EARTHQUAKE-INDUCED SUBSIDENCE AND BURIAL OF LATE HOLOCENE ARCHAEOLOGICAL SITES, NORTHERN OREGON COAST

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Fire hearths associated with prehistoric Native American occupation lie within the youngest buried lowland soil of the estuaries along the Salmon and Nehalem rivers on the northern Oregon coast. This buried soil is the result of sudden subsidence induced by a great earthquake about 300 years ago along the Cascadia subduction zone, which extends offshore along the North Pacific Coast from Vancouver Island to northern California. The earthquake 300 years ago was the latest in a series of subsidence events along the Cascadia subduction zone over the last several thousand years. Over the long term, subsidence and burial of prehistoric settlements as a result of Cascadia subduction zone earthquakes have almost certainly been an important factor contributing to the limited time depth of the archaeological record along this section of the North Pacific Coast.

The archaeological record along the North Pacific Coast in Washington, Oregon, and northern California is characterized by relatively young sites. Of 38 sites with radiocarbon dates in this region considered in a recent study, 35 produced dates indicating occupation within the last 1,000 to 2,000 years (Lyman 1991:30-34). Only two sites had produced radiocarbon dates suggesting substantial occupation before ca. 3,000 B.P. In contrast, evidence of prehistoric occupation spanning the Holocene has been documented along the Pacific Coast to the north in British Columbia and Alaska as well as to the south in southern California (for recent syntheses, see Lightfoot 1993; Moss and Erlandson 1995a).

The paucity of early sites along the North Pacific Coast in Washington, Oregon, and northern California is generally attributed to erosion and inundation resulting from eustatic sea level rise due to the melting of continental ice sheets. Sea level in this region rose rapidly until about 5,000-4,000 B.P., but only rose slowly after that time (Hutchinson 1992). A temporal lag seems to exist, then, between the time when sea level more or less stabilized and the time when most archaeological sites were occupied within the last 1,000 to 2,000 years (cf. Lyman 1991:33–39).

Recent paleoseismic research suggests that this temporal lag may be, at least in part, the result of submergence of the coastal margin in connection with past tectonic activity. Findings made within the last 10 years indicate that the Cascadia subduction zone, which lies offshore along this section of the North Pacific Coast, has produced a number of great earthquakes over the last several thousand years (Atwater 1987; Atwater et al. 1995).

This report presents site-specific evidence of earthquake-related impacts on two late prehistoric
Figure 1. Map of the Cascadia subduction zone showing the location of places mentioned in the text.
Native American settlements along the Salmon and Nehalem rivers on the northern Oregon coast. This is the first direct evidence so far reported of earthquake-induced submergence and burial of archaeological sites along this section of the North Pacific Coast.

Paleoseismic Background

While not active in the historic period, the Cascadia subduction zone (Figure 1) is known to be capable of producing great (magnitude 8-9+) subduction earthquakes similar to earthquakes produced by other subduction zones (Heaton and Hartzell 1987; Heaton and Kanamori 1984; Hyndman and Wang 1995; Rogers 1988; Savage and Lisowski 1991; Spence 1989; Verdonek 1995). Subduction zone earthquakes produced trench-parallel belts of uplift and subsidence in Chile and Alaska during the 1960s. In both locations, most of the uplift occurred offshore over the rupture area, and the zone of subsidence included much of the adjoining coast. The subsidence—as much as 2–3 m—caused submergence and consequent burial of formerly well-vegetated coastal lowlands (Plafker 1969, 1972; Plafker and Savage 1970).

If subduction earthquakes occurred along the Cascadia subduction zone during the Late Holocene, evidence of zones of uplift and/or subsidence should be preserved along the adjacent section of the North Pacific Coast (Atwater 1987, 1992; Atwater and Yamaguchi 1991; Atwater et al. 1991; Hemphill-Haley 1995). Along both rivers, this buried soil contains abundant rhizomes and basal stems of Baltic rush (Juncus balticus), which in most modern Oregon marshes is only minimally submerged during daily high tides. Also rooted in this buried soil along the Nehalem River are stumps of Sitka spruce (Picea sitchensis), which inhabits wetlands above most high tides. The buried soil at both estuaries is abruptly overlain by upward-fining silt and sandy silt similar to modern tideflat deposits. The silt and sandy silt strata contain diatoms typical of intertidal environments as well as well-preserved rhizomes of bulrush (Scirpus maritimus), seashore saltgrass (Distichlis spicata), seaside arrowgrass (Triglochin maritimurn), and Lyngbye’s sedge (Carex lyngbyeii), all of which are colonizers of the modern tideflats along the Salmon and Nehalem rivers.

The amount of submergence recorded in the Nehalem and Salmon river estuaries can be estimated by comparing the vertical zonation of plants in the modern marsh with fossils of the same plants entombed in the buried soil and in the silt that buried the soil. At the Nehalem River, the top of the buried soil marks a change from a spruce forest to a mudflat that was initially colonized by seaside arrowgrass. This change corresponds to submergence of 1–2 m or more. Plant fossils in the buried soil at the Salmon River estuary indicate presubmergence vegetation like that of the present-day high marsh: submergence of approximately .5 m would suffice to have changed the marsh to unvegetated mudflat. At both rivers this submergence must have occurred rapidly to produce the observed change in vegeta-
Figure 2. Schematic diagram of buried hearths at 35LNC64 on the Salmon River estuary.

Along the Salmon River, a unit of fine- to medium-grained sand that ranges up to 10 cm thick occurs between the buried soil and the overlying tideflat deposits (Figure 2). This sand sheet thins both upriver and toward the uplands, indicating that the sand must have been transported in a landward-directed surge of sandy water. A lack of lamination in the sand unit indicates that the sand was transported in suspension and deposited rapidly. This sandy surge was probably caused by a tsunami generated by the same event that caused the rapid submergence of the soil. Although it is possible that a storm or tsunami emanating from a distant source could have deposited the sand sheet, the presence of the sand unit directly on top of the buried soil and the lack of widely distributed sand sheets elsewhere in the marsh stratigraphy favor the local tsunami hypothesis.

At both the Nehalem and Salmon rivers, riverbank outcrops of fire-cracked rock from Native American fire hearths embedded within the buried lowland soil indicate prehistoric occupation before the submergence. Although formal test excavations have not yet been conducted, the low-elevation setting, as well as the apparently limited nature of the cultural remains, suggests that these particular sites were seasonal fishing camps rather than more permanently occupied villages.

At archaeological site 35LNC64 on the Salmon River, fire-cracked rocks and pieces of flaked stone are exposed at low tide for 180 m along the base of the riverbank. Remnants of several hearths were observed at the base of the buried soil, which caps a former sand dune complex (Figure 2). Charcoal from one of these hearths yielded a radiocarbon age of 470 ± 60 B.P. (Beta-27876). A peat sample from the uppermost several centimeters of the buried soil yielded a radiocarbon age of 370 ± 80 B.P. (Beta-27877). Charcoal from a second hearth at this site (not shown in Figure 2) produced a radiocarbon age of 550 ± 60 B.P. (Beta-45954).

At archaeological site 35TI56 on the North Fork Nehalem River, fire-cracked rocks are exposed at low tide for 50 m along the base of the river bank. A linear cluster of fire-cracked rock examined at this site occurs within a buried soil
horizon that contains abundant roots and spruce stumps in growth position (Figure 3). Charcoal from this hearth yielded a radiocarbon age of 660 ± 60 B.P. (Beta-27865), while spruce roots present along the upper margin of the buried soil horizon yielded a radiocarbon age of 430 ± 60 B.P. (Beta-27866).

Radiocarbon dating cannot prove that the Salmon and Nehalem estuaries both subsided during a single earthquake. However, average radiocarbon ages for the latest buried soils at Salmon River (nine samples = 246 ± 25 B.P.) and Nehalem River (12 samples = 230 ± 18 B.P.) are statistically indistinguishable from each other, suggesting that both estuaries may have undergone concurrent subsidence (Grant 1992). Moreover, these average ages are time correlative with ages for the most recent subsidence episode identified at localities ranging from Vancouver Island south to Humboldt Bay, a distance of over 1000 km (Atwater et al. 1995). It now appears that this most recent subsidence episode was associated with a rupture, or a series of ruptures, along most of the length of the Cascadia subduction zone. High-precision radiocarbon dating of subsidence-killed vegetation places this event at about 300 years ago (Atwater et al. 1991; Carver et al. 1992; Nelson et al. 1995).³

Supporting Archaeological and Ethnographic Evidence

The archaeological and geological evidence of rapid subsidence of tidal marshes along the Salmon and Nehalem rivers is consistent with previous reports of submerged cultural strata at other archaeological sites along the northern Oregon coast. At site 35T11, a late prehistoric village on the sand spit at Netarts Bay (Figure 1), the earliest evidence of occupation was found in a deeply buried artifact-bearing stratum (20–25 cm thick) presently inundated at high tide. Charcoal from a fire hearth in this stratum yielded a radiocarbon age of 550 ± 150 B.P. (Newman 1959:56). It was estimated that this cultural stratum would have had to have been 1–2 m higher in order for the inhabitants to have lived there (Newman 1959:57–58). At site 35T14, a late prehistoric village on Nehalem Bay (Figure 1), a waterlogged twined mat woven from Douglas fir root recovered from cultural deposits situated at approximately -6 m msl (mean sea level) yielded a radiocarbon age of 380 ± 60 B.P. (Woodward 1986:221; Woodward et al. 1990:61). The radiocarbon ages suggest that submergence of these villages at Netarts and Nehalem bays was associated with the most recent episode of coastal sub-
Aside from direct inundation of prehistoric settlements, abrupt subsidence of the shoreline may have affected prehistoric coastal populations by altering landforms (e.g., bays, spits, and river mouths). Abrupt changes in shoreline elevation may have disrupted the distribution of marine shellfish and sea mammals, resources on which coastal peoples depended to a considerable degree. In this regard, several recent studies have inferred a possible connection between the timing of prehistoric earthquakes (as reflected in marsh subsidence events) and abrupt changes in marine resource exploitation and settlement patterns at archaeological sites along the Oregon coast (Connolly 1992:169-171; Hall and Radosevich 1995; Minor 1989:75-77; 1991:188-189; Woodward 1986; Woodward et al. 1990). While suggestive, correlation of these changes in the archaeological record with prehistoric earthquakes has not yet been confirmed by direct stratigraphic evidence.

The archaeological evidence from the coast paralleling the Cascadia subduction zone is consistent with references to earthquakes in the ethnographic and ethnohistorical literature of the native peoples who occupied this section of the North Pacific Coast. These accounts include references to ground shaking among the Chinook (Boas 1894:148); references to inundation of settlements by tidal waves among the Makah (Eells 1878:70-72), Tillamook (Jacobs and Jacobs 1959:83-84), Coos (Jacobs 1939:53), and Tolowa (Dubois 1932:261); and ground sinking and replacement of prairie by ocean among the Yurok (Kroeber 1976:460-465). The idea that these events occurred in the not-too-distant past is conveyed by early ethnologist George Gibbs, who observed that “at Shoalwater [Willapa] bay, where evidences of elevation and depression of the land, apparently at no very ancient date, are visible, the Chinooks, it is said, have traditions of earthquakes that have shaken their houses and raised the ground” (Clark 1955:321).

**Implications of Earthquake History**

The earthquake about 300 years ago was the latest in a series of subsidence events known to have occurred along the Cascadia subduction zone over at least the last several thousand years. Given the evidence cited above, these earthquakes undoubtedly affected the archaeological record along this section of the North Pacific Coast. Archaeologists should be aware of the earthquake history in this region and the implications of these events for archaeological interpretation.

Evidence of as many as six subduction earthquakes spanning the last 3,100 years has been reported from estuaries along the Washington coast (Atwater 1987, 1992; Atwater and Yamaguchi 1991). As many as five subduction earthquakes spanning the last 1,690 years are in evidence in estuaries along the northern California coast (Clarke and Carver 1992).

In the most detailed examination of a single section of the North Pacific Coast, a study of submerged and buried marshes in seven estuaries along a 175-km-long section of the northern Oregon coast found evidence that subduction earthquakes probably occurred synchronously at least four and possibly five times during the last 3,000 years. These earthquakes are estimated to have had magnitudes of no less than 7.8 and possibly as large as 8.8; the average recurrence interval is estimated at 400 years (Darienzo and Peterson 1995).

Current evidence indicates, then, that the section of the North Pacific Coast opposite the Cascadia subduction zone has been subjected to repeated episodes of earthquake-induced subsidence during the Late Holocene. Based on evidence found in submerged tidal marshes, subsidence of the coastal margin by 0.5-2.0 m is estimated to have occurred in conjunction with earthquakes along the Cascadia subduction zone (e.g., Atwater 1987:943; Darienzo and Peterson 1990:18; Nelson 1992a:297). Only at the northern and southern ends of the subduction zone is coseismic uplift in evidence, and at both Vancouver Island and Cape Mendocino this uplift has been punctuated by episodes of earthquake-induced subsidence (Clague and Bobrowsky 1994; Clarke and Carver 1992).

The record of coseismic subsidence in coastal estuaries and tidal marshes is relatively well documented over approximately the last 3,000 years. The oldest submerged and buried marsh so far
reported, represented by a deeply buried (> 5 m) peaty horizon at Alsea Bay, produced a radiocarbon date of 4,510 ± 80 B.P. (Peterson and Darienzo 1991). The record of earthquakes in this region has been extended even farther back in time by a study of turbidites observed in cores taken from the Cascadia sea channel offshore, which indicates that 13 great earthquakes have occurred along the Cascadia subduction zone since the eruption of Mt. Mazama about 7,000 years ago (Adams 1990).

Repeated episodes of earthquake-induced subsidence associated with great earthquakes along the Cascadia subduction zone probably account, at least in part, for the time lag between the time when the postglacial sea level more or less stabilized (5000-4000 B.P.) and the time when Native American occupation of the coastal margin becomes well represented (1000-2000 B.P.). Over the long term, the cumulative effects of repeated coseismic subsidence events almost certainly contributed, along with eustatic sea level rise, to submergence of the coastal margin, resulting in the scarcity of Early and Mid-Holocene archaeological sites evident in the archaeological record along this section of the North Pacific Coast. As illustrated by the submergence and burial of the two late prehistoric sites on the Salmon and Nehalem rivers reported here, the consequences of earthquake-induced subsidence for the archaeological record, as well as for the prehistoric inhabitants, must be taken into account in future interpretations of prehistoric cultural developments along this section of the North Pacific Coast.

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Notes

1. The number of radiocarbon dates from the Oregon coast is being greatly expanded by a study currently in progress (Erlandson and Moss 1993; Moss and Erlandson 1994, 1995b). Of the 178 additional radiocarbon dates from 117 sites so far reported, “87% of the calibrated dates are less than 1500 years old” (Moss and Erlandson 1995b:119).

2. Subsequent investigations since Lyman’s (1991) study
have been successful in identifying a number of older sites. Currently, 10 sites on the Oregon coast have been reliably radiocarbon dated to earlier than ca. 3000 B.P. No sites dated to earlier than ca. 3000 B.P. have yet been documented on the Pacific coast of Washington or northern California.

3. Tsunami specialist Kenji Satake of the University of Michigan determined in a computer model that a magnitude 9 earthquake emanating from the Cascadia subduction zone would have generated a tsunami 2 m high across the Pacific to Japan. Coincidentally, Japanese records indicate that a seismic tsunami estimated to measure 2–3 m high struck along a 1,000-km section of the Japanese coast on January 27, 1700. The source of this tsunami has not been determined, but the date of its occurrence is consistent with the time span estimated for the last Cascadia subduction zone earthquake about 300 years ago (Kerr 1995:962).

4. There is some evidence that subsidence associated with the earthquake 300 years ago may have extended inland along the Lower Columbia River as far as the Portland Basin some 150 km upstream. The occurrence of partially inundated archaeological sites in this area has led to speculation that submergence of the river banks was due to an earthquake (Strong 1972, 1973). The most noteworthy of these sites, Sunken Village (35MU4), has produced radiocarbon dates of 450 ± 60 B.P. and 220 ± 60 B.P. (Newman 1991:80), which are within the range of radiocarbon dates from marshlands on the coast submerged by the earthquake 300 years ago. The zone of subsidence resulting from the magnitude 9.2 Alaska earthquake in 1964 extended 150–200 km inland (Plafker 1969). While suggestive, correlation of the submergence of archaeological sites in the Portland Basin with an earthquake along the Cascadia subduction zone has not been confirmed by stratigraphic evidence.

5. While the earthquake about 300 years ago appears to be widely represented in tidal marshes from Vancouver Island to northern California, correlation of earlier subsidence events has been more difficult, in part because of the lack of precision in radiocarbon dating. It is possible, if not likely, that some of the earlier events were earthquakes of smaller magnitude that only affected segments of the Cascadia subduction zone (Nelson 1992a, 1992b; Nelson and Personius 1991; McCaffrey and Goldfinger 1995).

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