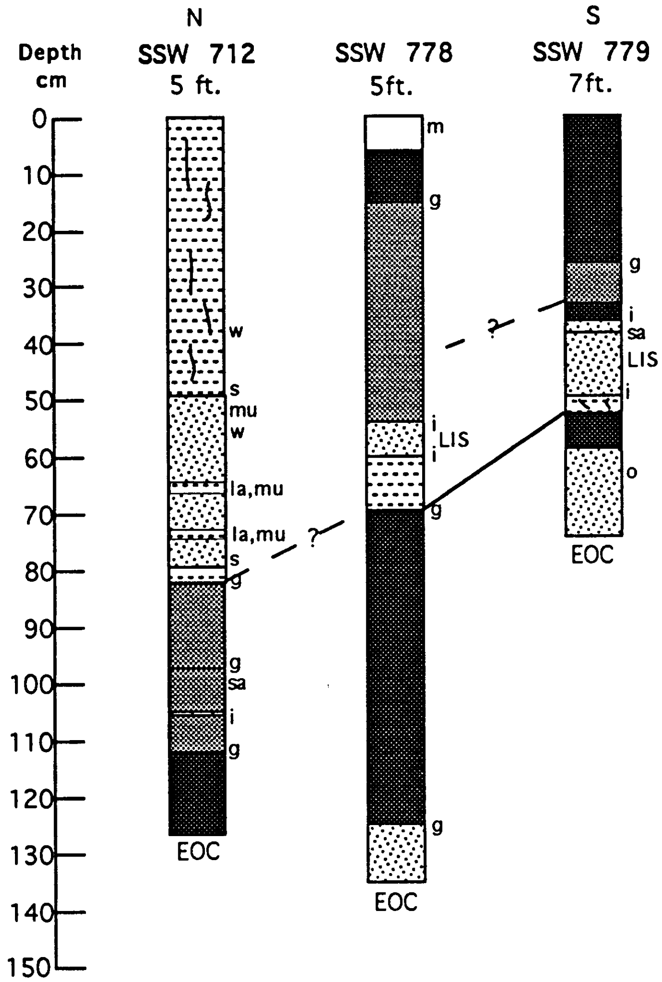


Figure 54. Neawanna Creek cores SSW 712, 778, and 779.

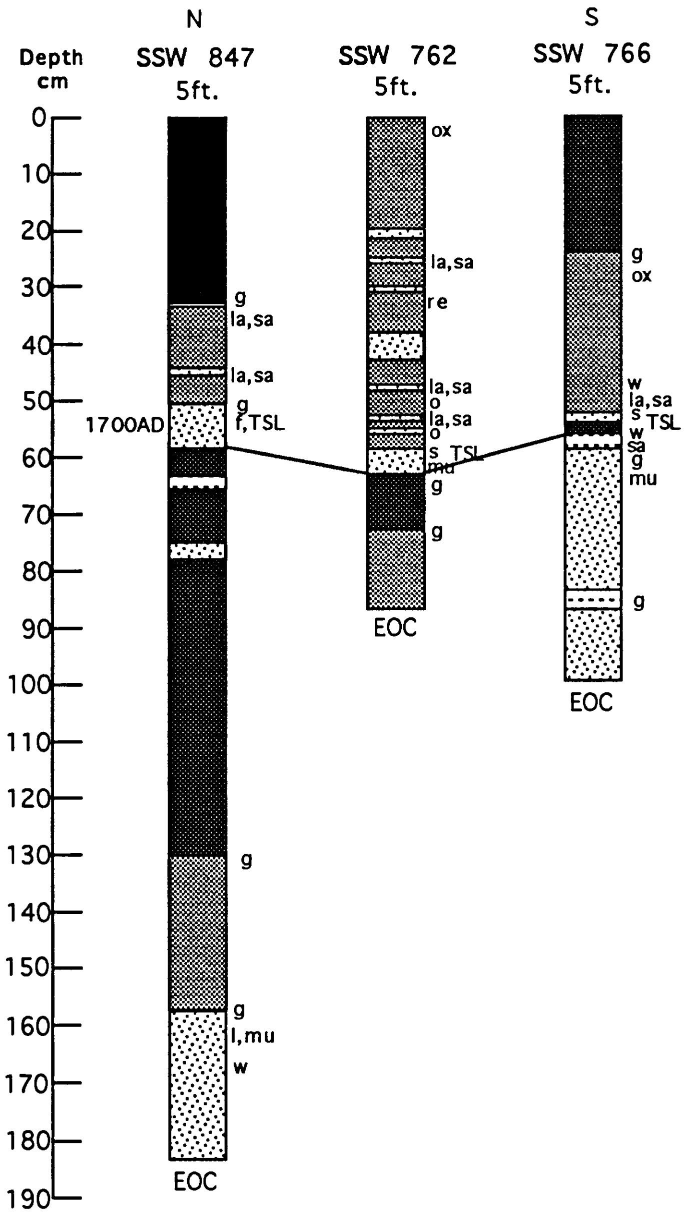


Figure 55. Neawanna Creek cores SSW 847, 762, 766.

Broadway Drive to S Avenue (Figure 45)

Cores SSW 808, 806, 803 show a subsidence event between 50 and 70 cm. All three have an overlying rooted mud with some sand. Site SSW 768 contains a buried muddy peat with an overlying three centimeters thick sand. Site SSW 803 also contains debris flow material at 73 cm, which underlies a subsidence interval (Figure 56). Sites SSW 782 and 783 contain irregular stratigraphy (Figure 57). These buried layers have underlying sand deposits with intruded contacts implying liquefaction origin.

Cores SSW 823-825 contain primarily rooted mud with a peaty mud at depth (Figure 58). The peaty mud ranges in depth from 75 to 100 cm, and it contains a thin sand layer towards the upper portion of the peaty mud. A large cobble (10 cm x 6 cm x 2 cm) was found at 70 cm in SSW 823. Site SSW 824 contains a dike sand lamination which cuts through the upper portion of the peaty mud at 73 cm.

Sites SSW 789, 788, 787, 784, 818 are found to the north of S Avenue bridge. Sites SSW 789, 788, and 787 have a muddy peat in sharp contact with the overlying sand deposits, some of which fine upward. Some of these sands are overlain by rooted mud. Subsidence was indicated at SSW 784 by a rooted mud overlying a muddy peat at 72 cm. Core site SSW 818 contained another distinct example of a peaty mud overlain by a thin sand layer at 73 and 125 cm. Site SSW 788 has a sequence of muddy peat, sand, and rooted mud with a lower sand contact at 162 cm. Cores 784, 787-789 show a subsidence event at around 50 cm (Figure 59). Site SSW 787 has an overlying

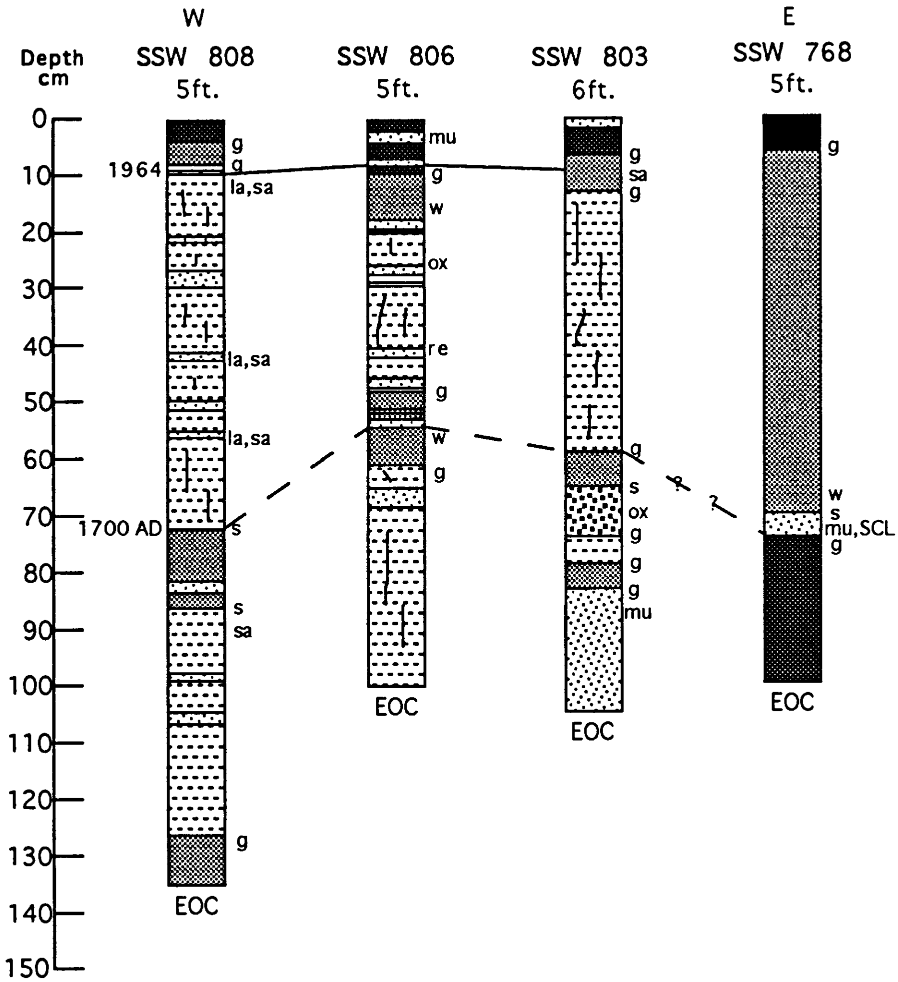


Figure 56. Neawanna Creek 808, 806, 803, and 768.

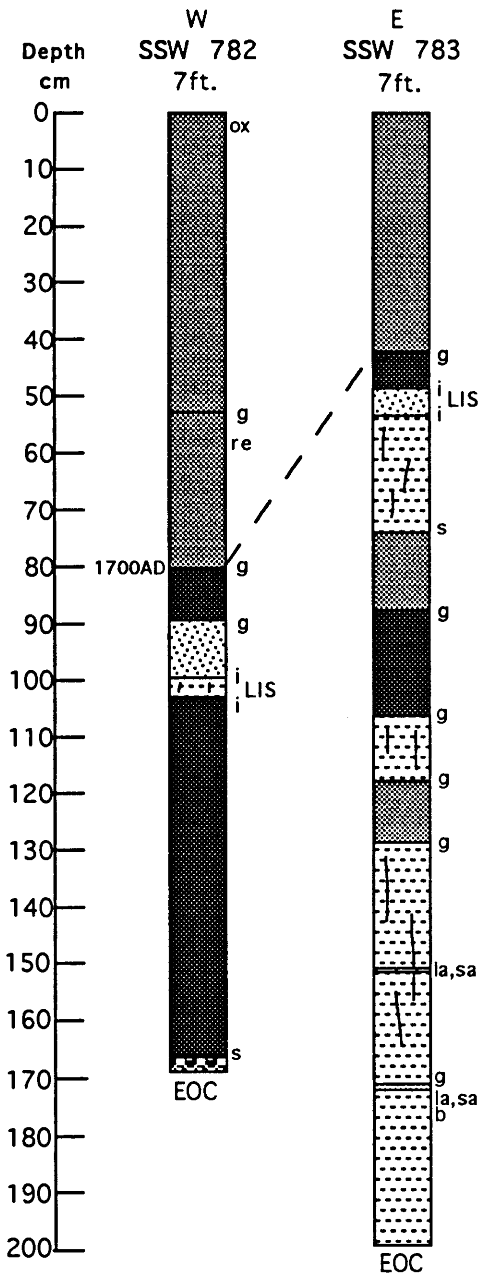


Figure 57. Neawanna Creek cores SSW 782 and 783.

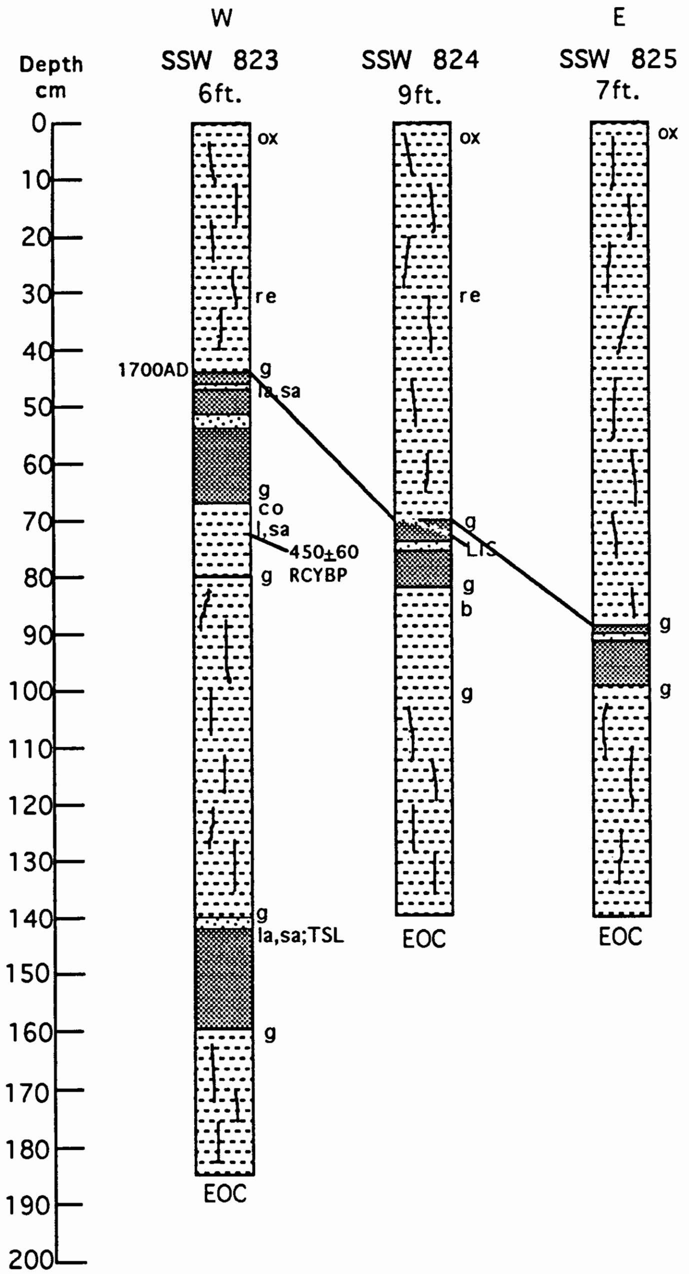


Figure 58. Neawanna Creek cores SSW 823-825.

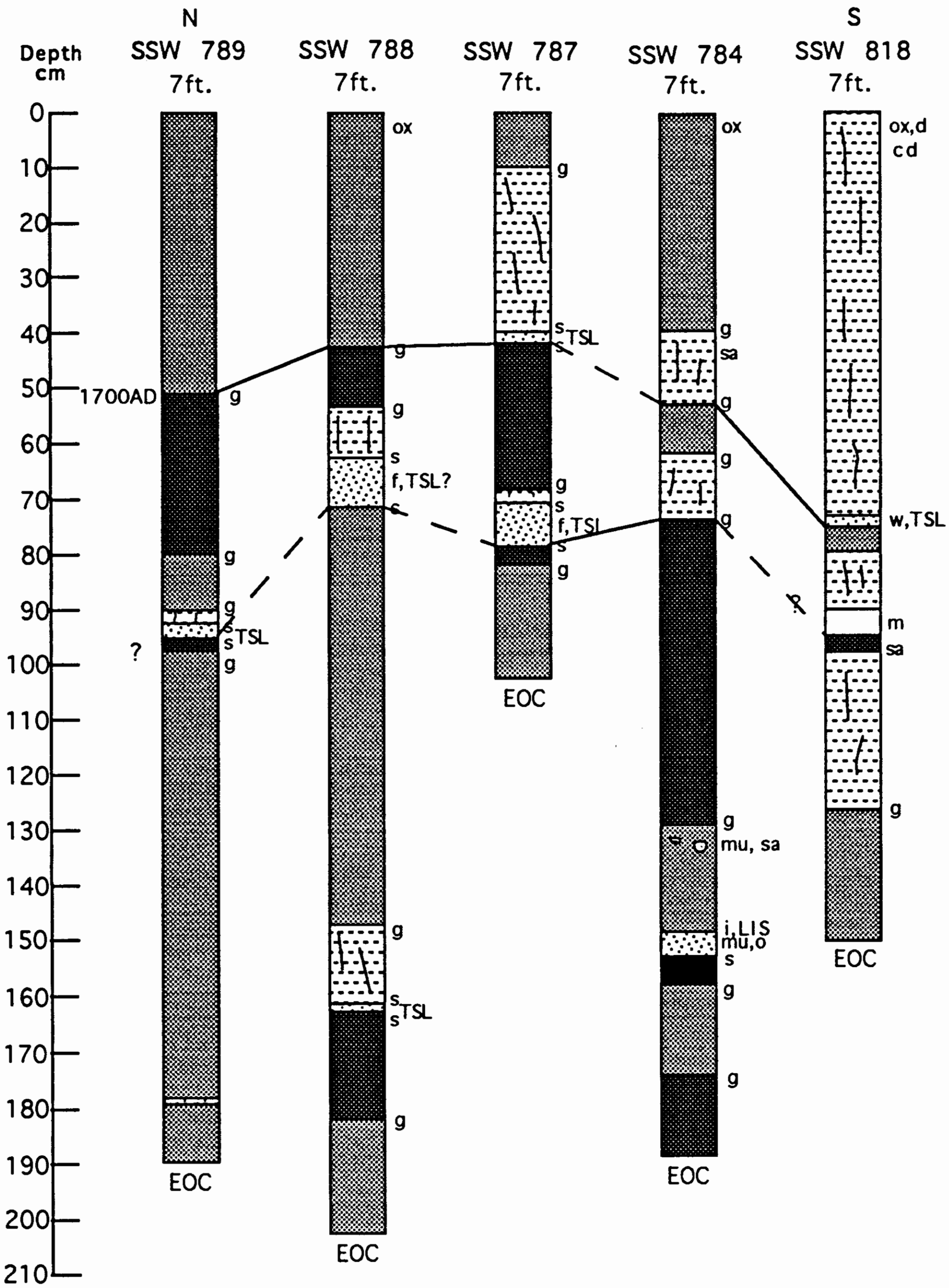


Figure 59. Neawanna Creek cores SSW 789-787, 784, and 818.

sand layer (TSL) whereas the remaining cores do not.

S Avenue to the Mill Ponds (Figure 60)

South of S Avenue and to the west around the Mill ponds, cores SSW 735, 730, 828-832 indicate probable tsunami deposited sand layers above subsidence contacts (Figure 61). Site SSW 735 has a sand layer within a muddy peat. However, the remainder of the samples have muddy peats to peaty mud with overlying sand deposits. These sites SSW 730, 828, and 830 grade into a muddy peat above the sand layers. Sites SSW 830 and 831 have buried contacts at 130-140 cm. Both SSW 830 and 831 have a peaty mud underlying a rooted mud. Finally, SSW 828 contains several short buried intervals of peaty mud underlying a rooted mud.

Radiocarbon Samples

Five cores consisting of seven samples were taken for radiocarbon dating in the Neawanna Creek wetlands. Core site SSW 716 had a date of 360 ± 70 RCYBP at a depth of 81 cm. This wood sample was collected just below the sand/muddy peat contact which occurs at 78 cm. Another wood sample was collected at 84 cm just below a sand lamination within mud in core SSW 823. Because a buried peat does not underlie the sand lamination, subsidence is not associated with this particular contact. A date of 450±60 RCYBP was derived from this horizon. A fairly young date (190±50 RCYBP) was obtained for a spruce cone obtained at 84 cm in SSW 729. This sample was taken from a muddy peat below a sand layer. Additional wood fragments were collected at 83 cm in SSW 831. A date of 620 ± 40 RCYBP was returned. Finally, in

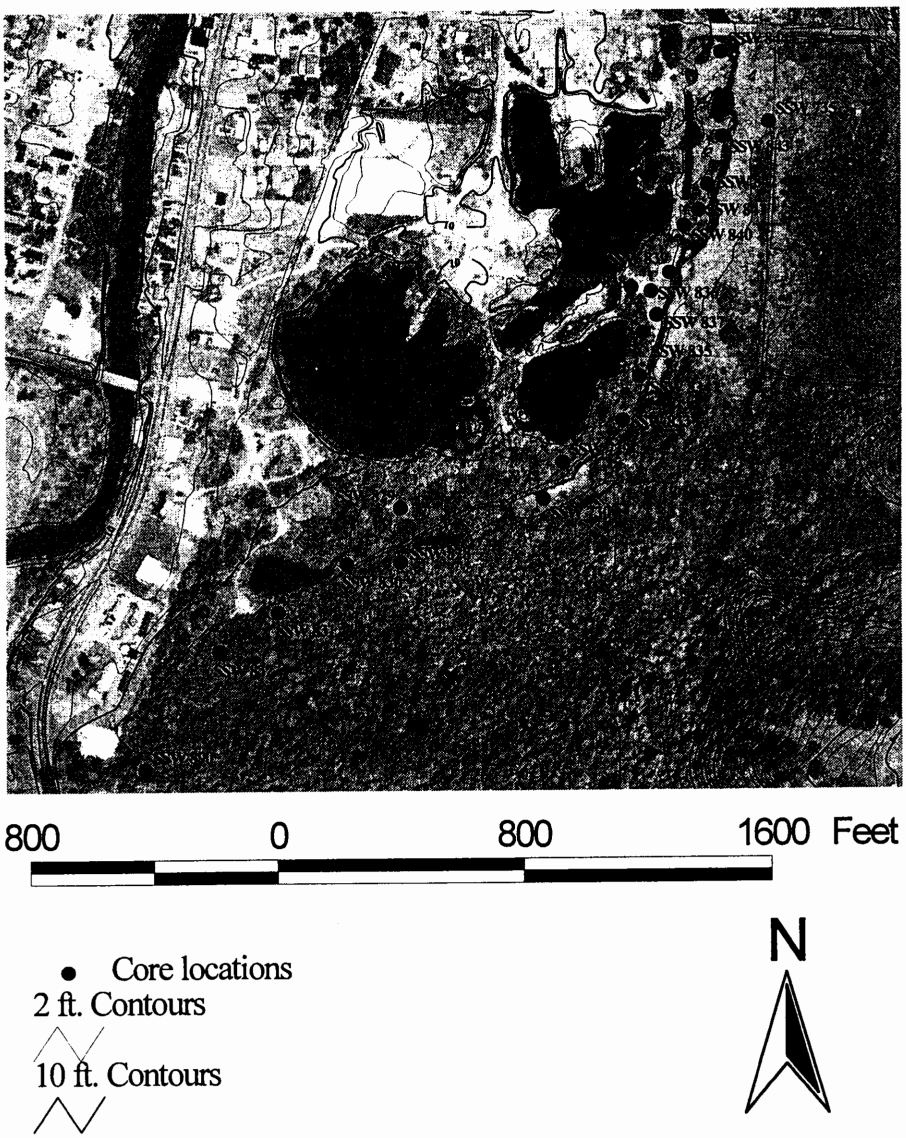


Figure 60. Neawanna Creek observation sites and core locations from S Ave. to the Mill Ponds.

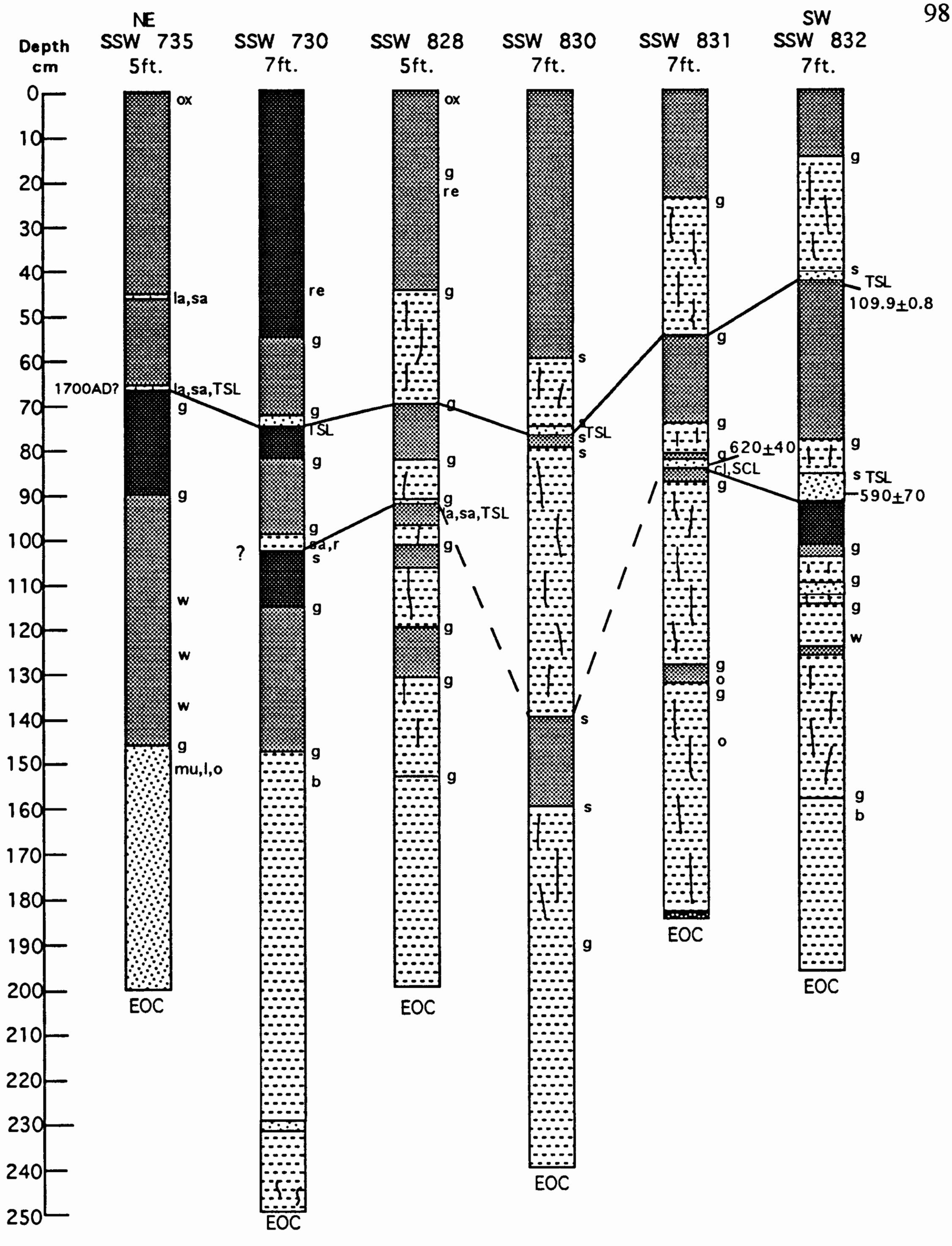


Figure 61. Neawanna Creek cores SSW 735, 730, 828, 830, 831, 832.

SSW 832, wood fragments were dated at both 43 and 90 cm. Dates returned were 109.9±0.8% and 590±70 RCYBP.

Sites SSW 729, 831, and 832 at the lower Neawanna Creek near the Mill Ponds contained extensive modern root contamination throughout the intervals sampled for radiocarbon ages. At sites SSW 831 and 832 wood sticks (roots?) were sampled from below the contact between the sand and buried peat. The true relationship of the wood sample (e.g. detrital or descending roots) with the horizon containing it was difficult to establish. These radiocarbon dates could have been contaminated by young carbon from descending roots. Obvious detrital fragments such as pine cones or seed pods were not observed in the returned cores.

Diatom Analysis

SSW 831 was analyzed for a change in diatom presence above and below the contact at 83 cm. Sample SSW 831 at 84 cm indicated a dominance of fresh to slightly brackish diatoms. *Eunotia petinalis*, *Gomphonema augustat*, and *Gomphonema parvulum* were the abundant species in this lower interval. However, in the interval above the contact (82 cm) the diatom presence changed to a brackish/marine influence, shown by *Pinnularia virdis* and *Biddulphia dubia*, with considerable reduction in the amount of the freshwater diatoms. This influence of marine to brackish diatoms above a peat horizon containing mainly freshwater to brackish diatoms supports the evidence that this contact represents a subsidence event. This youngest apparent subsidence contact is assumed to represent the last Cascadia earthquake event at 1700 AD.

Seaside Paleogeography

In order to help constrain the paleogeography of the Seaside tidal systems and associated wetlands, the intervening cobble ridges were mapped and some ridges were profiled with ground penetrating radar (GPR).

Cobble Ridge Mapping

The cobble ridges throughout Seaside trend roughly N10°E (Figure 62). The basaltic cobbles originate from Tillamook Head and extensively cover the southern portion of Seaside in the areas of the cove, Avenue U, and the Seaside Golf Course. Toward the north, the ridges taper and are covered by greater dune sand thickness. The Necanicum River has patchy cobble ridge evidence to the north on both sides of the river. There is also an increased amount of sand. On the east side of the Necanicum River, a cobble ridge extends from near Indian Way south to Broadway Drive. The western portion of the Necanicum River is densely packed with cobbles. This occurs from Broadway Drive all the way to the cove and Avenue U. In the area to the south, cobbles are evident on the beach. Seaside Golf Course is also built on some of these cobble ridges.

Cobble ridge mapping in the Neacoxie Creek area shows evidence that the eastern boundary of Neacoxie Creek is bounded by a gravel ridge with overlying dune deposits. Walking along the east bank of Neacoxie Creek toward the mouth, the cobbles become evident.

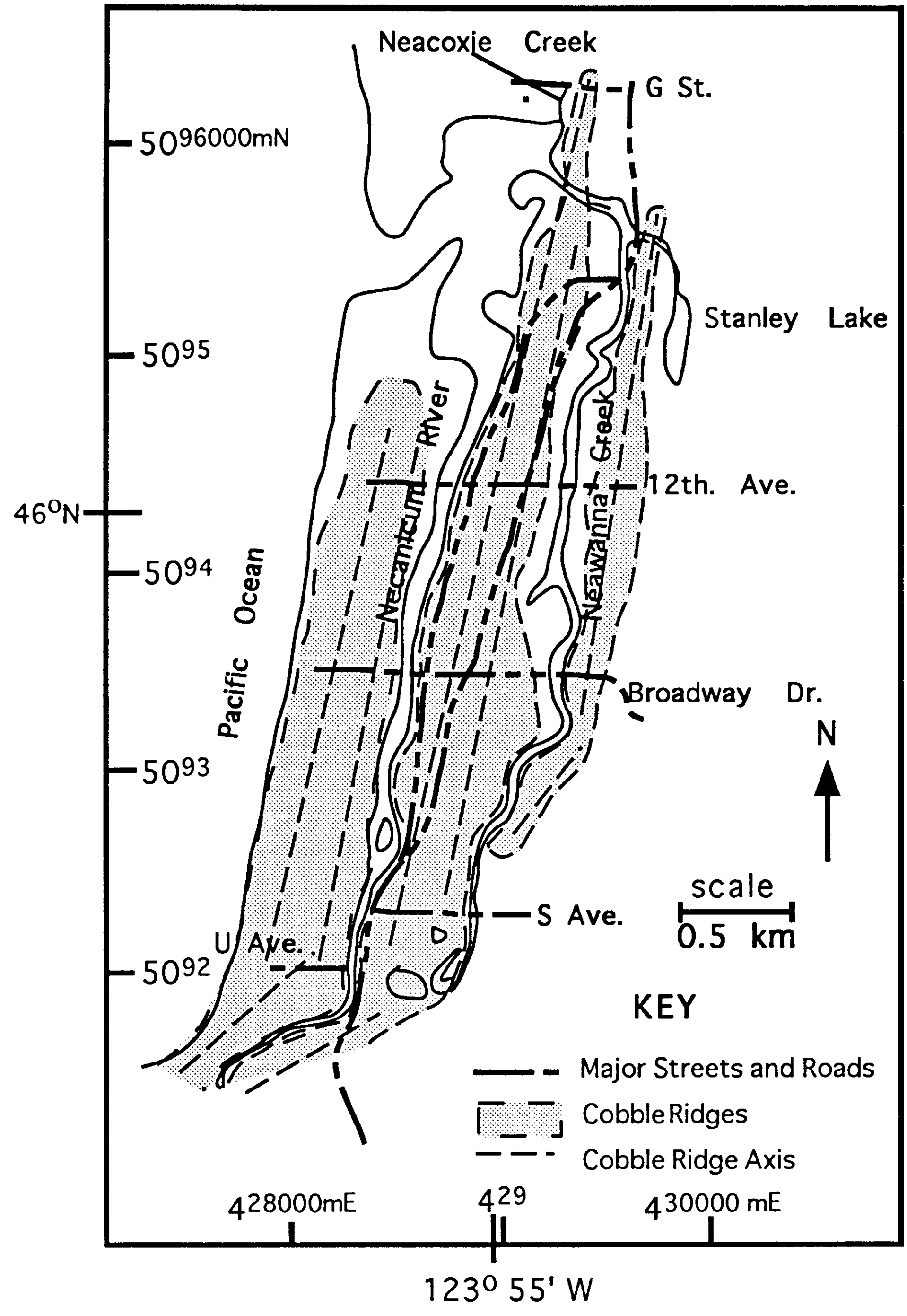


Figure 62. Locations of cobble ridges extending throughout Seaside.

The western boundary of Stanley Lake is composed of a cobble ridge which is evident both in cores and the local surfaces.

Neawanna Creek has patchy evidence of cobble ridges on the east side. Areas composed of cobbles lie along Wahanna Road running parallel to Neawanna Creek on the east side primarily between Mill Creek Road (near HWY. 101) and Broadway Drive. There is also a patch near Neawanna Creek across from the Wahanna Road baseball fields. On the western side of Neawanna Creek, a rather extensive, dense cobble ridge runs from just north of Broadway Drive south to the Mill Ponds and Avenue U.

Ground Penetrating Radar

The High School athletic practice fields at the northern portion of Seaside were used to run three GPR lines. One continuous line (1r1) ran S-N along the length of the football field (Plate 1). The E-W line (1c1) was split into two sections. One originated west of the football field near the pole vault pit extending toward the tennis courts and eventually crossing HWY. 101 (Plate 2). The second line originated at the beginning of the S-N line and ran west extending to Necanicum Drive and to the east bank of the Necanicum River (Plate 3).

Both the N-S and E-W GPR profiles show relatively horizontal beds and a shallow reflection indicating the freshwater table. This 206 m S-N GPR profile showed relatively horizontal layers down to roughly 13 m. The lack of channel cut and fill structures argues against E-W channelization in this area in late prehistoric times. The two E-W GPR profiles also indicate relatively horizontal layers down to 15 m.

These profiles at Seaside High School do not show cut and fill channel features either parallel or normal to the present cobble ridge axis. The basal cobble ridge near present sea level apparently built northward, constraining the Neawanna flow to the east. A thick sand cap (5+ m) on top of the basal cobbles required a direct connection to dune fields to the west, southwest, and/or the northwest. This indicates that the Necanicum mouth was located to the south of its present position in late prehistoric time. Northward migration of the Necanicum mouth to its present position, and subsequent breaching of the N-S cobble/dune ridge (that extends N-S of Seaside High School) permitted the development of a confluence between the Neawanna and the Necanicum near its present location. The lack of wetland stratigraphic layers older than the 1700 AD subsidence event at the northern end of the Neawanna argue that the confluence of these two tidal systems at the present location is a relatively recent development (probably less than 1 Ka). A recent northward migration of the Necanicum mouth would also explain the lack of prehistoric wetland stratigraphy along its northern banks and the lack of prehistoric buried wetlands in the Neacoxie Creek immediately to the north.

The Seaside golf course first fairway provided a locality to examine the cobble ridges originating from Tillamook Head. One N-S line (100c) ran the length of the fairway-cobble ridge (Plate 4). The two E-W profiles 100 meters apart (100a and

100b) dissected the N-S profile (Plates 5 and 6). The 100 m N-S profile shows inclined reflections prograding from south to north. These layers extend to about ten meters below the present surface. The E-W profiles 100a and 100b cover 141 and 123 m respectively, and they indicate relatively horizontal layers to about ten meters in depth. However, farther to the west, the layers become inclined toward the ocean (westward). Jol and others (1996) ran a radar line along an E-W profile which is located at the north end of the Tides Motel on Avenue U and ends at the promenade. This profile showed an inclined cobble strata dipping west at angles of up to 23° to a depth of 11 m. They interpreted this as being a paleobeach surface possibly deposited during storm events, providing supporting evidence for westward progradation of the beach cobble ridge.

Summary

The Seaside wetlands represent N-S valleys constrained between beach cobble ridges. The southern reaches of the Neawanna Creek and the Necanicum River have been separated from each other for at least the last several hundred years (prior to the 1700 AD event). Northward migration of the Necanicum mouth to its present position and confluence with the Neawanna and Neacoxie Creeks in their present geometry apparently occurred only relatively recently (possibly just before or after the 1700 AD event).

Discussion

This study aids in evaluating the potential hazards of nearfield tsunami inundation in the Seaside area from the geological record of prehistoric Cascadia tsunami deposits within the surrounding coastal wetlands. This discussion section first identifies areas affected by amplification and attenuation for the 1964 farfield tsunami in Seaside based on historic records. Then prehistoric geomorphology of the Necanicum estuary system and the geologic records of coseismic subsidence, liquefaction, and nearfield tsunami inundation in Seaside are interpreted.

1964 Event

Surge hydrodynamics of the 1964 tsunami prior to entering the Seaside beach or Necanicum estuary aids in determining the strength of the wave and possible height upon reaching shore. Although a considerable amount of damage occurred at Seaside, little specific wave information is available. The two closest recordings were taken at Astoria, Oregon (A), and Crescent City, California (CC), and the information provided here will reflect those ranges (Lander and others, 1993). At the time of inundation (A= 11:56 PM PST; CC = 11:54 PM PST), high tide was just receding. The period of the waves ranged from 29.0 to 20.0 minutes for Crescent City and Astoria, respectively. The maximum wave amplitude for Seaside was not instrumentally recorded. In Astoria the wave height was 0.4 m (1.3 ft.) and in Crescent City the wave height was 4.8 m (15.7 ft.) (Lander and others, 1993). In Seaside, there was no prior warning, some people woke with water under their beds. Word did reach the local sheriff, who tried to evacuate people, but there was not enough time to notify everyone (Lander and others, 1993). Waterfront residents were awaked by surge noises. Evacuation occurred at night (in the dark) with no preparation.

Historic 1964 Tsunami Surges in Seaside Tidal Creeks

Observations of the 1964 historic tsunami runup and associated deposits in Seaside provide a unique analog to help interpret prehistoric tsunami inundation from geologic records in the immediate areas.

Amplification

Reported observations of the 1964 tsunami runup in Seaside indicate that local amplification occurred in the Necanicum estuary (Venice Park), immediately south of the Necanicum River mouth, south of the G Street bridge crossing Neacoxie Creek, and south of the HWY. 101 bridge crossing Neawanna Creek (point bar) (Figure 63). The inundated elevation of Venice Park ranges from 0-4.3 m (0-14 ft.), with the majority of the home sites at about 2.4 m (8 ft.). Runup of 4.1 m (13.5 ft.), 2 m (6.5 ft.) above present ground elevation, was measured at SSN 684. The powerful surge(s) entered the estuary and encountered the Venice Park cobble-dune barrier. Runup over the western side of the barrier caused damage to residences on the barrier ridge. The surge(s) diverged with one component heading up the Necanicum River and the other traveling east towards the Neawanna confluence. Some local amplification might have occurred in the northern part of the Necanicum River (Figure 63) where high runup elevation and flooding debris caused damage to the 12th Avenue bridge (SSN 666).

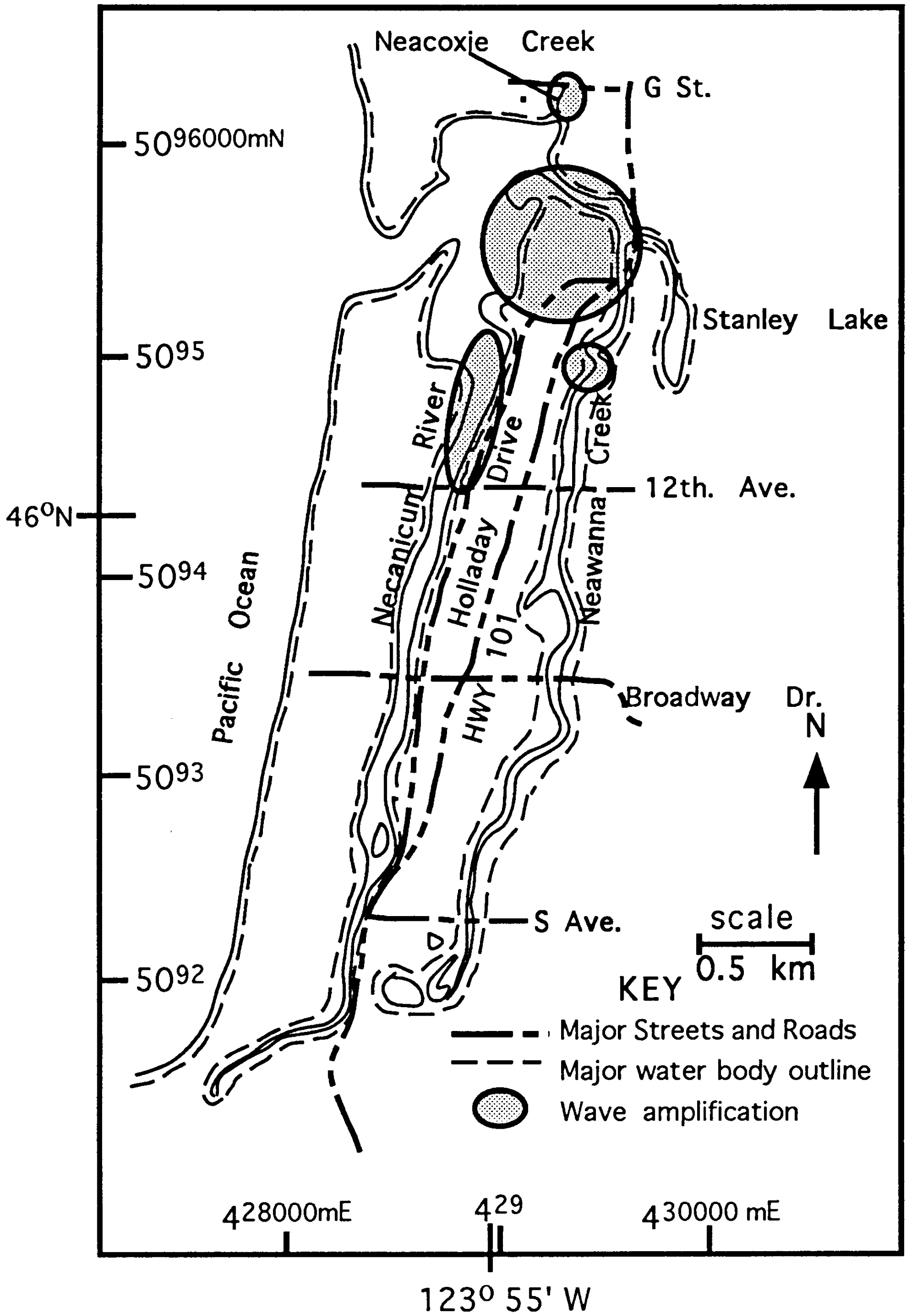


Figure 63. Areas in Seaside affected by wave amplification during the 1964 tsunami.

The surge(s) generally attenuated with increasing distance up the Necanicum River.

Water backed up in the bay area between the Necanicum and Neawanna confluence causing extensive flooding along the northern side of Venice Park (Figure 29 and Figure 63). Runup elevations in excess of 3-4.6 m (10-15 ft.) caused damage to houses and vehicles. Fish (unknown kind) were deposited in a field, to the north of Seaside High School (SSW 705).

A substantial surge propagated up the Neacoxie Creek channel and was greatly slowed by G Street. The elevation of the marsh area surrounding the creek ranges from 0-3 m, and all observation sites but one (SSX 649, 4 m) are located within this elevation range. Water levels observed were 0.3-1.1 m (1-3.5 ft.) above the present surface elevation. Reported observation sites indicate that a considerable amount of debris and drift logs clogged the culvert. Debris deposits on the road pavement (SSX 650 and 651), provide evidence that the road fill slowed the surge enough to deposit sand and logs. Flooding occurred on the western banks (SSX 647, 648, and 652) 1) due to the high dune/cobble ridge on the eastern bank of Neacoxie Creek and 2) the water backing up due to the clogged culvert at G Street. A water mark observation site (SSX 646) up the creek north of G Street indicated a smaller surge surpassing the bridge and continuing up the creek, but no sand deposits were identified north of G Street.

Amplification in the eastern portion of the Necanicum estuary is demonstrated by runup of about 4-4.6 m (13-15 ft). in the vicinity of the 101 bridge (SSN 697-699). A sharp bend and narrowing of the Neawanna confluence together with debris jamming at the HWY. 101 bridge are probably responsible for the amplification in the eastern part of the bay.

With one exception, the surge(s) generally attenuated with increasing distance up the Neawanna tidal channel. The exception is a sharp meander bend in the Neawanna channel located just upstream of the HWY. 101 bridge (Figure 39). At this site, a remnant of the cobble ridge projecting west from the Neawanna Creek east bank, caused significant flow deflection onto the west bank of the Neawanna Creek. The tsunami surge(s) eroded about one third of the projection (J. Spillman, Personal communication, 1996).

A point bar on Neawanna Creek just south of the meander bend was flooded by a prolonged surge yielding standing waves. The eye-witness located on the east bank opposite of the point bar, evacuated within minutes of the onset of the first prolonged surge. No further observations were made after that time.

Surge Attenuation in the Tidal Creeks

Observation sites up the channelized creeks document tsunami flooding for distances of 4.0 and 1.5. km up the Necanicum and Neawanna channels, respectively (SSG 654 and SSW 707) (Figure 64). The narrow valleys are controlled by the underlying cobble ridges that restrict lateral movement of the creeks and result in channelized flow. However, wider floodplain wetlands on the sides of the channels that accommodated some water volume, enabled surges to attenuate along these channel areas. Flooding and debris were noted all along the Necanicum River wetlands to the

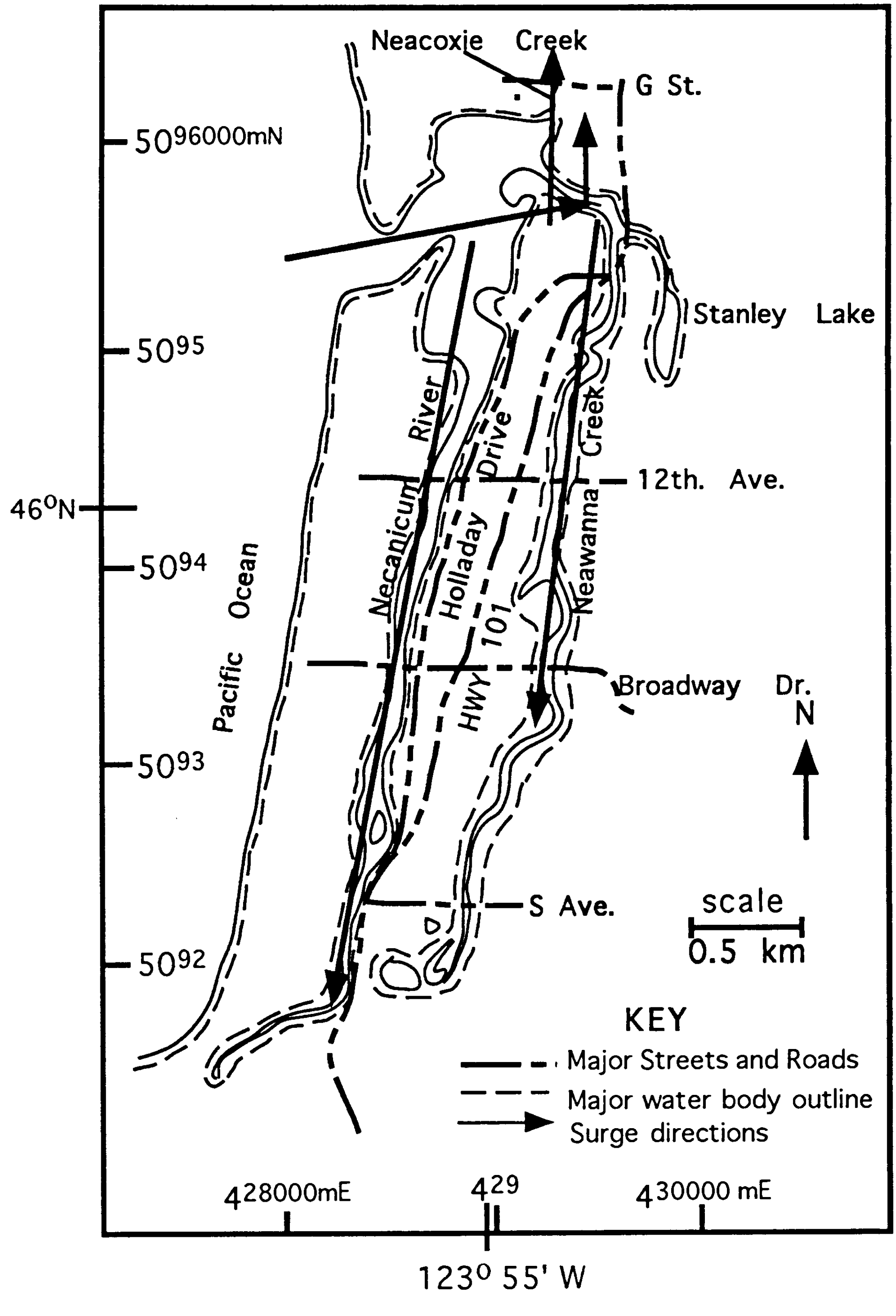


Figure 64. Seaside wetlands affected by tsunami attenuation during the 1964 event. Arrows indicate distance of flooding up river.

Seaside golf course (SSN 663; SSG 653 and 654). Site SSG 653 indicates two water marks two feet apart, possibly indicating two surges up the Necanicum River. Many of the bridges crossing the Necanicum River recorded surge levels by structural damage, debris, and sand deposition (SSN 666, 660). Residents along the lower Neawanna Creek observed water levels flush with their yards (SSX 700 and 701, 3 m). However, no reported flooding was observed south of the 12th Avenue bridge along the Neawanna Creek banks (SSW 708-711).

Historic 1964 Tsunami Deposits in Seaside Tidal Creek Wetlands

Deposit Characteristics

The geologic record for the 1964 farfield tsunami inundation in Seaside is based on well preserved, shallow sand deposits on the wetland creek banks. These shallow sand deposits are contained within muddy or peaty layers, that extend to the modern surface. The anomalous sand layers thin with distance upstream, evidence for surge attenuation and/or dilution for example, progressive loss of suspended sand. Changing lithologic composition of the sand from rounded quartz-rich beach sand to angular lithic-rich river sand was found to occur with distance up the Necanicum River. Sands from the river channel are incorporated with the wave as it surges forward, and then they are redeposited up channel as the wave loses speed with increasing distance from the bay mouth. There was no evidence for coseismic liquefaction being produced in either the 1964 sand layer or in sandy muds immediately below the 1964 sand layers.

The 1964 tsunami sand deposits generally had lower sharp and upper gradational contacts with host deposits of peaty mud.

Some exceptions to these upriver, thinning sand sheets exist. For example, the tsunami sand deposits thicken anomalously at areas where obstructions are present such as at clogged culverts and point bars. These obstructions greatly reduce the surge velocity and cause the wave to drop some of its suspended sand load. Dammed water occurred at G Street crossing Neacoxie Creek. This occurrence created sand deposits up to 10 cm thick which are significantly thicker than the adjacent (mouthward) deposits associated with gradual surge attenuation up the channel.

Thick tsunami sand deposits occur (25 cm thick at SSX XI) near the mouth of the Neacoxie Creek east bank. These deposits were probably produced by the incoming wave crashing into the dune/cobble ridge and depositing some of its load. Part of the surge continued up the channel and hit G Street where the remainder of the load was deposited.

South of Neawanna Creek from the HWY. 101 bridge, a prominent point bar slowed the surge resulting in tsunami sand deposits of 8-12 cm thick (SSW XV and XVI). To the immediate south of this point bar, the sand deposits thin considerably (SSW 718-719; XI-XXX; <5 cm) indicating that channel sand resuspension and deposition fell below critical values necessary to leave distinctive tsunami sand sheet deposits.

Multiple Surges

Core and trench sites of the Necanicum River, Neacoxie Creek, and Neawanna Creek include evidence for deposition of multiple, thin, shallow sand layers separated by mud laminae (SSN 747, SSX 771-774, SSW 723, XXII and XXVIII). These deposits of alternating sand and mud (MSL) probably reflect multiple surge deposits. An explanation for such sequences is as follows: the first surge rolls in and deposits its load, and then mud settles out on top of the sand before a second surge occurs to deposit its suspended load. The process repeats for several surges. However, these deposits in Seaside are contained within only a few cores and are not continuous over local areas. It is not known whether the depositional surges correspond to time variable fluctuations of velocity within one tsunami wave or to different tsunami waves. However, the time required for mud (silt and clay flocculates) to settle out of suspension is probably on the order of minutes, so the discrete mud laminae implies different tsunami waves.

Comparisons of the 1964 Tsunami Impacts in Seaside with other Pacific Northwest Localities

The observed amplification and attenuation of the 1964 tsunami surges in Seaside are compared to runup evidence from other nearby localities including Warrenton, Gearhart, and Cannon Beach, Oregon and Sea View, Washington (on Long Beach peninsula). Sea View had a maximum wave amplitude of 3.8 m (12.5 ft.) and no damage occurred (Lander and others, 1993). At Warrenton no runup heights were observed, but some damage occurred along the waterfront. Gearhart, immediately to the north of Seaside, encountered some flooding and deposits of sand, but wave heights were not observed wave heights. Cannon Beach (immediately south of Tillamook Head) sustained a considerable amount of damage. The HWY. 101 bridge crossing Elk Creek was washed 0.3 km upstream and logs, debris, and sand were deposited in the street (Lander and others, 1993). From these comparisons, the Seaside runup and corresponding damage were anomalously large, relative to nearby localities.

The 1964 tsunami runup in Seaside is also compared to two of the other most impacted farfield sites in the Pacific Northwest, including Port Alberni on Vancouver Island, British Columbia and Crescent City, in northern California. Three surges of the 1964 tsunami inundated Port Alberni up to 4-4.9 m (13-16 ft.), leaving a 1-2 cm thick sand deposit 11 cm below the present marsh surface. There was some amplification due to a pipeline which impeded the wave progress, resulting in a 15 cm thick sand deposited locally (Clague and others, 1994). In Crescent City, four surges attacked the waterfront, the last being the largest and most destructive (6.3 m above MLLW). The first surge at Crescent City was 4.3 m (14 ft.) above MLLW (Lander and others, 1993). The inundation distances in small tidal creeks for both Port Alberni and Crescent City were not as extensive as Seaside. However, both localities showed local amplification due to obstructions and attenuation across overland flats and upstream in narrow tidal creeks.

Correspondence between 1964 Tsunami Runup and Tsunami Depositional Record

In Seaside, the historic geologic record of 1964 tsunami deposition corresponds very well with reported observations of runup height, multiple surges, and localized amplification or attenuation in the tidal creek wetlands.

Fining upward sequences were apparent in the 1964 sand layers however, no sedimentary structures establishing paleoflow direction were observed. No cross-bedding or evidence of flop-overs were observed in recovered cores or trench walls, even where standing waves and buried flop-overs were reported (sites SSW 725, 726, 1A and 1B). The lateral changes in sand layer thickness over distance scales of 10's to 100's of meters clearly corresponds to areas of rapid flow deceleration and catastrophic deposition of suspended sand-sized sediment (Figure 65 and Figure 66).

The preservation potential of historic geologic records is likely to be low in many of the upland sites in Seaside. Rain, wind, vegetation growth, and burrowing organisms are likely to have disturbed the 1964 tsunami deposits beyond recognition in upland soil sites. For example, shallow cores in supratidal dune-ridge deposits of the west Neacoxie Creek valley (1.8 m in elevation) showed weak or no evidence of distinct tsunami sand layers, where such layers were reported to have been deposited in 1964 (SSW 703,704). In contrast, the 1964 tsunami deposits are very-well preserved in the Necanicum and Neawanna tidal creek wetland soils. The tsunami-deposited sand layers in the wetland soils are intact, show little disturbance by root growth, and preserve both contact relations and alternating sand and mud laminae.

Figure 65. 1964 SSX grid isopach, determining thickness of the sand sheet in Seaside.

Figure 66. 1964 SSW grid isopach, determining thickness of the sand sheet in Seaside.

1964 Runup

Based on the observation sites and core locations for the 1964 event in Seaside, an inundation map of the area has been produced (Figure 67). This map includes Priest's (1995) worse case scenario Cascadia inundation line for the Seaside area, based on three scenarios of computer models, local topography, and historic and prehistoric tsunami inunation evidence. Primary inundation by the 1964 tsunami occurred within the wetlands of the Necanicum River (4 km), Neacoxie Creek (0.5 km), and Neawanna Creek (3.5 km). There was also wave runup along the shoreline of Seaside reaching the promenade (4-4.9 m in height). The remainder of this discussion section will focus on the prehistoric records of Seaside wetland stratigraphy and Cascadia (nearfield) tsunami inundation.

Paleogeography of the Seaside Wetlands

Some understanding of the recent paleogeography of the Seaside tidal creeks is necessary for interpretations of paleotsunami inundation of the Seaside wetlands in late prehistoric time. The primary objective in investigating the paleogeography of Seaside is to establish the location of the Necanicum River during the time of the last prehistoric tsunami. The study by Rankin (1983) and the cobble locality mapping for this thesis established that the cobble ridges are extensive throughout the southern portion of Seaside and gradually thin to the north. The ridges of northern Seaside trend N-S, and in the south near the cove, they have a NE-SW trend reflecting shoreline attachment to Tillamook Head to the south. These cobble ridges primarily control the channelways of the Necanicum River and Neawanna Creek. Rankin (1983)

Figure 67. 1964 observation sites and gouge core deposit locations including 1964 inundation line. Bold line represents Priest's (1995) worse case scenario inundation line.

believed that the cobble ridges were deposited in pulses separated by periods of erosion and stabilization over the last 3,500 years. Also, he attempted to correlate the age of the northern dunes of the Clatsop Plains to the cobble ridges of Seaside. He determined that the eastern bank of Neawanna Creek would be the 1500 year ridge line, whereas the 400 year ridge line would be just east of the primary dune in Seaside (west of the Necanicum River). Darienzo's work (Connolly, 1992) for the native American midden sites (Figure 5) found that some of the correlations Rankin made do not coincide with the radiocarbon ages for the midden sites (Connolly, 1992). For example, the Palmrose site has an occupation radiocarbon age of approximately 3650 years BP that roughly agrees with the ridge age by Rankin extrapolated to be 3200-3500 years. However, the Avenue Q site lies on a gravel ridge east of the Necanicum River (estimated by Rankin as 800 years) with a radiocarbon occupation date of 3280 years BP. In addition, tidal marsh deposits in the Neawanna Creek extend back to 2,000 RCYBP (Darienzo and others, 1993). Rankin (1993) then noted that the gravel ridges must react independently of the dune ridges to the north.

Phebus and Drucker (1979) produced radiocarbon dates for the abandonment of two midden sites as approximately 1300 and 1600 years BP for the Avenue Q and Palmrose sites, respectively. From the results of this study and from Darienzo (1991), none of the midden site abandonments correlate with the youngest subsidence/tsunami event dated to about 1700 AD. Bay clams from these middens suggest that there may have been a nearby bay from which to obtain these clams between 1300 and 3650 years

PB. An abandonment of the youngest midden after 1300 RCYBP implies a disappearance of the bay clam source after this period. Toward the last years of midden occupation, sand presence increased, indicating that the bay was filling in with sand (Connolly, 1992). This might indicate that there was not a bay influence in the southern portion of Seaside during the most recent Cascadia event.

The Lewis and Clark sketch maps of the Seaside area from their expedition west in 1804-1806 yield more questions than answers in dealing with the late-prehistoric geomorphology of the Seaside area (Figure 4). Only one dominant river channel is indicated on the map, and it is labeled the Clatsop River. The river labeled the Necanicum flows to the north, and its mouth empties into the ocean north of present day Seaside. This sketch map makes it difficult to determine the paleoshoreline due to the lack of consistency with the naming and presence of today's waterbodies. The maps of Lewis and Clark could be correct if the Necanicum River was not in its present position in 1806. However, an outlet to the south of its present position is not shown in their sketch. This would also mean that Neawanna Creek is the Clatsop River in the sketch map.

These discrepancies are difficult to reconcile. Lewis and Clark were competent mappers, but could they have missed the Necanicum River? Or is it the Necanicum River that is mapped (as Clatsop River), and they missed Neawanna Creek? If the Necanicum River was not mapped, it would have had to establish itself within the interval between the exploration by Lewis and Clark and the appearance of the first settlers (less than 100 years).

From what is known from the cobble and dune ridge stratigraphies at the Seaside High School, the mouth of the present Necanicum River must have been slightly south of its present location to allow sand transport from the beaches to cover the cobble ridges. This mouth migration to the north could have occurred within the last several hundred years. No definite conclusions about the Seaside paleoshoreline and river mouth locations can be reached from the Lewis and Clark sketch maps.

Finally, prehistoric landslide debris (debris flow deposits reported by Darienzo and others, 1993) was identified in the central Neawanna Creek wetlands. Initially, shaking from a Cascadia earthquake was thought to be the cause of a landslide from the foothills of the Coast Range to the east. If that is correct, then the deposits of the landslide should occur in the stratigraphic position overlying a muddy peat (SSW 790, 793-94, 803, 819-821). However, they are associated within a rooted or peaty mud. At present there is no evidence to indicate correlation between the landslide deposit and a prehistoric Cascadia earthquake, contradicting the hypothesis introduced by Darienzo and others, 1993.

Paleosubsidence Horizons in Seaside

Regional abrupt coastal subsidence provides timelines for correlation of paleotsunami deposition resulting from nearfield Cascadia interplate earthquakes in the Seaside area.

In the Necanicum River wetlands, 35 sites out of 37 showed no evidence of buried peaty horizons in the upper 50-100 cm of the cores. Only two sites (SSN 882, 884) had any evidence of a buried peaty horizon, but SSN 884 at 71-80 cm yielded an age of 109±0.9%, possibly too young to be correlated to the 1700 AD event. Weak subsidence from the 1700 AD event was found in 1 out of 10 core sites in the Neacoxie Creek wetlands, 4 out of 10 sites in the drainage to the east of Neacoxie Creek, and 4 out of 18 sites in the Stanley Lake area.

The core sites that do show some evidence of buried wetlands indicate relatively small amounts of abrupt sea-level change. For example, most sections include rooted mud (colonizing marsh) overlying peaty mud or muddy peat (established marsh). Barnett (1997) reports these transitions to represent one meter or less of subsidence in the Seaside tidal-creek wetlands. Although diatom salinity changes across these subtle burial contacts do confirm abrupt paleosubsidence in the Mill Creek site (SSS 879-881) the patchy record of wetland burial along the northern and eastern margins of the Necanicum estuary implies weak tidal influence there. As previously noted, the lack of multiple buried wetlands in these core sites indicates that tidal influence in this area began only shortly before the last paleosubsidence event about 300 years ago.

By comparison, the Neawanna wetlands north of 12th Avenue bridge contain more consistent evidence of paleosubsidence. In this area, 7 out of 12 core sites record evidence of a buried wetland within 50-80 cm depth. Although possibly contaminated by descending roots, the radiocarbon dates (101.6±0.9% -360±70 RCYBP) from the shallowest 1-2 buried wetlands are consistent with the shallow depths of these horizons. The record of paleosubsidence in this core depth interval diminishes with increasing distance south (upstream). For example, 17 out of 71 core sites demonstrate clear evidence of significant subsidence, e.g., rooted mud overlying peaty mud or muddy peat between the 12th Avenue bridge and the S Avenue bridge. Whereas lateral channel migrations have eroded out some buried marsh sections directly adjacent to the Neawanna channel, some core sites located 10's of meters away from the modern channel contain one or more buried wetland horizon above one meter depth.

1700 Subsidence Horizon

Subsidence horizons of the youngest buried peat (1700 AD) events have been identified in Washington (Atwater, 1987) and Oregon (Darienzo and Peterson, 1990). Yamaguchi and others (1989) produced a more accurate date for the 1700 AD event by dendrochronology. Satake and others (1996) found prehistoric tsunami evidence along with written historic records in Japan which indicate a possible Cascadia earthquake on January 26, 1700 AD at 2100 local time. These studies confirm the evidence for a 1700 AD subsidence horizon and an interplate earthquake generating a large tsunami along the Cascadia margin.

Tsunami-deposited sand layers of the prehistoric events are identified in part by their position above an abrupt subsidence contact. However, throughout the Seaside wetlands, the subsidence intervals are weak (<0.5m), and many do not contain overlying sand deposits. The wetlands of Seaside lie in a dilute-brackish setting. They experience weak tidal influence, and they probably record minor coseismic subsidence (<1.0 m). In some cases, sand has been injected into overlying muddy peats or muds. The coseismic liquefaction creates a reverse stratigraphy where the intruded clastic sills underlie the abrupt subsidence contact.

From the above information, a horizon for the 1700 AD subsidence event can be determined. The shallowest, i.e., the youngest buried interval, represents the 1700 AD event i.e., last large proximal earthquake to occur in the central Cascadia margin. No overlying buried peats or liquefaction features indicators should exist above this interval. Furthermore, it should have a relatively young prehistoric date (< 500 RCYBP).

Stanley Lake area contains some possible young subsidence horizons. Only core sites SSS 879-881 exhibit the correct stratigraphy which includes a thin TSL above the buried peat horizon. Diatom samples at SSS 879 indicate an increase of marine diatoms relative to brackish diatoms just above the buried subsidence horizon at 54 cm depth below the modern marsh surface.

The Neawanna Creek wetlands contain the best evidence of preserved prehistoric subsidence horizons. The youngest buried horizon fits the criteria for the 1700 AD event. This horizon ranges from 45-85 cm from the present surface. The radiocarbon dates from some sites are younger than would be expected from this horizon, but these deposits are likely contaminated by young carbon from descending roots. The only exception to this is core site SSW 716. This core contains a subtle peaty mud (at 54 cm) above the 1700 AD horizon (at 81 cm). The lower radiocarbon date (at 81 cm) seems to be correct, having a 1700 AD horizon date of 360±70 RCYBP for a peaty unit below a TSL, a prime example for the subsidence stratigraphy. Also, Darienzo's radiocarbon date of 480±60 RCYBP at 50 cm for his Neawanna 2 core site correlates well with the stratigraphy of core SSW 787, and it verifies the upper Neawanna Creek 1700 AD horizon. The younger radiocarbon dates near the Mill Ponds (SSW 729, 831, and 832) were most likely contaminated by the modern roots observed to be extending into the lower peat and mud.

Older Subsidence Horizons

This study is focused on the historic 1964 and prehistoric 1700 AD events, therefore deep coring was not conducted. Areas northeast of the S Avenue bridge and near the Mill Ponds contained the only evidence for older prehistoric horizons. The next buried horizon under the 1700 AD event north of S Avenue occurs 72-100 cm from present surface. Darienzo's (1991) Neawanna 2 correlates with core SSW 787 indicating an approximate age for the horizon of 1100±70 RCYBP. The second buried horizon near the Mill Ponds ranges 82-100 cm from present surface, however the radiocarbon samples at SSW 831 and 832 again have younger radiocarbon dates than expected. This is interpreted to be the result of modern root contamination of the samples. Diatom evidence in core SSW 831 at the 81 cm contact indicates an abrupt change from fresh/brackish to marine/brackish conditions at the buried wetland contact. The diatom data confirms the evidence for a subsided horizon. Therefore, the second buried horizon is correlated to the second horizon (1,100 RCYBP) northeast of S Avenue bridge. A possible third horizon northeast of S Avenue bridge occurs in core sites SSW 788 and 784 at roughly 160 cm, and both buried horizons have a TSL above. This horizon can possibly be correlated to Darienzo's (1991) Neawanna 2 date at the fourth buried interval. The fourth buried horizon was dated at 1370±70 RCYBP by Darienzo (1991).

In summary, the longest records of episodic burial in the Seaside wetlands, extending back to 2,000 RCYBP, are from the Neawanna wetlands just north of S Avenue bridge (Darienzo, 1991; Darienzo and others, 1993). The south-central portion of the Neawanna Creek valley has been connected to tidal flow during the last 2,000 years.

Upstream of the S Avenue bridge, the record of paleosubsidence is reduced to very subtle changes in peat content, such as sites SSW 828, 830, and 831. Confirmation of subsidence is documented by significant changes in diatom salinity tolerance from site SSW 831 southeast of the Mill Ponds. However, an abundance of freshwater species above and below the shallowest burial contact testifies to minimal tidal influence at the southern end of the Neawanna wetlands. A lack of channel sand within the top two meters of peaty mud from the Mill Pond sites (Figure 61) demonstrates that the south end of the Neawanna wetlands have not been in direct contact with the Necanicum channel or a proximal tidal inlet in the last 1,000 years. The cobble ridge that currently separates the southern reaches of the Necanicum and

Neawanna is presumed to have been in place and unbreached by tidal flow during this time.

Discrimination of Potential Paleotsunami Deposits from Liquefied Intruded Sand Features

Perhaps the most unexpected finding of this study was the abundant and widespread evidence of late-Holocene coseismic liquefaction in the Seaside area. In this section, the evidence of coseismic liquefaction in Seaside is reviewed and compared to other coastal paleoliquefaction sites in the region.

Distinguishing tsunami-deposited sand layers (TSL) from liquefied intruded sands (LIS) relies upon contact relations and associations with the surrounding core site stratigraphy. TSL's are identified by their typical sharp lower contacts with the underlying buried peat, clean sand dominated by quartz, occasional fining upward trends, and overlying rooted mud to mud. Typically, these layers are continuous over some distance, thinning or thickening according to relative location to source of tsunami surge propagation.

LIS layers become difficult to distinguish from TSL's where they occur at or near subsidence contacts. However, many of the LIS layers identified in this study have intruded contacts, where the sand fingers into the host deposit, above or below the intruded clastic sills (SSW 778 and 779). Nearly all the LIS layers underlie buried wetland contacts and are thus easily discriminated from nearfield Cascadia tsunami deposition. Figure 68 shows the distribution of LIS associated with the 1700 AD event

Figure 68. Distribution of LIS related to the 1700 AD event liquefaction zones in the Seaside wetlands.

and liquefaction zones in the Seaside wetlands.

During this reconnaissance study, the primary technique used for observing the subsurface stratigraphy, particularly for the prehistoric deposits, involved a gouge core. With this limited view, some sand layers identified as a TSL could be a LIS. However, when the lateral stratigraphy of target sand layers was inconsistent or discontinuous from core to core in an area, then extensive tightly-spaced coring was performed.

Areas along the Columbia River and central Cascadia margin have been examined for coseismic liquefaction evidence such as dikes and sills (Atwater, 1994; Obermeier, 1995; Peterson and Madin, 1997). The evidence of coseismic liquefaction reported by those authors is very similar to what was found in Seaside. Atwater (1994), Obermeier (1995), and Peterson and Madin (1997) agreed that liquefaction features of the lower Columbia River were produced by at least one subduction zone earthquake (CSZ), the latest features being directly correlated to the most recent Cascadia event of 1700 AD. Such indicators of liquefaction include forceful injection of intruded sand from sand source beds at greater depths. Atwater (1994) and Obermeier (1995) indicated that vertical dikes were generally a few centimeters wide. Dikes were found inland at least 90 km from the coast on islands in the Columbia River. Maximum dike widths and density decrease upstream (Obermeier, 1995; Peterson and Madin, 1997).

In this study, the dominant liquefaction features observed were clastic sills. The sills extended along the bottoms of peaty horizons for 10's of meters in lateral extent. Small clastic feeder dikes were rarely observed. No large dikes were found in cutbanks of the Neawanna Creek. The similarities between these features and those reported for the Copalis River site (event dated at 1,100±200 RCYBP) by Atwater (1992) implies similar origins for both. That is to say that these similarities between the Copalis and Seaside paleoliquefaction sites indicate the sills in Copalis may represent liquefaction from a subduction earthquake, and not from deep fissures, as initially proposed by Atwater (1992).

1700 AD Paleotsunami Inundation

The 1700 AD subsidence horizon is fairly continuous throughout the Seaside wetlands of Neawanna Creek. However, evidence for tsunami deposits (TSL or SCL) at this contact is fairly weak and patchy or non-existent (see results). In the following section, the aeral distribution of TSL deposits are compared to evaluate possible inundation mechanisms of the 1700 AD paleotsunami in Seaside.

Test of Barrier Overtopping

Barrier overtopping occurs when a tsunami surges over the higher elevations of a spit barrier. By comparison, channelized surge occurs when the tsunami remains within the low lying channels of rivers, creeks, and their wetlands. Barriers are now developed for residential, commercial, and recreational use. The potential danger of a tsunami overtopping a barrier, and thereby causing extensive loss of life and damage, depends upon the magnitude and proximity of the generating earthquake. For example, the 1964 farfield tsunami at Seaside inundated the mouth of the Necanicum estuary and surged up the major channels. Wave splash or minor flooding occurred along the promenade, but no major barrier overtopping occurred.

By examining the 1700 AD horizon and the spatial distributions of TSL and SCL, hypotheses can be formulated as to how this nearfield tsunami inundated the Seaside area. Generally, the TSL and SCL deposits for the 1700 AD event are thin and patchy in the Neawanna wetlands and have yet to be found anywhere west of the Neawanna wetlands. The majority of the TSL deposits occur in the areas just north of the 12th Avenue bridge (SSW 716) and northeast of the Mill Ponds. Central SCL deposits are very localized and are possibly of LIS origin, and they occur near Broadway Drive bridge crossing Neawanna Creek (SSW 847 and 762). Cores located just north of S Avenue bridge and to the southeast of the Mill Ponds contain the greatest abundance of TSL and SCL deposits. However, the TSL and SCL deposits are consistently very thin ($\leq$ 2 cm), so source directions are difficult to establish there. The majority of the cores containing the 1700 AD prehistoric subsidence horizon on the western banks of the Neawanna Creek do not contain any TSL or SCL sand deposits. Only cores SSW 716 and 717 (797, 806, and 813 weak) contain TSL on the west bank. Therefore, widespread overtopping of the cobble barrier separating the Necanicum and Neawanna valleys is ruled out. Even a dilute surge (carrying no sand over vegetative surfaces) would have resuspended sediment in the Neawanna channel axis and deposited sand on the eastern marsh banks. There is no evidence for such overtopping tsunami surge deposition throughout the central Neawanna reaches.

By comparison, channelized surges entering the north or south end of the Neawanna Creek may be more plausible. In the 1964 event, the sand deposits are well preserved along both banks of the rivers and creeks. So, a channelized surge origin along the full length of the Neawanna channel is ruled out for the 1700 AD event.

A mix of localized overtopping and channelization probably occurred at both the northern and southern portions of Seaside (Figure 69). The surge(s) most likely entered the Necanicum mouth area (somewhere to the south of its present location) and surged north and south along the valley, possibly together with some primary barrier ridge overtopping. The combined flow was apparently sufficient to propagate or locally inundate the northern portion of the Neawanna wetlands and Mill Creek sites. However, the thinning of the TSL (≤ 2 cm) in close proximity to channel banks and exposed channel sand implies very weak transport energies. Far less, for example, than the channelized surges in the Neacoxie, Necanicum, and northern Neawanna channels from the 1964 tsunami event. Where damaging runup occurred from the 1964 tsunami, the TSL deposits average 6 cm in thickness. Clearly the hydrography of the modern Necanicum/Neawanna confluence must differ greatly from conditions during the large 1700 AD tsunami event.

The southern surge possibly entered the Neawanna Creek wetlands from local overtopping the cobble ridge that separates the Necanicum and Neawanna wetlands. The abrupt subsidence horizons are locally very distinct and the majority of buried horizons do contain TSL/SCL deposits (SSW 789, 787, 818, 735, 730, 830, 832).

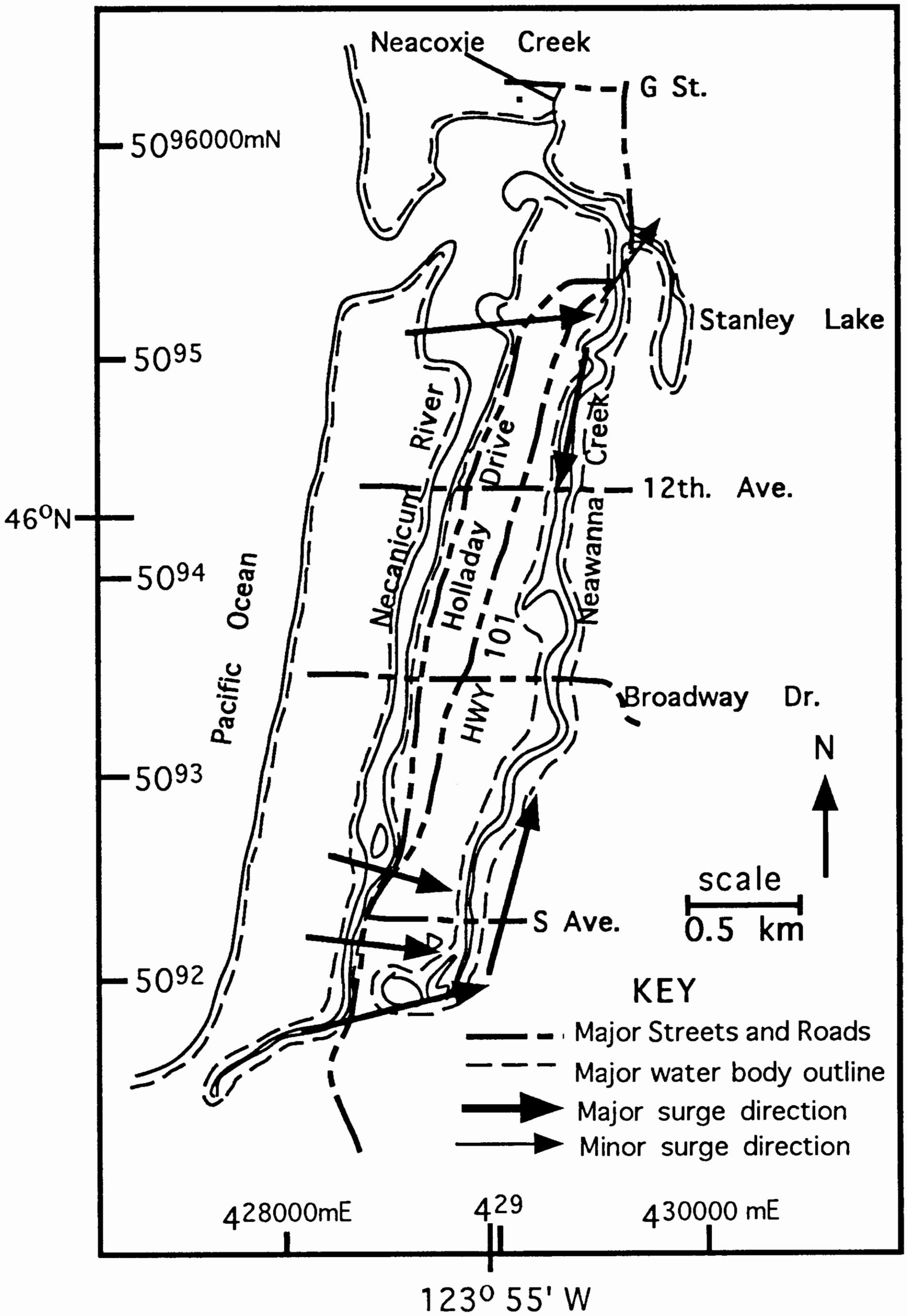


Figure 69. Arrows indicating propagation which possibly occurred during the 1700 AD event in Seaside.

Minimum Overland Inundation

From the above discussion and the distribution of cores containing SCL and TSL deposits, the minimum inundation for the Seaside area can be determined. (Note: both SCL and TSL deposits include a subsidence burial deposit in addition to sand layers) According to Dawson (1994), minimum inundation and runup estimates are represented by the upper limit of the tsunami deposits. Therefore, it can be determined that the minimum inundation from the 1700 AD event is < 1.5 kilometers from the present day shoreline for the southern to central Seaside wetlands. This information can then be applied to produce a possible inundation map for the 1700 AD event (Figure 70), and practical guidelines for evacuation planning.

Comparisons with other studies

Historic Events

The comparison of the findings of this study for the historic 1964 event with Darienzo and others (1993) contain many similarities. Historic sands were identified in the wetlands of the Necanicum River just south of the Avenue G bridge. These sands seem to change in lithology from a beach dominated deposit to the north to river sand-rich to the south, and they appear to thin with distance from source, also indicated in this study. Only one core was taken in the Neacoxie Creek (NX 1) wetlands, and it indicates a historic sand layer with a stratigraphy similar to the cores in this study. The cores along the Neawanna Creek obtained historic 1964 deposits just to the north of 12th Avenue bridge. However, cores from this study further to the south show additional evidence of possible 1964 sand layers (SSW 803). Darienzo and

Figure 70. Inundation line for the 1700 AD event in Seaside.

others (1993) also determined that surges affected the Necanicum River and Neawanna and Neacoxie Creeks, although they did not discuss the characteristics of the waves or the deposits.

Numerous historic tsunami have occurred throughout the world. Some historic events have been chosen to compare wave characteristics and runup levels to the 1964 event at Seaside. The Kamchatka area (Kuril-Kamchatka arc and trench of the Pacific Rim) is notorious for the occurrence of earthquake tsunami, and in 1923 a M 7.2 earthquake produced a tsunami depositing a thin (2-3 cm), traceable sand layer up to three kilometers inland (Minoura and others, 1996). At the time of the tsunami event, the land was snow covered, possibly contributing to the extensive inland inundation. Generally, attenuation produces sand deposits which thin landward (Dawson and others, 1988) similar to what was seen along the channelized surges for Seaside. However, in Kamchatka, the deposit is of a fairly uniform thickness introducing an unusual depositional mechanism.

In the last decade, historic tsunami have occurred in Nicaragua (1992), East Java (1994), and Manzanillo, Mexico (1995). The Nicaraguan earthquake (Ms 7.2) produced landward deposits that were correlated to runup heights of 4-6.1 m (13-20 ft.) along the Nicaraguan coast. The deposits thinned and fined landward eventually becoming undetectable beyond 500 m inland. Larger clasts were also combined within the deposits, indicating powerful waves that were influenced by local topography and sediment supply (Bourgeois and Reinhart, 1993). No large clasts were found within the 1964 deposits in Seaside.

A Ms 7.2 earthquake produced a tsunami in 1994 at the east end of the Java trench. Severe fatalities and damage occurred 250 kilometers from the source. Runup heights for west Bali were 0-4.9 m (0-14 ft.) and .9-13.7 m (3-45 ft.) in southeast Java (Synolakis and others, 1995). Studies also determined that pocket beaches may be more susceptible to tsunami, where deposition does not always occur. Observations of tsunami watermark runup included undercut trees, sand encrusted bark, and sand covered leaves. By comparison, the 1964 event for Seaside did not produce severe damage to vegetation, but did leave abundant evidence of sand deposition, associated with the movement of drift logs, cars, and other debris.

In 1995, an earthquake (Mw 8.0) along the Northern Middle America Subduction Zone produced a tsunami. This tsunami affected 200 km of coastline and produced .9-4.9 m of runup (Borerro and others, 1997). At localities with steep onshore topography, damage was minor. Shallow beaches received the most damage. From the north end of Santiago Bay, people on steep cliffs felt the shaking, observed the withdrawal of water from the bay, and then witnessed the wave crashing up the cliff. This area had the highest runup of 11 m (36 ft.). Four to five wave surges were noted, the first being the largest. This is similar to the 1964 event in Seaside where observation sites and people verified multiple surges, however, none of the other historic studies showed evidence for amplification or surges as recorded in deposits left behind by these historic events.

Prehistoric Events

There are many similarities between Darienzo and others (1993) and this study. The correspondance for the 1700 AD horizon (Darienzo's 1MT) are consistent for both studies. The 1700 AD subsidence horizon is widespread but laterally discontinuous in the wetlands of Neawanna Creek. The core interpretations in this study for the lower wetlands of Stanley Lake (SSW 872-875) have differing stratigraphies compared to Darienzo and others, 1993 (SL 1 and 3). The radiocarbon dates for SL3 did not support a 1700 AD horizon. The lack of evidence for prehistoric horizons within the Necanicum and Neacoxie wetlands were consistent for both studies. Prehistoric deposits may be underlying the dense basal sand of these areas. Additional reconnaissance investigation into the drainage east of Neacoxie Creek obtained a possible subsidence horizon, but the horizon was inconsistent and lacked some criteria for abruptly buried wetland sequences.

The apparent mechanism of 1700 AD tsunami inundation are also similar for both studies. Although additional cores were taken throughout the wetlands of Seaside, only patchy sand layers are apparent for the 1700 AD event. The location of the buried horizons and TSL are consistent with Darienzo and others (1993). In this study, the propagation of the 1700 AD event along the central reaches of the Neawanna Creek are ruled out. Darienzo and others (1993) indicate a north and south corridor for the surge to enter, similar to the interpretation for this study. However, they did not take into account the slightly more southern location for the Necanicum River mouth, allowing for a more southerly entrance for the northern corridor. The southern corridor is very similar to Darienzo and others (1993), although the surge possibly reached farther to the north, due to the increased topography on the east bank of the Neawanna Creek (NE of S Ave. bridge) confining the flow.

Implications for Evacuation

Based on the this study, recommendations for evacuation are suggested. Primary evacuation should be to the east of the Necanicum River but not along the Neawanna channel banks. Minimal safety locations are located along higher elevation ridge tops and away from the channel wetlands between the Necanicum and Neawanna channel valleys. Ideal localities (maximum safety) would be the foothills of the Coast Range east of Wahanna Road. Due to the potential for liquefaction of sandy deposits, bridges, buildings, and roadways developed for evacuation should be designed for some loss of foundation support.

Conclusions

During the past decade, a considerable amount of research has been conducted into the evidence for prehistoric earthquakes along the Cascadia margin of the United States. Tsunami can be produced by these megathrust earthquakes which enter the low-lying coastal wetlands shortly after the coseismic subsidence occurs, depositing sand and sediment in these areas which slow the wave. Seaside, Oregon, was chosen as a study area due to its low elevation and high population at risk. In addition, it has been affected by a historic tsunami in 1964 which serves as a analog for tsunami surge deposition of sand in wetland settings. The primary objectives of this study were to determine the geologic record of the 1964 tsunami event, and then use this information to evaluate mechanisms of inundation for the youngest prehistoric Cascadia event (1700 AD).

1964 Event

Geologic evidence of shallow sand deposits from 4-32 cm depth from the present surface corresponds well with the reports of runup, multiple surges, and local amplification or attenuation of the 1964 tsunami surges in Seaside. Amplification of the tsunami wave occurred at the Necanicum River mouth/estuary, producing water heights up to 3.9-4.6 m (13-15 ft.) and depositing 10-31 cm (4-12 in.) of sand along northern Venice Park. Channelized surges traveled up the Necanicum River, Neacoxie Creek, the drainage to the east of Neacoxie Creek, and Neawanna Creek; and these waves attenuated (deposits generally thinning up river). Some areas contain exceptions where the deposits thicken due to obstructions, such as the Neacoxie Creek south of G Street. There is weak preserved evidence indicating two possible surges. Intruded contacts, sand boils, dikes or sills suggesting liquefaction were not present or observed for any of the 1964 localities. With this evidence, the inundation zone for the 1964 event in Seaside was determined (Figure 67).

1700 AD Event

The horizon for the 1700 AD prehistoric tsunami deposits (ranging from 45 to 85 cm depth) contained weak subsidence sequences with little or no sand deposits at the subsidence contacts. The coastal wetlands of the Neawanna Creek contained the majority of the preserved 1700 AD and other prehistoric subsided horizons. From the characteristics of these deposits, one scenario is preferred in how the wave entered the Seaside wetlands. Specifically, the wave propagated in shore through a northern channelized corridor and southern corridor with localized overtopping of an intact cobble ridge, separating the Neawanna and Necanicum channels. The northern corridor is somewhat south of the present mouth of the Necanicum estuary and the southern corridor is along the low-lying reaches of the Neawanna Creek and the Necanicum River near Avenue U. With this information, an inundation map for the 1700 AD event is produced (Figure 70) that shows localized inundation to 1.5 kilometers from the present coast.

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APPENDIX A

1964 OBSERVATIONS

Site Number	Date 1996	State Northing	Plane Easting	UTM Northing	UTM Easting	Surf. Elev.	Event Record	Record Type	Runup Des.	Runup Elev.	Veri
SSB 640	10-May	866710	1128684	5093494	428059	16.0	1964	TDL	SL	17.0	NP
SSB 641	10-May	866724	1128700	5093498	428064	23.0	1964	TWM	SPL		NP,PCx2
SSB 642	10-May	866806	1128687	5093523	428059	16.0	1964				
SSB 643	10-May	869727	1129545	5094421	428293	20.5	1964	TWM	FL		PC
SSB 644	10-May	860789	1126742	5091672	427523	16.0	1964	TWM	WL	16.0±2.0	PC
SSB 645	10-May	862657	1127521	5092249	427743		1964	TDD		16.0±2.0	PC
SSX 646	10-May	876362	1132805	5096472	429223	6.5	1964	TWM			PC
SSX 647	10-May	875769	1132510	5096289	429139	8.5	1964	TSL			PC
SSX 648	10-May	875770	1132479	5096289	429130	9.5	1964	TSL/TWM	WL	12.5	PC
SSX 649	10-May	876092	1132463	5096387	429122	13.8	1964	TDD		13.5	PC
SSX 650	10-May	876081	1132866	5096387	429245	12.0	1964	TSL/TDL		13.2	PC
SSX 651	10-May	876079	1132695	5096385	429193	11.0	1964	TDL		13.0	PC
SSX 652	10-May	875823	1132421	5096304	429112	9.0	1964	TDD		11.0	PC
SSG 653	10-May	861714	1128788	5091973	428137	9.5	1964	TDD		9.5,7.5	PC
SSG 654	10-May	861006	1128828	5091758	428156	9.0	1964	TDD		9.5	PC
SSN 655	10-May	862781	1129198	5092302	428252	10.0	1964			10.0	
SSN 656	10-May	864229	1128866	5092740	428138	11.0	1964	TWM	WL	11.8	PCx2
SSN 657	10-May	864850	1129279	5092933	428257	10.5	1964	TWM		11.0	PC
SSN 658	10-May	865339	1129762	5093086	428400		1964				PC
SSN 659	10-May	865990	1130337	5093290	428569	12.5	1964	TWM	WL	12.5	PC
SSN 660	10-May	866329	1130185	5093392	428520	12.5	1964	TDD		12.5	GP
SSN 661	10-May	867194	1129815	5093652	428399	12.0	1964	TML	WL,FL	13.0,14.0	
SSN 662	10-May	867267	1129552	5093672	428318	11.5	1964	TWM	WL	11.5	PC
SSN 663	10-May	867503	1130111	5093749	428486	12.5	1964	TWM	FL,SL	14.0,13.5	GP
SSN 664	10-May	867164	1130382	5093648	428572	12.5	1964	TWM	WL	12.5	PC
SSN 665	10-May	868305	1130312	5093995	428540	12.5	1964	TWM	SL	12.5	PCx2
SSN 666	10-May	869717	1130874	5094430	428698	14.5	1964	TWM	SL	14.5	PC
SSN 667	10-May	869855	1130620	5094470	428619	11.5	1964	TDD		11.5+	PC
SSN 668	10-May	872212	1132092	5095201	429045	20.0	1964	TDD	SL	21.0	PC
SSN 669	10-May	872812	1132253	5095386	429089	19.5	1964	TWM	SL/FL	20.5	PC
SSN 670	10-May	873794	1132450	5095687	429139	11.5	1964	TWM	WL	13.0	GP,PC
SSN 671	10-May	873653	1132456	5095644	429143	13.0	1964	TDD	WL	13.0+	GP
SSN 672	10-May	873947	1132618	5095735	429189	13.0	1964	TDD	WL	13.0+	PC
SSN 673	10-May	873944	1132824	5095736	429252	11.0	1964	TDD	WL	11.5	PC
SSN 674	10-May	874047	1133043	5095769	429318	7.5	1964	TWM	WL	10.5	PC
SSN 675	10-May	873737	1133134	5095676	429348	8.0	1964	TWM	WL	11.1	GP
SSN 676	10-May	873883	1133095	5095720	429335	8.0	1964	TSL/TDL	WL	11.0	ST
SSN 678	10-May	873999	1133131	5095755	429345	7.0	1964	TDL	WL	10.5	
SSN 679	10-May	874014	1133010	5095759	429308	8.5	1964	TWM	WL	11.2	PC
SSN 680	10-May	873872	1133080	5095716	429330	8.5	1964	TDL	WL	11.1	PC
SSN 681	10-May	873471	1133125	5095595	429348	8.5	1964	TDL	WL	10.7	GP
SSN 682	10-May	873679	1133291	5095659	429397	7.0	1964	TDL	WL	11.5	PC
SSN 683	10-May	873483	1133074	5095598	429332	8.5	1964	TWM	WL	10.7	NP,PC
SSN 684	10-May	873759	1133399	5095685	429429	7.0	1964	TWM	SL	13.5	PC
SSN 685	10-May	873705	1133362	5095668	429418	7.0	1964	TDL	WL	12.5	PC

Site Prefix: SSN=Necanicum River, SSW=Neawanna Creek, SSX=Neacoxie Creek, SSXa=Drainage to east of SSX, and SSS=Stanley Lake, SSB= Promenade (Boardwalk), and SSG= Seaside golf course.

State Plane: North American Datum 1927, northern Oregon, in U.S. survey feet.

UTM: Universal Transverse Mercator coordinates in North American Datum 1927, zone 10, in meters.

Surface Elevation: CH2MHILL 1973 Datum to the nearest extrapolated one foot (+ 1 ft.).

Event Record: 1964, 1700 AD, PHU (Prehistoric Unknown)

Record Type: TWM=Tsunami high water mark, TDD=Tsunami drift debris, TDL=Tsunami drift logs, TSL=Target sand layer, and TML= Tsunami mud layer.

Runup Designators: WL=Water level, SL=Surge level, SPL=Splash level, and FL=Foam line.

Runup Elevation: CH2MHILL 1973 datum (note: Runup surface=water column height) in feet.

Verification: NP=Newspaper, PC=Personal communication, GP=Ground Photography, and ST=Soil trench.

Site Number	Date 1996	State Northing	Plane Easting	UTM Northing	UTM Easting	Surf. Elev.	Event Record	Record Type	Runup Des.	Runup Elev.	Veri
SSN 686	10-May	873574	1133560	5095630	429479	7.5	1964	TSL/TDL	WL	11.5	PC
SSN 687	10-May	873546	1133521	5095621	429468	7.5	1964	TSL/TWM	WL	11.5	GP
SSN 688	10-May	873568	1133588	5095628	429488	7.5	1964	TSL/TDL	WL	11.5	GP
SSN 689	10-May	873379	1133452	5095570	429448	8.5	1964	TSL/TDL	WL	11.5	PC
SSN 690	10-May	873344	1133312	5095558	429406	8.5	1964	TSL	WL	11.5	GP
SSN 691	10-May	873139	1133571	5095498	429487	8.5	1964	TSL	WL	11.0	PC
SSN 692	10-May	873044	1133539	5095468	429478	8.5	1964	TSL/TDL	WL	11.0	PC
SSN 693	10-May	872845	1133471	5095407	429459	10.5	1964	TML	WL	11.0	PC
SSN 694	10-May	872873	1133170	5095413	429367	8.5	1964	TML	WL	10.5	PC
SSN 695	10-May	872887	1132671	5095412	429215	12.0	1964	TSL/TWM	WL	12.0	PC
SSN 696	10-May	873484	1132717	5095595	429224	11.0	1964	TWM	WL	12.0	PC
SSN 697	10-May	874137	1133867	5095804	429568	15.0	1964	TWM	SL	15.0	PC
SSN 698	10-May	873994	1133991	5095762	429607	14.5	1964	TWM	SL	15.5	PC
SSN 699	10-May	873398	1133813	5095579	429558	12.5	1964	TWM		13.0	PC
SSW 700	10-May	871994	1133593	5095149	429504	10.0	1964	TWM	WL	10.0	PC
SSW 701	10-May	871387	1133449	5094963	429466	10.0	1964	TWM	WL	10.0	PC
SSW 702	10-May	871862	1132904	5095102	429296	10.5	1964	TWM	WL	10.5	PC
SSW 703	10-May	871595	1133307	5095025	429421	6.5	1964	TSL/TWM	SL	10.0+	PC
SSW 704	10-May	871444	1133161	5094978	429378	7.5	1964	TWM		10.0+	PC
SSW 705	10-May	872753	1132620	5095371	429201	10.0	1964	TWM		11.0+	PC
SSW 706	10-May	872096	1132715	5095172	429236	9.0	1964	no flooding			PC
SSW 707	10-May	869577	1132952	5094407	429332	6.5	1964	TWM		6.5	PC
SSW 708	10-May	869566	1133010	5094404	429350	7.0	1964	no flooding			PC
SSW 709	10-May	867775	1133244	5093861	429438	9.0	1964	no flooding			PC
SSW 710	10-May	866591	1132817	5093496	429319	9.5	1964	no flooding			PC
SSW 711	10-May	865419	1132020	5093132	429087	7.0	1964	no flooding			PC

Site Prefix: SSN=Necanicum River, SSW=Neawanna Creek, SSX=Neacoxie Creek, SSXa=Drainage to east of SSX, and SSS=Stanley Lake, SSB= Promenade (Boardwalk), and SSG= Seaside golf course.

State Plane: North American Datum 1927, northern Oregon, in U.S. survey feet.

UTM: Universal Transverse Mercator coordinates in North American Datum 1927, zone 10, in meters.

Surface Elevation: CH2MHILL 1973 Datum to the nearest extrapolated one foot (+ 1 ft.).

Event Record: 1964, 1700 AD, PHU (Prehistoric Unknown)

Record Type: TWM=Tsunami high water mark, TDD=Tsunami drift debris, TDL=Tsunami drift logs, TSL=Target sand layer, and TML= Tsunami mud layer.

Runup Designators: WL=Water level, SL=Surge level, SPL=Splash level, and FL=Foam line.

Runup Elevation: CH2MHILL 1973 datum (note: Runup surface=water column height) in feet.

Verification: NP=Newspaper, PC=Personal communication, GP=Ground Photography, and ST=Soil trench.

APPENDIX B

GOUGE CORE LOG LOCATIONS AND DESCRIPTIONS

Site Number	Date 1996	State Northing	Plane Easting	UTM Northing	UTM Easting	Surf. Elev.	Event Record	Record Type	Veri	Core Depth
SSW 712	19-Jun	868068	1132863	5093947	429319	5.0	1700 AD	SBD	SC	82
SSW 713	19-Jun	868064	1132926	5093946	429338	5.0	1700 AD	SL	SC	56
SSW 714	20-Jun	869981	1132940	5094530	429324	5.0	1700 AD	SBD	SC	88
SSW 715	20-Jun	869974	1133037	5094529	429354	5.0	1700 AD	SBD	SC	51
SSW 716	20-Jun	870483	1132679	5094680	429240	7.0	1700 AD	TSL	SC	78
SSW 717	20-Jun	870341	1132684	5094637	429243	5.0	1700 AD	TSL	SC	72
SSW 718	20-Jun	871047	1133205	5094857	429395	7.0	1964/1700 AD	TSL/SBD	SC	27/59
SSW 719	20-Jun	871126	1133164	5094881	429382	7.0	1964/1700 AD	TSL/SBD?	SC	16/72
SSW 720	20-Jun	871151	1133117	5094888	429367	7.0	1964/1700 AD	TSL/SBD	SC	11/79
SSW 721	20-Jun	866135	1132971	5093359	429370	5.0	1700 AD/PHU	TSL/SBD	SC	44/94
SSW 722	21-Jun	872362	1133576	5095261	429496	5.0	1964	TSL	SC	24
SSW 723	21-Jun	872044	1133294	5095162	429413	7.0	1964	MSL	SC	23
SSW 724	21-Jun	872080	1133256	5095172	429401	8.0	1964	TSL	SC	
SSW 725	21-Jun	871400	1133210	5094965	429393	7.0	1964	TSL	SC	9
SSW 726	21-Jun	871602	1133050	5095025	429343	8.0	1964	MSL	SC	15
SSW 727	21-Jun	867603	1132396	5093801	429181	5.0	1700 AD ?	SBD?	SC	72?
SSW 728	21-Jun	864162	1131305	5092742	428881	7.0	1700 AD ?	SBD?	SC	74
SSW 729	24-Jun	861404	1130667	5091896	428713	7.0	1700 AD	SBD	SC	75
SSW 730	24-Jun	861265	1130506	5091853	428665	7.0	1700 AD/PHU	SCL/SBD	SC	75/103
SSN 731	24-Jun	863991	1129521	5092674	428339	8.0	1964?	MSL	SC	26-48
SSN 732	24-Jun	863795	1129597	5092615	428364	5.0	1964?	MSL	SC,ST	37-50
SSS 733	25-Jun	872572	1134787	5095336	429863	3.0	?		SC	
SSS 734	25-Jun	872183	1134744	5095217	429853	3.0	1700 AD?	SCL	SC	88
SSW 735	25-Jun	862485	1131331	5092232	428905	5.0	1700 AD	SL	SC	66
SSW 736	25-Jun	863032	1131458	5092400	428938	7.0	?/PHU	LSD/SBD	SC	31/93
SSN 737	26-Jun	864475	1129590	5092822	428356	5.0	1964	TSL	SC	15
SSN 738	26-Jun	864676	1129602	5092883	428357	5.0	1964	TSL	SC	21
SSN 739	26-Jun	864736	1129582	5092901	428351	5.0	1964	TSL	SC	19
SSN 740	27-Jun	864610	1129520	5092862	428333	5.0	1964	MSL	SC	11-19
SSN 741	27-Jun	864441	1129459	5092810	428316	5.0	1964	MSL	SC	8-18
SSN 742	27-Jun	864284	1129290	5092761	428266	5.0	1964	TSL	SC	30
SSN 743	27-Jun	864834	1129603	5092931	428356	6.0	1964	TSL	SC	27
SSN 744	27-Jun	865509	1129943	5093140	428454	6.5	1964	TSL	SC	33
SSN 745	27-Jun	865599	1129981	5093168	428464	6.0	1964	MSL	SC	31-34
SSN 746	27-Jun	865390	1129895	5093103	428440	7.0	1964	MSL	SC	23-29
SSN 747	27-Jun	865409	1130005	5093110	428473	5.0	1964	MSL	SC	14-20
SSN 748	27-Jun	865438	1130055	5093119	428488	5.0	1964	MSL	SC,ST	11-19
SSN 749	28-Jun	865387	1130091	5093104	428500	5.0	1964	TSL	SC	28
SSN 750	28-Jun	865583	1130100	5093164	428501	5.0	1964	TSL	SC	17
SSX 751	28-Jun	875749	1132782	5096285	429222	5.0	1964	TSL	SC	15
SSX 752	28-Jun	875803	1132792	5096302	429225	5.0	1964	TSL	SC	14
SSX 753	28-Jun	875878	1132806	5096325	429228	5.0	1964	MSL	SC	8-22
SSX 754	28-Jun	875923	1132822	5096338	429233	5.0	1964	MSL	SC,ST	7-39
SSW 755	1-Jul	867010	1132493	5093621	429216	5.0	1964?/1700 AD?	TSL	SC	10-14
SSW 756	1-Jul	867082	1132511	5093643	429221	5.0	1700 AD?	SL	SC	53
SSW 757	1-Jul	867328	1132822	5093721	429313	7.0	1964	TSL	SC	13
SSN 758	2-Jul	865860	1130244	5093250	428542	5.0	1964	MSL	SC	13-22
SSN 759	2-Jul	865918	1130261	5093267	428547	5.0	1964	TSL	SC	17
SSN 760	2-Jul	865225	1129829	5093052	428421	5.0	1964	MSL	SC	13-32
SSN 761	2-Jul	864594	1129907	5092861	428451	5.0	1964	CSL?	SC	25
SSW 762	2-Jul	866368	1132553	5093426	429240	5.0	1964?/1700 AD	MSL/SCL	SC	20-30/63
SSW 763	2-Jul	866296	1132567	5093404	429245	5.0	1964	MSL	SC	4.5-31
SSW 764	2-Jul	866427	1132728	5093446	429293	5.5	1700 AD	SBD	SC	65
SSW 765	2-Jul	866356	1132722	5093424	429292	5.0	1700 AD	SCL	SC	72
SSW 766	9-Jul	866301	1132702	5093407	429286	5.0	1700 AD	SCL	SC	53
SSW 767	10-Jul	866207	1132749	5093379	429302	5.0	?		SC	
SSW 768	10-Jul	866078	1132967	5093341	429369	5.0	1700 AD	SCL	SC	73
SSX 769	10-Jul	875831	1132740	5096310	429209	5.0	1964/1700 AD?	TSL/TSL	SC	26/73
SSX 770	10-Jul	875499	1132767	5096209	429220	5.0	1964	TSL	SC	19
SSX 771	10-Jul	875600	1132705	5096239	429200	5.0	1964	TSL	SC	18

Site Prefix: SSN=Necanicum River, SSW=Neawanna Creek, SSX=Neacoxie Creek, SSXa=Drainage to east of SSX, and SSS=Stanley Lake, SSB= Promenade (Boardwalk), SSG= Seaside golf course.

State Plane: North American Datum 1927, northern Oregon, in U.S. survey feet.

UTM: Universal Transverse Mercator coordinates in North American Datum 1927, zone 10, in meters.

Surface Elevation: CH2M HILL 1973 Datum to the nearest extrapolated one foot (+ 1 ft.).

Event Record: 1964, 1700 AD, PHU (Prehistoric Unknown)

Record Type: TSL=Tsunami-deposited sand layer, MSL=Mud and sand layers, SL= Sand layer, SBD=Subsidence burial deposit, LSD=Landslide deposit, LIS=Liquified intruded sand, and SCL=Sand capping layer,

Verification: SC=Subsurface Core, ST=Soil Trench, and CB=Cutbank.

Core Depth: Subsurface depth to TSL/CSL/SL lower contact, buried peat and landslide material upper contact, in centimeters.

Site Number	Date 1996	State Northing	Plane Easting	UTM Northing	UTM Easting	Surf. Elev.	Event Record	Record Type	Veri	Core Depth
SSX 772	10-Jul	875727	1132682	5096277	429192	5.0	1964	MSL	SC	12-15
SSX 773	10-Jul	875814	1132631	5096303	429176	6.0	1964	MSL	SC	13-24
SSX 774	10-Jul	875902	1132650	5096330	429181	6.0	1964	MSL	SC	11-18
SSW 775	11-Jul	867228	1133107	5093693	429401	5.0	1700 AD?	SL	SC	47
SSW 776	11-Jul	867246	1133006	5093698	429370	5.0	?		SC	
SSW 777	11-Jul	867243	1133063	5093697	429387	5.0	1700 AD?	SCL?	SC	85
SSW 778	11-Jul	867489	1133116	5093773	429401	5.0	1700 AD?	LIS,SBD	SC	60,70
SSW 779	11-Jul	867477	1133181	5093770	429421	7.0	1700 AD?	LIS,SBD	SC	50,58
SSW 780	11-Jul	868557	1132929	5094096	429334	5.0	1700 AD?	LIS,SBD	SC	48,55
SSW 781	11-Jul	869210	1132631	5094292	429237	5.0	1700 AD	TSL?	SC	54
SSW 782	11-Jul	865341	1132636	5093114	429275	7.0	1700 AD?/PHU	SBD,LIS	SC	80,100
SSW 783	11-Jul	865286	1132822	5093099	429332	7.0	1700 AD?/PHU	SBD/LIS,SBD?	SC	43/50,118
SSW 784	12-Jul	863050	1131154	5092402	428845	7.0	1700 AD/PHU	SBD/LIS/SBD	SC	73/153
SSW 785	12-Jul	863046	1131236	5092402	428870	7.0	1700 AD?/PHU?	SBD?	SC	56/73,143
SSW 786	12-Jul	863033	1131406	5092399	428922	7.0	1700 AD	SBD?	SC	65
SSW 787	12-Jul	863293	1131407	5092479	428920	7.0	1700 AD/PHU	TSL	SC	42/78
SSW 788	12-Jul	863316	1131493	5092486	428946	7.0	1700 AD?/PHU	SBD/SCL,TSL	SC	43/71,162
SSW 789	12-Jul	863492	1131441	5092540	428929	7.0	1700 AD?/PHU	SBD?/TSL	SC	51/95
SSW 790	12-Jul	863783	1131457	5092628	428931	7.0	1700 AD?	LSD	SC	188
SSW 791	16-Jul	865271	1132080	5093087	429107	7.0	1700 AD/PHU	SBD?/TSL	SC	65/78
SSW 792	16-Jul	865346	1132441	5093114	429216	7.0	1700 AD?	SBD?	SC	58
SSW 793	24-Jul	864771	1131906	5092933	429058	5.0	1700 AD?/PHU?	SBD?/LSD	SC	72/94
SSW 794	24-Jul	864462	1132051	5092841	429105	7.0	?	LSD	SC	104
SSW 795	24-Jul	864543	1131953	5092864	429075	7.0	PHU	TSL	SC	117
SSW 796	24-Jul	864288	1131863	5092786	429050	7.0	1700 AD	SBD?	SC	32
SSW 797	25-Jul	862979	1131118	5092380	428835	6.0	1700 AD/PHU	TSL/SBD?	SC	41,76
SSW 798	25-Jul	863051	1131091	5092402	428826	6.0	1700 AD?/PHU	SBD?	SC	70
SSW 799	25-Jul	863509	1131153	5092542	428841	7.0	1700 AD?	SBD?	SC	52
SSW 800	25-Jul	863765	1131146	5092620	428836	7.0	?		SC	
SSW 801	30-Jul	864480	1131635	5092842	428978	7.0	1700 AD?	SBD?	SC	40
SSW 802	30-Jul	865401	1132046	5093127	429095	5.0	1700 AD?	SBD?	SC	43?
SSW 803	30-Jul	865454	1132130	5093144	429120	6.0	1964?/1700 AD/PHU	TSL?/SBD?/LSD/SBD	SC	7?/60/74/82
SSW 804	30-Jul	865541	1132253	5093171	429157	6.0	1964?	TSL	SC	7
SSW 805	30-Jul	865632	1132383	5093200	429195	7.0	1964?	TSL	SC	17
SSW 806	30-Jul	865602	1132527	5093192	429240	5.0	1964?/1700 AD	MSL/TSL	SC	4/50
SSW 807	30-Jul	865740	1132504	5093234	429231	7.0	1964?	TSL?	SC	20
SSW 808	30-Jul	865835	1132724	5093265	429297	5.0	1964?/1700 AD	TSL/SBD	SC	10/73
SSW 809	30-Jul	865968	1132605	5093305	429260	5.0	1700 AD?	SBD?	SC	30
SSW 810	30-Jul	866073	1132556	5093336	429244	5.0	?		SC	
SSW 811	30-Jul	864816	1131392	5092942	428901	5.0	1700 AD?	SBD?	SC	61
SSW 812	30-Jul	865043	1131632	5093014	428972	7.0	1700 AD	SCL	SC	36
SSW 813	30-Jul	864991	1131766	5092999	429014	7.0	1700 AD/PHU	TSL/SBD	SC	31/83
SSW 814	30-Jul	864993	1131853	5093001	429040	5.0	PHU	SBD	SC	125
SSW 815	30-Jul	865104	1131797	5093034	429022	7.0	1700 AD	SBD?	SC	37?,43?
SSW 816	30-Jul	865185	1131831	5093059	429032	5.0	?		SC	
SSW 817	6-Aug	862936	1131212	5092368	428864	7.0	1700 AD	SBD?	SC	67
SSW 818	6-Aug	862894	1131497	5092358	428951	7.0	1700 AD	SCL	SC	75
SSW 819	6-Aug	864313	1132578	5092800	429267	9.0	?	LSD	SC	55
SSW 820	6-Aug	864901	1132882	5092982	429354	10.0	?	LSD	SC	70
SSW 821	6-Aug	864715	1132815	5092925	429336	11.0	?	LSD	SC	43/90
SSW 822	6-Aug	864272	1131771	5092780	429022	5.0	1700 AD/PHU	SBD?/SCL	SC/CB	53/90
SSW 823	6-Aug	864240	1131830	5092771	429040	6.0	1700 AD?/PHU	SBD?/TSL	SC/CB	45/141
SSW 824	6-Aug	864136	1132173	5092743	429146	9.0	1700 AD?	LIS,SBD?	SC	70
SSW 825	6-Aug	864418	1132176	5092829	429144	7.0	1700 AD?	TSL?,SBD?	SC	90
SSN 826	6-Aug	859815	1126302	5091372	427398	9.0	PHU		SC	
SSN 827	6-Aug	859621	1126194	5091311	427367	13.0	PHU		SC	
SSW 828	7-Aug	861047	1130071	5091782	428534	5.0	1700 AD/PHU	SBD?/TSL/SBD	SC	69/92
SSW 829	7-Aug	861185	1130096	5091824	428541	7.0	1700 AD?	SBD?	SC	60
SSW 830	7-Aug	860921	1129953	5091743	428500	7.0	1700 AD/PHU	SCL/SBD?	SC	77/140
SSW 831	7-Aug	860895	1129725	5091733	428430	7.0	1700 AD/PHU	SBD?/TSL/SBD	SC	56/83/130

Site Prefix: SSN=Necanicum River, SSW=Neawanna Creek, SSX=Neacoxie Creek, SSXa=Drainage to east of SSX, and SSS=Stanley Lake, SSB= Promenade (Boardwalk), SSG= Seaside golf course.

State Plane: North American Datum 1927, northern Oregon, in U.S. survey feet.

UTM: Universal Transverse Mercator coordinates in North American Datum 1927, zone 10, in meters.

Surface Elevation: CH2M HILL 1973 Datum to the nearest extrapolated one foot (+ 1 ft.).

Event Record: 1964, 1700 AD, PHU (Prehistoric Unknown)

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Verification: SC=Subsurface Core, ST=Soil Trench, and CB=Cutbank.

Core Depth: Subsurface depth to TSL/CSL/SL lower contact, buried peat and landslide material upper contact, in centimeters.

Site Number	Date 1996	State Northing	Plane Easting	UTM Northing	UTM Easting	Surf. Elev.	Event Record	Record Type	Veri	Core Depth
SSW 832	7-Aug	860751	1129530	5091687	428372	7.0	1700 AD/PHU	SCL\TSL\SBD?	SC	42/92/127
SSW 833	7-Aug	861533	1130863	5091938	428771	5.0	1700 AD	SCL	SC	43
SSW 834	7-Aug	861662	1130912	5091977	428785	6.0	1700 AD?	SCL?	SC	56
SSW 835	7-Aug	861807	1130923	5092022	428787	7.0	?		SC	
SSW 836	7-Aug	861961	1130929	5092069	428787	6.5	1700 AD?	SBD?	SC	72
SSW 837	8-Aug	861870	1130964	5092041	428799	7.0	1700 AD?	SBD?	SC	42
SSW 838	8-Aug	861972	1130878	5092071	428771	7.0	1700 AD?	SBD?	SC	63
SSW 839	8-Aug	862006	1131005	5092083	428810	6.0	1700 AD	SBD?	SC	40
SSW 840	8-Aug	862163	1131055	5092131	428824	7.0	?		SC	
SSW 841	8-Aug	862176	1131102	5092136	428838	7.0	1700 AD	SBD?	SC	52
SSW 842	8-Aug	862279	1131134	5092167	428847	7.0	1700 AD	SBD?	SC	60
SSW 843	8-Aug	862464	1131181	5092224	428859	7.0	1700 AD	SBD	SC	38
SSW 844	8-Aug	862734	1131162	5092306	428851	5.0	1700 AD	SBD?	SC	50
SSW 845	8-Aug	864710	1132176	5092917	429141	7.0	?		SC	
SSW 846	8-Aug	864903	1132239	5092977	429158	7.0	1700 AD	SBD	SC	40
SSW 847	9-Aug	866631	1132902	5093509	429344	5.0	1700 AD	SCL	SC	57
SSW 848	9-Aug	868019	1132038	5093924	429068	5.0	PHU	SBD	SC	180
SSXa 849	13-Aug	875137	1133262	5096103	429374	6.0	1964	TSL	SC	12
SSXa 850	13-Aug	875015	1133214	5096066	429361	7.0	1964/1700 AD?	SL/SBD?	SC,ST	9,50
SSXa 851	13-Aug	874925	1133308	5096039	429390	6.0	1964	TSL	SC	14
SSXa 852	13-Aug	874910	1133232	5096034	429367	5.0	1964	TSL	SC	14
SSXa 853	13-Aug	874919	1133218	5096036	429363	5.0	1964/?	TSL?/?	SC	12/45
SSXa 854	13-Aug	874916	1133178	5096035	429351	6.0	1964/1700 AD?	TSL/SCL?	SC	12/33
SSXa 855	13-Aug	875286	1133096	5096147	429322	7.0	1964/1700 AD?	TSL/SCL	SC	11/50
SSXa 856	13-Aug	875288	1133163	5096148	429342	7.0	1964/1700 AD?/?	TSL/SBD/SCL	SC	7/40/60
SSXa 857	13-Aug	875415	1133218	5096187	429358	7.0	?		SC	
SSXa 858	13-Aug	874681	1133237	5095964	429371	5.0	1964	TSL	SC	8?
SSN 859	14-Aug	870509	1131038	5094673	428740	7.0	1964	TSL	SC	24
SSN 860	14-Aug	870478	1131012	5094663	428733	7.0	1964	MSL	SC	14-22
SSN 861	14-Aug	870185	1130851	5094572	428686	7.0	1964	TSL	SC	16
SSN 862	14-Aug	869934	1130683	5094494	428637	7.0	1964	TSL	SC	17
SSN 863	14-Aug	870056	1130662	5094531	428630	7.0	1964	MSL?	SC	4-22
SSN 864	14-Aug	870480	1130944	5094663	428712	7.0	1964	MSL	SC,ST	4-12
SSN 865	14-Aug	870524	1130917	5094676	428703	7.0	1964	TSL	SC	8
SSS 866	14-Aug	872496	1134637	5095312	429818	3.0	1700 AD?	SL	SC	56
SSS 867	14-Aug	872335	1134615	5095263	429812	3.0	1700 AD?	SCL	SC	65
SSS 868	14-Aug	872237	1134534	5095232	429789	3.0	1700 AD?	SL	SC	83
SSN 869	15-Aug	871013	1131715	5094833	428942	9.0	1964	TSL	SC	15
SSN 870	15-Aug	871410	1131860	5094955	428982	9.0	1964	TSL	SC	31
SSN 871	15-Aug	870805	1131037	5094763	428737	7.0	1964	TSL	SC	26
SSS 872	15-Aug	870349	1134293	5094655	429733	5.0	PHU?		SC	
SSS 873	15-Aug	870724	1134431	5094770	429771	5.0	PHU?		SC	
SSS 874	15-Aug	871094	1134518	5094884	429794	3.0	PHU?	SL	SC	45
SSS 875	15-Aug	871529	1134459	5095016	429772	5.0	PHU?	SL	SC	50
SSS 876	15-Aug	870014	1133851	5094548	429601	5.0	PHU?	SL	SC	62
SSN 877	16-Aug	862573	1129242	5092239	428268	7.0	PHU?		SC	
SSN 878	16-Aug	862531	1129335	5092227	428296	5.0	1964?	TSL	SC	5
SSS 879	22-Aug	872881	1134513	5095428	429776	3.0	1700 AD	TSL	SC	54
SSS 880	22-Aug	873010	1134592	5095468	429799	3.0	1700 AD	TSL	SC	70
SSS 881	22-Aug	873119	1134483	5095500	429765	3.0	1700 AD	TSL	SC	64
SSN 882	22-Aug	863916	1129822	5092654	428432	5.0	1964/1700 AD?	TSL/SBD	SC	4/80
SSN 883	22-Aug	863919	1129876	5092655	428448	5.0	1964	TSL	SC	12
SSN 884	22-Aug	863908	1129786	5092651	428421	5.0	1700 AD?	TSL	SC	71
SSS 885	22-Aug	869415	1133985	5094367	429648	5.0	PHU	LIS	SC	
SSS 886	22-Aug	869423	1133821	5094368	429598	5.0	PHU	LIS	SC	36
SSS 887	22-Aug	869435	1133755	5094371	429578	5.0	PHU	LIS	SC	60
SSS 888	22-Aug	869446	1133677	5094374	429554	5.0	PHU	LIS	SC	50
SSS 889	23-Aug	869511	1133830	5094395	429600	5.0	PHU	LIS	SC	55
SSW 890	23-Aug	860563	1129247	5091627	428288	7.0	?		SC	

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APPENDIX C

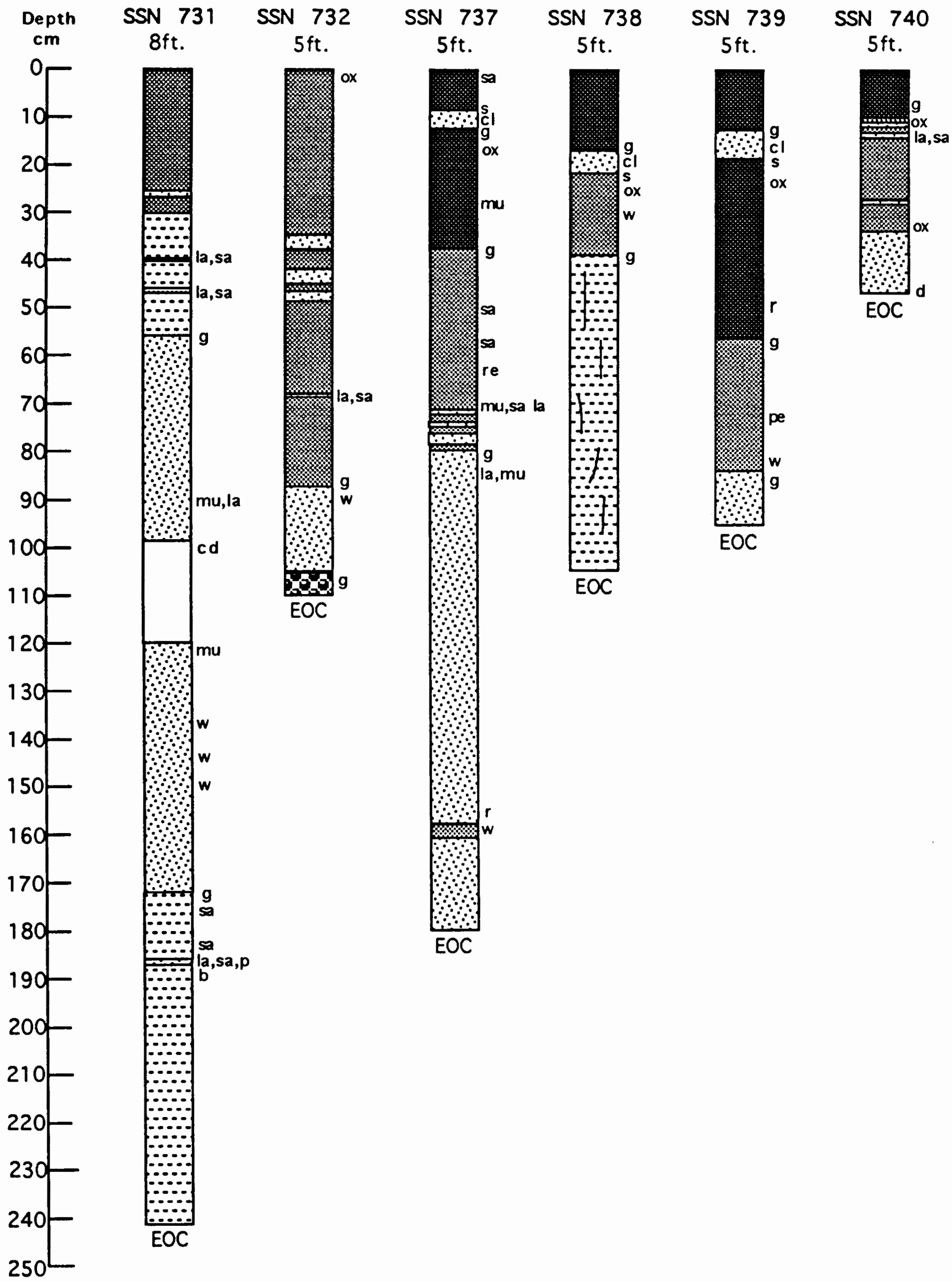
GOUGE CORE LOGS

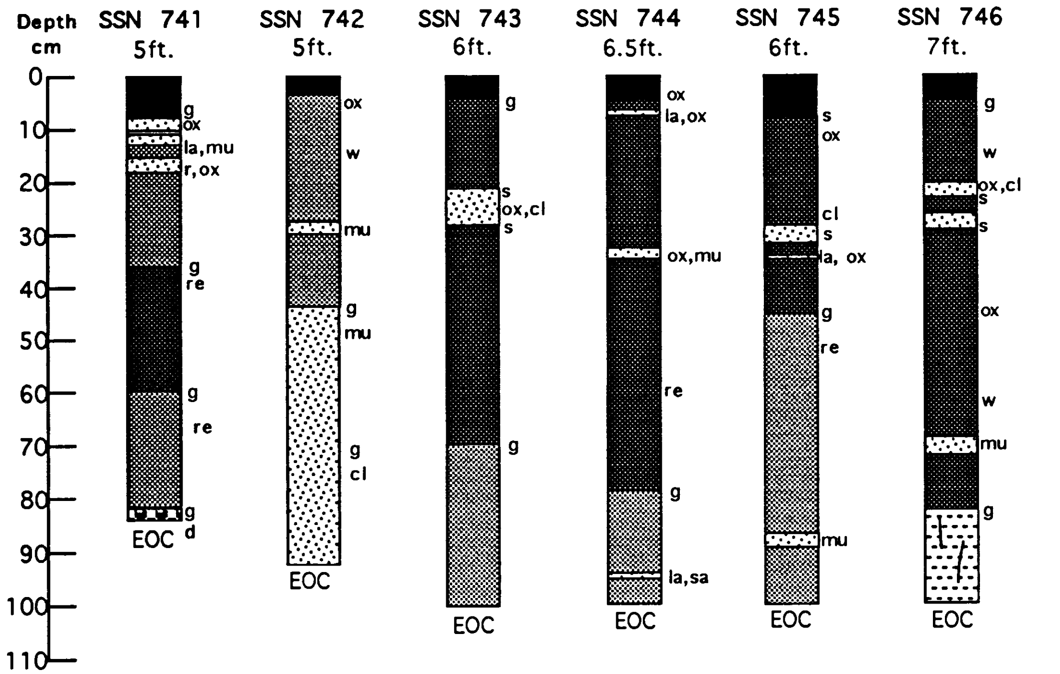
Core Log Legend

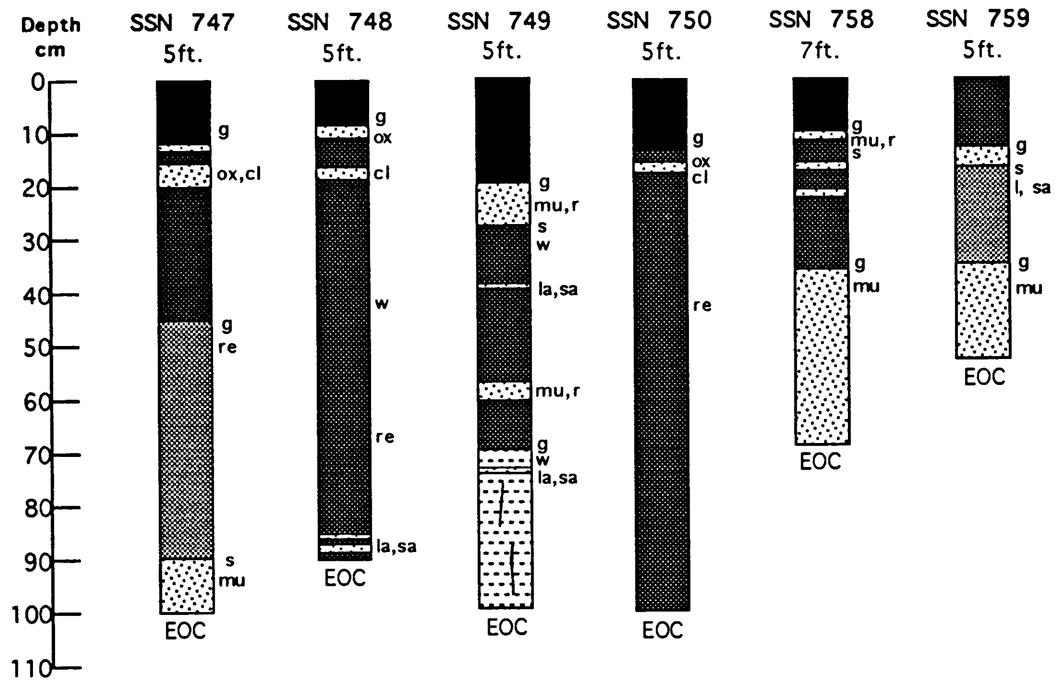
peat	sand	cobble
muddy peat	mud	landslide debris
peaty mud	rooted mud	

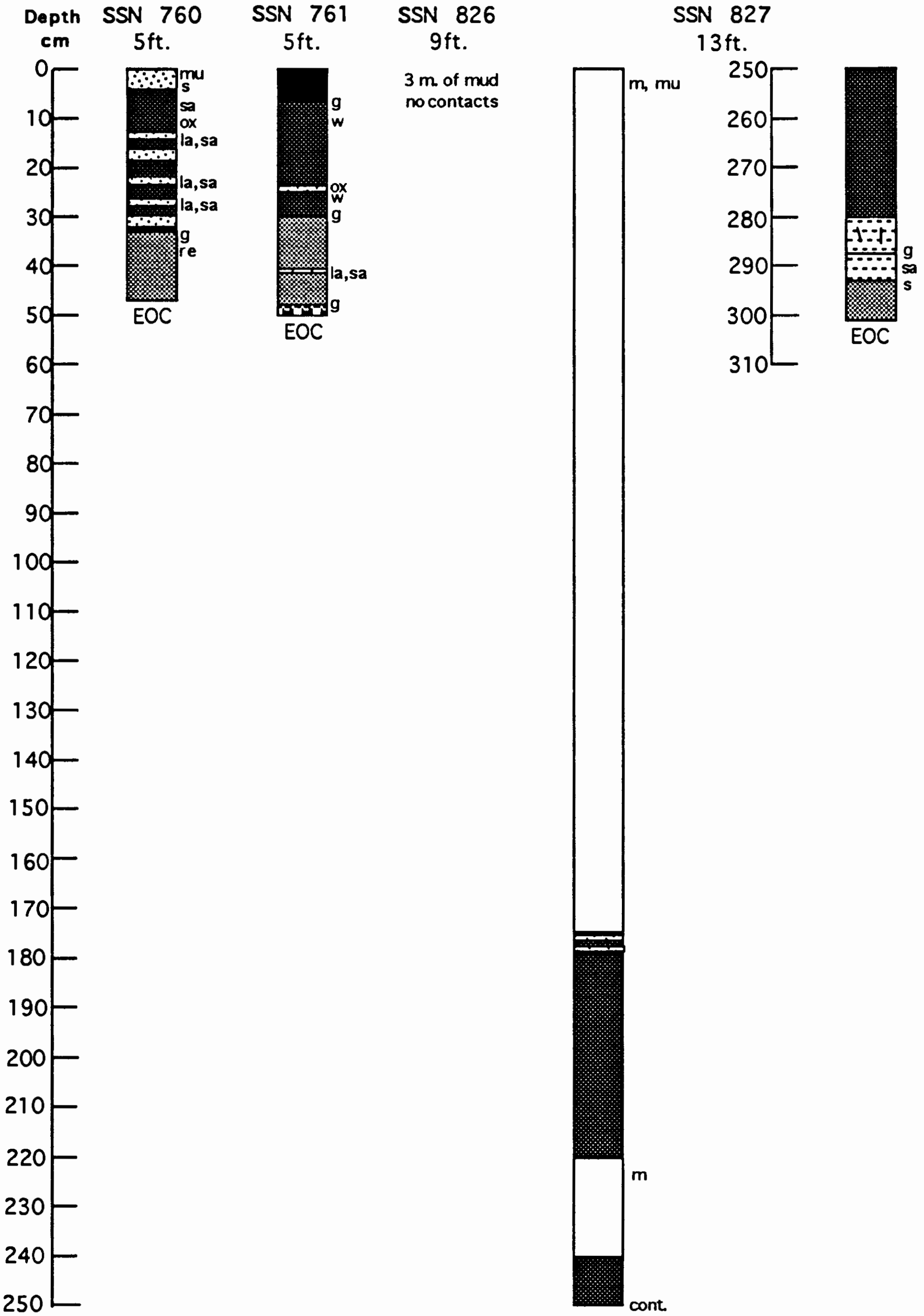
SSN	Necanicum River
SSS	Stanley Lake
SSW	Neawanna Creek
SSX	Neacoxie Creek
SSXa	Drainage to east of Neacoxie Creek

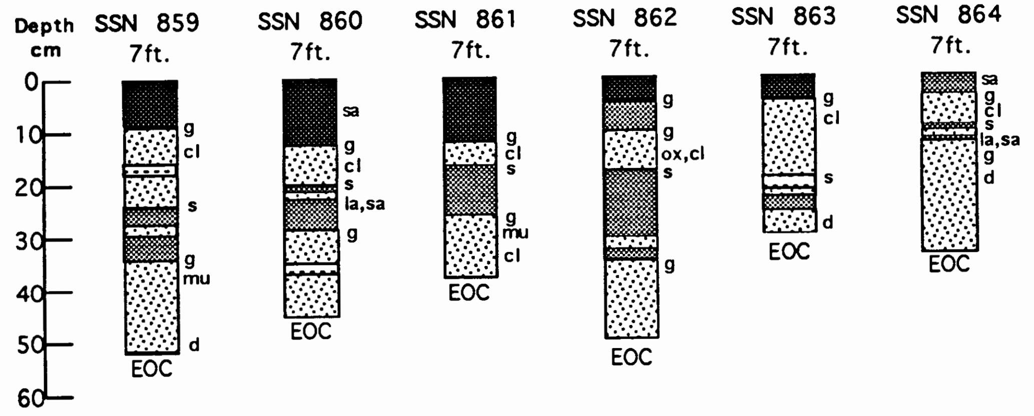
b	barren	f	fining upward	p	pebble
c	coarse	g	gradual	pe	peaty
cd	core drag	i	intruded/irregular	r	rooted
ch	charcoal	l	layer (>5mm)	RC	Radiocarbon sample
cl	clean	la	lamination (<5mm)	re	reduced
co	cobble	m	missing section	s	sharp
cont.	continued	mu	muddy	sa	sandy
d	dense	o	organic debris	w	wood fragments
EOC	end of core	ox	oxidized		

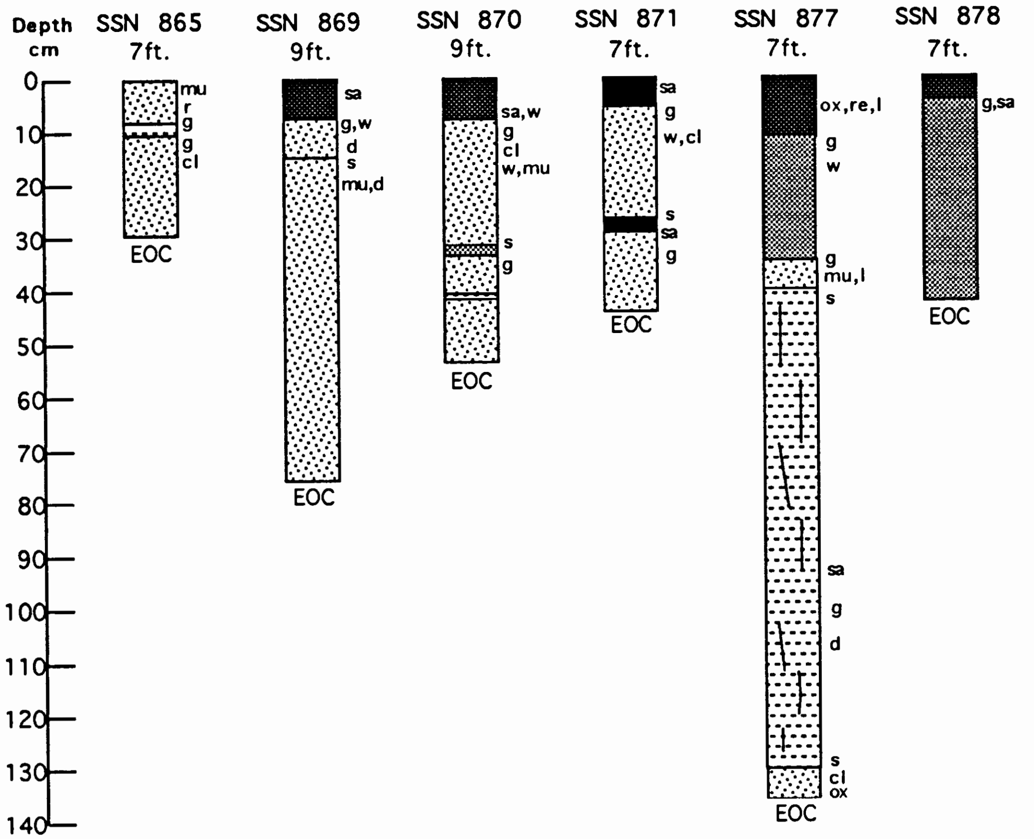

Depth cm
SSN 731 8ft.
SSN 732 5ft.
SSN 737 5ft.
SSN 738 5ft.
SSN 739 5ft.
SSN 740 5ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
la,sa
la,sa
g
mu,la
cd
mu
w
w
w
g
sa
sa
la,sa,p
b
EOC
ox
la,sa
g
w
g
EOC
sa
s
cl
g
ox
mu
g
sa
sa
re
mu,sa la
g
la,mu
r
w
EOC
g
cl
s
ox
w
g
EOC
g
cl
s
ox
r
g
pe
w
g
EOC
g
ox
la,sa
ox
d
EOC

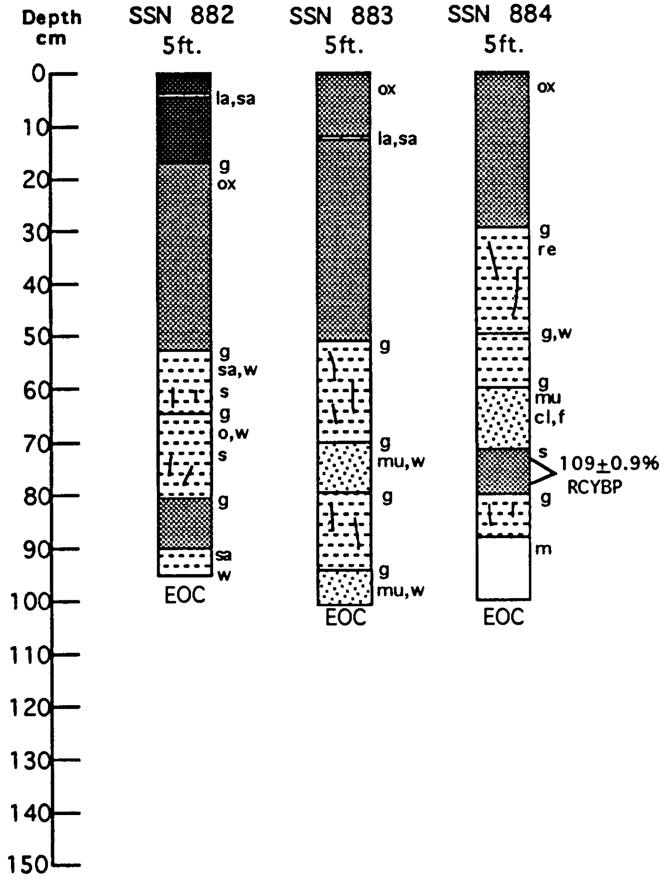

Depth cm
0
10
20
30
40
50
60
70
80
90
100
110
SSN 741 5ft.
g ox la,mu r,ox g re g re g d
EOC
SSN 742 5ft.
ox w mu g mu g cl
EOC
SSN 743 6ft.
g s ox,cl s g
EOC
SSN 744 6.5ft.
ox la,ox ox,mu re g la,sa
EOC
SSN 745 6ft.
s ox cl s la, ox g re mu
EOC
SSN 746 7ft.
g w ox,cl s s ox w mu g
EOC

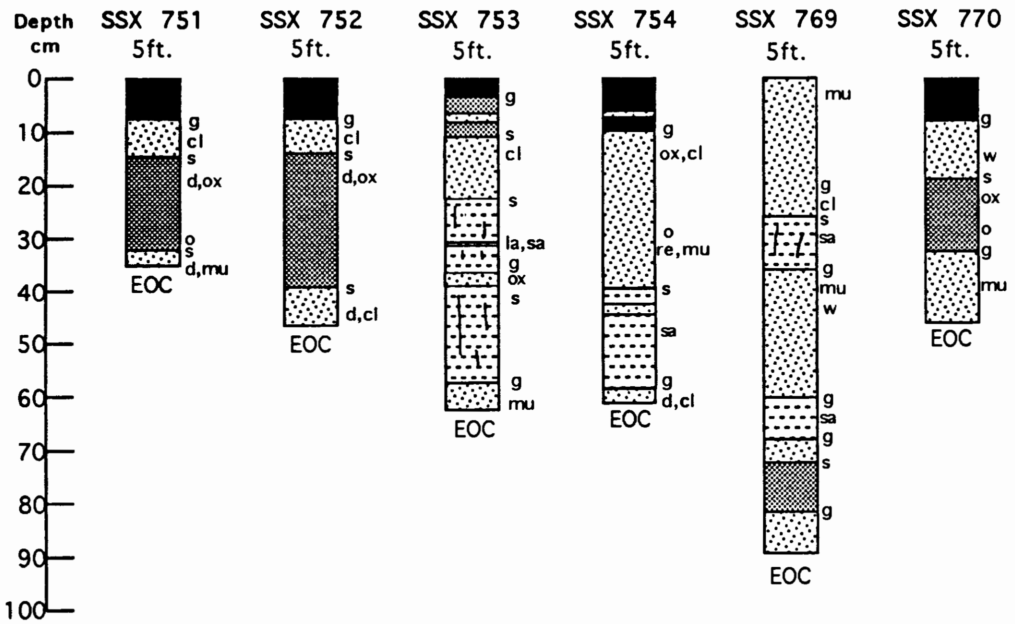

Depth cm
0
10
20
30
40
50
60
70
80
90
100
110
SSN 747 5ft.
g ox,cl g re s mu
EOC
SSN 748 5ft.
g ox cl w re la,sa
EOC
SSN 749 5ft.
g mu,r s w la,sa mu,r g w la,sa
EOC
SSN 750 5ft.
g ox cl re
EOC
SSN 758 7ft.
g mu,r s g mu
EOC
SSN 759 5ft.
g s l, sa g mu
EOC

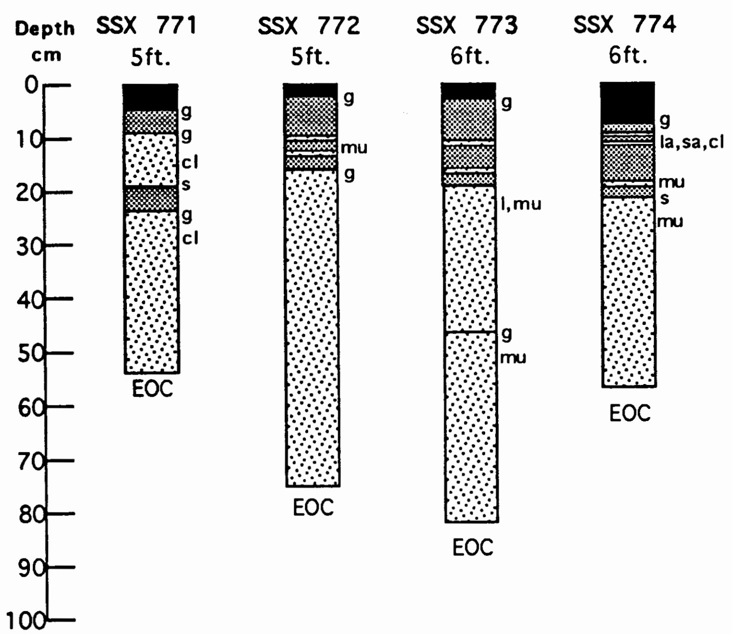

Depth cm
SSN 760 5ft.
SSN 761 5ft.
SSN 826 9ft.
3 m. of mud no contacts
SSN 827 13ft.
mu
s
sa
ox
la,sa
la,sa
la,sa
g
re
EOC
g
w
ox
w
g
la,sa
g
EOC
m, mu
m
cont.
g
sa
s
EOC

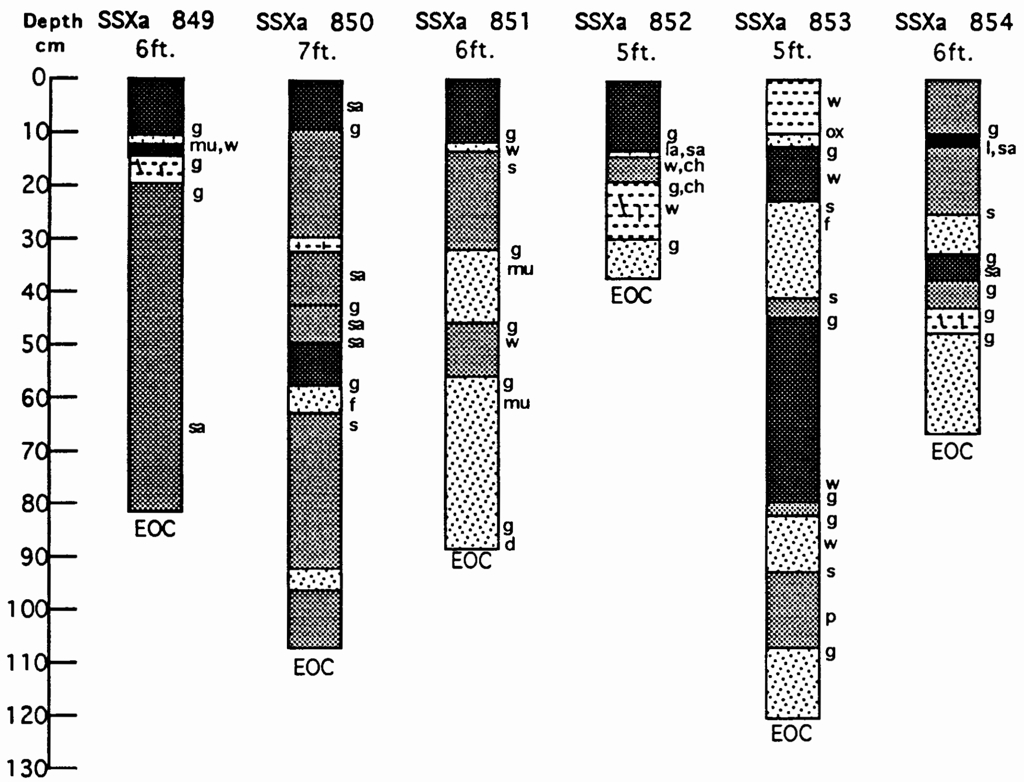

Depth cm
SSN 859 7ft.
SSN 860 7ft.
SSN 861 7ft.
SSN 862 7ft.
SSN 863 7ft.
SSN 864 7ft.
0
10
20
30
40
50
60
g cl s g mu d
sa g cl s la,sa g
g cl s g mu cl
g g ox,cl s g
g cl s d
sa g cl s la,sa g d
EOC

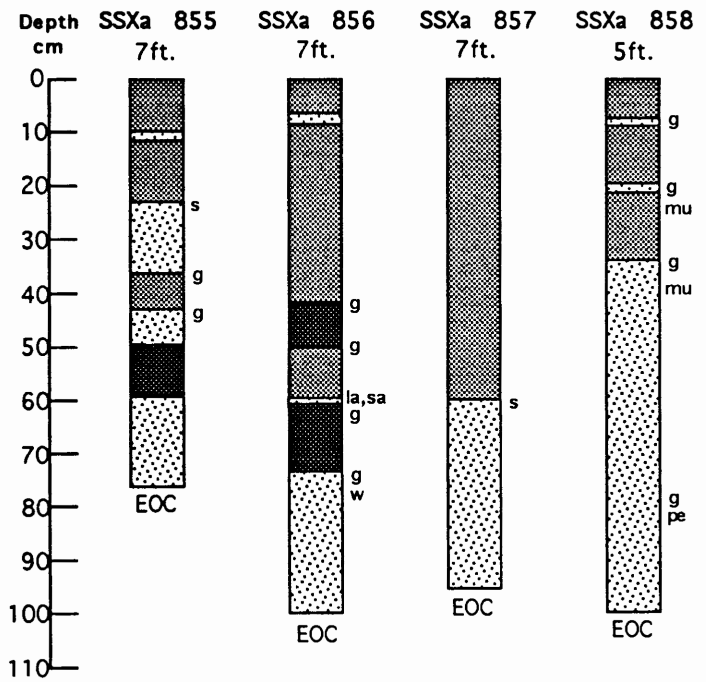

Depth cm
SSN 865 7ft.
SSN 869 9ft.
SSN 870 9ft.
SSN 871 7ft.
SSN 877 7ft.
SSN 878 7ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
mu r g g cl
sa g,w d s mu,d
sa,w g cl w,mu s g
sa g w,cl s sa g
ox,re,l g w g mu,l s sa g d s cl ox
g,sa
EOC

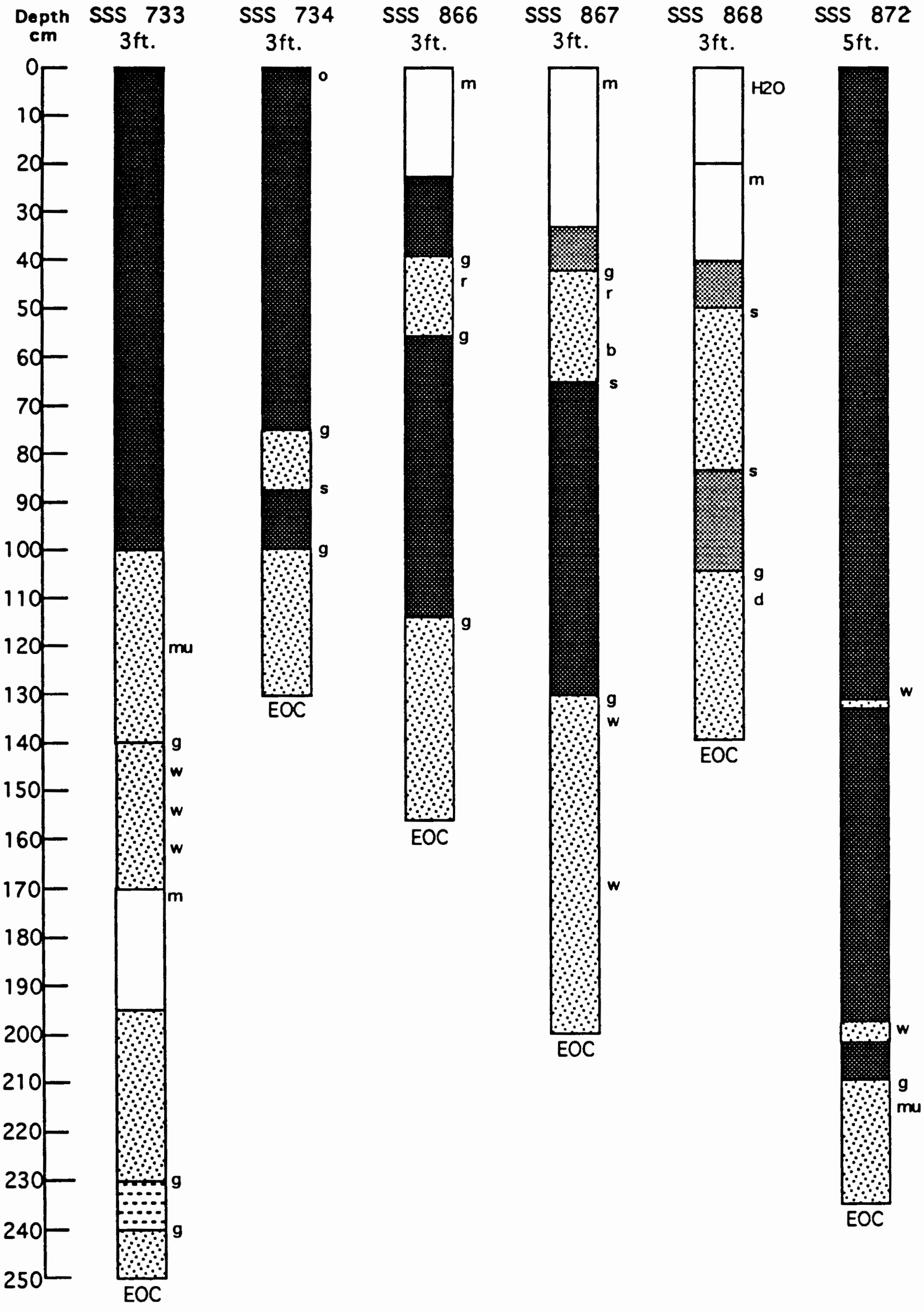

Depth cm
SSN 882 5ft.
SSN 883 5ft.
SSN 884 5ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
la,sa
g
ox
g
sa,w
s
g
o,w
s
g
sa
w
EOC
ox
la,sa
g
g
mu,w
g
g
mu,w
EOC
ox
g
re
g,w
g
mu
cl,f
s
109±0.9%
RCYBP
g
m
EOC

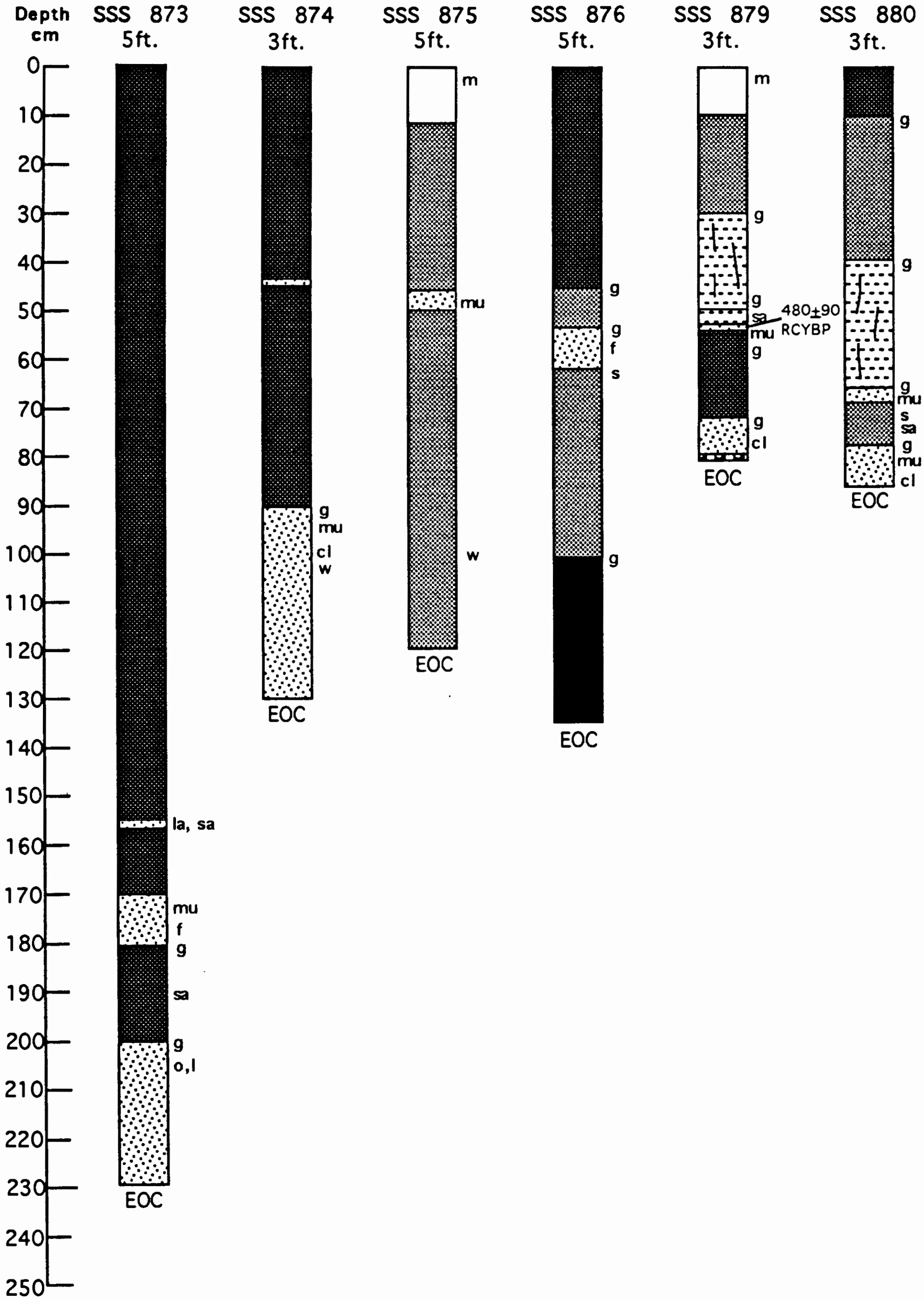

Depth
cm
0
10
20
30
40
50
60
70
80
90
100
SSX 751
5ft.
g
cl
s
d,ox
o
s
d,mu
EOC
SSX 752
5ft.
g
cl
s
d,ox
s
d,cl
EOC
SSX 753
5ft.
g
s
cl
s
la,sa
g
ox
s
g
mu
EOC
SSX 754
5ft.
g
ox,cl
o
re,mu
s
sa
g
d,cl
EOC
SSX 769
5ft.
mu
g
cl
s
sa
g
mu
w
g
sa
g
s
g
EOC
SSX 770
5ft.
g
w
s
ox
o
g
mu
EOC

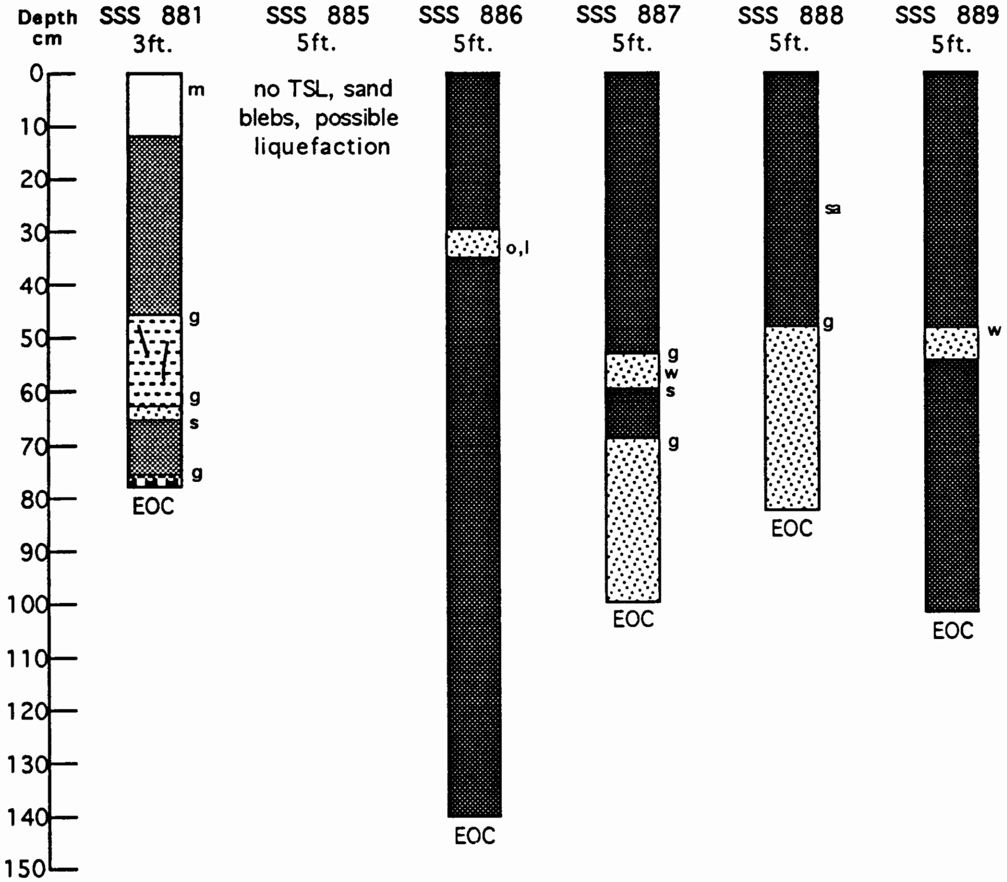

Depth
cm
0
10
20
30
40
50
60
70
80
90
100
SSX 771
5ft.
g
g
cl
s
g
cl
EOC
SSX 772
5ft.
g
mu
g
EOC
SSX 773
6ft.
g
l,mu
g
mu
EOC
SSX 774
6ft.
g
la,sa,cl
mu
s
mu
EOC

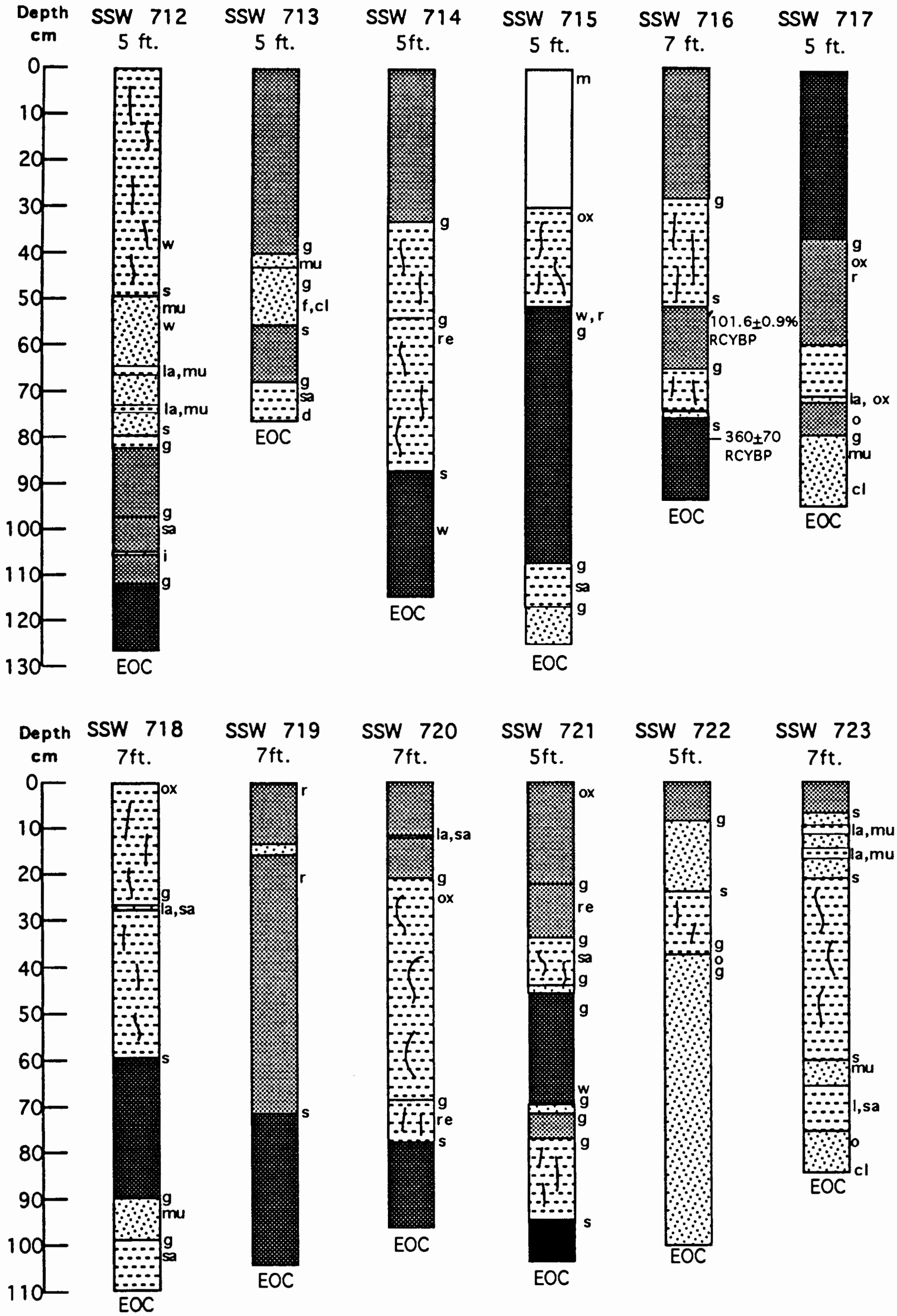

Depth cm
SSXa 849 6ft.
SSXa 850 7ft.
SSXa 851 6ft.
SSXa 852 5ft.
SSXa 853 5ft.
SSXa 854 6ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
g
mu,w
g
g
sa
EOC
sa
g
sa
g
sa
sa
g
f
s
EOC
g
w
s
g
mu
g
w
g
mu
g
d
EOC
g
la,sa
w,ch
g,ch
w
g
EOC
w
ox
g
w
s
f
s
g
w
g
g
w
s
p
g
EOC
g
l,sa
s
g
sa
g
g
g
EOC

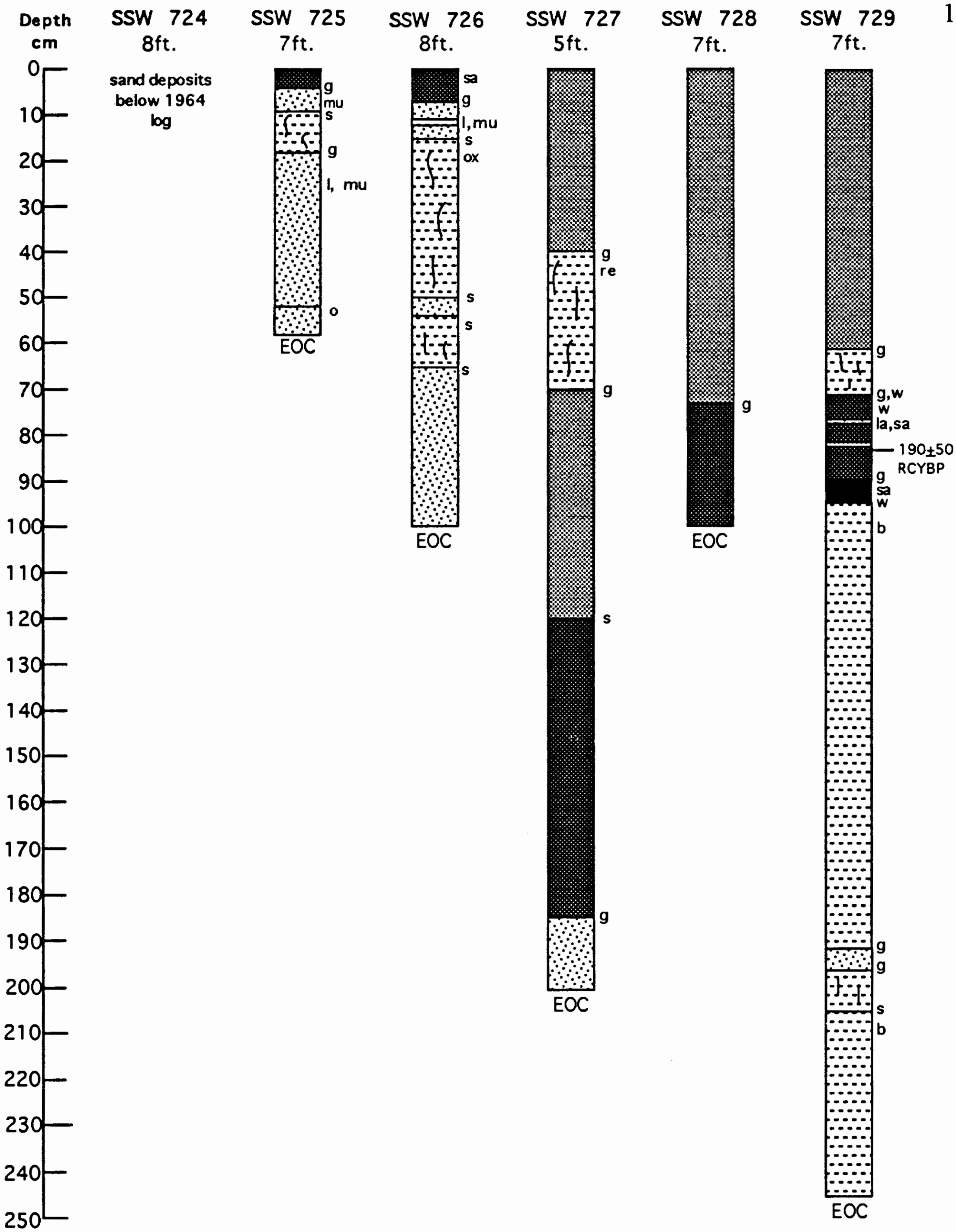

Depth cm
SSXa 855 7ft.
SSXa 856 7ft.
SSXa 857 7ft.
SSXa 858 5ft.
0
10
20
30
40
50
60
70
80
90
100
110
s
g
g
EOC
g
g
la,sa
g
g
w
EOC
s
EOC
g
g
mu
g
mu
g
pe
EOC

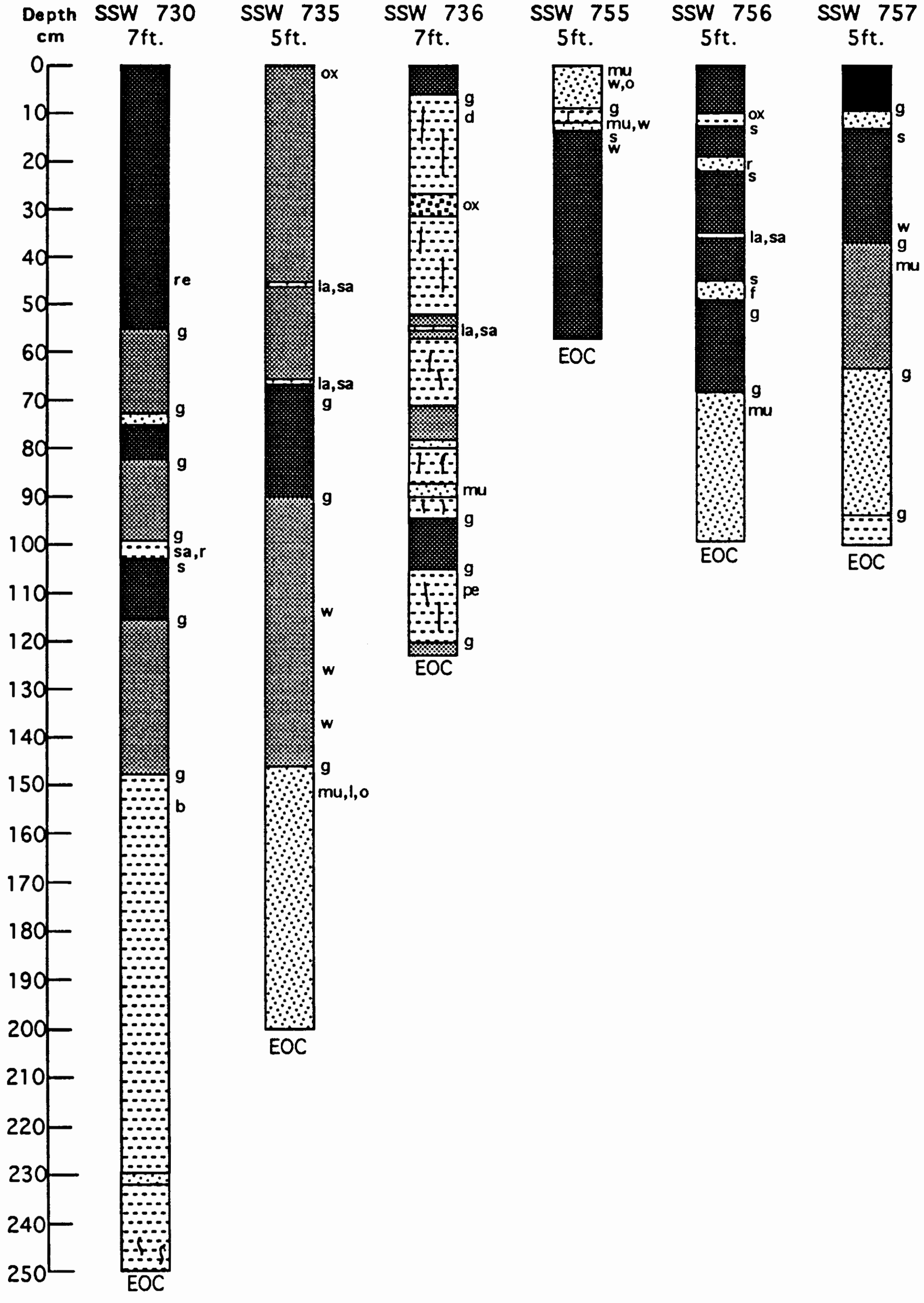

Depth cm
SSS 733 3ft.
SSS 734 3ft.
SSS 866 3ft.
SSS 867 3ft.
SSS 868 3ft.
SSS 872 5ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
mu
g
w
w
w
m
g
g
EOC
o
g
s
g
EOC
m
g
r
g
g
EOC
m
g
r
b
s
g
w
w
EOC
H2O
m
s
s
g
d
EOC
w
w
g
mu
EOC


Depth cm
SSS 873 5ft.
SSS 874 3ft.
SSS 875 5ft.
SSS 876 5ft.
SSS 879 3ft.
SSS 880 3ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
la, sa
mu
f
g
sa
g
o,l
EOC
g
mu
cl
w
EOC
m
mu
w
EOC
g
g
f
s
g
EOC
m
g
g
sa
mu
g
g
cl
480±90 RCYBP
EOC
g
g
g
mu
s
sa
g
mu
cl
EOC

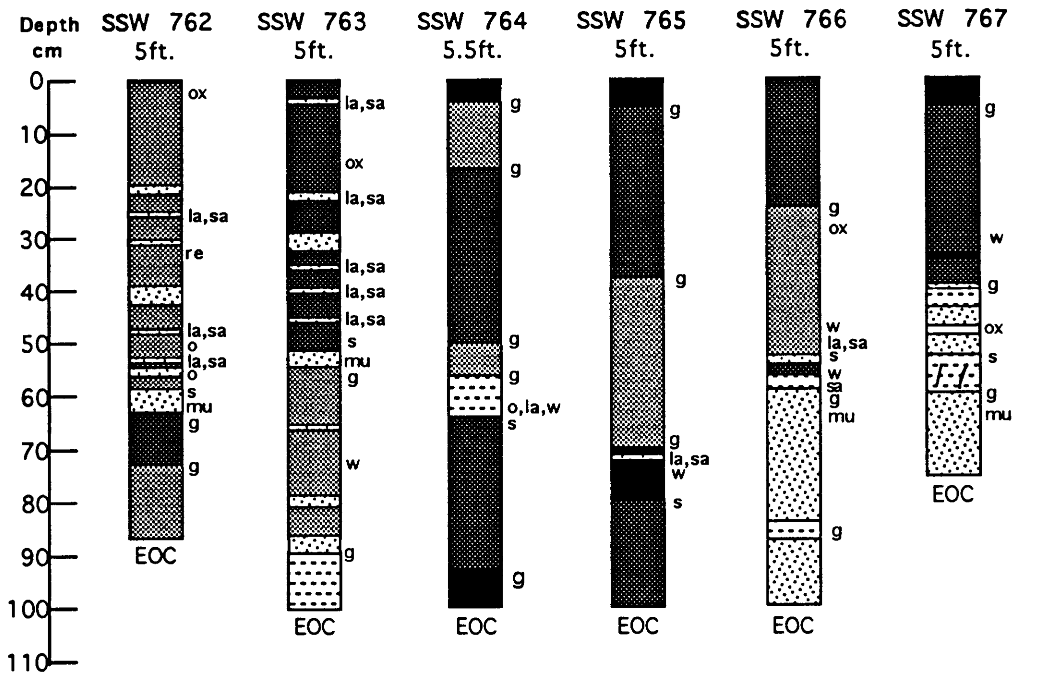

Depth cm
SSS 881 3ft.
SSS 885 5ft.
SSS 886 5ft.
SSS 887 5ft.
SSS 888 5ft.
SSS 889 5ft.
no TSL, sand blebs, possible liquefaction
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
m
g
g
s
g
o,l
g
w
s
g
sa
g
w
EOC
EOC
EOC
EOC
EOC

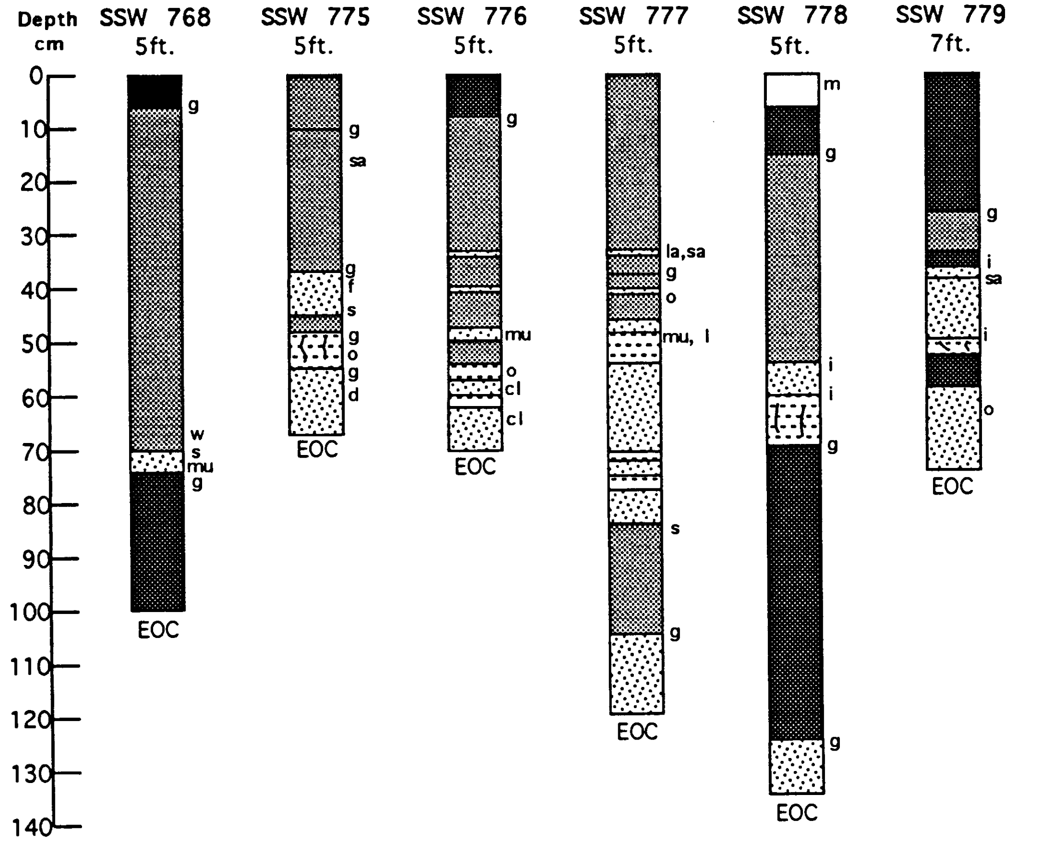

Depth cm
SSW 712 5 ft.
SSW 713 5 ft.
SSW 714 5ft.
SSW 715 5 ft.
SSW 716 7 ft.
SSW 717 5 ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
w
s
mu
w
la,mu
la,mu
s
g
g
sa
i
g
EOC
g
mu
g
f,cl
s
g
sa
d
EOC
g
g
re
s
w
EOC
m
ox
w, r
g
g
sa
g
EOC
g
s
101.6±0.9%
RCYBP
g
s
360±70
RCYBP
EOC
g
ox
r
la, ox
o
g
mu
cl
EOC
Depth cm
SSW 718 7ft.
SSW 719 7ft.
SSW 720 7ft.
SSW 721 5ft.
SSW 722 5ft.
SSW 723 7ft.
0
10
20
30
40
50
60
70
80
90
100
110
ox
g
la,sa
s
g
mu
g
sa
EOC
r
r
s
EOC
la,sa
g
ox
g
re
s
EOC
ox
g
re
g
sa
g
g
w
g
g
g
s
EOC
g
s
g
o
g
EOC
s
la,mu
la,mu
s
s
mu
l,sa
o
cl
EOC

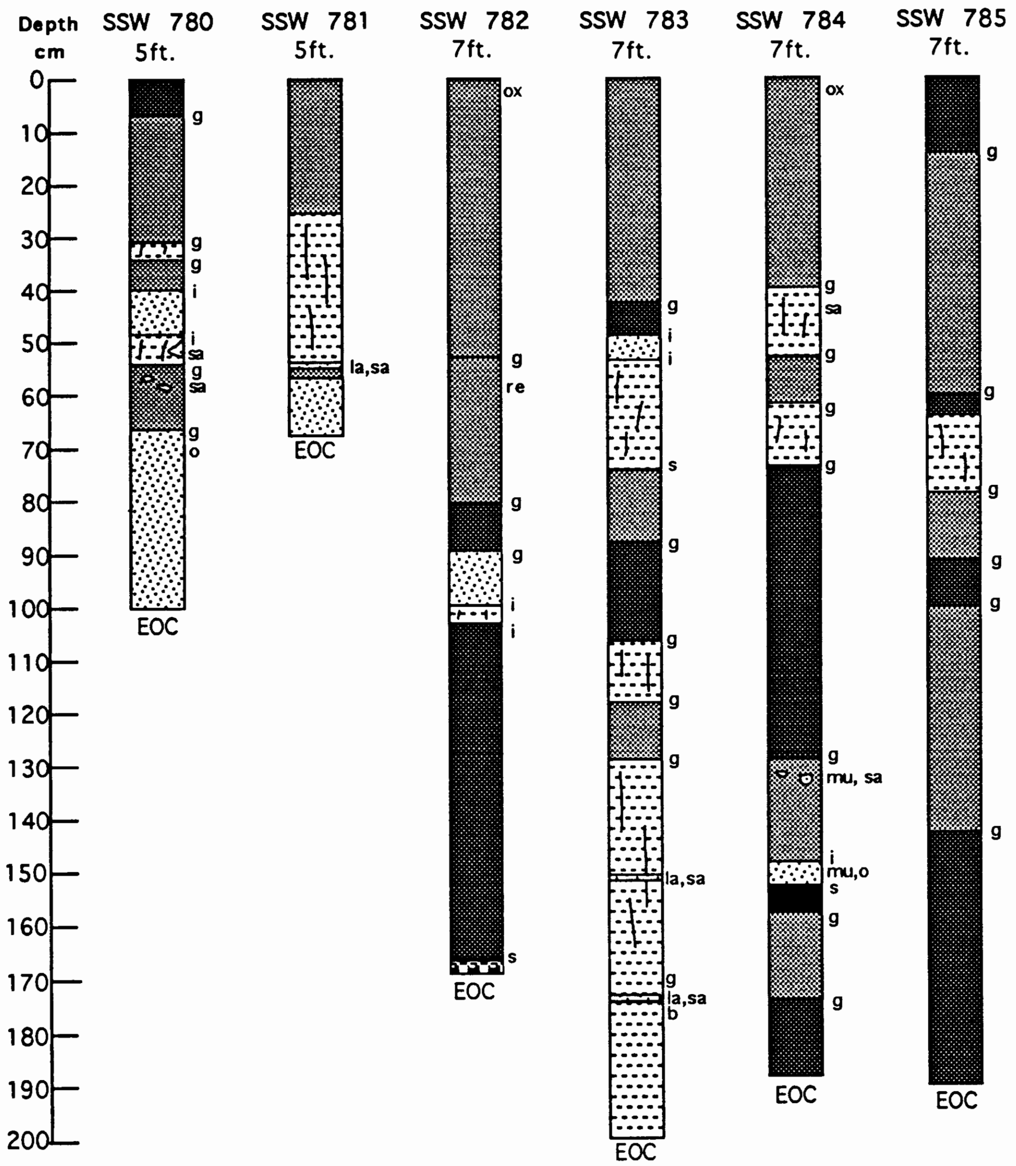

Depth cm
SSW 724 8ft.
sand deposits below 1964 log
SSW 725 7ft.
SSW 726 8ft.
SSW 727 5ft.
SSW 728 7ft.
SSW 729 7ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
g
mu
s
g
l, mu
o
EOC
sa
g
l,mu
s
ox
s
s
s
EOC
g
re
g
s
g
EOC
g
EOC
g
g,w
w
la,sa
190±50 RCYBP
g
sa
w
b
g
g
s
b
EOC

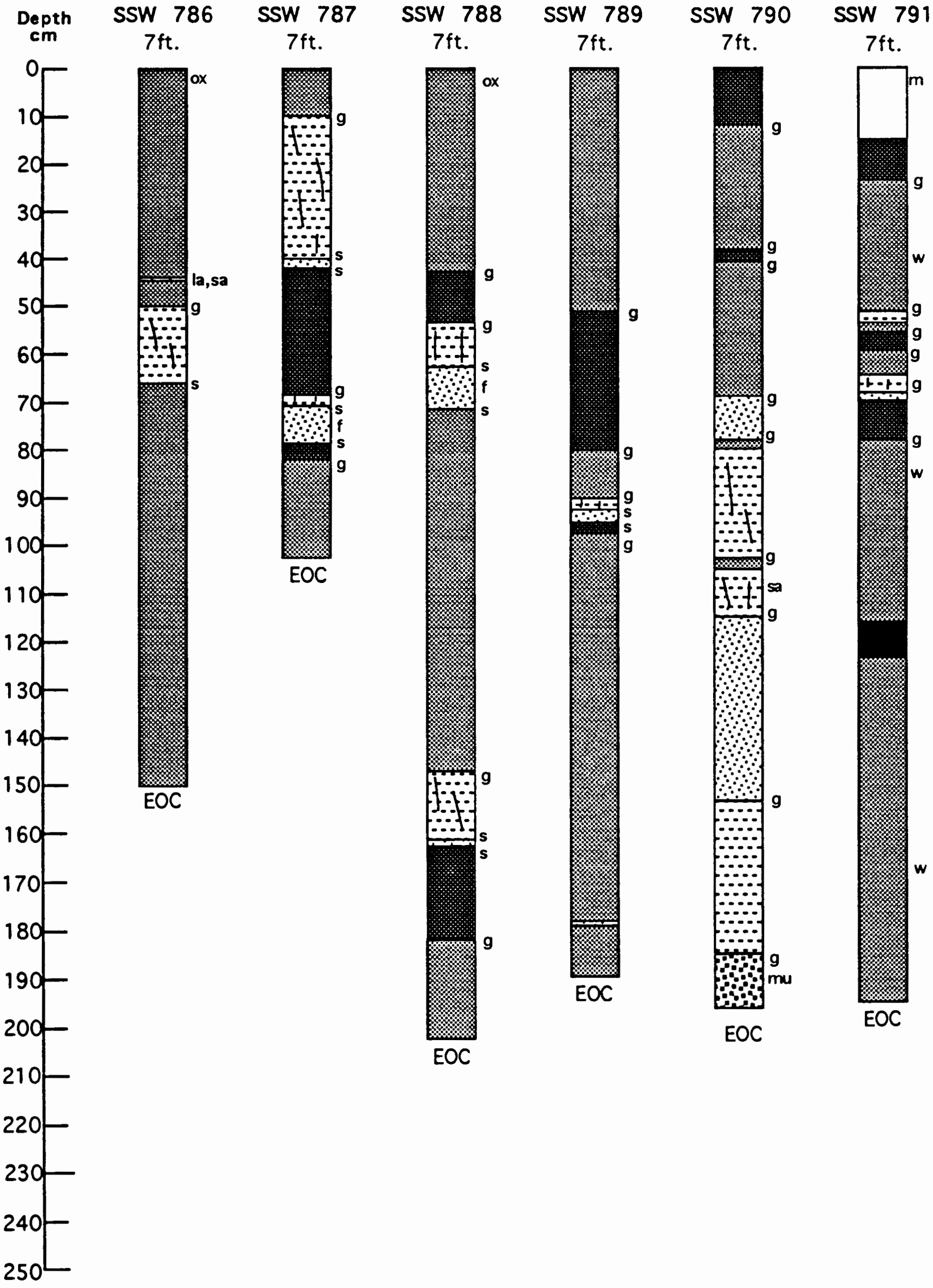


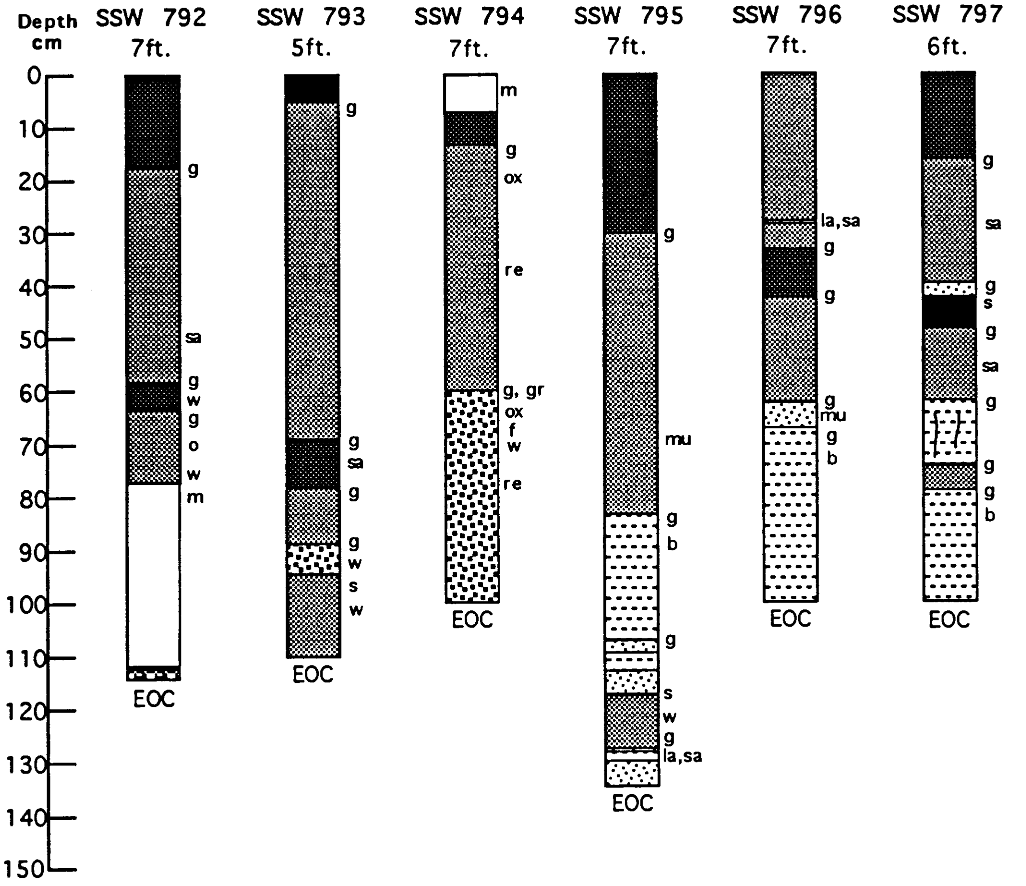
Depth cm
SSW 730 7ft.
SSW 735 5ft.
SSW 736 7ft.
SSW 755 5ft.
SSW 756 5ft.
SSW 757 5ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
re
g
sa,r
s
b
ox
la,sa
w
mu,l,o
d
mu
pe
w,o
mu,w
r
f
EOC

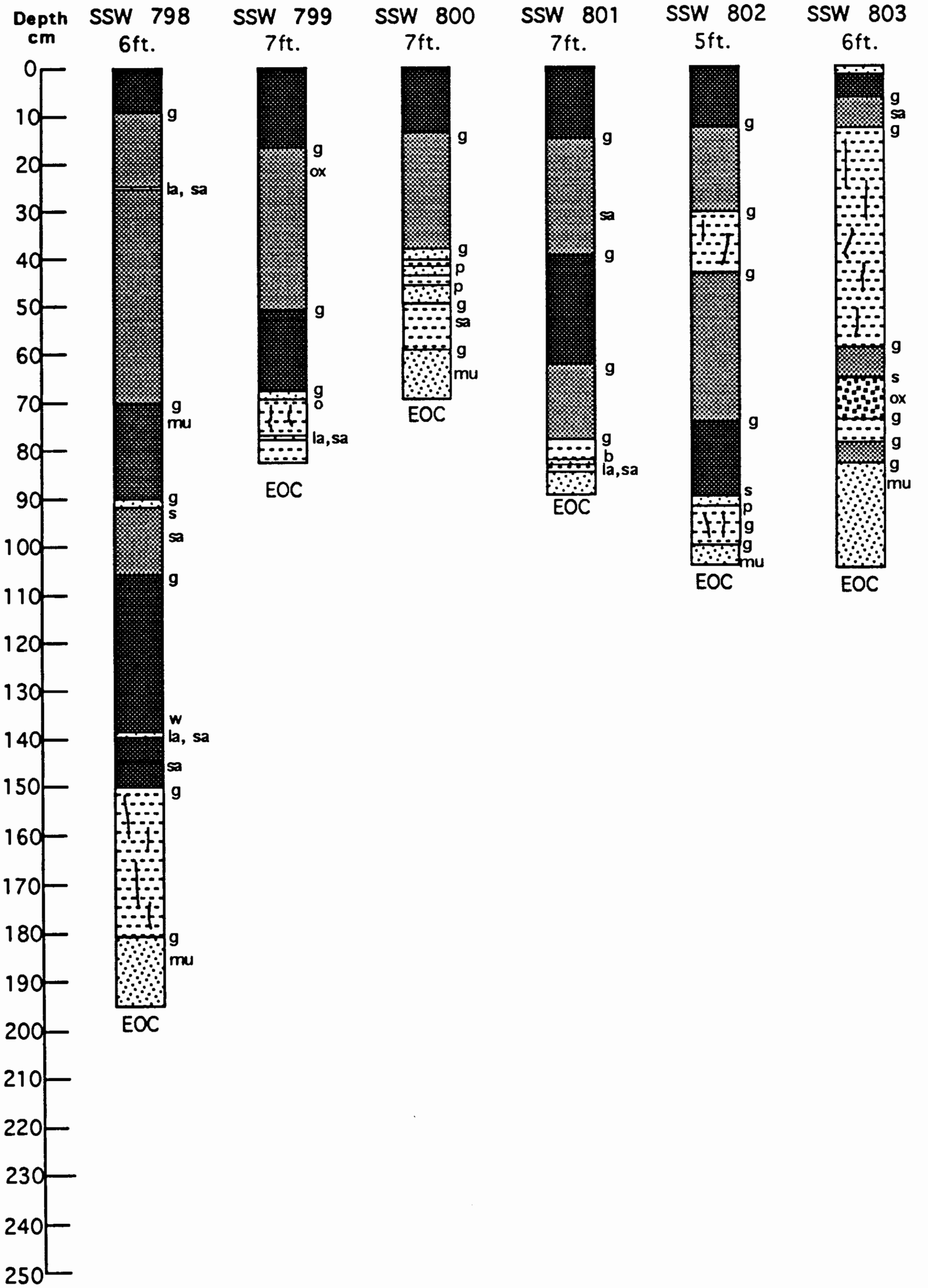

Depth cm
SSW 762 5ft.
SSW 763 5ft.
SSW 764 5.5ft.
SSW 765 5ft.
SSW 766 5ft.
SSW 767 5ft.
0
10
20
30
40
50
60
70
80
90
100
110
ox
la,sa
re
la,sa
o
la,sa
o
s
mu
g
g
EOC
la,sa
ox
la,sa
la,sa
la,sa
la,sa
s
mu
g
w
g
EOC
g
g
g
g
o,la,w
s
g
EOC
g
g
g
la,sa
w
s
EOC
g
ox
w
la,sa
s
w
sa
g
mu
g
EOC
g
w
g
ox
s
g
mu
EOC

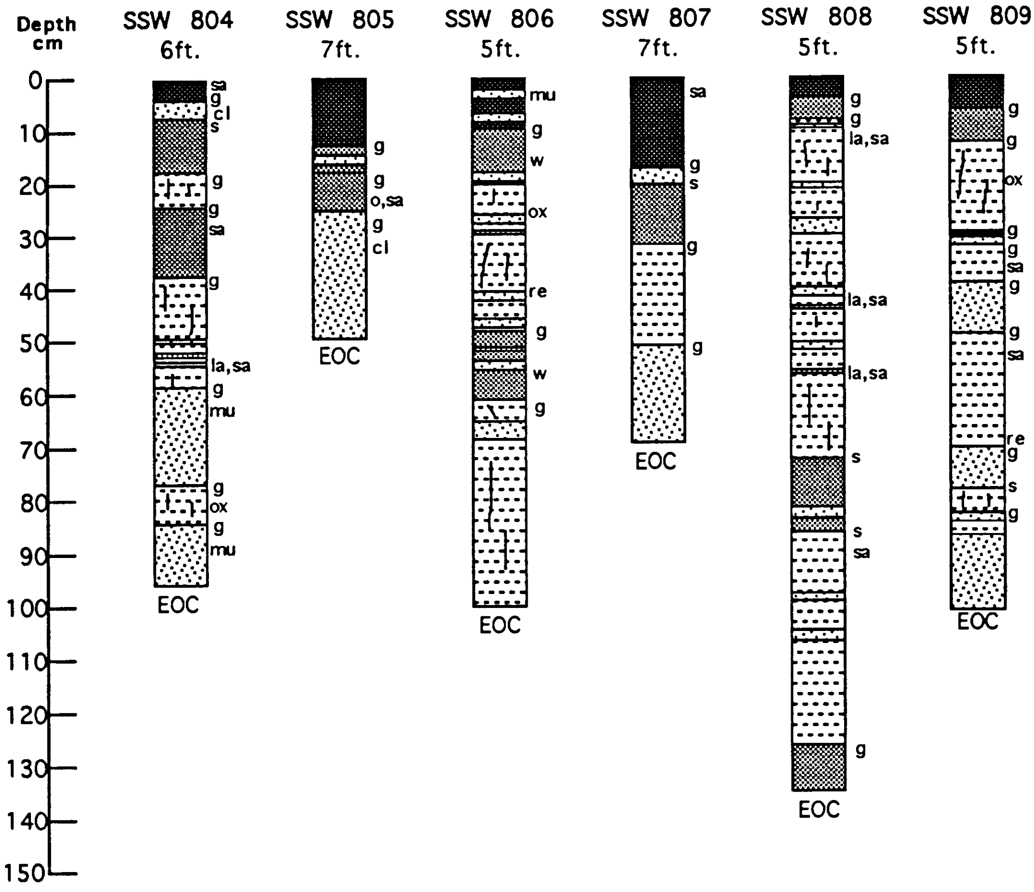

Depth cm
SSW 768 5ft.
SSW 775 5ft.
SSW 776 5ft.
SSW 777 5ft.
SSW 778 5ft.
SSW 779 7ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
g
w
s
mu
g
EOC
g
sa
g
f
s
g
o
g
d
EOC
g
mu
o
cl
cl
EOC
la,sa
g
o
mu, l
s
g
EOC
m
g
i
i
g
g
EOC
g
i
sa
i
o
EOC

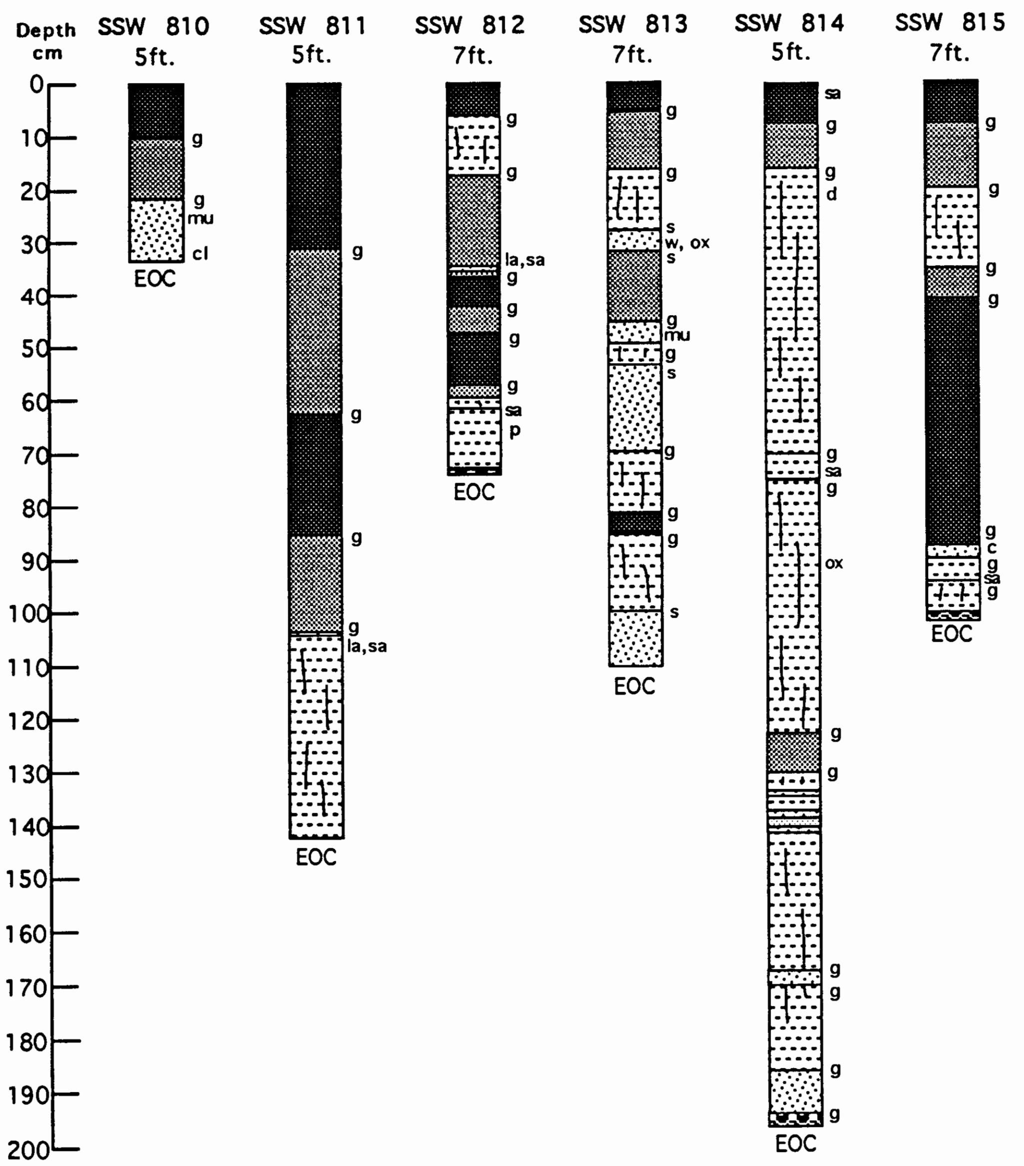

Depth
cm
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
SSW 780
5ft.
g
g
g
i
i
sa
g
sa
g
o
EOC
SSW 781
5ft.
la,sa
EOC
SSW 782
7ft.
ox
g
re
g
g
i
i
s
EOC
SSW 783
7ft.
g
i
i
s
g
g
g
g
la,sa
g
la,sa
b
EOC
SSW 784
7ft.
ox
g
sa
g
g
g
g
mu, sa
i
mu,o
s
g
g
EOC
SSW 785
7ft.
g
g
g
g
g
g
EOC

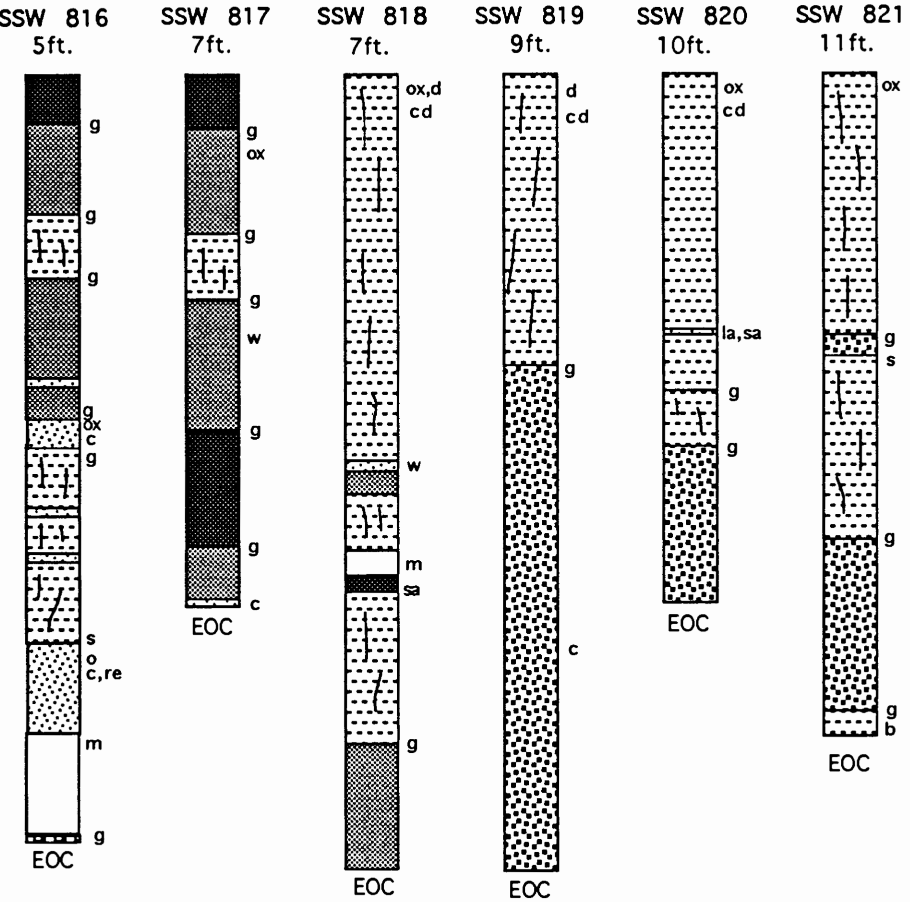

Depth cm
SSW 786 7ft.
SSW 787 7ft.
SSW 788 7ft.
SSW 789 7ft.
SSW 790 7ft.
SSW 791 7ft.
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
ox
la,sa
g
s
EOC
g
s
s
g
s
f
s
g
EOC
ox
g
g
s
f
s
g
s
s
g
EOC
g
g
g
s
s
g
EOC
g
g
g
g
g
g
sa
g
g
g
mu
EOC
m
g
w
g
g
g
g
g
w
w
EOC

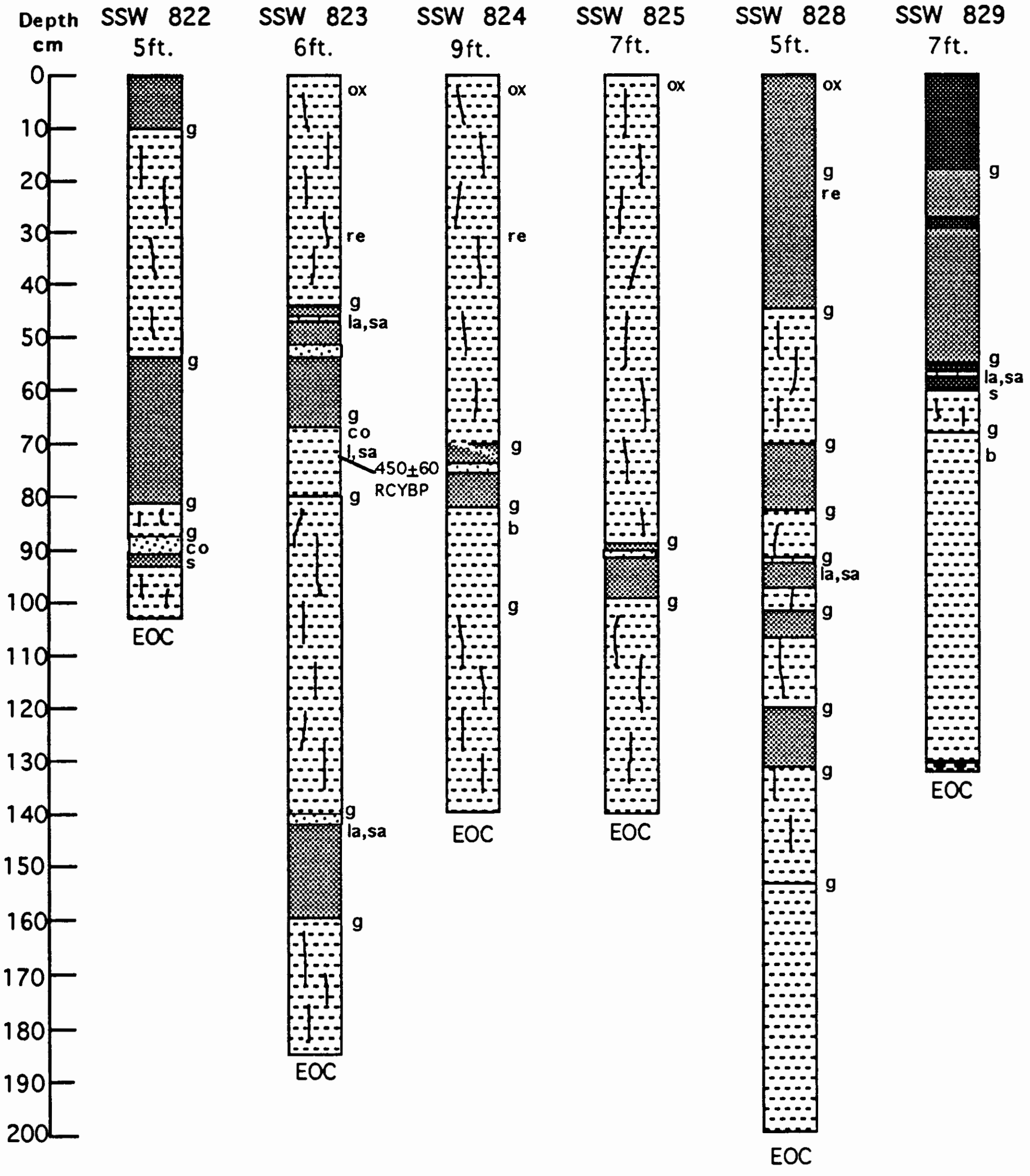

Depth cm
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
SSW 792 7ft.
g
sa
g
w
g
o
w
m
EOC
SSW 793 5ft.
g
g
sa
g
g
w
s
w
EOC
SSW 794 7ft.
m
g
ox
re
g, gr
ox
f
w
re
EOC
SSW 795 7ft.
g
mu
g
b
g
s
w
g
la,sa
EOC
SSW 796 7ft.
la,sa
g
g
g
mu
g
b
EOC
SSW 797 6ft.
g
sa
g
s
g
sa
g
g
g
b
EOC


Depth cm
SSW 798 6ft.
SSW 799 7ft.
SSW 800 7ft.
SSW 801 7ft.
SSW 802 5ft.
SSW 803 6ft.
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210 220 230 240 250
g
la, sa
g
mu
g
s
sa
g
w
la, sa
sa
g
g
mu
EOC
g
ox
g
g
o
la,sa
EOC
g
g
p
p
g
sa
g
mu
EOC
g
sa
g
g
g
b
la,sa
EOC
g
g
g
g
s
p
g
g
mu
EOC
g
sa
g
g
s
ox
g
g
g
mu
EOC

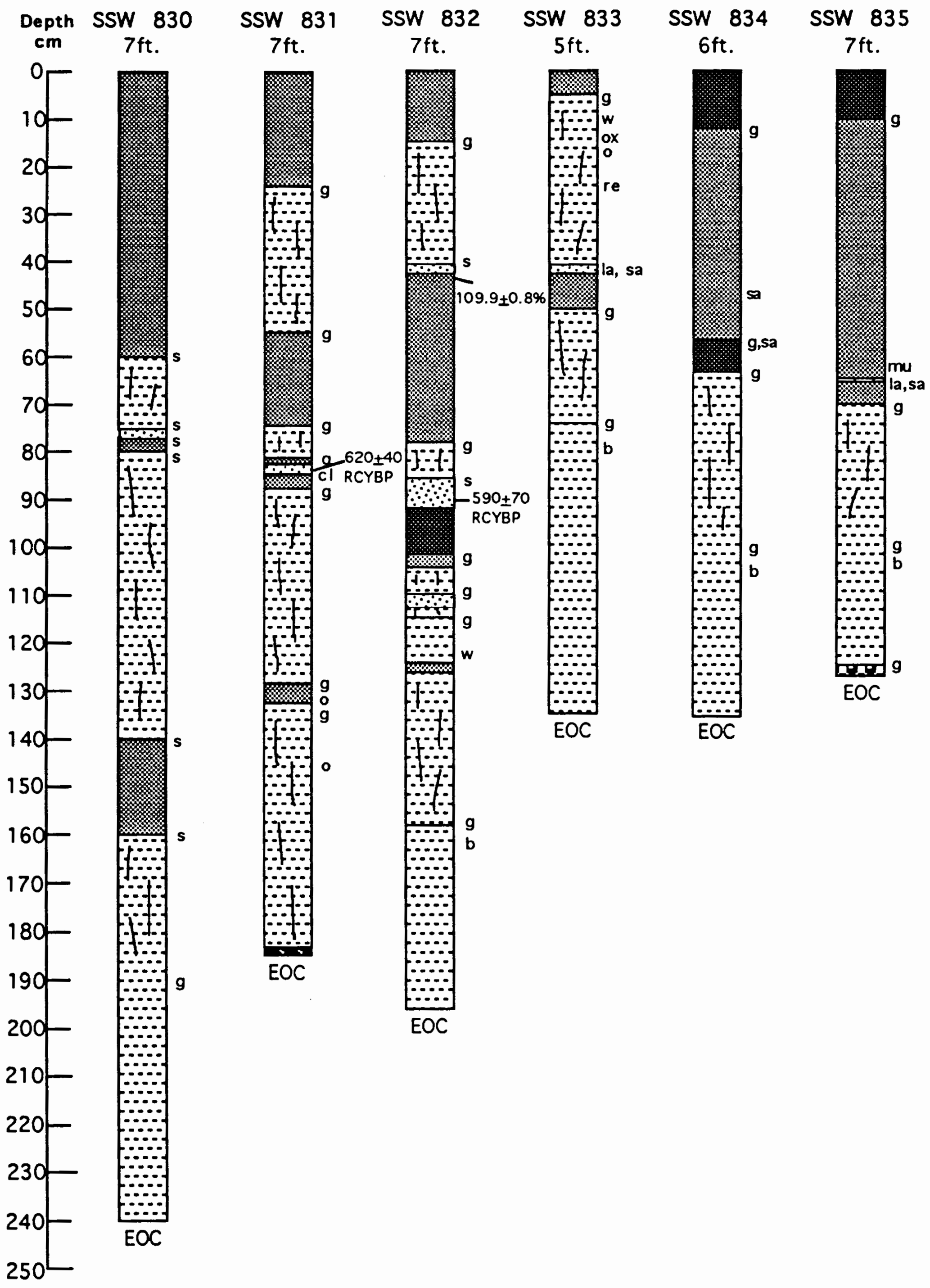

Depth cm
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
SSW 804 6ft.
sa g cl s g g sa g la,sa g mu g ox g mu
EOC
SSW 805 7ft.
g g o,sa g cl
EOC
SSW 806 5ft.
mu g w ox re g w g
EOC
SSW 807 7ft.
sa g s g g
EOC
SSW 808 5ft.
g g la,sa la,sa la,sa s s sa g
EOC
SSW 809 5ft.
g g ox g g sa g g sa re g s g
EOC


Depth cm
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
SSW 810 5ft.
g
g
mu
cl
EOC
SSW 811 5ft.
g
g
g
g
la,sa
EOC
SSW 812 7ft.
g
g
la,sa
g
g
g
g
sa
p
EOC
SSW 813 7ft.
g
g
s
w, ox
s
g
mu
g
s
g
g
g
s
EOC
SSW 814 5ft.
sa
g
g
d
g
sa
g
ox
g
g
g
g
g
g
EOC
SSW 815 7ft.
g
g
g
g
g
c
g
sa
g
EOC

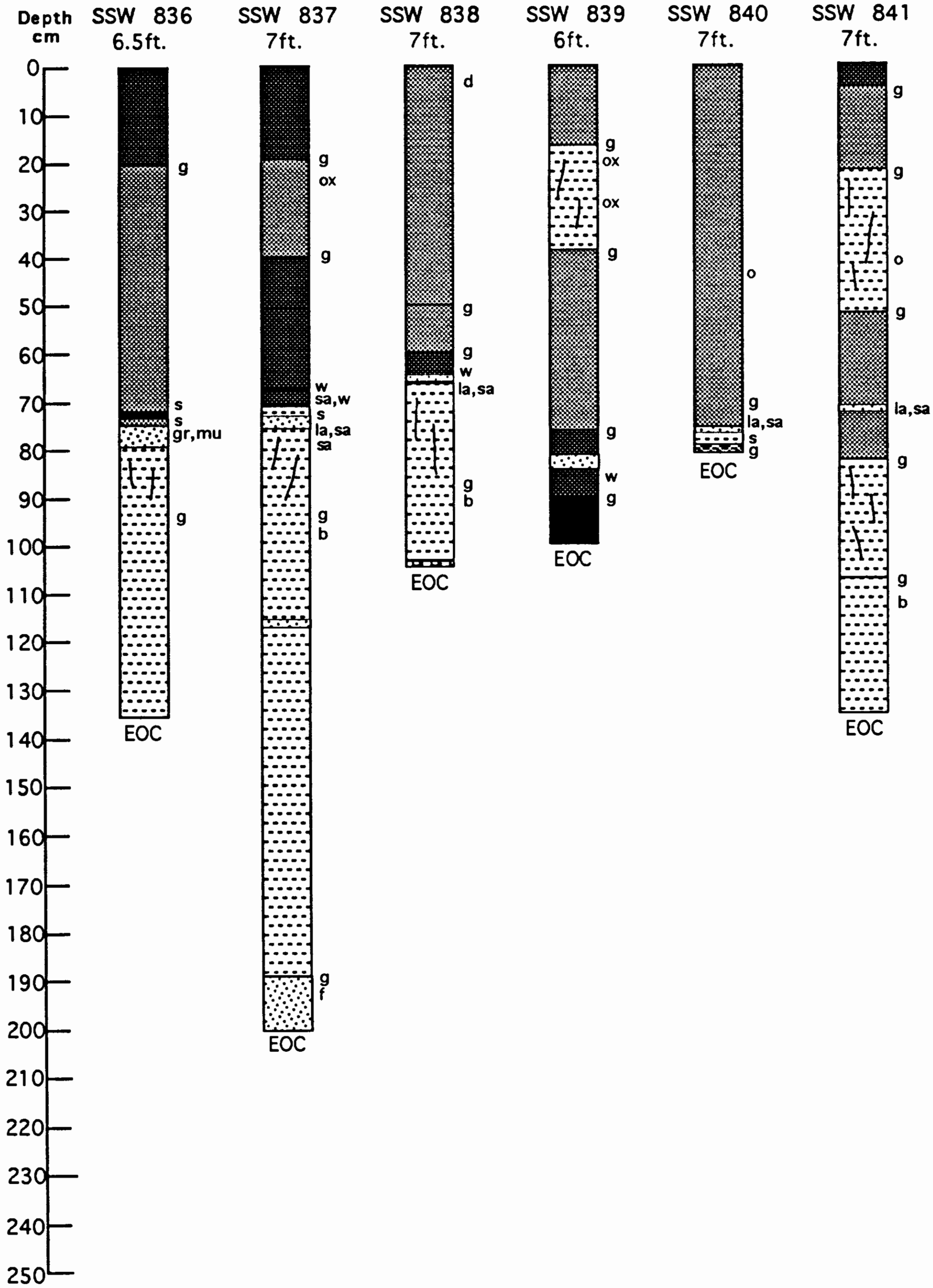

SSW 816
5ft.
g
g
g
g
ox
c
g
s
o
c,re
m
g
EOC
SSW 817
7ft.
g
ox
g
g
w
g
g
c
EOC
SSW 818
7ft.
ox,d
cd
w
m
sa
g
EOC
SSW 819
9ft.
d
cd
g
c
EOC
SSW 820
10ft.
ox
cd
la,sa
g
g
EOC
SSW 821
11ft.
ox
g
s
g
g
b
EOC

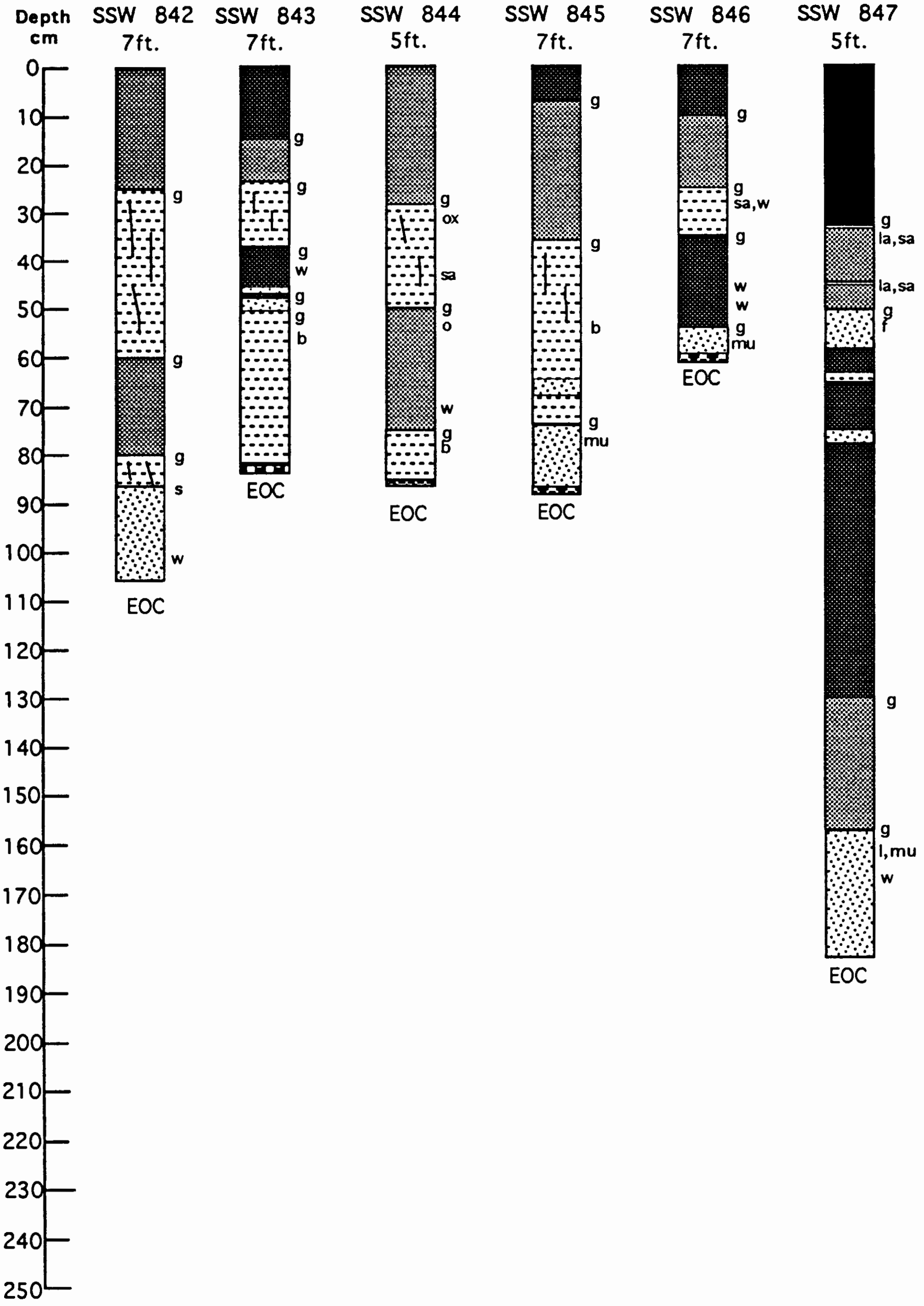


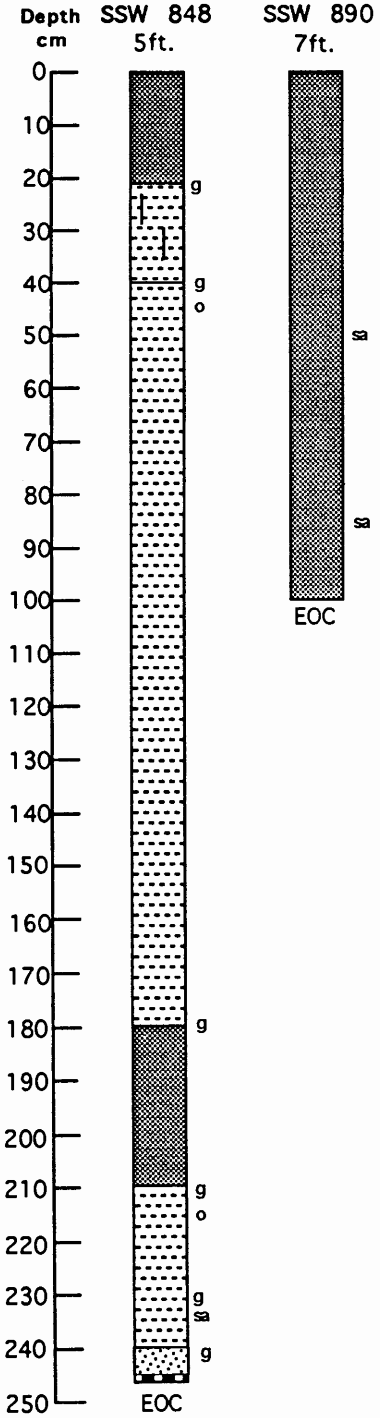
Depth cm
SSW 822 5ft.
SSW 823 6ft.
SSW 824 9ft.
SSW 825 7ft.
SSW 828 5ft.
SSW 829 7ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
ox
re
g
la,sa
co
l,sa
s
b
450±60 RCYBP
EOC



Depth cm
SSW 830 7ft.
SSW 831 7ft.
SSW 832 7ft.
SSW 833 5ft.
SSW 834 6ft.
SSW 835 7ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
s
s
s
s
s
s
g
EOC
g
g
g
g
cl
g
620±40 RCYBP
g
o
g
o
EOC
g
s
109.9±0.8%
g
s
590±70 RCYBP
g
g
g
w
g
b
EOC
g
w
ox
o
re
la, sa
g
g
b
EOC
g
sa
g,sa
g
g
b
EOC
g
mu
la,sa
g
g
b
g
EOC


Depth cm
SSW 836 6.5ft.
SSW 837 7ft.
SSW 838 7ft.
SSW 839 6ft.
SSW 840 7ft.
SSW 841 7ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
g
s
s
gr,mu
g
EOC
g
ox
g
w
sa,w
s
la,sa
sa
g
b
g
f
EOC
d
g
g
w
la,sa
g
b
EOC
g
ox
ox
g
g
w
g
EOC
o
g
la,sa
s
g
EOC
g
g
o
g
la,sa
g
g
b
EOC


Depth cm
SSW 842 7ft.
SSW 843 7ft.
SSW 844 5ft.
SSW 845 7ft.
SSW 846 7ft.
SSW 847 5ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
g
g
g
s
w
EOC
g
g
g
w
g
g
b
EOC
g
ox
sa
g
o
w
g
b
EOC
g
g
b
g
mu
EOC
g
g
sa,w
g
w
w
g
mu
EOC
g
la,sa
la,sa
g
f
g
g
l,mu
w
EOC


Depth
cm
SSW 848
5ft.
SSW 890
7ft.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
g
g
o
g
g
o
g
sa
g
EOC
sa
sa
EOC

APPENDIX D

LIST OF RADIOCARBON DATED SAMPLES
REFERENCED TO BETA LAB NUMBERS

CORE NUMBER	DEPTH OF SAMPLE	^{14}C AGE YEARS B.P. ± 1σ	BETA LAB NUMBERS
SSS 879	55-56 cm	910±70 RCYBP	BETA-96834
SSS 879	54 cm	480±90 RCYBP	BETA-099234
SSW 716	54 cm	101.6±0.9% MODERN	BETA-96836
SSW 716	81 cm	360±70 RCYBP	BETA-96837
SSW 729	84 cm	190±50 RCYBP (AMS)	BETA-099233
SSW 823	74 cm	450±60 RCYBP	BETA-96835
SSW 831	83 cm	620±40 RCYBP (AMS)	BETA-099232
SSW 832	43 cm	109.9±0.8% MODERN	BETA-96839
SSW 832	90 cm	590±70 RCYBP	BETA-96840
SSN 884	71-80 cm	109.0±0.9% RCYBP	BETA-96838
Neawanna 2*	1.02 m	480±60 RCYBP	BETA-42112
	0.8 m	800±60 RCYBP	BETA-42113
	0.39 m	1100±70 RCYBP	BETA-42088
	-0.08 m	1370±70 RCYBP	BETA-44595
	-1.18 m		BETA-42114
Neawanna 5*	114 cm	680±80 RCYBP	BETA-43127
	126 cm	2200±90 RCYBP	BETA-42115
Neawanna CB4*	136 cm	410±50 RCYBP	BETA-43485
Stanley Lake 3*	44 cm	780±90 RCYBP	BETA-57850
	84 cm	2370±60 RCYBP	BETA-57852
Necanicum 3*	90-100 cm	170±90 RCYBP	BETA-58074

* Radiocarbon dates from Darienzo and others, 1991, depth of samples noted according to mean tidal level.

APPENDIX E

FIELD DATA GRID CORE LOCATIONS

NEACOXIE CREEK (SSX)
AND
NEAWANNA CREEK (SSW)

SSX Site Number	Date 1996	State Northing	Plane Easting	UTM Northing	UTM Easting	Surf. Elev.
I	17-Jul	876019	1132835	5096368	429236	5.0
II	17-Jul	875934	1132827	5096342	429234	5.0
III	17-Jul	875853	1132815	5096317	429231	5.0
IV	17-Jul	875771	1132805	5096292	429229	6.0
V	17-Jul	875689	1132794	5096267	429226	6.0
VI	17-Jul	875606	1132704	5096241	429200	5.0
VII	17-Jul	875524	1132776	5096216	429222	6.0
VIII	17-Jul	875447	1132764	5096193	429219	6.0
IX	17-Jul	875366	1132753	5096168	429217	6.0
X	17-Jul	875205	1132744	5096119	429216	6.0
XI	17-Jul	875218	1132738	5096123	429214	5.5
XII	17-Jul	876029	1132762	5096370	429213	7.0
XIII	17-Jul	875957	1132749	5096348	429210	5.0
XIV	18-Jul	875873	1132733	5096322	429206	5.0
XV	18-Jul	875790	1132720	5096297	429203	0.0
XVI	17-Jul	875968	1132670	5096351	429186	7.0
XVII	17-Jul	875889	1132655	5096327	429182	6.0
XVIII	17-Jul	875806	1132639	5096301	429178	6.0
XIX	17-Jul	875725	1132622	5096276	429174	6.0
XX	18-Jul	875710	1132704	5096272	429199	5.0
XXI	18-Jul	875627	1132690	5096247	429195	7.0
XXII	18-Jul	875547	1132675	5096223	429191	7.0
XXIII	18-Jul	875466	1132659	5096198	429187	7.0
XXIV	18-Jul	875836	1132645	5096310	429180	7.0
XXV	18-Jul	875309	1132631	5096150	429180	7.0
XXVI	18-Jul	875239	1132640	5096128	429184	8.0
XXVII	18-Jul	875116	1132726	5096092	429211	5.0
XXVIII	18-Jul	875058	1132719	5096074	429209	5.0

State Plane: North American Datum 1927, northern Oregon, in U.S. survey feet.

UTM: Universal Transverse Mercator coordinates in North American Datum 1927, zone 10, in meters.

Surface Elevation: CH2MHILL 1973 Datum to the nearest extrapolated one foot (+ 1 ft.).

All cores taken were subsurface gouge cores.

SSW Site Number	Date 1996	State Northing	Plane Easting	UTM Northing	UTM Easting	Surf. Elev.
I	26-Jul	872632	1133631	5095344	429510	5.0
II	26-Jul	872543	1133611	5095316	429505	5.0
III	26-Jul	872438	1133593	5095284	429500	5.0
IV	26-Jul	872354	1133575	5095259	429495	5.0
V	26-Jul	872259	1133555	5095229	429490	5.0
VI	26-Jul	872257	1133459	5095228	429461	6.0
VII	26-Jul	872156	1133443	5095197	429457	5.0
VIII	26-Jul	872058	1133430	5095167	429454	5.0
IX	26-Jul	872156	1133344	5095196	429427	7.0
X	26-Jul	872060	1133341	5095167	429427	7.0
XI	26-Jul	871590	1133338	5095024	429430	7.0
XII	26-Jul	871518	1133331	5095002	429429	7.0
XIII	26-Jul	871467	1133317	5094986	429425	7.0
XIV	26-Jul	871432	1133222	5094974	429397	7.0
XV	26-Jul	871521	1133226	5095002	429397	7.0
XVI	26-Jul	871431	1133115	5094973	429364	8.0
XVII	26-Jul	871534	1133122	5095005	429365	9.0
XVIII	26-Jul	871444	1133015	5094976	429333	9.0
XIX	26-Jul	871537	1133028	5095005	429337	8.0
XX	29-Jul	871157	1133225	5094891	429400	7.0
XXI	29-Jul	871079	1133213	5094867	429397	7.0
XXII	29-Jul	871079	1133219	5094867	429399	7.0
XXIII	29-Jul	871161	1133133	5094891	429372	7.0
XXIV	29-Jul	871000	1133125	5094842	429371	7.0
XXV	29-Jul	870926	1133121	5094819	429371	7.0
XXVI	29-Jul	870922	1133036	5094817	429345	7.0
XXVII	29-Jul	871005	1133046	5094843	429347	7.0
XXVIII	29-Jul	871081	1133052	5094866	429348	7.0
XXIX	29-Jul	870839	1133029	5094792	429343	7.0
XXX	29-Jul	870775	1132961	5094772	429323	5.0

State Plane: North American Datum 1927, northern Oregon, in U.S. survey feet.

UTM: Universal Transverse Mercator coordinates in North American Datum 1927, zone 10, in meters.

Surface Elevation: CH2MHILL 1973 Datum to the nearest extrapolated one foot (+ 1 ft.).

All cores taken were subsurface gouge cores.

APPENDIX F

FIELD DATA GRID CORE LOGS

NEACOXIE CREEK (SSX)

AND

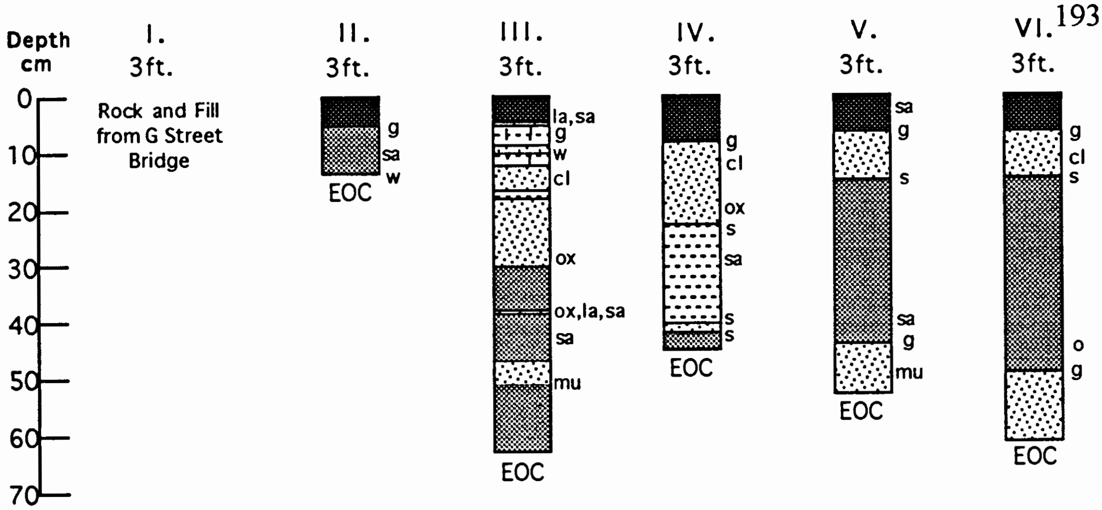
NEAWANNA CREEK (SSW)

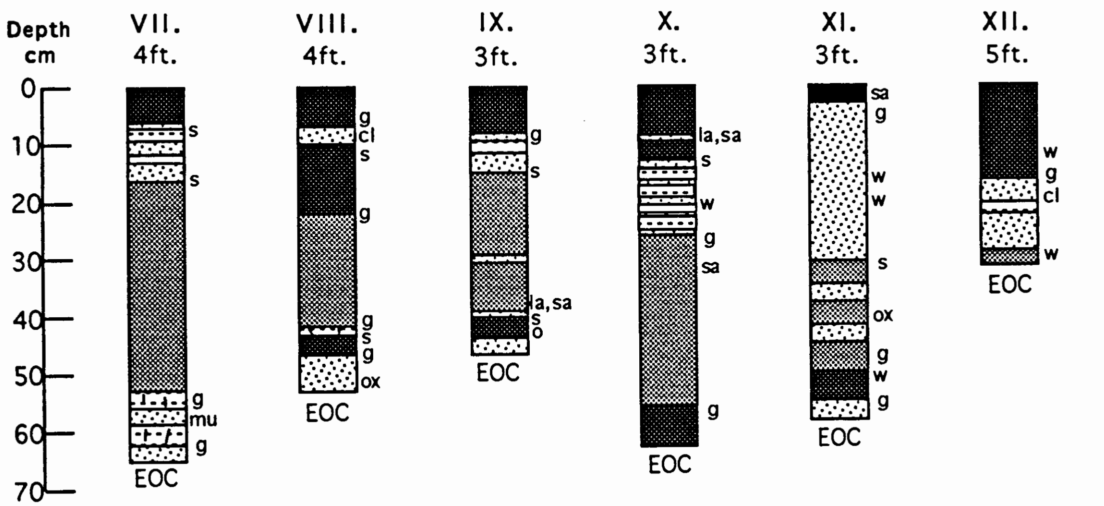
Core Log Legend

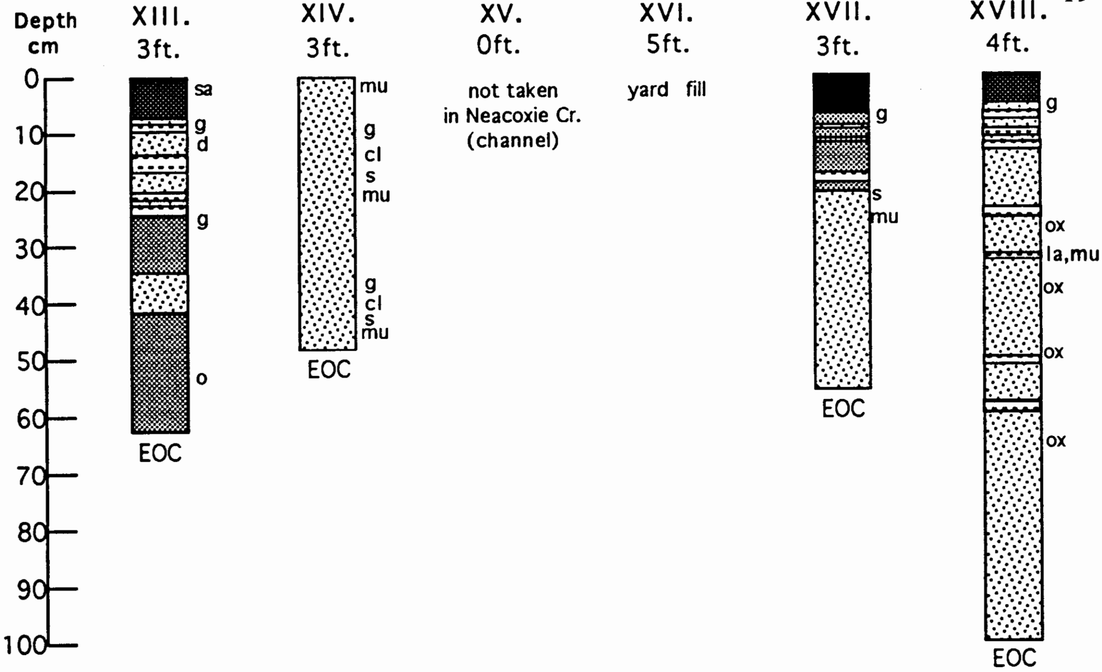
peat	sand	cobble
muddy peat	mud	landslide debris
peaty mud	rooted mud	

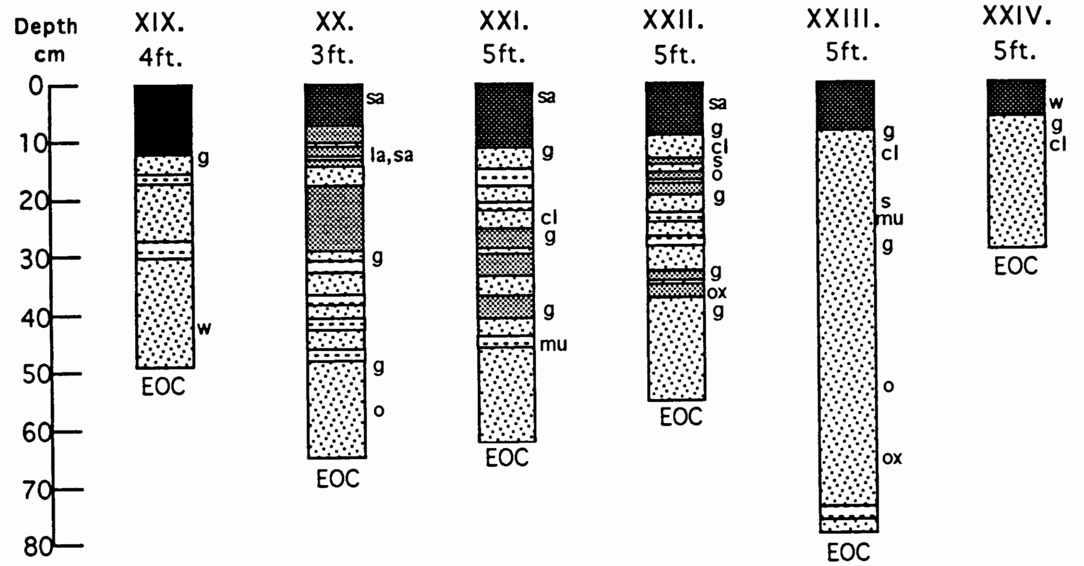
SSN	Necanicum River
SSS	Stanley Lake
SSW	Neawanna Creek
SSX	Neacoxie Creek
SSXa	Drainage to east of Neacoxie Creek

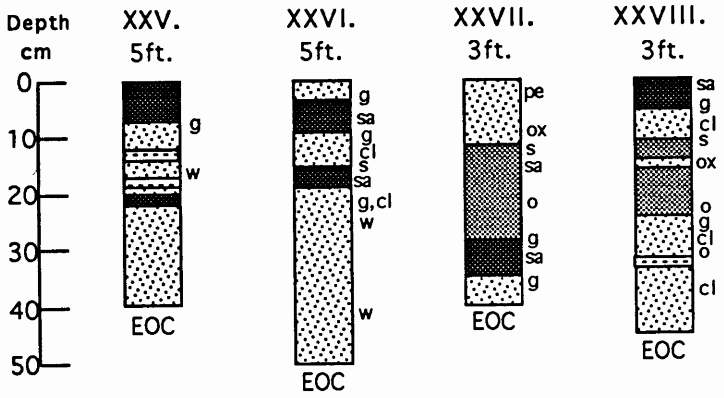
b	barren	f	fining upward	p	pebble
c	coarse	g	gradual	pe	peaty
c d	core drag	i	intruded/irregular	r	rooted
c h	charcoal	l	layer (>5mm)	R C	Radiocarbon sample
c l	clean	l a	lamination (<5mm)	re	reduced
c o	cobble	m	missing section	s	sharp
cont.	continued	mu	muddy	s a	sandy
d	dense	o	organic debris	w	wood fragments
EOC	end of core	ox	oxidized		

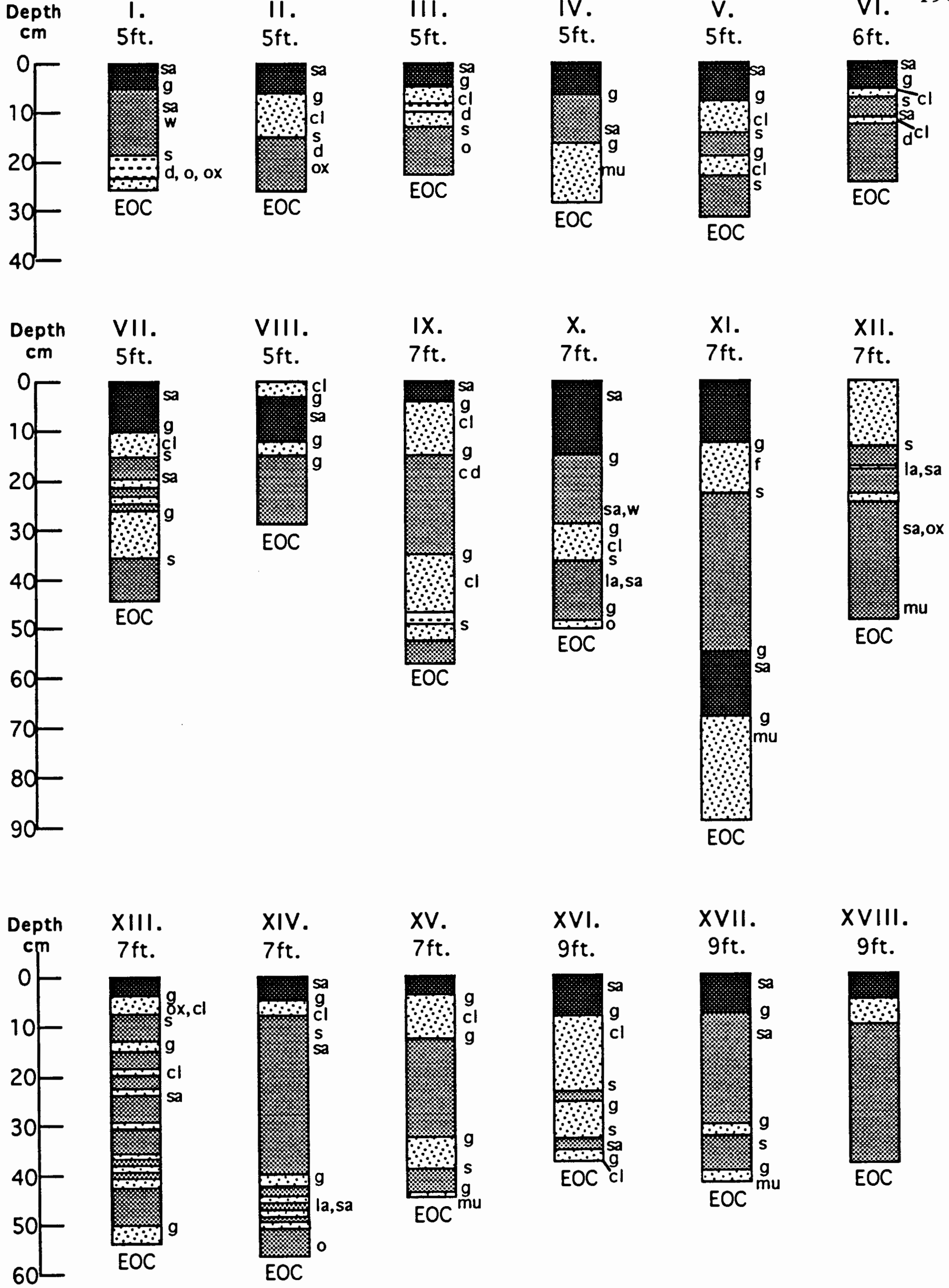

Depth cm
0
10
20
30
40
50
60
70
I. 3ft.
Rock and Fill from G Street Bridge
II. 3ft.
g
sa
w
EOC
III. 3ft.
la,sa
g
w
cl
ox
ox,la,sa
sa
mu
EOC
IV. 3ft.
g
cl
ox
s
sa
s
s
EOC
V. 3ft.
sa
g
s
sa
g
mu
EOC
VI. 3ft.
g
cl
s
o
g
EOC

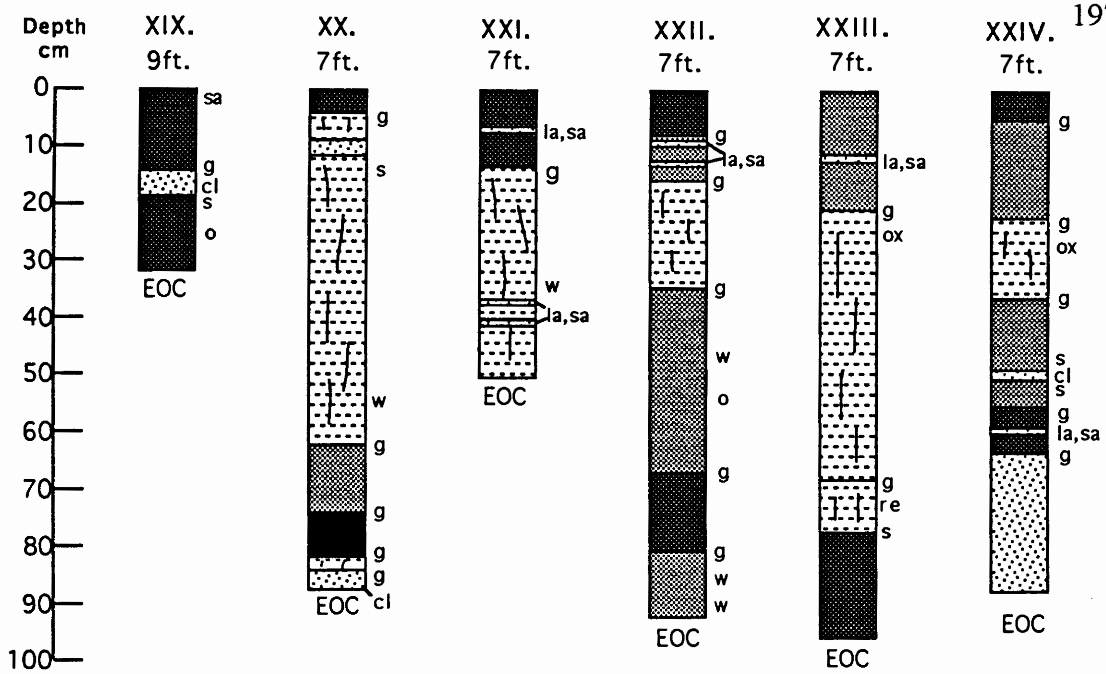

Depth cm
0
10
20
30
40
50
60
70
VII. 4ft.
s
s
g
mu
g
EOC
VIII. 4ft.
g
cl
s
g
g
s
g
ox
EOC
IX. 3ft.
g
s
la,sa
s
o
EOC
X. 3ft.
la,sa
s
w
g
sa
g
EOC
XI. 3ft.
sa
g
w
w
s
ox
g
w
g
EOC
XII. 5ft.
w
g
cl
w
EOC


Depth
cm
0
10
20
30
40
50
60
70
80
90
100
XIII.
3ft.
sa
g
d
g
o
EOC
XIV.
3ft.
mu
g
cl
s
mu
g
cl
s
mu
EOC
XV.
0ft.
not taken
in Neacoxie Cr.
(channel)
XVI.
5ft.
yard fill
XVII.
3ft.
g
s
mu
EOC
XVIII.
4ft.
g
ox
la,mu
ox
ox
ox
EOC


Depth
cm
0
10
20
30
40
50
60
70
80
XIX.
4ft.
g
w
EOC
XX.
3ft.
sa
la,sa
g
g
o
EOC
XXI.
5ft.
sa
g
cl
g
g
mu
EOC
XXII.
5ft.
sa
g
cl
s
o
g
g
ox
g
EOC
XXIII.
5ft.
g
cl
s
mu
g
o
ox
EOC
XXIV.
5ft.
w
g
cl
EOC


Depth
cm
0
10
20
30
40
50
XXV.
5ft.
g
w
EOC
XXVI.
5ft.
g
sa
g
cl
s
sa
g,cl
w
w
EOC
XXVII.
3ft.
pe
ox
s
sa
o
g
sa
g
EOC
XXVIII.
3ft.
sa
g
cl
s
ox
o
g
cl
o
cl
EOC


Depth cm
0
10
20
30
40
I. 5ft.
sa g sa w s d, o, ox
EOC
II. 5ft.
sa g cl s d ox
EOC
III. 5ft.
sa g cl d s o
EOC
IV. 5ft.
g sa g mu
EOC
V. 5ft.
sa g cl s g cl s
EOC
VI. 6ft.
sa g s cl sa d cl
EOC
Depth cm
0
10
20
30
40
50
60
70
80
90
VII. 5ft.
sa g cl s sa g s
EOC
VIII. 5ft.
cl g sa g g
EOC
IX. 7ft.
sa g cl g cd g cl s
EOC
X. 7ft.
sa g sa,w g cl s la,sa g o
EOC
XI. 7ft.
g f s g sa g mu
EOC
XII. 7ft.
s la,sa sa,ox mu
EOC
Depth cm
0
10
20
30
40
50
60
XIII. 7ft.
g ox,cl s g cl sa g
EOC
XIV. 7ft.
sa g cl s sa g la,sa o
EOC
XV. 7ft.
g cl g g s g mu
EOC
XVI. 9ft.
sa g cl s g s sa g cl
EOC
XVII. 9ft.
sa g sa g s g mu
EOC
XVIII. 9ft.
EOC


Depth cm
0
10
20
30
40
50
60
70
80
90
100
XIX. 9ft.
sa
g
cl
s
o
EOC
XX. 7ft.
g
s
w
g
g
g
g
cl
EOC
XXI. 7ft.
la,sa
g
w
la,sa
EOC
XXII. 7ft.
g
la,sa
g
g
w
o
g
g
w
w
EOC
XXIII. 7ft.
la,sa
g
ox
g
re
s
EOC
XXIV. 7ft.
g
g
ox
g
s
cl
s
g
la,sa
g
EOC

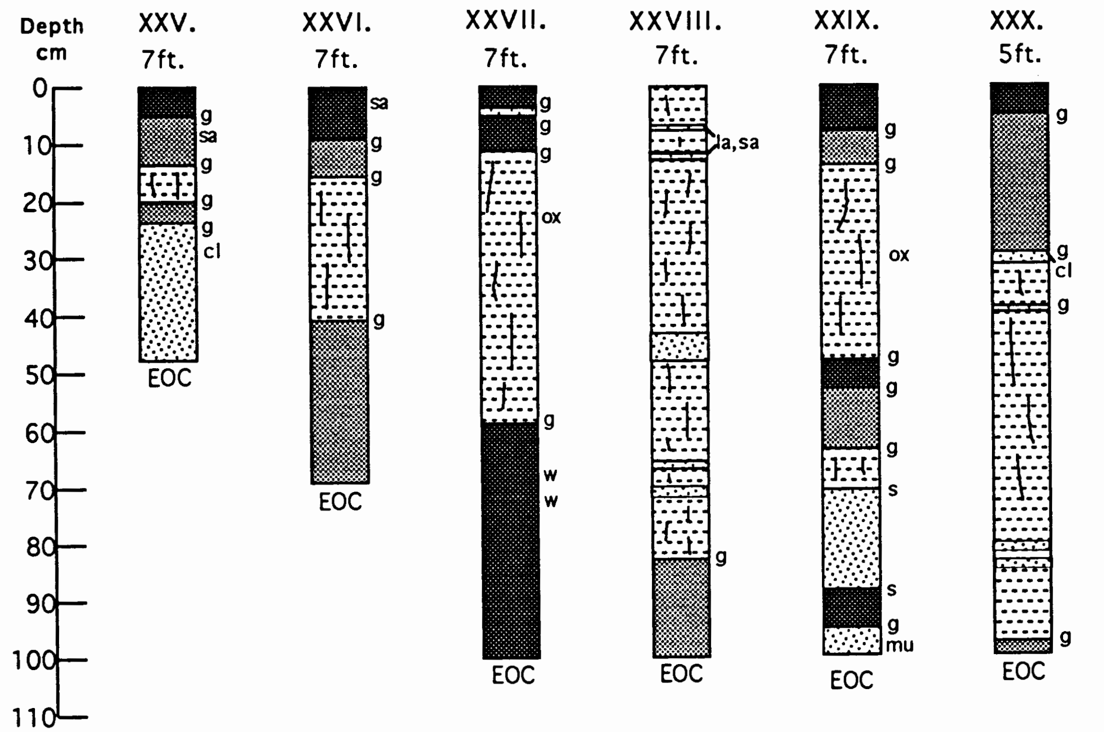

Depth cm
0
10
20
30
40
50
60
70
80
90
100
110
XXV. 7ft.
g
sa
g
g
g
cl
EOC
XXVI. 7ft.
sa
g
g
g
EOC
XXVII. 7ft.
g
g
g
ox
g
w
w
EOC
XXVIII. 7ft.
la,sa
g
EOC
XXIX. 7ft.
g
g
ox
g
g
g
s
s
g
mu
EOC
XXX. 5ft.
g
g
cl
g
g
EOC

Plate 1. Seaside High School N-S GPR profile (1r1, sehi-ra).

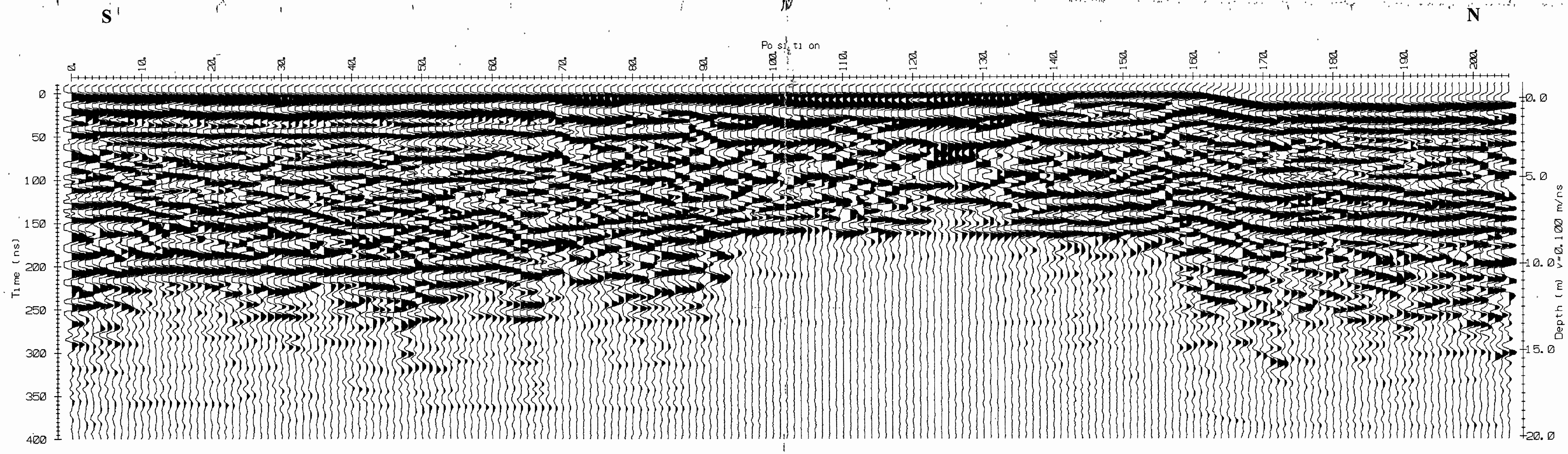


Plate 2. Seaside High School E portion of the E-W GPR profile (1c1, sehi-ca).

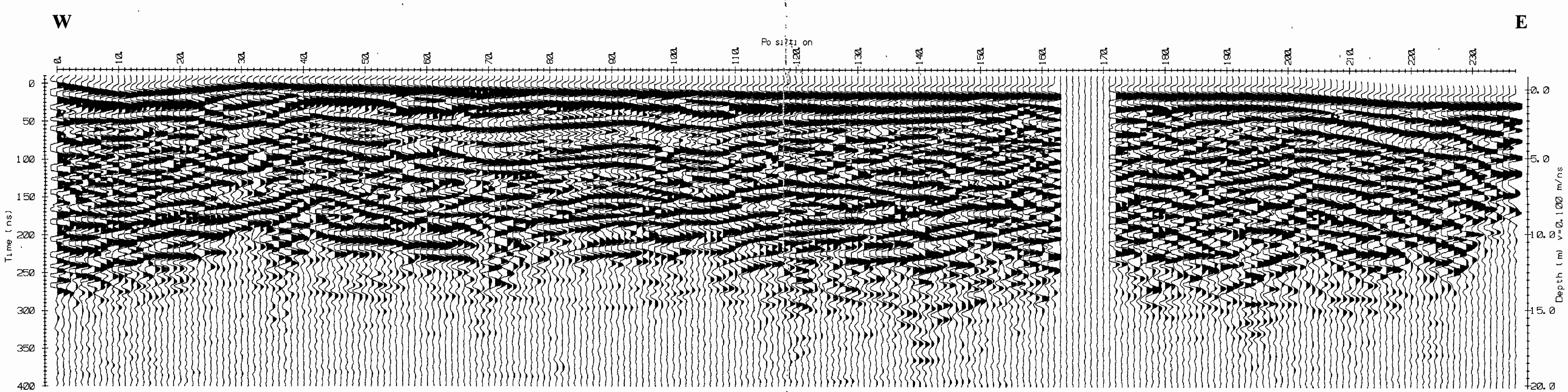


Plate 3. Seaside High School W portion of the E-W GPR profile (1c1, sehi-cb).

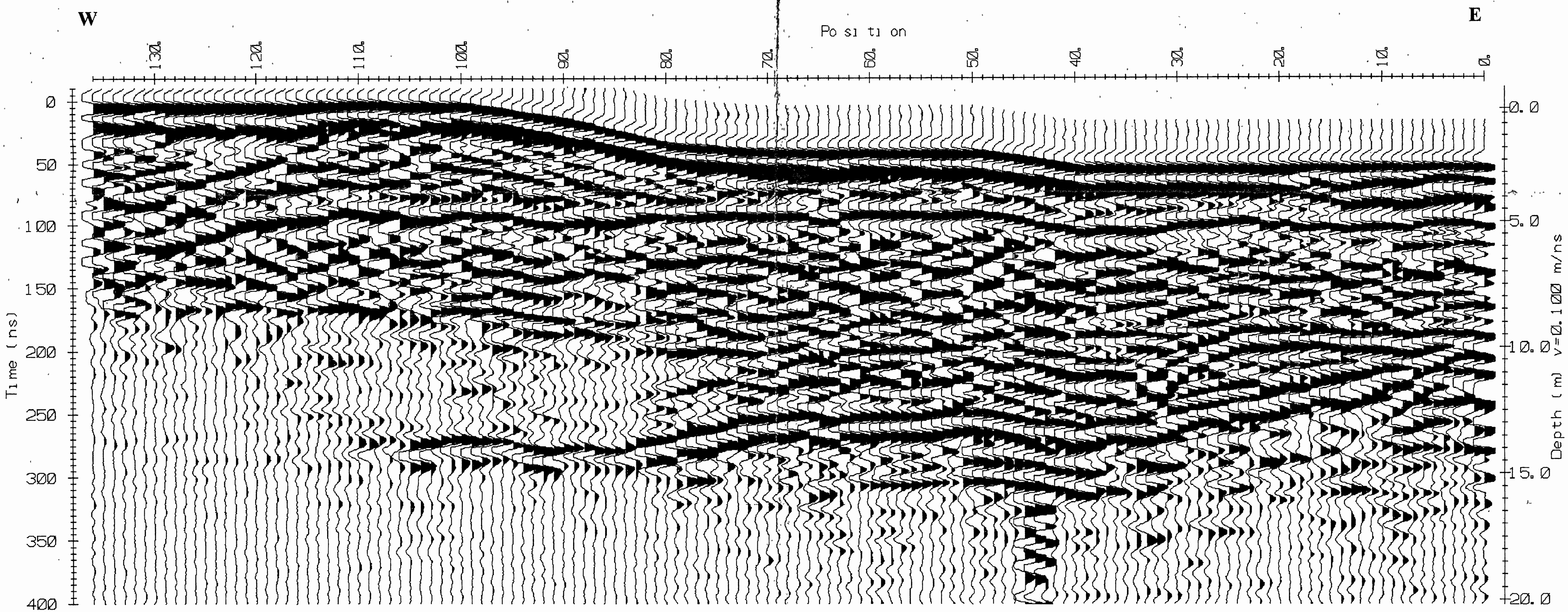


Plate 4. Seaside golf course N-S GPR profile (100c).

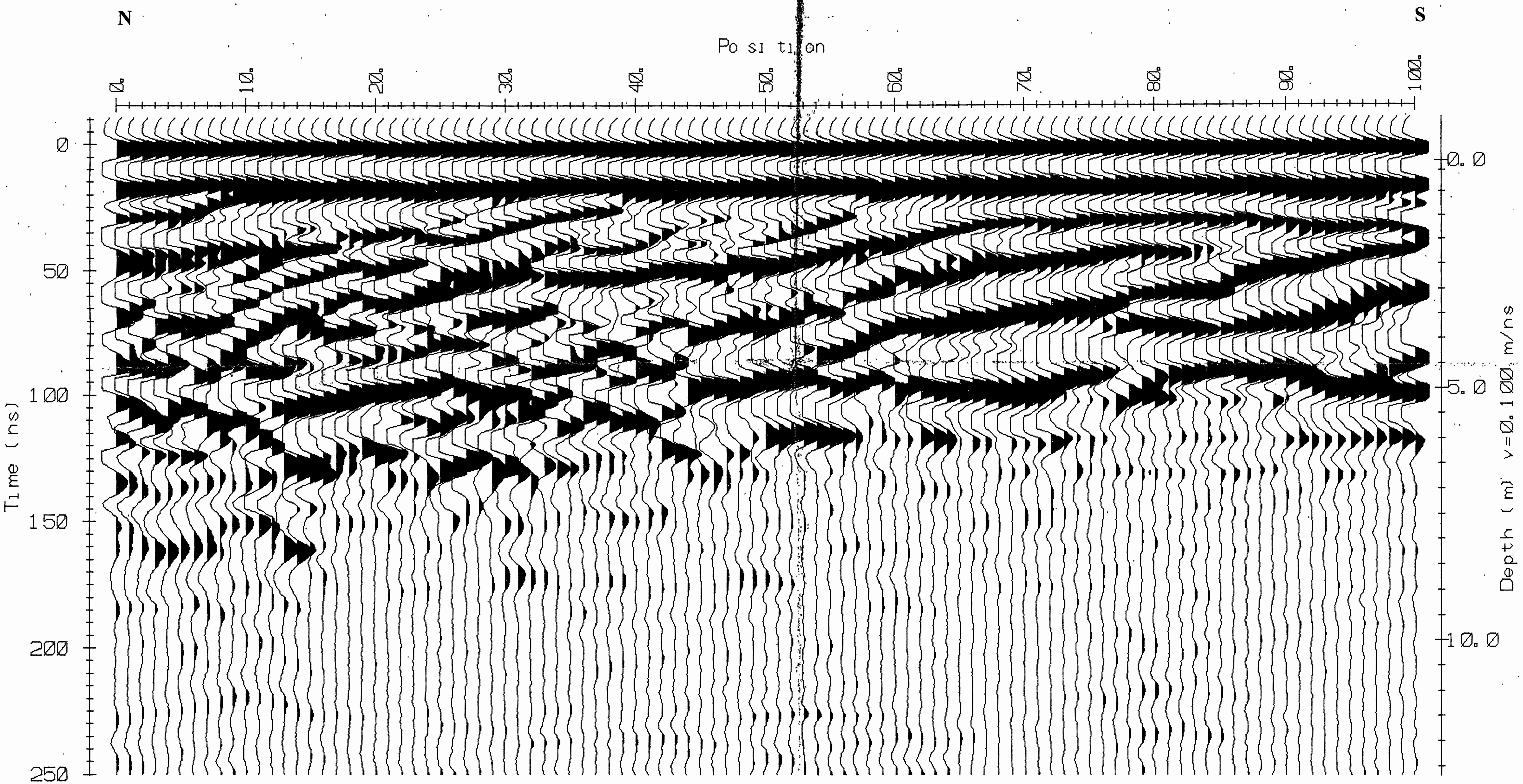


Plate 5. Seaside golf course northern E-W GPR profile (100a).

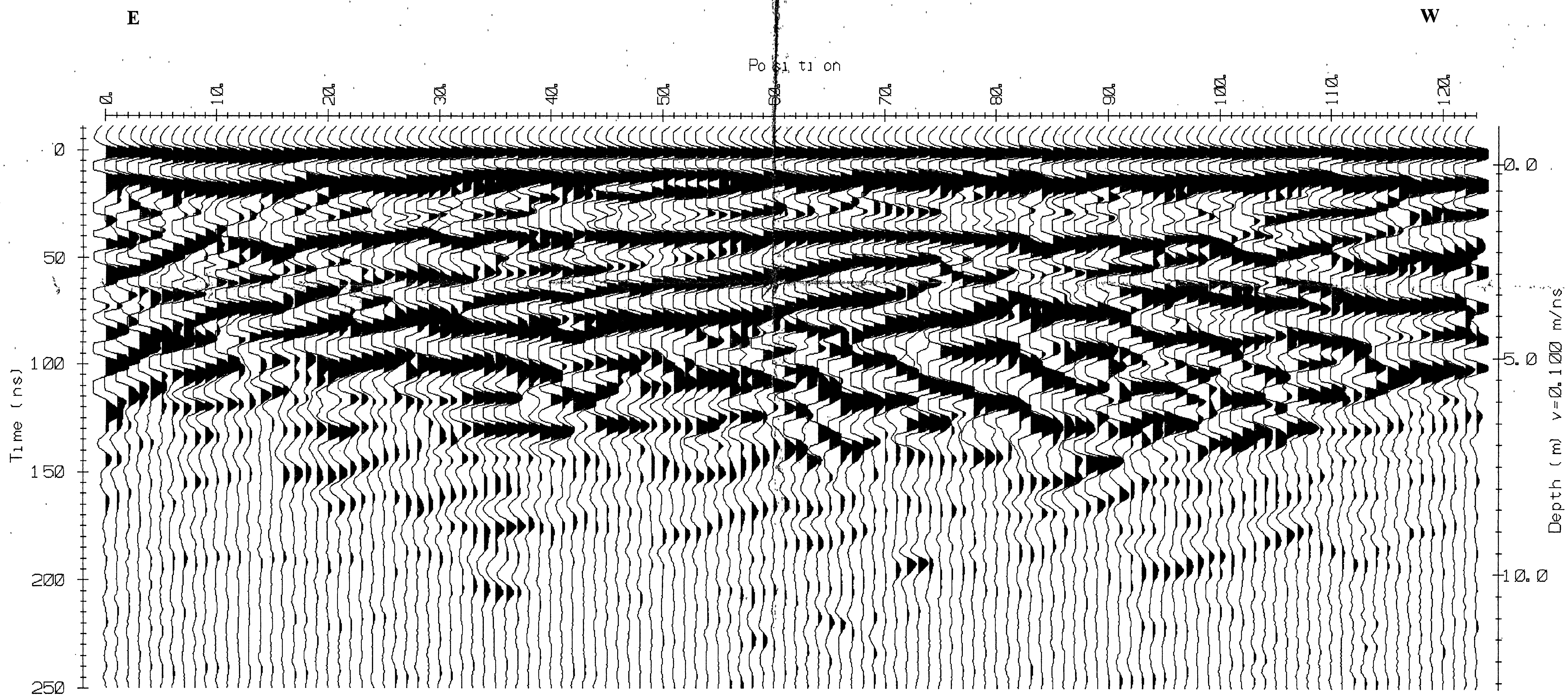


Plate 6. Seaside golf course southern E-W GPR profile (100b).