This draft report (written communication to Nelson, dated 8Novemeber 1994) is included in the Supplemental Files because 1) it provides key stratigraphic and dating information on the primary outcrop investigated in this paper, and 2) of its historical significance for coastal investigations of great earthquake stratigraphy at Cascadia. The lower part of the outcrop, as described in this report, has not been exposed for at least 15 years. With the exception of Minor and Grant (1996), which reported only on the youngest wetland soil buried by subsidence in 1700 CE, no other publications describe the stratigraphy of great earthquakes at the Nehalem River estuary in any detail and more than half the radiocarbon ages summarized in this report have never been published. Grant wrote a report similar to this one as part of her requirements for an M.S. degree (a non-thesis report summarizing original research) in the Department of Geological Sciences at the University of Washington, Seattle. The report was supposed to be kept permanently on file with the department, but it was discarded when the department moved temporarily to a new building in 2003. Because this report is well prepared, highly significant for our investigations at the Nehalem River estuary, and not available anywhere else, we reproduce it here.

PALEOSEISMIC EVIDENCE FOR LATE HOLOCENE EPISODIC SUBSIDENCE ON THE NORTHERN OREGON COAST

by WENDY C. GRANT

ABSTRACT

The tidal marshes of the Salmon and Nehalem river estuaries on the northern Oregon coast contain at least four buried wetland soils below the current marsh surface. The two best preserved of these buried soils contain the remains of plants that presently inhabit high marsh or forested wetland environments above the intertidal zone. These former wetland surfaces are overlain by deposits of mud that contain remains of plants that grow in intertidal environments. This abrupt transition from extratidal to low- intertidal species in the deposits indicates that an abrupt change in relative sea-level occurred that produced the submergence of the former vegetated marshes. Each of these buried soils represents an episode of submergence, probably resulting from earthquake-induced subsidence from a large or great earthquake on the Cascadia subduction zone (CSZ). Evidence that a tsunami accompanied some of these earthquakes is present; the evidence is strongest for the most recently buried soil at the Salmon River.

Radiocarbon dating from the four buried soils at both the Nehalem and Salmon rivers yield four episodes of burial during the last 2000 years. The age of the most recent of these events (approximately 1700 AD) agrees with the timing of coastal subsidence along the southwestern Washington coast, at other sites on the Oregon coast, and at the southern end of the CSZ in northern California indicating that the entire Pacific Northwest coast could have subsided during one earthquake. Although the radiocarbon ages of the deeper buried units are similar to those from southwestern Washington, the case for subsidence of the entire coast during one earthquake is weaker.

INTRODUCTION

During the past few years, evidence has mounted that the coastal regions of the Cascadia subduction zone (CSZ) have undergone numerous episodes of submergence during the late Holocene (Atwater, 1987; Darienzo and Peterson, 1990; Atwater, 1992; Clarke and Carver, 1992; Nelson, 1992). At least some of these episodes are thought to have been induced by coseismic subsidence produced by movement on the thrust interface of the CSZ during a large or great earthquake.

In this paper, I present geologic evidence from the Nehalem and Salmon rivers on the northern Oregon coast (fig. 1) that at least four episodes of submergence have occurred in the last 2000 years. The evidence that at least two of these episodes were caused by tectonic subsidence is strong. These conclusions are consistent with Atwater's (1987; 1992) findings in estuaries on the southwestern Washington coast 100 km to the north and extend the length of the coast, which may have subsided during at least one single subduction earthquake.

Because tidal marshes form near the mean tidal level, tectonic lowering of coastal regions would result in marsh vegetation being subjected to inundation of the wetlands by sea water. The soil that had formed at the surface of the tidal marsh would become buried by silt and sand deposits carried in by tidal action. Depending on the amount of subsidence, the increased salinity of the lowered marsh (from tidal flooding) could cause the death of the pre-existing vegetation. Once the silt and sand deposits had built up enough so that the surface was once again near sea-level, a new marsh surface would begin to become established. Fossil remains of vegetation in the sub-surface should reflect the apparent change in sea-level. Vegetation fossils would indicate a progression from intertidal conditions up through an extratidal zone as the marsh rebuilds as a response to deposition. In addition, the stratigraphy would indicate a change in depositional environments from a more energetic regime in which a coarser grain-sized sediment predominates to an environment in which finer grain-sized particles are deposited. Along both the Salmon and the Nehalem rivers, both of

these type of changes (vegetation and sediment) are visible in the marsh stratigraphy.

Processes other than slip during a thrust earthquake on a subduction interface can cause tectonic lowering of coastal wetlands. Some of these processes that can cause the submergence and consequent burial of coastal wetlands are floods, seiches, tsunamis from distant earthquakes, changes in barrier structures which protect a wetland, and storms. However, the most plausible mechanism for most of the submerged coastal wetlands described in this report is sudden tectonic subsidence. This conclusion is reached primarily because of the change in vegetation composing the former surface of the buried soils to the plants entombed in the overlying deposits. Detailed study of the paleo-environment of these plant remains indicates that mean sea level underwent a significant change across the burial boundary for some of these soils. This change in mean sea level must have occurred quickly to preserve the plant remains in the dynamic intertidal environment. The evidence for this sudden change in sea level is presented below.

BACKGROUND

TECTONIC SETTING OF THE CASCADIA SUBDUCTION ZONE

In the last several years, the Cascadia subduction zone has come under renewed scrutiny as to whether or not subduction is still occurring along the coast of the Pacific Northwest, and if it is, whether the slip is accommodated aseismically or whether the plates are 'locked'. If the plates are locked, it is possible that the Pacific Northwest may experience a large subduction earthquake that initiates along the contact of the subducted North American and overlying Juan de Fuca plates. The question as to whether the Pacific Northwest could experience a large or great subduction-style earthquake or not has many important implications for the region. Although the hypocenter of the earthquake would be near to or under the coast, strong ground shaking of several minutes duration could occur in the Willamette Valley, Puget Lowland and

Fraser Valley regions. Several million people live in these areas and damage and loss of life could be extensive since they are within several hundred kilometers of the source region for these subduction earthquakes. Damage and loss of life in the coastal regions themselves would be even more severe, with a lot of the destruction resulting from a tsunami, which would most likely accompany the earthquake.

One of the reasons the Cascadia subduction zone has often been considered currently aseismic is because no conclusively thrust earthquakes have been located along the subduction interface since the beginning of the seismic network in this area in 1972 (Crosson, 1972; Crosson, 1983). And in the historical record, no large shallow earthquakes have been felt in the coastal regions since the beginning of recorded history in this region about 150-200 years ago. However, the repeat times for large subduction earthquakes can be hundreds or thousands of years (Heaton and Kanamori, 1964; Jarrad, 1986) and it is possible that the zone is in a period of quiescence prior to a subduction earthquake.

TECTONICS OF SUBDUCTION ZONES THAT MAY BE ANALOGS TO THE CSZ

In May 1960, Chile experienced a magnitude 9.5 earthquake that had a rupture area of roughly 1000 km in length and 200 km in width (Plafker and Savage, 1970); in March of 1964 Alaska was subject to a magnitude 9.2 earthquake that ruptured over an area of 850 km by 250 km (Plafker, 1969). The two earthquakes are the largest to occur in this century and may serve as possible analogs to the CSZ. It was observed that as a result of both the Alaskan and Chi1ean earthquakes that large areas in and around the source region had either subsided or had been uplifted during the earthquake (Plafker, 1969; Plafker and Savage, 1970). In Alaska, uplift ranged up to ~10 m, while maximum subsidence was on the order of 2-3 m (Plafker, 1969). In Chile, uplift was ~6 m and subsidence 2-3 m) (Plafker and Savage, 1970). It was with these scenarios in mind, that the first investigations for possible earthquake-induced subsidence along the Pacific Northwest coast was undertaken (Atwater, 1987).

Previous researchers had primarily investigated coastal regions for evidence of coastal uplift in the form of late Holocene terraces without success (i.e.; Golder Associates, 1986).

DESCRIPTION OF STUDY AREAS

Tidal marshes can be classified in numerous ways. In this report, I use the convention of Eilers (1975) and Mitchell (1981) who studied plant communities along the Nehalem and Salmon rivers, respectively. They divide tidal marshes into three classifications based upon inundation of the daily tides. These classifications are 1) intertidal, 2) transitional, and 3) extratidal marsh. The terminology–high marsh–is sometimes used interchangeably with the term–extratidal. Individual species of plants grow in communities that are readily identifiable based on their elevation above mean lower low water (MLLW). Plant communities that inhabit an elevation around MLLW are inundated twice daily by tidal action. Plant communities at mean higher high water (MHHW) are normally inundated just once a day by the higher tide.

Along both the Nehalem and Salmon Rivers, only the most uppermost buried soil is widely distributed under the present day tidal marsh. The deeper buried soils are preserved only in protected inlets and along lengths of the riverbanks where river migration has not previously 'erased' the stratigraphic record. Thus, at both rivers, only the uppermost buried soil is most extensively preserved and studied.

SALMON RIVER

The Salmon River estuary is a relatively small estuary containing about 200 acres, of which 125 acres are tidelands (State of Oregon, 1973). It is characterized by having a fairly extensive tidal marsh environment that has been relatively undisturbed by man. Part of the marsh has been diked in the past for pasture land. Some of these dikes were removed during the summers of 1978 and 1987 by the Forest Service in an effort to restore the estuary to its original state. An excavation ditch that was dug as

part of this effort on the south side of the river provided a fresh exposure of the subsurface stratigraphy and allowed for the identification and collection of vegetation samples that are relatively unoxidized as compared to those along the present riverbank outcrops.

At the Salmon River, the intertidal environment ranges from about 0.5-1.1 m, transitional marsh from 1.1-1.7 m and extratidal marsh as above 1.7 m; all these elevations are in reference to MLLW. The tidal range in the study area is approximately 1 m (Mitchell, 1981). Most of the present marsh surface is above the level of the diurnal tides and is inundated by tidal action only during storms and by extreme high tides. Thus, the vegetation that grows on much of the surface is characterized by plants representative of high transitional to extratidal marsh elevations, such as *Juncus balticus*, *Potentilla pacifica*, and *Deschampsia caespitosa* (Mitchell, 1981).

UPPERMOST BURIED SOIL

Stratigraphy

The uppermost buried soil at the Salmon River was, at the time of its formation, a soil very similar to that of the present day tidal marsh. Over much of the former marsh surface, it is characterized by a fine to medium sand grading up into sandy silt and silt, and gradually (over several centimeters) becoming very organic-rich, so that the horizon is typically composed of peat or muddy peat. The peaty horizons range generally from several up to about 10 cm in thickness and have a sharp upper contact with the overlying sediments. In most areas, this contact is very sharp; less·seldomly, the contact occurs over a centimeter or two. A fine-medium grain-sized sand overlies the buried peaty soil in most areas. This sandy unit ranged in thickness (where present) from a trace up to approximately 10 cm in thickness. Overlying this sand unit are laminated (but mostly bioturbated) silts and sands that grade up into the present day peaty marsh surface. The depth of the uppermost buried peaty surface

ranges from approximately 3 to 100 cm below the present marsh surface. Although the entire buried unit is composed of the basal laminated silts and sands, which grade up to the peaty horizon, it is this peaty horizon that is referred to as the buried soil throughout this report.

In the southwestern part of the estuary near SR140 (fig. 2), the stratigraphy is slightly different. Prior to the last episode of submergence, this part of the estuary was composed of sand dunes and was probably very similar to the present day terrain of stabilized sand dunes. The basal section of the buried soil consists of aeolian lain sand, which grades up into a fibrous peaty sand, which is very similar to the peaty sand that tops the present day dune complex. This peaty sand has a very sharp upper contact but undulates on the scale of centimeters so that little peaks and valleys are apparent. The sand unit that mantles most of the rest of the estuary is evident here as well and lies in contact with the peaty soil, which in tum, is overlain by a silty mud. This silty mud grades up into a sandy unit that shows faint cross-bedding typical of aeolian deposition, and then into the moden soil capping the dune complex.

Inference of land-level changes from vegetation

By comparing the vegetation remains found in the buried soils to the vegetation that inhabits various levels of the present tide flats and marshes, we can infer the change in elevation that must have occurred across the contact from the peaty units to the overlying sediments. Examination of the vegetation remains near the top of the buried soil along most of the outcrops reveals abundant rhizomes and basal stems of a rush, *Juncus balticus*, and the Pacific silverweed, *Potentilla pacifica*. These rhizomes are in growth position and are often found sticking up into the overlying sediments. Although these two plants are widely distributed in elevation in modern tidal marshes in the Pacific Northwest, they primarily only grow in dense stands in the high-transitional to extratidal marsh environment (Mitchell, 1981; Eilers, 1975). Because of the abundance of *J. balticus* and *P. pacifica* rhizomes and the paucity of low-marsh indicator species, coupled with the

high-organic content of the peaty soil, the buried soil horizon was determined to be similar to the present day marsh surface.

Although *Juncus* rhizomes appear to be the most identifiable and common plant remnant found in the buried soil, in some areas the former marsh appears to have been at a lower elevation since the primary vegetation fossil is *Carex lyngbyei*, an early colonizer of tidal marshes (Mitchell, 1981). Portions of the marsh that appear to have been at a lower elevation at the time of submergence and burial grade laterally into the former *Juncus* marshes in much the same way that the modern marsh vegetation changes, particularly as one moves away from the river and toward the uplands.

Abundant rhizomes of two plants that are primary colonizers of the mudflat zone along this part of the coast, *Triglochin maritima* and *Distichlis spicata*, are found in the sediments that overlie the peaty horizon. *T. maritima* rhizomes are fairly large and are present in large masses in much of the subsurface. In some places, remnants of this plant can be traced upward from just above the contact of the buried peaty soil through the overlying sediments and into the lower portion of the modem peaty marsh surface. These rhizomes are more and more decomposed as they are traced upward presumably due to increased oxidation.

The plant fossils that are found in the buried peaty soil at the Salmon River indicate that the vegetation in the buried marsh was very similar to the present marsh surface and was primarily composed of vegetation which inhabits a high-transitional to extratidal marsh environment. Submergence of only about 0.5-1.0 m would have been sufficient to change the marsh to a mudflat in which laminated silts and sands were deposited by tidal action before the present marsh elevation was regained. This relative sea-level rise must have occurred rapidly to produce the observed change in vegetation over the few centimeters burial contact. Earthquake-induced subsidence best explains this phenomena.

Earthquake-induced subsidence is also the best explanation for the buried dune

complex near SR140 (fig. 2). In this part of the estuary, the silty mud which overlies the peaty soil and the mantling sand sheet was deposited in a mudflat environment. Although leveling was not done in this area, it appears as if the sand dune complex is about 0.5 m higher than the adjacent marsh surface. Thus, subsidence on the order of approximately 1-1.5 m would have been sufficient to deposit intertidal silts over the former dune complex.

Compaction and settlement of sediments from ground shaking could cause an apparent larger component of subsidence than might have actually occurred during the shaking that accompanies a large earthquake. However, the peaty buried soil with its overlying intertidal deposits can be traced over colluvium at the base of the riverbank outcrop near·SR31 (fig. 2). The depth of the buried soil is about 60 cm below the present surface. Because of its grain size, colluvium is not object to much compaction and settlement during shaking. Thus, this exposure indicates that the burial of the marsh was primarily due to earthquake-induced subsidence and not compaction.

Evidence for a Tsunami

The uppermost buried soil is at the Salmon River is mantled over much of its extent by a clean, fine-medium grain-sized sand, which is typically quartz-rich and sub-rounded. Where the upper contact of the peat is undulatory, the sand fills the small valleys in the peat yet has a planar upper surface. This sand unit ranges from a trace (where it is present) up to about 12 cm in thickness. Extensive sand units like this are not found anywhere else in the stratigraphy. The unit is thickest closest to the mouth of the river, and thins both upriver and towards the uplands (fig. 4), indicating that the sand must have been transported in a landward-directed surge of sandy water. In general, the sand unit is massive in structure and shows no laminae indicating that it was transported in suspension and deposited rapidly. However, in the vicinity of SR140, the sand unit shows some heavy mineral lamination indicating that successive

waves of deposition may have occurred. Its stratigraphic position in between the buried soil and the overlying tide flat deposits indicates that it was deposited soon after the lowering of the marsh surface. The best explanation for the deposition of this unit is a tsunami that accompanied the subduction earthquake. The mineral laminations near SR140 indicate that successive waves may have washed over at least this part of the estuary. The source for the sand in the tsunami waves is the sand that forms the beach and dune complex near the mouth of the estuary.

DEEPER BURIED SOILS

Although up to five peaty soil units are found in boreholes under the present day tidal marshes along the Salmon River, only the uppermost buried soil is exposed in the riverbank outcrops during low tide. The deeper buried soils are not observed to outcrop anywhere along the present channel or excavation ditch and thusly, are not as well described as the uppermost buried soils since they were investigated only with boreholes. However, a transect of closely spaced boreholes has shown the presence of four of these units in a protected area of the present day estuary (fig. 2).

The investigation in this part of the estuary was done to determine the number of buried soils and to investigate how well these deeper soils could be correlated on the basis of closely spaced boreholes. The surface elevations were determined by leveling. Thirty boreholes were made, most with a spacing of 5 m (fig. 5). The deepest of these boreholes reached about 4 m below the surface before the hole collapsed. On the northern end of this transect, the sub-surface of this part of the estuary was a dune complex composed of a fine-medium grain-sized quartz-rich sand. Bordering this dune complex to the south was an embayment of which the base was a medium-coarse grained gray sand which contains many shell fragments. Up to four buried soils are preserved above the former dune complex and embayment, but these soils are hard to correlate with each other since channel migration has erased much·of the stratigraphic record (fig. 5).

In this part of the estuary, the deeper stratigraphy is best preserved over the former dune field. No plant fossils were identified in any of the peaty buried soils, but these peaty horizons are very similar to the uppermost peaty horizon that underlies most of the rest of the Salmon River estuary and probably indicate subsided former·wetlands. In the silty intervals that overlie each of the deeper peaty units, *T. maritima* rhizomes were found which probably indicate that a change in relative sea level occurred. A thin mantling of a quartz-rich fine-medium grain-sized sand overlies the second and third buried soils in this area. However, because the boreholes reveal a very limited area, it was not possible to determine whether these sand laminae were deposited by tsunamis or aeolian transport. A much more intensive coring and trenching effort than was part of this study would be needed to interpret the late Holocene stratigraphy of the deeper buried soils at the Salmon River.

NEHALEM RIVER

The Nehalem River estuary is a much larger system than the Salmon River estuary. Tidelands compose approximately 1100 acres of the 2300 acreage in the estuary (State of Oregon, 1973). It is bounded on the west and northwest by the Nehalem sand spit and by the Manzanita dune complex (fig. 3)·.

At this estuary, Eilers (1975) divides the marsh into an intertidal zone (below 2.12 m), a transitional zone (2.12-2.76 m) and the extratidal zone above 2.76 m above MLLW. The extratidal zone is rarely inundated by tidal action and the species that grow at this elevation are relatively intolerant to much salt-water intrusion for long periods. This part of the marsh is characterized by plants such as *Aster subspicatus*, *Potentilla pacifica* and *Oenanthe sannentosa*. *Picea sitchensis* (Sitka spruce) and *Salix hookeriana* (willow) are dominant at elevations at the high end of the extratidal zone and are prominent inhabitants of the dikes fringing the marshes. P. sitchensis also grows on the natural levees of the riverbank on the extratidal marshes

further upstream.

The tidal range at the Nehalem River is approximately 2.5 m. Therefore, a much greater extent of the riverbank outcrops is exposed at low tide than at the Salmon River (tidal range of approximately l m). In particular, four buried soils are exposed along two sections of the river (an upstream site and a downstream site, labeled in fig. 3) and provide much information on the paleo-environment at the time of submergence and burial of these soils. Boreholes were made throughout the tidal marshes over the rest of the estuary and, in particular, core transects were made on the marsh west and north of Dean's Point and Lazarus Island. Typically though, these boreholes revealed only the uppermost buried unit. The lower units are presumed to either have been wiped out by channel migration, or alternatively, it is only prior to the last episode of burial that the islands formed enough·so that a burial event could be recorded. Since the riverbank exposures yield much more information about both the uppermost as well as the deeper buried soils, I will primarily utilize the data collected from these exposures.

UPSTREAM SITE

Along this part of the North Fork of the Nehalem·River, a natural levee forms the top of the·riverbank. The surface vegetation consists of a wetland forest with *Picea sitchensis* (Sitka spruce) predominating. This part of the river is affected by the diurnal tides but only the highest spring tides come up to the top of the levees.

Four buried units are visible along this length of the riverbank (fig. 6). The uppermost and the fourth unit down are characterized by containing many spruce stumps and the second and third units are not as obvious in outcrop. However, the second buried unit forms a small 'bench' along this section of the river that can be traced for quite a distance downstream.

A 22-m segment of this outcrop was carefully measured and sketched. After the outcrop was cleaned, elevations of the buried soil horizons were obtained by

using the rising tide level as a horizontal datum.

Uppermost buried soil

The uppermost buried soil along this section of the riverbank is composed primarily of many roots and stump systems. The soil associated with this woody.layer is thin and not very obvious in outcrop. When cored right behind the outcrop, it appears as a peaty mud containing many twigs and woody roots. In boreholes, the contact of this unit with the overlying sediments is very sharp. There is both a definite color change (from gray to brown) which reflects an increase in the amount of organic material contained in the peaty horizon. There is also a definite grain-size change across the boundary with a change·from a silty mud to a sandy silt. This sandy silt grades upward into silt and the present forested wetland surface.

The only plant fossils identified in the peaty interval is the woody roots and stumps of Sitka spruce. The sandy silt that overlies the peaty horizon contains probable *C. lyngbyei* thizomes. These plant fragments are quite decomposed, however, and are hard to positively identify along this portion of the outcrop.

Second buried soil

The second buried soil horizon is most obvious because it forms a prominent bench in the mid-tidal region. The contact of the muddy peat horizon is fairly sharp and there is a definite grain-size change from the silt in the peaty unit to a very fine sandy silt just above the contact. This sandy silt grades upward into a silt and the organic-rich horizon of the overlying uppermost buried soil. The peaty horizon contains some questionable *D. spicata* and *C. lyngbyei* rhizomes as well as twigs and numerous spruce cones. Numerous *T. maritima* rhizomes are located in the sandy silt approximately 5 cm above the peaty unit. It is actually these rhizomes that form the bench since their roots are very fibrous and tend to prevent erosion of the sandy silt matrix.

Third buried soil

The third buried soil only appears faintly in both outcrop and boreholes along this section of the riverbank. It appears to primarily be a fairly degraded peat at this site although a *Juncus* rhizome was found near the right side of the outcrop in the top of the peaty soil. Some wood and bark fragments were found lying in contact (above) the peaty soil. This peaty former surface is overlain·by silt, which grades up into the peaty second buried soil. The elevation of this buried soil lies just below MLW, which means that it is difficult to ordinarily see in outcrop.

Fourth buried soil

The fourth buried soil at this outcrop is inundated by all but the lowest tides. It is visible on the sloping mudflats at the base of the vertical riverbanks. The most obvious feature associated with this buried unit are the large spruce stumps (about 2 m across), which are partially buried in the intertidal silts. In boreholes, the soil associated with these stumps is a very woody and organic-rich unit with a sharp upper contact with the overlying sediments. This peaty unit is overlain by a thin mantling of fine sand, which grades up into a very fine sandy silt and then the silt of the overlying third buried soil.

DOWNSTREAM SITE

The stratigraphy at the downstream site at the Nehalem River (fig. 7) is similar to that found upstream. Both the uppermost buried soil and the fourth buried soil are very obvious because of their woody horizons. The two intervening buried units (second and third buried soils) are much harder to see in outcrop. This outcrop is on the outside edge of the river and is actively being eroded. A dike has been built about 5 m behind the outcrop and its surface vegetation is characterized by Sitka spruce and willow. The small expanse of marsh adjoining the dike is primarily a high marsh

environment and is characterized.by high marsh plants such as the bentgrass, *Agrostis*, *Aster subspicatus*, *Q. sannegtosa*, and *P. pacifica*, as well as *J. balticus*. Dense stands of *C. lyngbyei* and *T. maritima* grow on some of the blocks that have slumped off the riverbank and lie in the intertidal zone.

This outcrop extends for at least 160 m. All four buried soils extend over the entire length of the exposure except in the vicinity of a large slump near the center of the outcrop. (fig. 7). All of the elevations in this outcrop were determined by leveling and are relative to one spot on the marsh surface near the center of the outcrop.

Uppermost buried soil

The uppermost buried soil along this section of the riverbank varies·quite a bit from a slightly peaty mud to a fully developed wetland peat containing woodland litter and spruce cones. At several places along the outcrop, extensive root systems and stumps are preserved·in the soil. Around 10 cm of very fine to fine sandy silt containing twigs and wood fragments overlies the peaty horizon and then grades upward into a few centimeters of a fine to medium .sand. Fossil remnants of abundant *T. maritima* rhizomes form a cohesive mat that produces a prominent 'bench' at this level. Laminated silts and sands grade upwards from this sand unit up into the silty mud of the present marsh surface.

Paleo-elevations are easy to determine from the uppermost buried soil along this section of the estuary because the plant fossils are well-preserved. The roots and stumps in the peaty horizon are probably Sitka spruce. This peaty unit also contains *Juncus* and *Potentilla* rhizomes, which stick up through the top of the unit into the overlying sediments. In the sandy silt that composes the 'bench' overlying the peaty unit, abundant *T. maritima* and *Scirpus maritimus* rhizomes are found. *S. maritimus* and *T. maritima* are the primary invaders of mudflats in the Nehalem River estuary and are found colonizing mudflats as low as l.3 m above MLLW (Eilers, 1975). *P. sitchensis* is first found at about 3.0 m above MLLW in this estuary (Eilers, 1975),

indicating that approximately 1.5 m of subsidence could have changed conditions from a wetland spruce forest to mudflat conditions. As was stated for the Salmon River, this change in elevation must have occurred very rapidly to preserve the plant remnants that stick up into the sediments overlying the buried peaty horizons.

Second buried soil

The second buried marsh soil along this section of the river outcrops right under the vertical cut bank of the riverbank. It is composed of a muddy peat and is overlain by a few centimeters of fine sand. This sand unit grades up into the silt and then the peaty horizon of the uppermost soil. Abundant *T. maritima* rhizomes are rooted in the sand layer, which overlies this second buried soil, but it was not possible to identify any plant remains in the peaty horizon itself.

Third buried soil

The third buried soil at this outcrop is very similar to the second buried soil. It, too, is overlain by a few centimeters of fine sand, which contains *T. maritima* rhizomes rooted in the sand. The sand grades up into silt and the peaty horizon associated with the second buried soil. The peaty horizon of this third buried soil is approximately 50-80 cm below the second buried soil.

Fourth buried soil

The fourth buried soil along this part of the estuary is very similar to its exposure at the upstream site and is characterized by large spruce stumps sitting in the sloping tide flats below the outcrop. In boreholes, the soil associated with this fourth buried unit is a muddy peat containing a lot of wood fragments. The peaty horizon is overlain with sandy silt which grades upward into the muddy peat of the third buried soil. *T. maritima* rhizomes are located within the sandy silt strata indicating a rapid change in paleo-elevations across the burial boundary, very similar to the uppermost

buried soil. Thus, subsidence on the order of 1.5 m occurred during the time of burial of this wetland spruce forest, similar to the amount of subsidence that buried the uppermost buried soil.

ARCHAEOLOGICAL DISCOVERIES

Prior to the most recent subsidence event at both the Nehalem and Salmon rivers, there is evidence that these two areas were utilized as seasonal fishing camps by the native inhabitants of this region of the coast. The evidence for this is in the discovery of the remains of firepits or hearths that are evident just below the uppermost buried soils at both river systems. These sites were found at SR140 (fig. 2) on the Salmon River and at the upstream site (fig. 3) at the Nehalem River. In both cases, the evidence for these encampments consists of exposures of fire-cracked rock and charcoal fragments scattered along many meters of the outcrop. These hearths and the implications for the coastal prehistory of this part of the Oregon coast are described in more detail in another paper (Minor and Grant, in preparation), but a schematic diagram of two of these hearths is presented in figure 8.

RADIOCARBON DATING

Samples were collected for radiocarbon dating for each of the four buried units at both the Salmon and Nehalem Rivers. In most cases, I collected samples of materials that I thought would most closely date the episode of submergence, but I occasionally sampled materials that would provide limiting ages on the submergence as well. In actuality, since most of the samples collected were within the buried peat horizon, these samples provide ages that should predate the episode of submergence. Types of samples which predate the submergence include bulk peat (obtained from the uppermost 2 or 3 cm of the buried peaty horizons), spruce roots and stump fragments, charcoal, and detritus, such as spruce cones, sticks, and bark fragments lying on the buried surfaces or within the uppermost centimeter or so of the peaty horizon.

Samples which postdate the subsidence are the *Triglochin* rhizomes since this plant is an early colonizer of the tide flats.

An assumption was made·that the spruce trees that were living on the marsh surface at the time of submergence and burial probably died soon after the submergence due to the increased salinity conditions. Thus, samples of spruce roots and stumps were taken from the outermost rings that I could find (usually ~20 rings or so) in the hope that this age would closely approximate the time of tree death. However, since I was not able to find intact bark on all the roots and stumps I sampled, it is not certain that these outermost rings necessarily date the age of death of the tree since some outermost rings could have eroded away. However, because of the large uncertainties contained in the radiocarbon dating of the samples, the samples I collected may approximate the time of subsidence closely enough.

Since radiocarbon ages do not correspond on a one to one basis with calendar years, the computer program of Stuiver and Reimer (1986), which is based on the calibration curves of Stuiver and Pearson (1986), was used to convert the radiocarbon ages to calendar years (AD and BC) and years before present (yrs BP, by convention, 'present' refers to the year 1950). These calibrations were done using the one standard error limits provided by Beta Analytic (which is partly a function of counting time) and with an error multiplier of 2.0. This error multiplier was chosen to be consistent with the calibrations done by other coastal workers who felt that this value included most of the sources of error (e.g., Atwater, 1992).

All samples were dated by conventional radiocarbon means by a private laboratory: Beta Analytic, Inc. The results of the dating, a description of the sample, and the calibrated ages are presented in Table 1.

Table 2 presents average radiocarbon ages and their calibrated equivalents from both river systems. The radiocarbon ages were averaged using a weighted mean average with a 1-standard-error range. An error multiplier of 2.0 was used in the calibration to calendar years and years before present, the same as in the calibration of

the single radiocarbon ages. Samples that were used in the average ages in Table 2 are marked by an asterisk in Table 1.

SALMON RIVER

Because only the uppermost buried soil at the Salmon River was exposed in outcrop, it was difficult to obtain samples of the deeper units for radiocarbon dating. I attempted to collect samples for the three buried deeper units from two of the boreholes in the closely-spaced transect (fig. 5). For all three deeper units, a single bulk peat sample for each layer was obtained by repeated coring. This type of collection leads to the introduction of possible errors into the sampling process since each repeated core can contain material that had been dragged into the column from higher levels. Nevertheless, these ages from the three deeper units provide·some information on the time of marsh burial. I did not average the ages for the three deeper units from this transect since I was uncertain about the correlation between the buried soils. Radiocarbon ages from these deeper three units are 1090±70, 1690±100, and 1410±70 radiocarbon years for buried soils two, three, and four, respectively. The calibrated ages that correspond to these radiocarbon ages are in Table 2.

In contrast, the uppermost buried unit was very easy to sample at the Salmon River and samples were obtained that should closely time the age of the subsidence of this soil. Eleven samples were collected from this unit in total; six of these samples were bulk peat, three were *Triglochin* rhizomes rooted in the soil above the buried peat, and the other two were single samples of *Triglochin* rooted about 50 cm below the peat, and a stick about 2.5 cm above the top of the peat. These two samples were excluded from the averaging. The *Triglochin* sample predates the peat and the age of the stick was so much older than the other samples in this horizon that I could justify excluding it on the basis that it must have been recently exhumed and redeposited on top of the uppermost buried soil. The average radiocarbon age obtained from the nine samples in the uppermost

buried soil is 246±25 radiocarbon years.

NEHALEM RIVER

More samples for radiocarbon dating were collected at the Nehalem River than the Salmon River because the deeper units are exposed in outcrop. Samples utilized for dating were obtained only from outcrops and none from boreholes. Even though all four buried soils were exposed in outcrops, it was easiest to obtain the best samples from the uppermost buried soil and consequently, this soil is the best dated at this locality. The results are presented in Table 1 and the average radiocarbon ages are contained in Table 2.

Twelve samples were collected for radiocarbon dating the time of subsidence of the uppermost buried soil at the Nehalem River (Table 1). These samples include two of peat, five of *Triglochin* rhizomes, two detrital (bark and twig) samples, and three samples of spruce roots. All twelve of these samples were averaged to give a radiocarbon age of 230±18.

For dating the second buried soil at the Nehalem River, nine samples were obtained. One of these was peat, three were detrital (a stick and two samples of spruce cones), and five were *Triglochin* rhizomes. The average age for this buried soil is 846±22 radiocarbon years.

It was harder to collect samples for radiocarbon dating from the third buried soil than from the two upper soils because this soil horizon was pretty well degraded. Only one sample of peat and one of *Triglochin* rhizomes was collected. The average age of these two samples is 1395±57 radiocarbon years.

Five samples from spruce stumps and one of *Triglochin* rhizomes were obtained for dating the fourth buried soil at the Nehalem River. The average age on these six samples is 1752±25 radiocarbon years.

INDIAN HEARTH SITES

Charcoal fragments from three of the hearth sites were obtained for radiocarbon dating. Two of these samples are from two different hearths at the Salmon River and

one from the Nehalem River. These samples are keyed as SR140A, SR140-91, and NR111- 21E in Table 1. The average radiocarbon age for these three samples is 560±35, which predates the age of the uppermost buried soil at both the Salmon and Nehalem Rivers.

DISCUSSION

It is difficult to envision a scenario other than earthquake-induced subsidence that could episodically drop coastal wetlands into the intertidal zone along this part of the Pacific Northwest coast during the late Holocene. Changes in barrier structures, floods, and storms could cause deposition over wetland surfaces; however, none of these processes could cause the rapid change in apparent sea level that is observed in the buried soils at the Salmon and Nehalem River.

Although all four buried soils at both the Nehalem and Salmon rivers appear to have peaty soils, which probably indicates that subsidence caused the submergence and burial of these soils, the case for subsidence can be made most strongly for only the uppermost buried soils at the Salmon River and Nehalem River, and the fourth buried soil at the Nehalem River. The other buried soils do not have the plant fossils that indicate that a change in elevation definitely caused the submergence of the soils. However, except for the absense of plant fossils that would indicate that a change in elevation occurred, these soils are very similar to soils which are better 'candidates' for subsidence. In most cases, these other buried soils are composed of a peaty structure that is indicative of soil development rather than detrital in nature. In addition, in many areas these peaty soils are overlain by silt and sand that contain numerous *Triglochin* rhizomes. At both rivers, in the present marsh where *Triglochin* is an early colonizer of unvegetated mudflats, there is no peaty soil associated with the presence of these plants. A well-formed surficial peaty soil was only observed in the high marsh environment.

The sudden upward thrusting of the seafloor during a subduction earthquake

generates a tsunami. These tsunamis inundate coastal regions in the earthquake source area within minutes following local subduction earthquakes. If a tsunami accompanied the subsidence of the coastal regions along the Oregon coast, it is expected that evidence of the wave might be found in the coastal stratigraphy. However, only the uppermost buried soil at the Salmon River shows any strong evidence that a tsunami closely followed the subsidence of the marsh. This evidence consists of a mantling of sand on top of the marsh surface. The sand deposition must have happened very soon after the subsidence since plant fragments in growth position are intact in the overlying sand. If subsidence occurred much earlier than the deposition of the sand sheet, it would be expected that the tidal currents sweeping across the lowered marsh would soon destroy these plant fragments. Although sand was observed on top of some of the deeper buried soils at this estuary, these deeper soils were not widespread enough so that a sand distribution map could be made.

There is little evidence that a tsunami accompanied any of the four episodes of subsidence at the Nehalem River. There is a fairly thin silt unit containing twigs and wood fragments that mantles the uppermost buried soil at this estuary. However, I believe this silt layer represents the initial settlement of sediment following the shaking which the earthquake must have caused. The existence of the 4-km-long Nehalem sand spit provides a protective barrier to most of the tidal marshes at Nehalem River. If a tsunami wave did travel up the channel of the river, it would have lost much of its momentum and dropped much of the sediment load by the time it got to the study area. This sand spit has probably been in existence for the last several thousand years since there are large spruce stumps in growth position on the spit. These stumps are not yet dated but may have been growing in the fourth buried soil at the time of its submergence since they occupy roughly the same current elevation as the stumps in the fourth buried soil at the upstream and downstream sites.

Although radiocarbon dating techniques will never be able to prove that both the Salmon and Nehalem Rivers underwent subsidence at the same time, dating of the

uppermost buried·unit at both rivers indicates a timing for subsidence that is indistinguishable between the sites (Table 2), suggesting that both rivers might have undergone concurrent subsidence. If the subsidence age for the uppermost buried soils at both rivers is averaged, an age of 235±15 ^{14}C yrs is obtained. This radiocarbon age calibrates to an age range of 285-304 calendar yrs BP, which corresponds to AD 646-1665. This timing of subsidence predates by several decades the age estimate of AD 1698±14 that Atwater et al. (1991) obtained from tree rings of trees that were presumably killed by earthquake-induced subsidence in coastal southern Washington. However, the samples I dated at the Nehalem and Salmon Rivers consisted of peat, and roots and detritus embedded in the peat, and these types of samples would be expected to predate the actual age of subsidence. Thus, the posibility that a segment of the coast extending from southwestern Washington into northern Oregon subsided during a single Cascadia subduction earthquake cannot be excluded from regional planning estimates of earthquake hazards. Moreover, while there is some question as to whether one or more earthquakes were responsible for subsidence along the entire Cascadia subduction zone, it is noteworthy that spruce trees were killed by sudden coastal subsidence as far south as Humboldt Bay in northern California between AD 1700-1720 (Carver et al, 1992). This time span includes the time of tree death (1698±14) that Atwater et al (1991) obtained for coastal southern Washington. Although not as precisely dated, other estuaries along the Pacific Northwest Coast, such as Coos Bay in southern Oregon (Nelson 1992) and Netarts Bay in northern Oregon (Darienzo and Peterson, 1990), also show ages of submerged coastal wetlands in the same age range as in southern Washington and northern California.

The deeper buried soils at both river systems are not as well dated as the uppermost buried soils. In particular, since only single radiocarbon ages were obtained for each of the deeper buried units at the Salmon River, the ages of these buried soils are not well constrained. Thus, it is not valid to compare the ages of the buried soils there to the Nehalem deeper buried soils, which are better constrained by

dating.

In evaluating earthquake hazards in a particular area, it is necessary to know something about the repeat times and recurrence rates of earthquakes generated on a particular structure. If each of the buried soils at the Nehalem River represent tectonic lowering of the former marsh surface as a result of subsidence due to a Cascadia subduction earthquake, then an estimate of the recurrence rates of abrupt marsh burial for the Nehalem River can be made. The midpoint of each age range of calendar years (AD) is obtained for each episode of subsidence from the ages in Table 2. The differences between these midpoints from one soil to the next represents the time between each event. These time intervals are 655 years between the first and second marsh burial, 523 years between the second and third burials, and 336 years between the third and fourth burial. These intervals ayerage out to a repeat time of 505 years for subsidence events in the Nehalem River estuary. However, since the level of uncertainty (due to the paucity of plant remains which conclusively indicate subsidence rather than just submergence) is much higher for the second and third buried soils, it may not be valid to include these two intervening soils as subsidence events in estimates of recurrence. If only the first and fourth buried soils are used as definite examples of marsh subsidence events at the Nehalem River, then an average repeat time of approximately 1600 years is obtained. The difference between repeat times of approximately 500 or 1500 years for Cascadia subsidence earthquakes would probably have a large effect on the earthquake hazard planning that is implemented for the Pacific Northwest Coast.

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Figure captions

Figure 1. Map of the Cascadia subduction zone showing the location of places mentioned in the text. The heavy line with the barbed arrows indicates the approximate location of the Cascadia deformation front where the Juan de Fuca plate subducts under the North American plate.

Figure 2. Map of the Salmon River estuary. The dark circles indicate sites from which samples were obtained for radiocarbon dating. SR140 and SR31 are sites that are referred to in the text. SR140 is also the site at which the Indian hearths (mentioned in the text) were observed. The dashed lines indicate transects with core spacing of approximately 25 m.

Figure 3. Map of the Nehalem River estuary. Downstream and upstream outcrops, Dean's Point and Lazarus Island are all places referred to in the text. The black dots indicate sites from which radiocarbon samples were obtained for dating.

Figure 4. Map of Salmon River showing distribution and thickness of tsunami-laid sand.

Figure 5. Cross-section of closely spaced core transect at the Salmon River showing subsurface stratigraphy and location of radiocarbon samples. This site is underlain by a former sand dune complex and has been abruptly submerged at least four times in the last 2000 years. The shell fragments indicate a deeper water depositional environment than the former soil surfaces. The radiocarbon samples are keyed (by number) to Table 1.

Figure 6. Schematic diagram of Nehalem River upstream outcrop showing four buried units and locations of radiocarbon samples. The radiocarbon samples are keyed (by number) to Table 1.

Figure 7. Schematic diagram of Nehalem River downstream outcrop showing four buried units and locations of radiocarbon samples. The radiocarbon samples are keyed (by number) to Table 1. The smaller black dots indicate control points for a leveling survey.

Figure 8. Schematic diagram of the buried hearths at the Salmon River. At this site, the buried hearths predate the subsidence of the overlying soil indicating that this estuary was utilized by Native Americans prior to the earthquake-induced subsidence. The fire-cracked rocks are remnants of rocks that were heated in the firepits and then dumped into baskets to heat water.

Tables

Table 1. Table of radiocarbon data showing location, type of sample, depth of sample, age and calibrated age with samples keyed to figures *5,* 6, and 7.

Table 2. Average radiocarbon ages for each buried unit at Nehalem and Salmon Rivers.

Figure 1

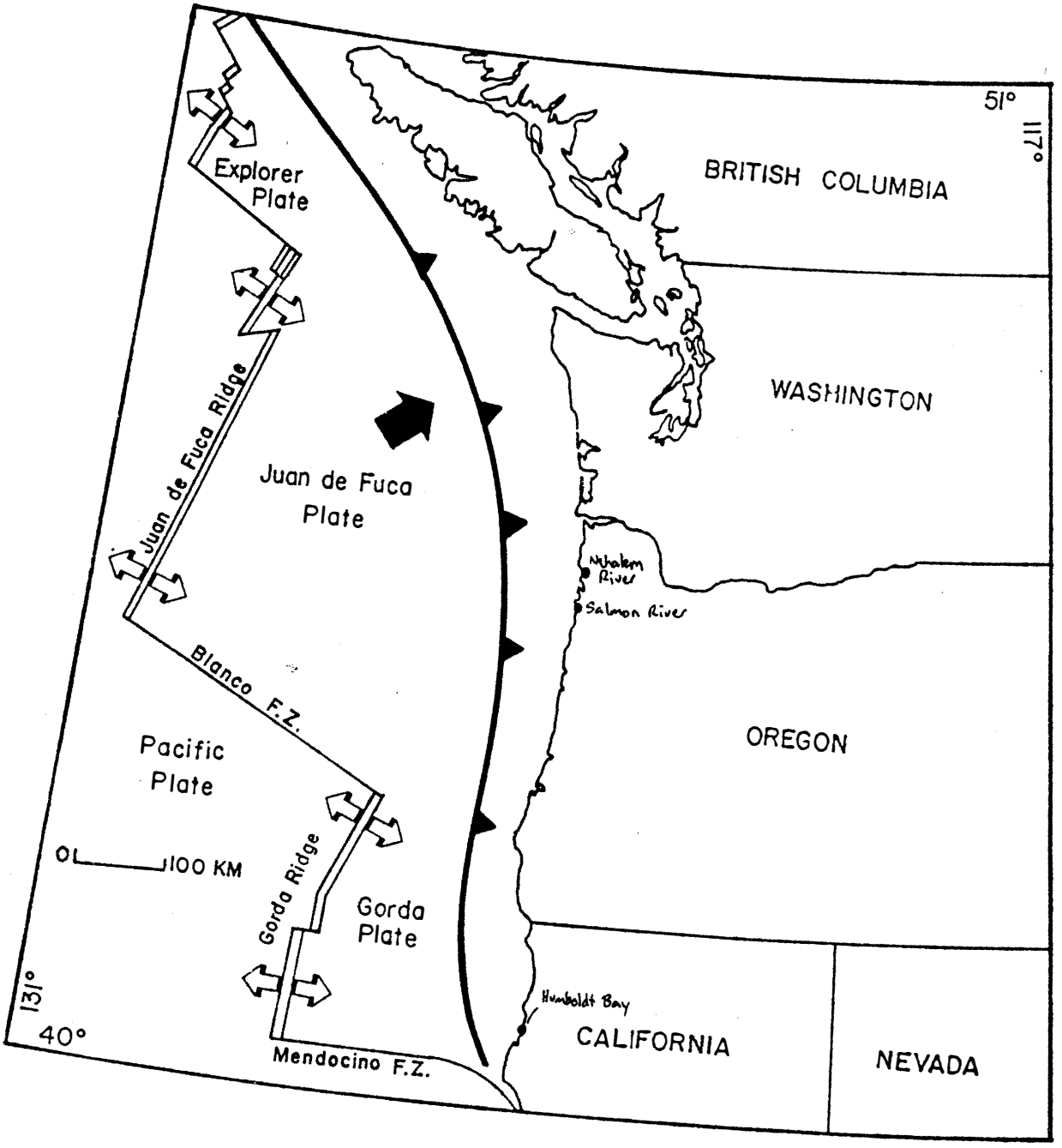

51°
117°
BRITISH COLUMBIA
WASHINGTON
OREGON
CALIFORNIA
NEVADA
Explorer Plate
Juan de Fuca Ridge
Juan de Fuca Plate
Blanco F.Z.
Pacific Plate
Gorda Ridge
Gorda Plate
Mendocino F.Z.
Nehalem River
Salmon River
Humboldt Bay
0
100 KM
131°
40°

Figure 2

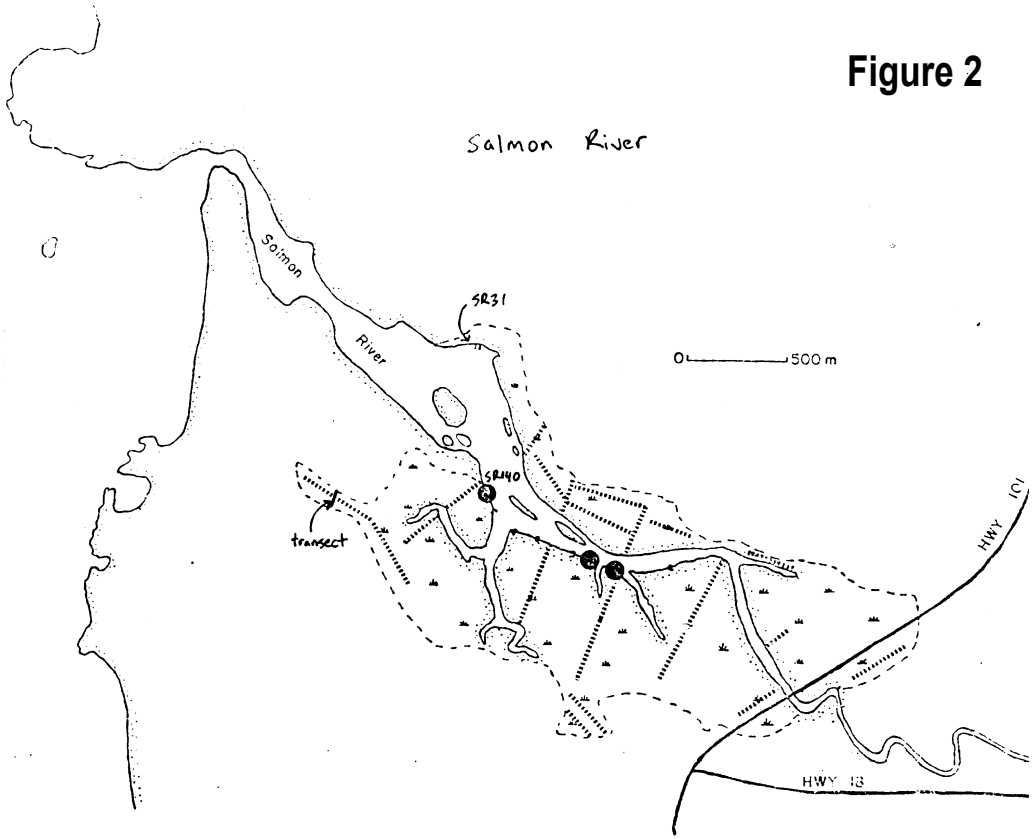


Figure # 2

Figure 3

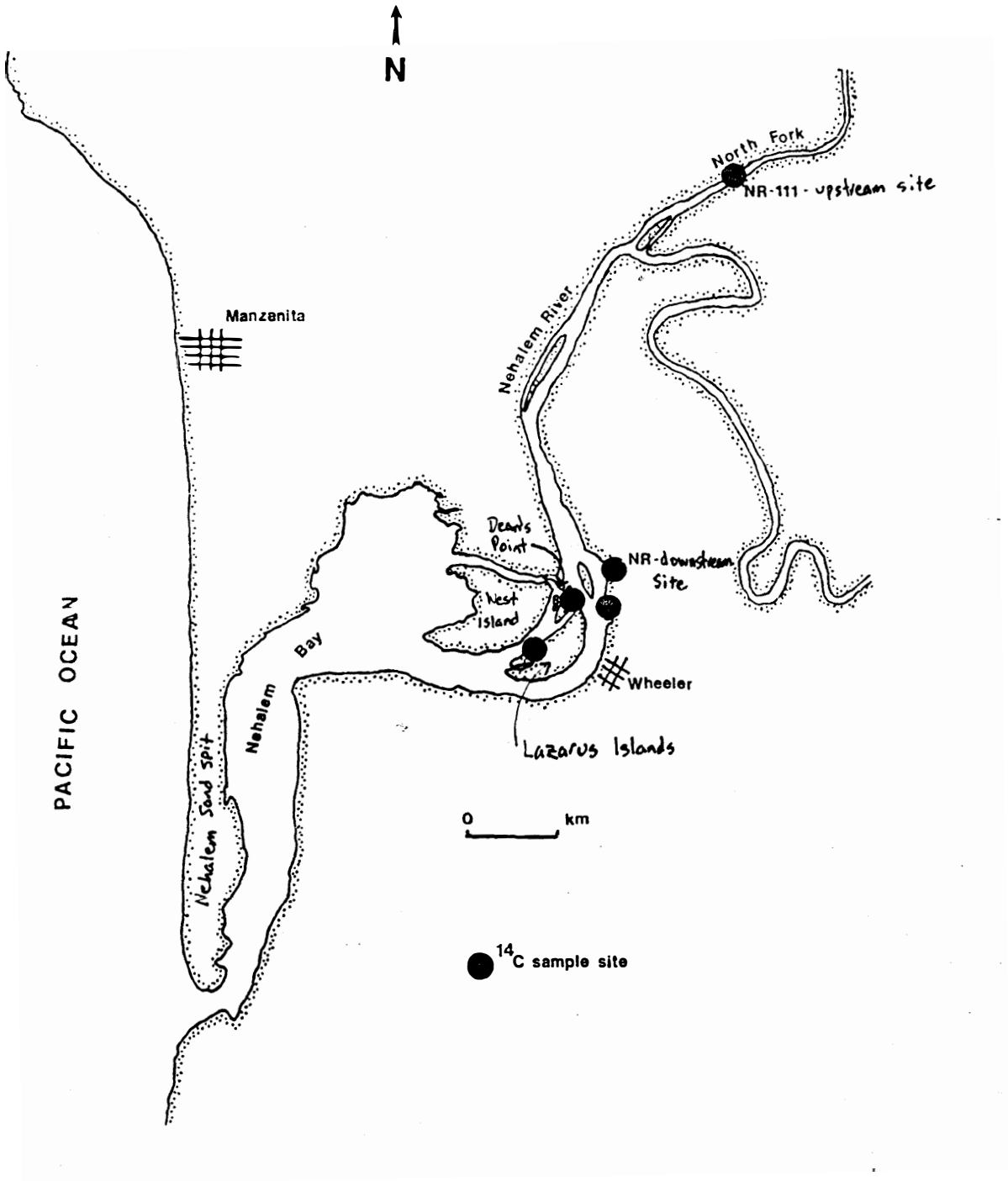

N
North Fork
NR-111 - upstream site
Nehalem River
Manzanita
Deans Point
NR-downstream Site
West Island
Bay
Nehalem
Wheeler
Lazarus Islands
PACIFIC OCEAN
Nehalem Sand Spit
0
km
14C sample site

Figure 4

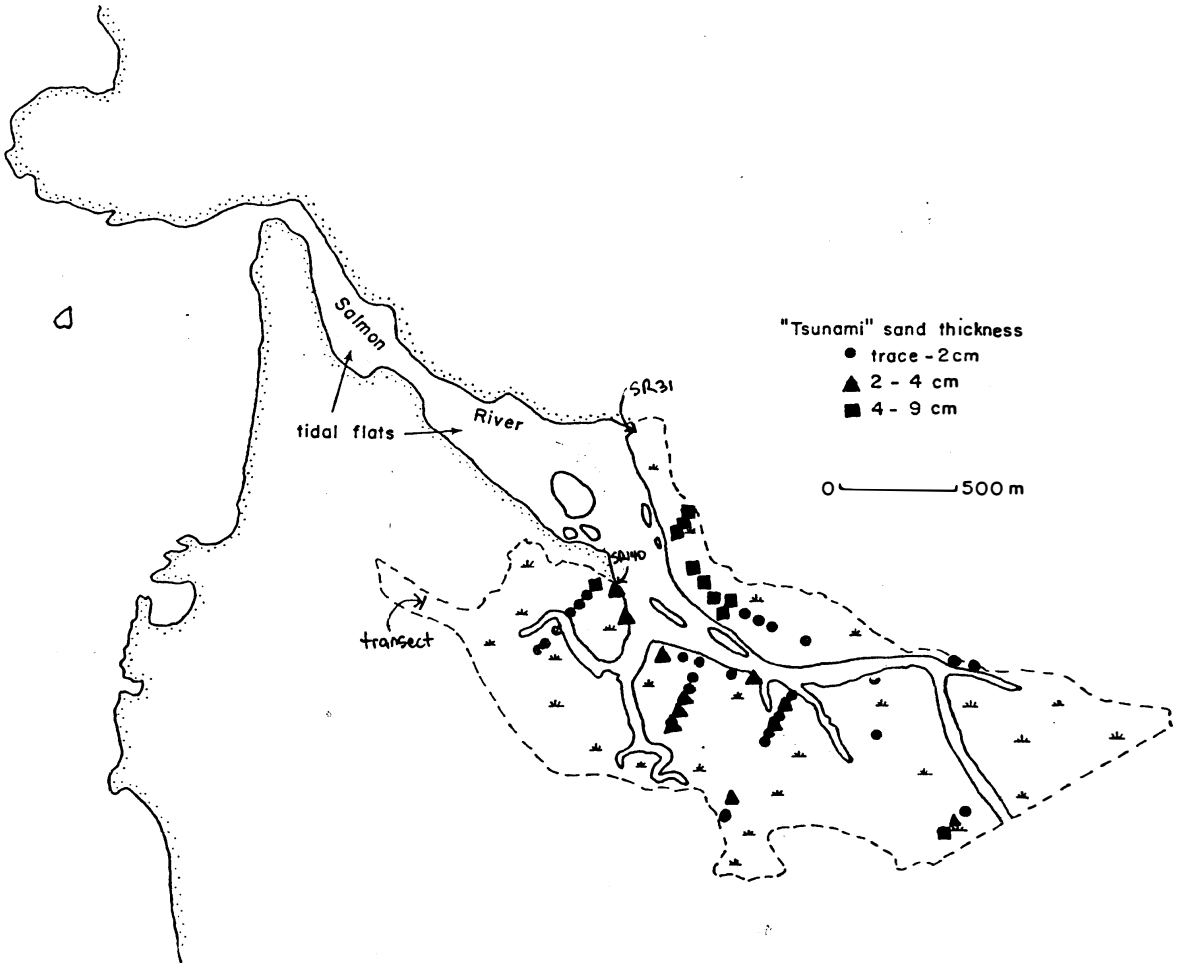

Salmon
River
tidal flats
SR 31
SAMO
transect
"Tsunami" sand thickness
trace - 2 cm
2 - 4 cm
4 - 9 cm
0
500 m

Figure 5

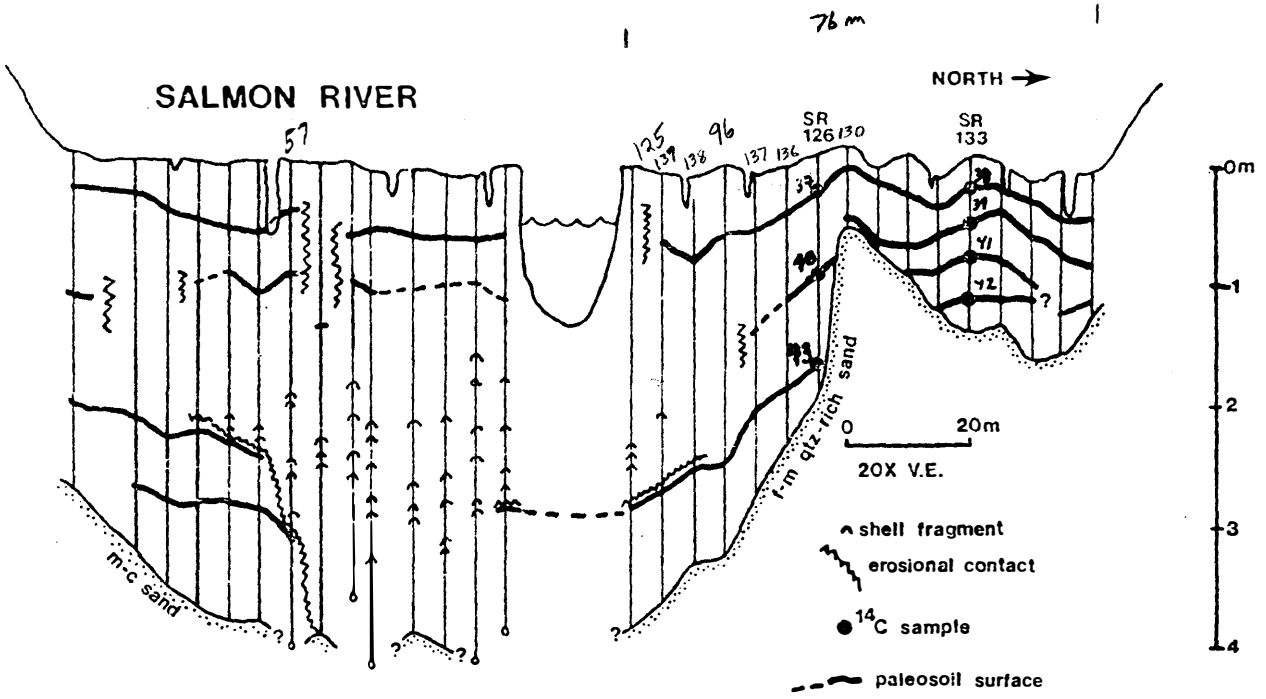
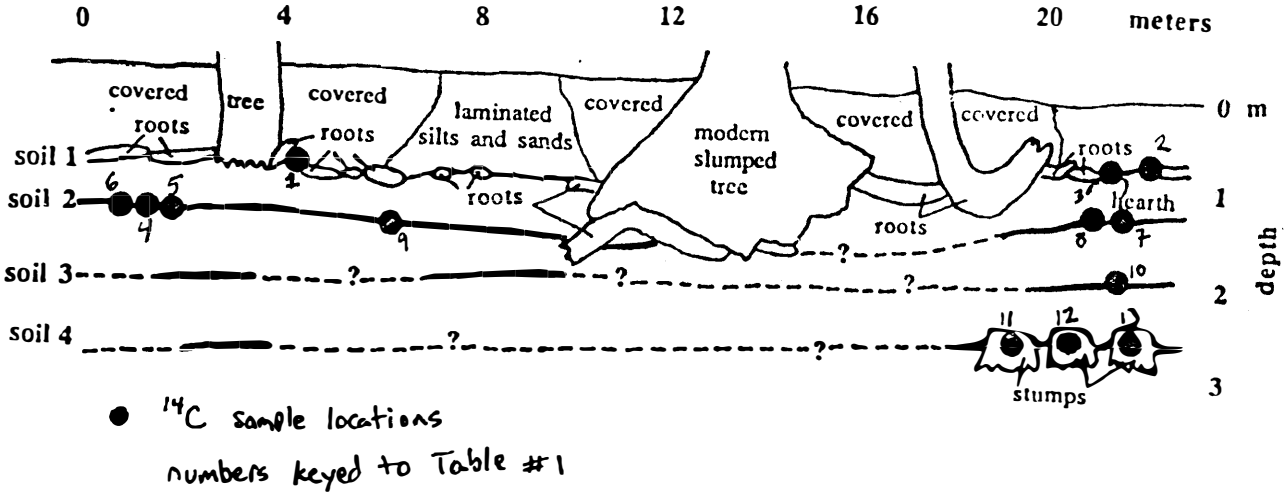

76 m
SALMON RIVER
NORTH
57
125
139
138
96
137
136
SR
126
130
SR
133
33
39
40
41
42
43
?
m-c sand
1-m qtz-rich sand
0
20m
20X V.E.
shell fragment
erosional contact
14C sample
paleosoil surface
0m
1
2
3
4

Figure 6



● ^{14}C sample locations

numbers keyed to Table #1

Figure 7

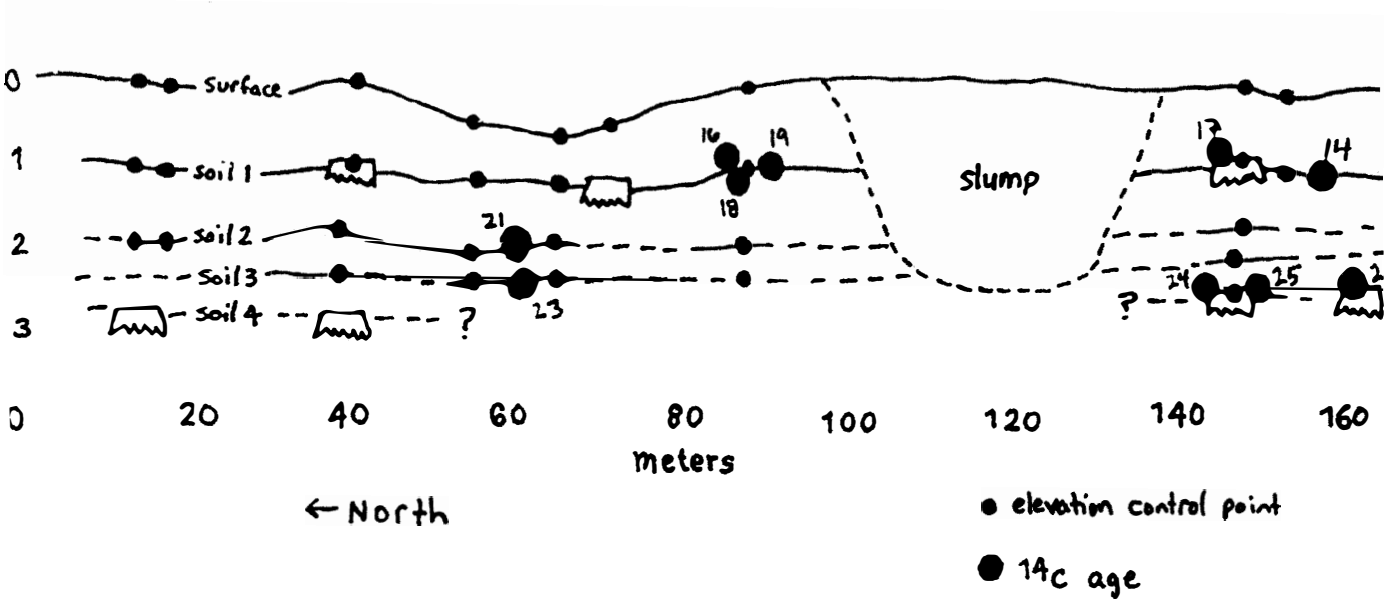

0
1
2
3
Surface
soil 1
soil 2
Soil 3
soil 4
?
16
19
18
21
23
slump
17
14
24
25
?
0
20
40
60
80
100
120
140
160
meters
← North
elevation control point
14C age

Figure 8

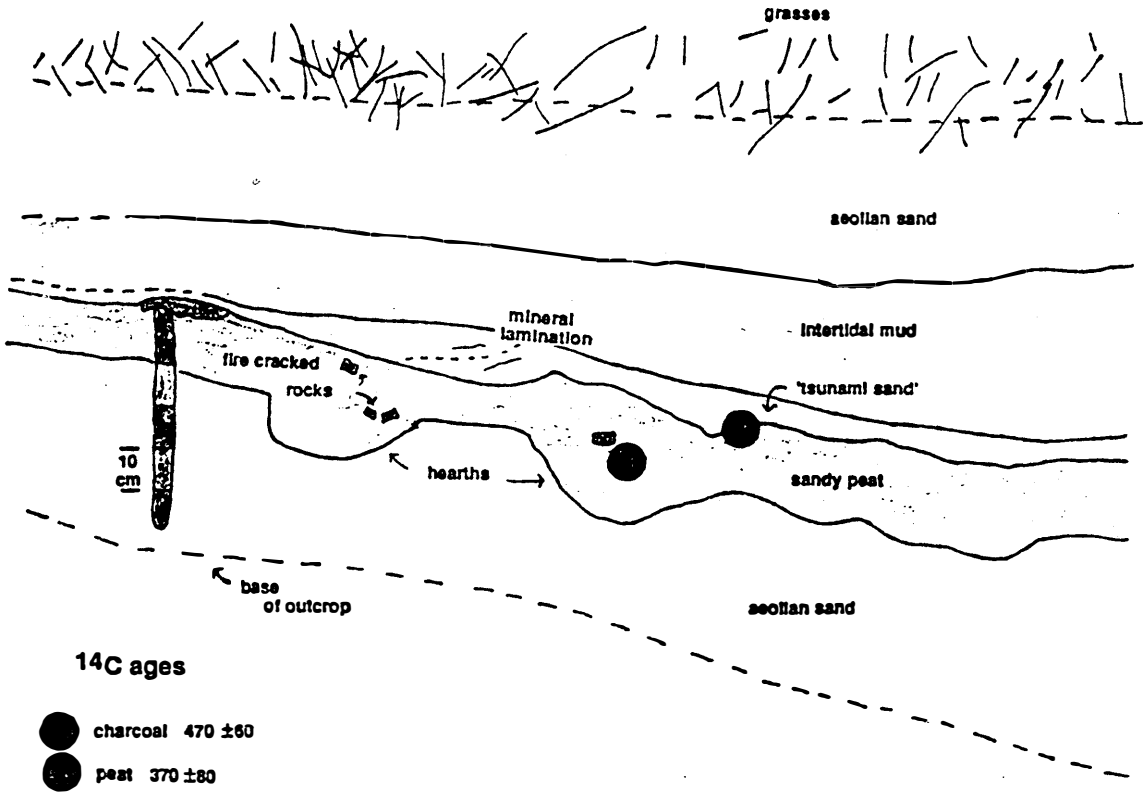

grasses
aeolian sand
mineral lamination
intertidal mud
fire cracked rocks
'tsunami sand'
10 cm
hearths
sandy peat
base of outcrop
aeolian sand
14C ages
charcoal 470 ±60
peat 370 ±80

Table 1 - Radiocarbon data for Nehalem and Salmon River sites

Radiocarbon Data - Nehalem River

Key #	Location ID	Depth Below Surface (cm)	Statigraphic Position Relative to Former Soil Surface (cm)	Material Dated	Age in Radiocarbon Years before A.D. 1950 (±1 σ)	Age Range in Calendric Years before A.D. 1950 Yrs BP Error Multiplier =2	Age Range in Calendric Years before A.D. 1950 Error Multiplier =2	Laboratory Number
1								
2				**45° 44.36', 123° 51.73'**				
3	NR111-4A	100	in soil 1	Spruce root	70 ± 50	0 - 276	1674 - 1955	Beta-27860
4	NR111-21F	105	in soil 1	Spruce roots	430 ± 60	317 - 550	1400 - 1633	Beta-27866
5	NR111-21E	105	~5 cm below soil 1 top	Charcoal	660 ± 60	540 - 690	1260 - 1410	Beta-27865
6	NR111-1C	140	~10 cm above soil 2	Triglochin rhizomes	780 ± 75	576 - 907	1043 - 1375	Beta-31815
7	NR111-1D	140	on top of soil 2	Spruce cones	680 ± 60	550 710	1240 - 1400	Beta-31816
8	NR111-1B	145	~5 cm above soil 2 top	Spruce cones	640 ± 70	530 - 690	1260 - 1420	Beta-27857
9	NR111-21D	150	top 3 cm soil 2	Peat	1355 ± 80	1094 - 1400	550 - 856	Beta-27864
10	NR111-21H	152	2.5 cm below soil 2 top	Stick	1060 ± 80	790 - 1160	790 - 1160	Beta-28595
11	NR111-6A	160	~10 cm below soil 2 top	Triglochin rhizomes	950 ± 60	730 970	980 - 1220	Beta-27861
12	NR111-21B	200	top 5 cm of soil 3	Peat	1630 ± 80	1350 - 1720	230 - 600	Beta-27862
13	NR111-3A	250	in soil 4	Spruce stump	1550 ± 80	1300 - 1830	268 - 650	Beta-27858
	NR111-25-4	250	in soil 4	Spruce stump	1600 ± 60	1350 - 1686	264 - 688	Beta-31817
14	NR111-3B	250	in soil 4	Spruce stump	1700 ± 60	1510 - 1740	210 - 440	Beta-27859
1				**45° 41.87', 123° 52.81'**				
16	NR112A	60	~15 cm above soil 1	Triglochin rhizomes	110 ± 60	0 - 290	1660 - 1955	Beta-27867
17	NR77A	75	~5 cm above soil 1	Triglochin rhizomes	260 ± 65	0 - 480	1470 - 1955	Beta-23210
18	NR114A	80	top 3 cm of soil 1	Peat	130 ± 60	0 - 300	1650 - 1950	Beta-27871
	NR122A	80	in soil 1	Spruce root	170 ± 60	0 - 310	1640 - 1950	Beta-31818
20	NR114C1	98	3 cm below top of soil 1	Sticks	290 ± 90	0 - 520	1430 - 1955	Beta-27874
19	NR114C2	98	3 cm below top of soil 1	Bark	350 ± 50	300 - 510	1440 - 1650	Beta-27875
	NR130A2	123	~2 cm above soil 2	Triglochin rhizomes	970 ± 50	780 - 970	980 - 1170	Beta-45952
21	NR130A	125	~5 cm above soil 2	Triglochin rhizomes	790 ± 70	660 - 907	1043 - 1290	Beta-45951
22	NR77C	125	~5cm above soil 2	Triglochin rhizomes	630 ± 70	520 - 690	1260 - 1430	Beta-23211
23	NR130B	178	~2cm above soil 3	Triglochin rhizomes	1160 ± 80	930 - 1280	670 - 1020	Beta-45954
24	NR113A	205	~20 cm above soil 4	Triglochin rhizomes	1970 ± 60	1820 - 2059	110BC - 130	Beta-27868
25	NR113B	225	in soil 4	Spruce stump	2060 ± 80	1860 - 2311	362BC - 90	Beta-27869
26	NR113C2	225	in soil 4	Spruce stump	1700 ± 60	1510 - 1740	210 - 440	Beta-27870

				45° 41.86', 123° 53.12'				
27	NR9A	85	~75 cm above soil 1	Triglochin rhizomes	120 ± 60	0 - 300	1650 - 1955	Beta-23207
28	NR9B	162	top 4 cm soil 1	Peat	560 ± 70	500 - 670	1280 - 1450	Beta-23208
29	NR9C	170	10 cm below soil 1 top	Triglochin rhizomes	390 ± 70	300 - 540	1410 - 1650	Beta-23209
				45° 41.55', 123° 53.41'				
30	NR8B	80	~30 cm above soil 1	Triglochin rhizomes	60 ± 60	0 - 279	1671 - 1955	Beta-23206

Radiocarbon Data - Salmon River

Key #	Location ID	Depth Below Surface (cm)	Statigraphic Position Relative to Former Soil Surface (cm)	Material Dated	Age in Radiocarbon Years before A.D. 1950 (±1 σ)	Age Range in Calendric Years before A.D. 1950 Yrs BP Error Multiplier =2	Age Range in Calendric Years before A.D. 1950 Yrs AD Error Multiplier =2	Laboratoty Number
				45° 02.39', 123° 59.13'				
31	SR153A	80	~5 cm above soil 1	Triglochin rhizomes	130 ± 70	0 310	1640 - 1955	Beta-27881
32	SR151B	85	top ~ 3cm of soil 1	Peat	400 ± 70	300 - 540	1410 - 1650	Beta-27880
				45° 02.04', 123° 59.19'				
33	SR12B	75	~3 cm top of soil 1	Peat	340 ± 80	0 530	1420 - 1955	Beta-23205
34	SR140E	75	top 3 cm of soil 1	Peat	370 ± 80	290 - 540	1410 - 1660	Beta-27877
35	SR140A	87	~12 cm below soil 1	Charcoal	470 ± 60	440 - 628	1322 - 1510	Beta-27876
36	SR140-91	87	~12 cm below soil 1	Charcoal	550 ± 60	500 - 660	1290 - 1450	Beta-45954
				45° 01.99', 123° 59.74'				
37	SR126-1	33	top 3 cm of soil 1	Peat	240 ± 70	0 - 480	1470 - 1955	Beta-29066
38	SR133-1	29	top 3 cm of soil 1	Peat	310 ± 70	0 - 510	1440 - 1955	Beta-29069
39	SR133-2	58	top 3 cm of soil 2	Peat	1090 ± 70	720 - 1170	780 - 1030	Beta-29070
40	SR126-2	96	top 3 cm of soil 2	Peat	1760 ± 80	1520 - 1870	80 430	Beta-29067
41	SR133-3	85	top 3 cm of soil 3	Peat	1690 ± 100	1354 - 1840	110 - 591	Beta-29071
42	SR133-4	118	top 3 cm of soil 4	Peat	1410 ± 70	1193 - 1420	530 - 754	Beta-29072
43	SR126-3	175	top 3 cm of soil 3	Peat	2080 ± 100	1830 - 2329	390BC # 2289	Beta-29068

				45° 01.81', 123° 58.84'				
44	SR144B	54	~2 cm above soil 1 top	Triglochin rhizomes	260 ± 90	0 - 510	1440 - 1955	Beta-27879
45	SR144A	53	2.5 cm above soil 1 top	Stick	1160 ± 70	940 - 1270	680 - 1010	Beta-27873
				45° 01.80', 123° 58.75'				
46	SR9A	84	~10 cm above soil 1 top	Triglochin rhizomes	100 ± 70	0 - 300	1650 - 1955	Beta-23204
47	SR1B	94	top 5 cm of soil 1	Peat	120 ± 70	0 300	1650 - 1955	Beta-23203
48	SR1A	145	~50 cm below soil 1	Triglochin rhizomes	550 ± 70	500 670	1280 - 1450	Beta-23202

Table 2 - Calibrated mean radiocarbon ages for buried soils

Buried Soil	^{14}C ages ($\pm 1\sigma$)	Calibrated ages (in calendar years before 1950) (1 σ range) error multiplier=2.0	Calibrated ages (in years BP before 1950) (1 σ range) error multiplier=2.0
Salmon River			
uppermost soil	246±25 n=9	1637-1953 AD	0-313 yrs BP
2nd soil	1090±70 n=1	780-1030 AD	920-1170 yrs BP
3rd soil	1690±100 n=1	110-591 AD	1359-1840 yrs BP
4th soil	1410±70 n=1	530-757 AD	1193-1420 yrs BP
Nehalem River			
uppermost soil	230±18 n=12	1646-1953 AD	0-304 yrs BP
2nd soil	864±22 n=9	1060-1226 AD	724-890 yrs BP
3rd soil	1395±57 n=2	550-690 AD	1260-1400 yrs BP
4th soil	1752±25 n=6	225-342 AD	1608-1725 yrs BP