AN ABSTRACT OF THE DISSERTATION OF

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Abstract approved:

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This study illustrates geoarchaeological and paleoenvironmental approaches to the investigation of an active margin coastal setting and provides examples of how information gleaned through examination of the stratigraphic record can reveal depositional signatures that provide insights into the geomorphic and tectonic forces active within coastal river basins. Three case studies from the southern Oregon coast illustrate the complex relationship between tectonics and geomorphic processes along an active margin coast such as Oregon's Cascadia subduction zone. This work illustrates that the differential preservation of late Pleistocene-age terrestrial deposits in Oregon's coastal landscape, and the early cultural sites they may contain, is not random but can be closely related to larger tectonogeomorphic processes operating at local and regional scales.

Detailed subsurface investigation of one case study site, the lower Sixes River valley, reveals a complex history of depositional environment evolution in relation to geomorphic and tectonic forces. Litho- and biostratigraphic data sets are used to develop a depositional environment reconstruction for the lower Sixes River site through time. This reconstruction of the depositional environment from the late Pleistocene to the present indicates a transgressive evolution that differs from models of transgressive coastal facies and from other studied Northwest coast estuarine life histories. Factors such as eustatic sea level rise, regional and local tectonic alteration of the landscape, sediment supply, or valley morphology may have played roles in the creation and preservation of this atypical depositional sequence.

Litho- and biostratigraphic evidence of six Cascadia subduction zone earthquakes younger than 6200 cal yr BP is recorded in a long sediment core from the Sixes River valley. All six of these events correlate with events previously reported for the area by Kelsey et al. (2002). At least five additional plate boundary earthquakes lowered tidal marshes and freshwater wetlands prior to 6200 cal yr BP. The presence within the lower Sixes River valley of an intertidal environment capable of recording Cascadia subduction zone earthquakes dating to the late Pleistocene and early Holocene has not been found at any other location on the Northwest coast.

Paleoenvironmental Reconstruction of an Active Margin Coast from the Pleistocene to the Present: Examples from Southwestern Oregon

by

Michele Leigh Punke

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APPROVED:

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Michele Leigh Punke, Author

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CONTRIBUTION OF AUTHORS

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Paleoenvironmental Reconstruction of an Active Margin Coast from the Pleistocene to the Present: Examples from Southwestern Oregon

CHAPTER 1: INTRODUCTION

This dissertation represents a culmination of investigations along the southern Oregon coast designed to explore the environmental context within which humans would have lived from the late Pleistocene until the present. Included in this consideration is an exploration of how the environment has changed over time and the implications of that change to the archaeological record of early human land use. Natural forces of change operating on local to global scales have impacted the southern Oregon coast during the last 10,000 years. These forces and the geomorphic expression of their activity on the landscape are addressed through study of coastal landforms and subsurface sediments. Chapter 2 has been submitted and accepted for publication at *Geoarchaeology: An International Journal.* Chapters 3 and 4 will be revised and submitted for publication at a future date.

Early human migration into the New World is hypothesized to have occurred along the Northwest Coast of North America as early as the late Pleistocene. Following initial coastal occupation, humans may have moved inland following coastal rivers where the archaeological remains of their occupation sites would presumably be easier to find. However, evidence of such inland mobility has yet to be discovered. The paucity of early sites in coastal river valleys is due, in part, to the dynamic geomorphic evolution of the Northwest Coast landscape during and after the late Pleistocene. Chapter 2 presents three case studies from the southern Oregon coast that illustrate the complex relationship between tectonic and geomorphic processes along an active margin coast such as Oregon's Cascadia subduction zone. The aim of this chapter is to determine what role local, upper plate tectonic structures play in the preservation and accessibility of Pleistocene-age stream terrace deposits and, in turn, the cultural deposits they may contain.

The subsurface sediments contained within a coastal Oregon river basin were analyzed in Chapter 3 to further decipher the relationship between coastal river valleys and geomorphic and tectonic processes. Depositional environments were reconstructed through the analysis of sediments recovered in a 27m long core representing over 10,000 years of depositional history from one of the study locations examined in Chapter 2, the lower Sixes

River valley. Litho- and biostratigraphic data extracted from core sediments were analyzed to determine downcore variation in depositional energies, sediment source, and intertidal setting. These characteristics were used to infer depositional environment evolution through time at the site.

Depositional facies analysis in Chapter 3 revealed a shifting history of a fluvial, estuarine, and marine-dominated depositional environments since the late Pleistocene. Comparison of the depositional environment facies represented in the core section from the lower Sixes River study site to models and case study examples of transgressive coastal facies evolution for the same time period revealed an unexpected period of intertidal deposition in the lowest section of the Sixes River core. Explanations of the origin of this anomalous deposit and the implications for early human use of the landscape were explored.

Evidence of great plate-boundary earthquakes and accompanying coseismic subsidence events is revealed at numerous land-sea interfaces along the Pacific Northwest coast. The 27 meter-deep core extracted from the lower Sixes River valley site contains a terrestrial stratigraphic record extending into the late Pleistocene. Chapter 4 presents litho-, bio-, and chronostratigraphic analyses of core sediments that reveal paleoseismic indicators of earthquakes along the Cascadia margin. This chapter presents stratigraphic evidence of six plate boundary earthquakes dating to younger than 6200 cal yr BP that correlate to earthquake events previously reported for the study area by Kelsey et al. (2002). Additionally, this chapter presents evidence for five older events that meet the stratigraphic criteria for a coseismic origin. This paleoseismic record represents the first onshore chronology of Cascadia subduction zone plate boundary earthquakes extending into the late Pleistocene, on a timescale comparable in length to the turbidite records offshore (Goldfinger et al. 2003).

PROBLEMS AND PROSPECTS IN THE PRESERVATION OF LATE PLEISTOCENE CULTURAL SITES IN SOUTHERN OREGON COASTAL RIVER VALLEYS: IMPLICATIONS FOR EVALUATING COASTAL MIGRATION ROUTES

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Introduction

Determining the route of initial human migration into the Americas has been a contentious issue among archaeologists for decades (Dixon, 2001). Since the 1970s, attention has shifted away from the traditionally-held model involving an overland migratory route eastward across Beringia and southward between the Laurentide and Cordilleran ice sheets (Haynes, 1969; Griffin, 1979) and has focused on evaluating the possibility of a Pacific coastal route of migration (Fladmark, 1979; Gruhn, 1988,, 1994; Easton, 1992). More recently, perspectives from geology, paleobiology, and archaeology have helped to evaluate whether a coastal migration route was ever available to Pleistocene hunter-gatherers (Barrie et al., 1993; Mann and Peteet, 1994; Heaton et al., 1996; Dixon et al., 1997; Josenhans et al., 1997; Dixon, 2001; Mandryk et al., 2001) and geoarchaeological studies have been designed to locate late Pleistocene sites on the Northwest Coast (Fedje and Christensen, 1999; Fedje and Josenhans, 2000; Davis et al., 2004). Initial results of this research have shown that late Pleistocene-age archaeological sites do exist on the Northwest Coast, but their preservation and accessibility depend upon their specific geomorphic setting (Davis et al., 2004; Fedje et al., 2004).

Hypotheses of initial coastal migration often include an element of inland mobility along coastal rivers following initial colonization of coastal areas (Dixon, 2001; Mandryk et al., 2001). To date, no archaeological evidence of late Pleistocene human occupation of the Northwest coast has been discovered from coastal river valleys. The lack of early sites along coastal rivers is partly due to the effects of dynamic geomorphic forces acting on the Northwest Coast during and after the late Pleistocene. Although the rate of post-glacial marine transgression is well known (Hanebuth et al., 2000), the specific effects and timing of post-glacial fluvial adjustment along the Northwest Coast are not. Drawing on examples from the Oregon coast, we will address issues of landscape evolution and site preservation in Northwest Coast river valleys as a means of bringing attention to the particular geoarchaeological challenges associated with these dynamic geomorphic settings.

Estuaries, Embayments, and Sea Level Rise

Research on several active-margin embayments and estuaries in Oregon and Washington reveals how fluvial environments have adjusted to sea level fluctuations, tectonic uplift, and sediment infilling of coastal river basins (Glenn, 1978; Peterson et al., 1984; Peterson and Phipps, 1992; Witter, 1999; Byram and Witter, 2000; Kelsey et al., 2002). Typically, shallow fluvial environments are recorded in the depositional record from around 10,000 to 7500 yr B.P. A shift to deeper, estuarine conditions followed as sea level rose and river valleys drowned. By ca. 5000 yr B.P., stability in sea level, sediment infilling, and continued localized tectonic uplift produced new conditions in depositional environments. Shallow-water estuaries, tidal flats, and salt- and fresh-water marshes appeared along Oregon's modern shoreline after 5000 yr B.P. Taken together, these studies present a generalized model of regional geomorphic response to marine transgression, sedimentation, and incremental tectonic uplift. However, the timing and nature of depositional system response to marine transgression varies from basin to basin and must include a consideration of other non-marine aspects. Interbasin variability in late Quaternary fluvial geology can be related to the timing, rate, and magnitude of sedimentary and structural factors operating at local scales along a coastline. A database of relative sea level rise and associated sediment accumulation has been assembled from radiocarbon dating of deep cores extracted from several river basins along the Oregon coast and is discussed below to illustrate differential patterns of post-glacial fluvial behavior.

Stratigraphic evidence from Alsea Bay (AB) on the central Oregon coast (Figure 1) indicates that nearly 55 meters of sediment accumulated during the Holocene (Peterson et al., 1984). From 10,000 to 7500 yr B.P., sedimentation rates ranged between 4 and 7 mm per year. From 7500 to 5000 yr B.P. an average of 11 mm of sediment accumulated in the bay per year. After 5000 yr B.P., sedimentation rates dropped to approximately 2.1 mm per year, reflecting a decline in the rate of eustatic sea level rise and the associated decrease in sediment accumulation (Peterson et al., 1984). Stratigraphic records from Tillamook Bay (TB), located on the northern Oregon coast (Figure 1), indicate that about 32 meters of sediment accumulated during the Holocene (Glenn, 1978). Prior to 7000 yr B.P., rates of sediment accumulation were 20 mm per year, but slowed to ca. 2 mm per year after 7000 yr B.P. (Glenn, 1978).

In 2002, the authors recovered a 27 m-long continuous sediment core from an abandoned meander along the lower Sixes River, which is located immediately north of Cape Blanco and about 35 km south of Bandon, Oregon (Figure 4). A charcoal sample from the base of this core, Core 4, dated to 10,190±60 yr B.P. (Beta-173811) (Punke and Davis, 2004). Prior to this work, Kelsey et al. (2002) conducted sediment coring at the same abandoned meander locality. Their efforts produced stratigraphic sediment columns 7 meters deep, which represent ca. 6000 years of depositional history. Based on preliminary analysis of Core 4 sediments and comparison with previous investigations (Kelsey et al., 2002), 21 m of fine- to coarse-grained sediments were deposited between 10,190 and 6000 yr B.P., suggesting a sedimentation rate of approximately 5mm per year. During the last 6,000 yr B.P., the Sixes River added nearly 7 meters of fine-grained, organic rich sediments (Kelsey et al., 2002), with a considerably lower sedimentation rate of just over 1 mm per year. The rates and amount of sedimentation recorded at the Sixes River since the late Pleistocene appear to be typical of Oregon coastal river valleys.

Undoubtedly, late Pleistocene inhabitants of the Northwest Coast used river valleys, and probably occupied estuary margins and river terraces. However, based on the data presented above, late Pleistocene deposits are deeply buried in many river valleys and hinder efforts to find early coastal sites. This situation promises to make archaeological discovery of early coastal riverine sites a difficult task and must be considered an inherent aspect of testing the coastal entry hypothesis. Despite these obstacles, there are indications that some river terrace deposits may have escaped complete inundation due to complexities in the local tectonogeomorphic context of some coastal settings. At certain localities, uplift on local, upper-plate tectonic structures coupled with regional positive vertical displacement may have allowed isolated landforms to remain exposed through time and/or relatively accessible to modern archaeological exploration. Understanding where these early sites may be found in the modern landscape is a critical first step toward their discovery and requires a knowledge of the structural geology of Oregon's coast.

Regional and Local Tectonics of Coastal Oregon

Coastal Oregon lies within the central portion of the Cascadia subduction zone, a shallow reverse fault extending over 1,200 km from offshore northern California to southern

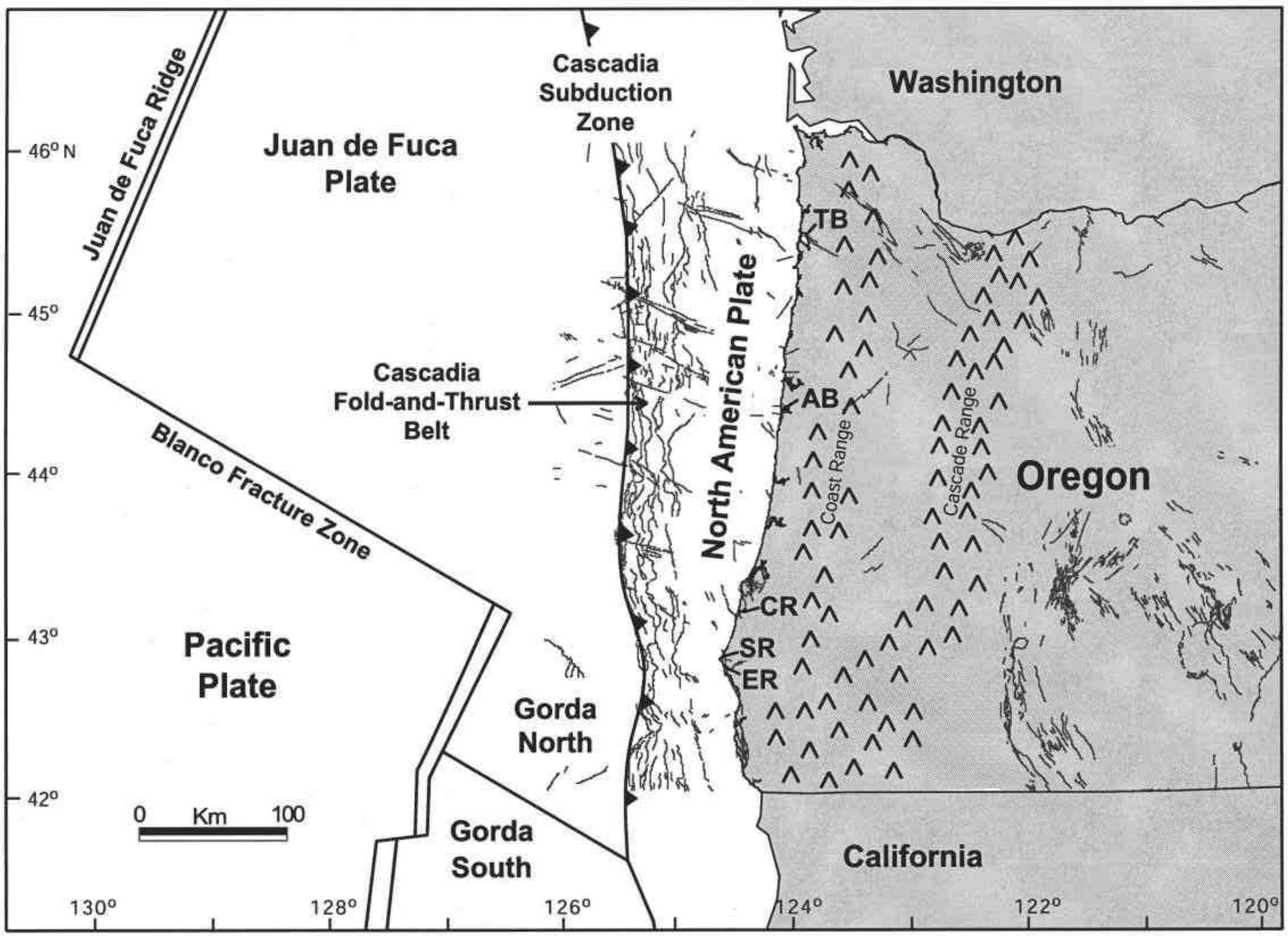


Figure 1. Map of the Cascadia Subduction Zone off the Oregon Coast, including associated plates, mountain ranges, and Quaternary faults and folds of the accretionary wedge and upper plate. Study locations indicated on map include Tillamook Bay (TB), Alsea Bay (AB), Coquille River (CR), Sixes River (SR), and Elk River (ER). Quaternary fault and fold data from Personius et al. (2003).

British Columbia (Figure 1). This zone has been subjected to significant tectonic deformation during the Quaternary as the Juan de Fuca Plate underrides the North American Plate at a rate of 3 to 4 cm per year (Heaton and Hartzell, 1987). Subduction of the Juan de Fuca Plate produces slow interseismic uplift of portions of the overriding North American Plate where the plates become seismogenically locked (Figure 2). Periodic and abrupt movement between locked plate segments produces an earthquake accompanied by coseismic movement of the overriding plate. This movement is expressed as subsidence or uplift depending on the landscape's spatial relation to the zero isobase (Plafker, 1969; 1972). Deposits on the trench side of the zero isobase will incur coseismic uplift, while deposits on the upper-plate side of the trench will be subject to coseismic subsidence (Figure 2). During periods between earthquakes, vertical movement relative to the zero isobase is of the opposite sign, with trenchward areas incurring interseismic subsidence while land on the upper plate side gradually uplifts.

The continental margin of Oregon is on the upper-plate side of the zero isobase (Darienzo and Peterson, 1990; McNeill et al., 1998), incurring gradual interseismic uplift periodically interrupted by coseismic subsidence. Modern-day, interseismic uplift rates along the Oregon coast range from 0-5 mm per year (Mitchell et al., 1994) and average long-term uplift rates for the region based on marine terrace data range from 0.1-0.9 m per thousand years (Muhs et al., 1990; Kelsey, 1990; Kelsey, 1996). Evidence of coseismic subsidence and tsunamis accompanying great plate-boundary earthquakes is revealed at numerous terrestrial locations along the Pacific northwest coast and counters gross uplift rates to varying degrees (Atwater, 1987; Darienzo and Peterson, 1990; Clarke and Carver, 1992; Atwater et al., 1995; Atwater and Hemphill-Haley, 1997; Nelson et al., 1996a; Nelson and Personius, 1996; Kelsey et al., 2002; Witter et al., 2003).

Small-scale, upper plate faults and folds within the broader Cascadia subduction zone also deform sediments of the forearc and accretionary wedge region, including portions of the Oregon coast mainland (Figure 1). The Cascadia fold and thrust belt is a series of north and north-northwest trending faults and folds that deform sediments of the continental slope and shelf off of Oregon's coast (Goldfinger et al., 1992; MacKay et al., 1992; Goldfinger et al., 1997; McNeill et al., 2000). Active folds and faults on the inner continental shelf generally trend perpendicular to the coastline and deformation front (Goldfinger et al., 1992; Goldfinger, 1994) and have a significant influence on the formation of raised marine terraces, headlands, estuaries and bays (Kelsey, 1990; Kelsey et al., 1996; McNeill et al., 1998; Kelsey

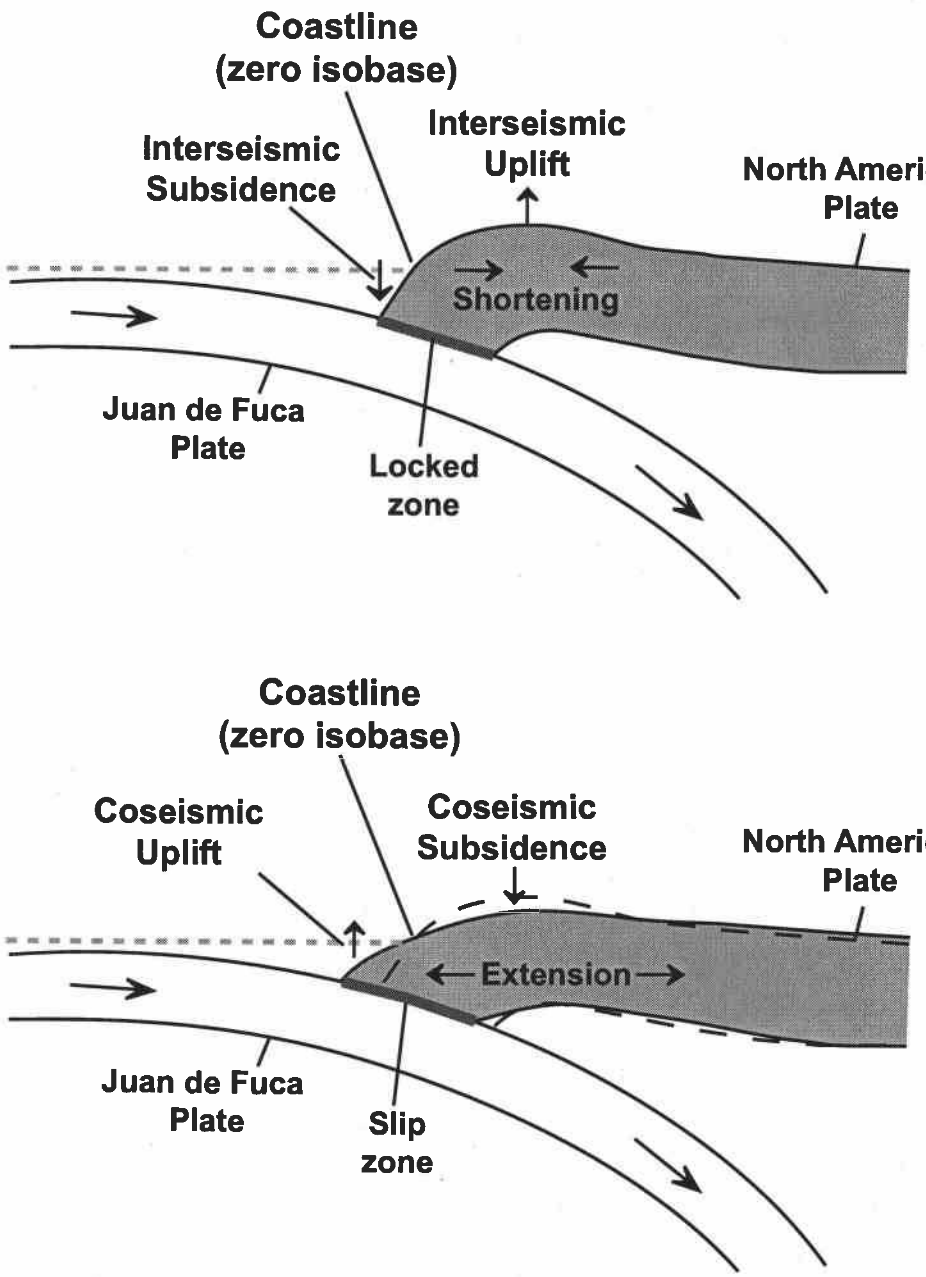


Figure 2. Deformation associated with an active subduction zone. Modified from Darienzo and Peterson (1990).

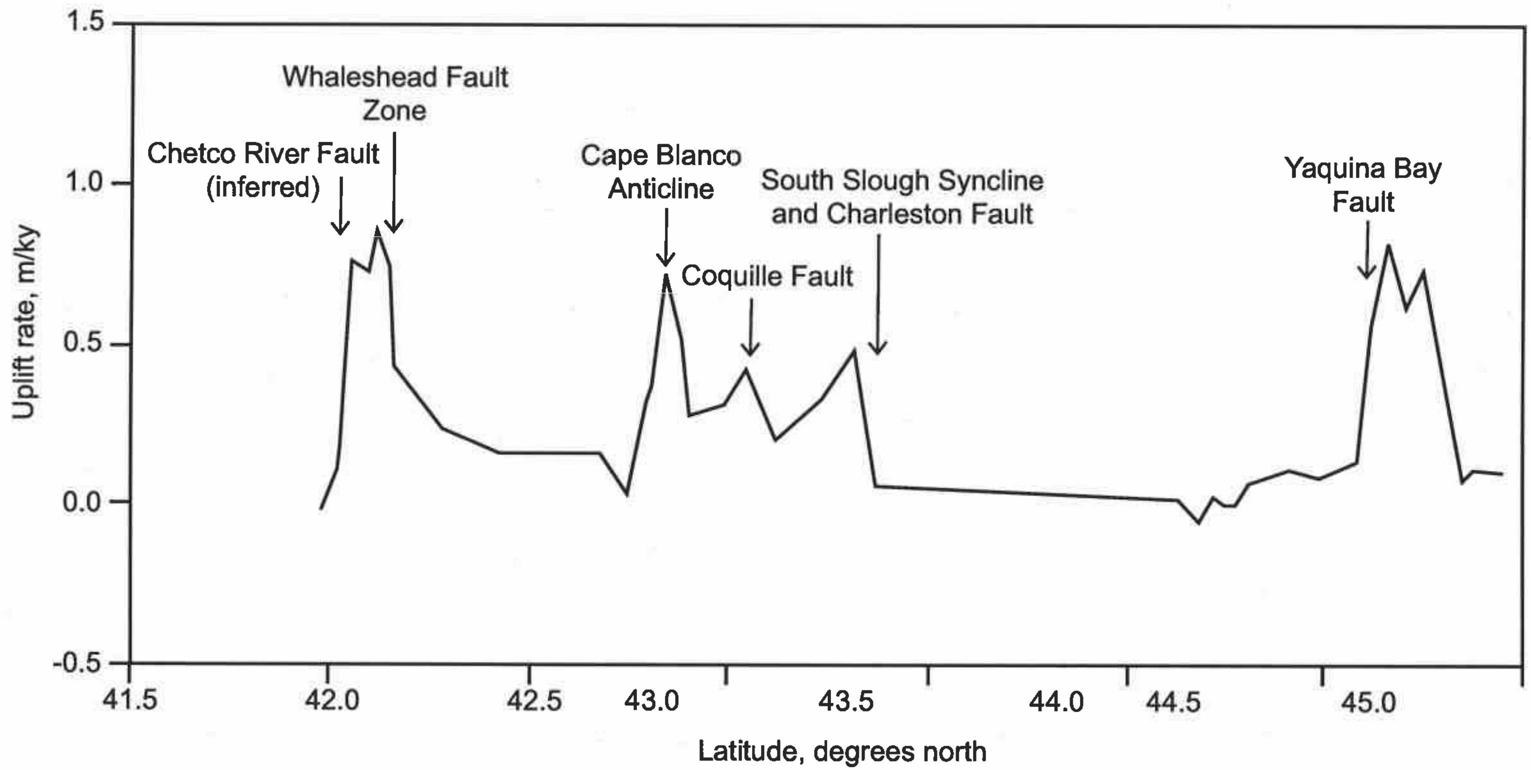


Figure 3. Latitudinal variation in uplift rates along the central and southern Oregon coast. Modified from Kelsey and Bockheim (1994: Fig.7).

et al., 2002; Witter et al., 2003). Many prominent embayments along the Oregon coast are associated with synclinal folding or lie on the downthrown sides of high-angle faults, while headlands and differentially uplifted marine terraces generally correlate with anticlines or the upthrown side of high-angle faults (Muhs et al., 1990; Kelsey, 1990; Kelsey et al., 1996; McNeill et al., 1998). Latitudinal variations in long-term uplift rates along the central and southern Oregon coast depicted in Figure 3 were derived through the mapping, dating, and correlation of uplifted marine terrace suites along the coastal margin (Kelsey, 1990; Muhs et al., 1990; McInelly and Kelsey, 1990; Bockheim et al., 1992; Kelsey and Bockheim, 1994). Offshore multichannel seismic reflection profiling reveal seafloor warping and faulting in areas adjacent to onshore topographic highs and lows (McNeill et al., 1997; McNeill et al., 1998).

Deformation on local, small-scale upper plate tectonic structures represents a major force in the preservation and accessibility of Pleistocene-age landforms along Oregon's coastal streams. While the association of topographic lows with synclinal downwarping or fault downthrow is generally consistent (Kelsey et al., 1996; McNeill et al., 1998), there are locations at estuaries or embayments where positive vertical deformation occurs in association with local faults or anticlinal folds. Such local structures allow for the preservation of stream- or bay-side terraces despite a transgressive depositional setting.

To illustrate the complex relationship between local, upper plate tectonic structures and the formation and preservation of late Pleistocene/early Holocene stream terraces, we present three case studies from the southern Oregon coast. These case studies provide a basis for contemplating the geoarchaeological context of early sites in Northwest Coast settings.

The Cape Blanco Anticline

The Cape Blanco anticline (Figure 4) is an east-striking, eastward plunging fold formed during ongoing compression of the forearc region of the Cascadia subduction zone (Kelsey, 1990). This upper plate structure is an onshore extension of the Cascadia fold and thrust belt mapped by Goldfinger et al. (1992) and McNeill et al. (1998). Onshore evidence of active deformation of the anticline is preserved in the underlying Cenozoic bedrock as well as in the warped Cape Blanco, Pioneer, and Silver Butte marine terrace platforms at Cape Blanco (Kelsey, 1990). These marine terraces have been correlated to the 80 ka, 105 ka, and

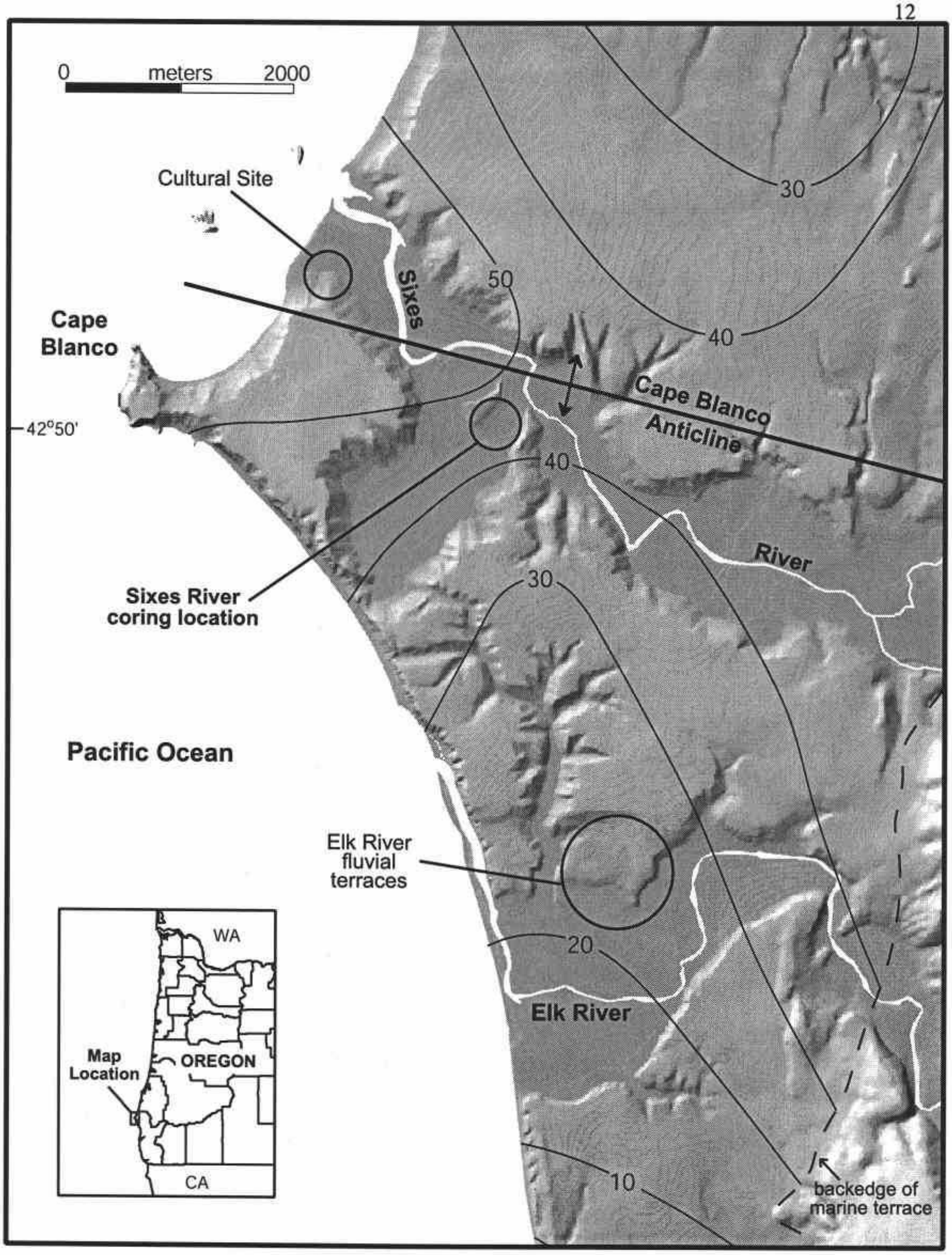


Figure 4. Cape Blanco and Elk River areas, indicating location of anticline and study locations mentioned in text. Elevation contours from Kelsey et al. (1990: Fig. 9); contour interval is 10m. Quaternary fault and fold data from Personius et al. (2003).

125 ka high sea stands, respectively (Kelsey, 1990; Muhs et al., 1990), indicating active uplift during the late Quaternary.

Witter (1999) and Kelsey et al. (2002) cite contrasting relative sea-level curves between areas nearer to versus further from the anticline axis as evidence for active fold deformation during the Holocene. Kelsey et al. (2002) compare amounts of tidal mud and peat accretion between localities 0.9-1.6 km and 2.3 km away from the anticline axis. They hypothesize that if coseismic slip occurred on a blind reverse fault underlying the anticline at the same time that a larger subduction zone earthquake took place, then contraction and uplift of the anticline would produce less net subsidence at areas nearest the anticline axis versus areas farther away. This would result in higher net sediment accretion over time at the areas further from the fault. Between ca. 5000 and 3000 yr B.P., over a meter more sediment accumulated in the area further from the axis (i.e., 2.91 m versus 1.62 m), suggesting that areas nearest to the fold axis incurred over a meter less net subsidence, i.e. a meter more net uplift, than areas further away from the axis (Kelsey et al., 2002).

It is unclear whether displacement of this upper-plate structure is always coupled with slip of the larger-scale Cascadia subduction zone fault or whether it operates independently of other tectonic structures (Kelsey et al., 2002; Witter et al., 2003). In either case, interseismic upper plate deformation appears to produce larger amounts of relative uplift in areas closer to the axis of the anticline, as well as in areas on the western end of the eastward plunging fold (Figure 4). Over the long term, the combined effects of interseismic uplift and coseismic subsidence yields ca. 0.85 to 1.25 meters of net uplift per thousand years in the Cape Blanco area (Muhs et al., 1990). Based on the information from Kelsey et al. (2002), it is clear that regional data must be examined more closely to fully understand where and at what rate the land is incurring the largest amount of uplift. These areas will have a higher likelihood of preserving river terraces and the sites they may contain than other areas due to the local structures that uplift them faster and lead erosional forces away from their deposits (Figure 5).

The earliest cultural site reported thus far in the Sixes River valley is found along the south side of the valley entrance where a small deposit of Holocene dune sand ramps up the side of an uplifted marine terrace (Figure 4). Cultural deposits within a weakly developed soil underlying the dune sand date to 5200 yr B.P. (Minor and Greenspan, 1991). During the time that this Holocene site was occupied, local relative sea levels were 1-3 meters lower than today (Kelsey et al., 2002). In the 5000 years that followed, many portions of the valley were

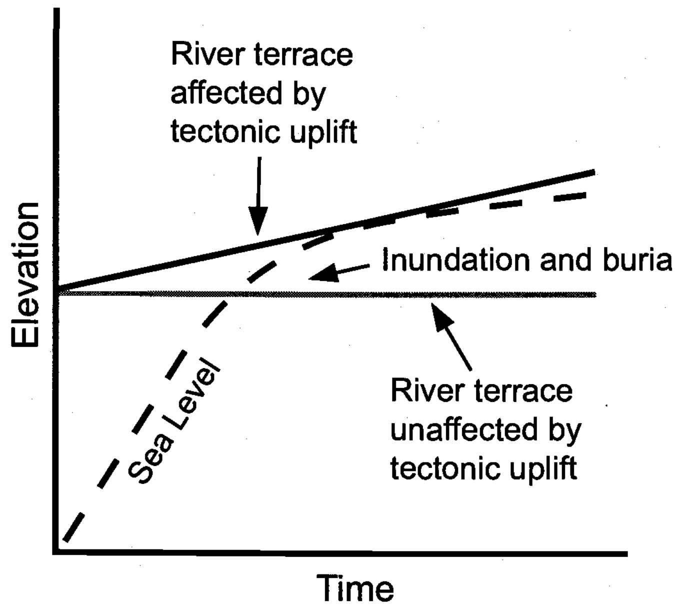


Figure 5. Chart depicting relationship between sea level rise and two river terrace deposits. The river terrace incurring tectonic uplift maintains an elevation above sea level during marine transgression, while the terrace unaffected by tectonic uplift is inundated and buried by sediment during this sea level rise.

inundated as the Sixes River adjusted to a marine transgression (Glenn, 1978; Peterson et al., 1982; Kelsey et al., 2002; Punke and Davis, 2004), burying any other sites closer to the river. However, perhaps because of the higher relative amount of uplift on the western end of the anticline axis, the landform within which the Holocene cultural site is located was preserved.

In addition to topographic deformation in the Sixes River valley, the Cape Blanco anticline also affects the topography of adjacent areas (Figure 4). The Elk River valley lies six kilometers south of the Cape Blanco anticline axis. In the lower portion of this valley on the northern side of the river, a series of three alluvial terraces descend from higher marine terraces deposits (Figure 6). Stratigraphic profiles cut into each of the terraces revealed alluvial facies corresponding to channel and floodplain deposition. Radiocarbon dates on charcoal and wood from the upper and lower alluvial terraces returned ages of 35,500 ±730 yr B.P. (Beta-171007) and 190 ±50 yr B.P. (Beta-171006), respectively. These three terraces are unpaired to the south of the river mouth (Figure 6), leading us to hypothesize that the differential uplift of areas closer to the axis of the Cape Blanco anticline has forced the Elk river to shift southward through time, preserving alluvial deposits along the northern valley margin. Terraces on the south side of the river that formed before the last glacial maximum marine lowstand were subsequently destroyed as the river eroded laterally and vertically in response to marine regression and regional and local interseismic uplift. By the time the Elk River began to aggrade to match the pace of post-glacial marine transgression, north side alluvial terraces had been uplifted beyond the limits of valley inundation. Any cultural deposits located within these alluvial terraces would have been preserved due to the effects of the differential uplift of areas closest to the upper-plate Cape Blanco anticline, those areas on the north side of the river.

Pioneer Anticline

The Pioneer anticline deforms sediments bounding the Coquille River on the southern Oregon coast (McInelly and Kelsey, 1990). The north-northwest striking axis of this north-south plunging anticline lies approximately eight kilometers inland from the river's mouth (Figure 7) and is an onshore extension of the broad fold and thrust belt which deforms offshore sediments of the accretionary wedge (Goldfinger et al., 1992; McNeill et al, 1998). Because the fault does not appear to warp underlying bedrock in the area, it is thought be a relatively young structure(McInelly and Kelsey, 1990; Personius et al., 2003). Deformation of 105 ka Pioneer terrace sediments indicates tightening of the anticline during the late

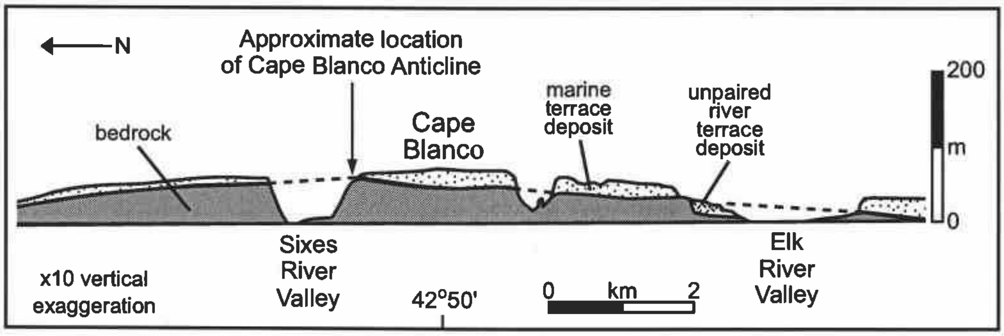


Figure 6. Coast-parallel profile along the region north and south of the Cape Blanco anticline showing the relation of the Sixes and Elk River valleys to uplifted marine terrace deposits. Also depicted is the unpaired river terrace deposits on the north side of the Elk River. Modified from Kelsey (1990:Fig.3).

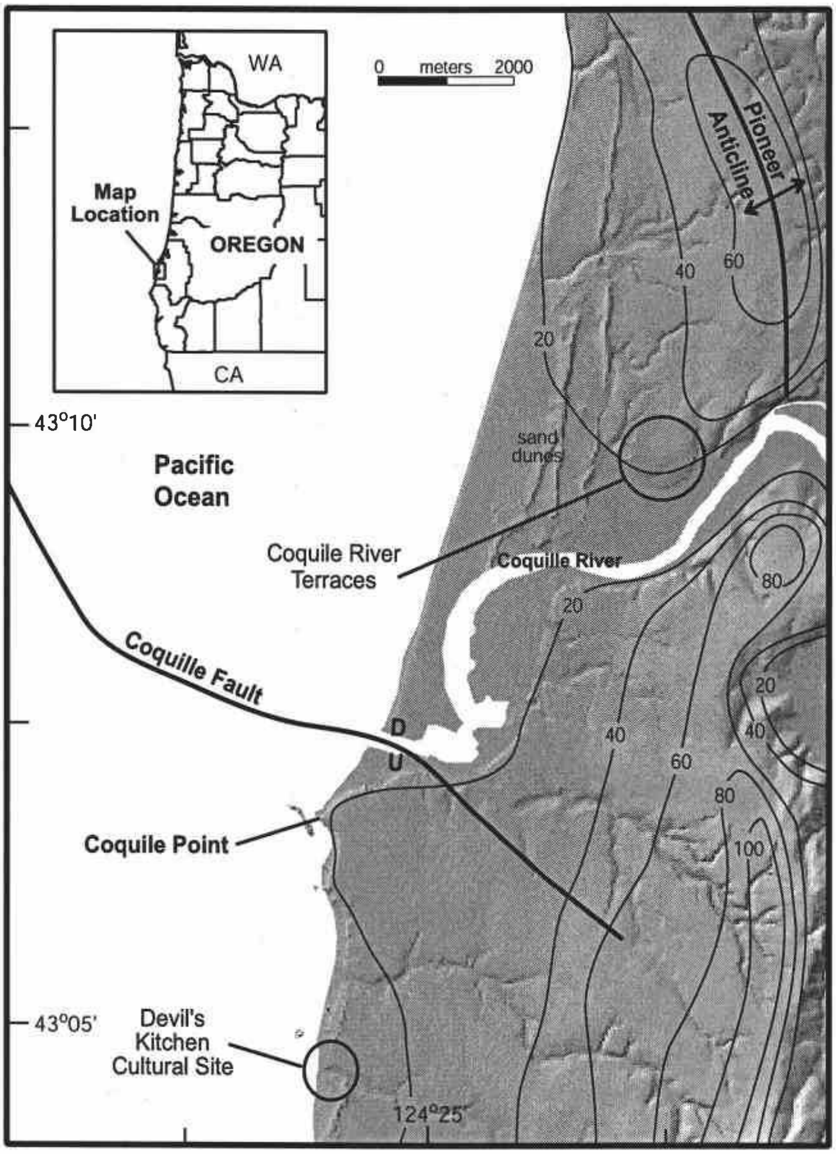


Figure 7. Coquille River area, indicating locations of tectonic structures and study locations discussed in text. Up-thrown (U) and down-thrown (D) sides of Coquille fault lie on the southern and northern sides of the axis, respectively. Elevation contour interval is 20m. Quaternary fault and fold data from Personius et al. (2003).

Quaternary, although no average slip rates over this time have been reported. Based on the elevations of local marine terraces, maximum long-term uplift rates range from 0.3-0.6 m per thousand years since the late Pleistocene at the latitude of the Coquille estuary (McInelly and Kelsey, 1990).

Alluvial terraces along the margins of the lower Coquille River valley may have escaped inundation due to the differential uplift of areas closest to the Pioneer anticline axis. Figure 7 depicts elevation contours of the area surrounding the axis of the anticline. Based on the contours, it is clear that areas closest to the anticline have been uplifted more relative to other areas along the margin of the river.

Trenching of terraces preserved on the northern edge of the Coquille River valley suggests that uplift along the Pioneer fault during the late Quaternary may have helped preserve a series of fluvial terraces along the northern margin of the Coquille River valley (Figure 8). Most areas along the margins of the Coquille River incurred lateral and vertical erosion during the period of marine regression of the last glacial maximum. In some cases, however, alluvial terraces on the river's margin were preserved when fluvial downcutting caused by rapid sea level fall and local and regional tectonic uplift outran the pace of river meandering and lateral planation. When sea level began to rise ca. 21,000 years ago, streamside terraces that experienced the greatest amount of uplift, including those areas nearest the axis of the Pioneer anticline, escaped complete inundation and burial. It is these areas where cultural deposits dating to the late Pleistocene or early Holocene are most likely to survive.

Coquille Fault

As with the Cape Blanco and Pioneer upper plate tectonic structures, the Coquille fault (Figure 7) is associated with the offshore fold and thrust belt that deforms sediments of the accretionary prism (Goldfinger et al., 1992; McNeill et al., 1998). The onshore portion of the Coquille fault is thought to be a northwest striking fault or fault-propagation fold overlying a blind, southwest-dipping reverse fault (Witter et al., 1997; Witter, 1999). The southern, upthrown side of the Coquille fault offsets sediments of the 80 ka Whiskey Run marine terrace vertically by ca. 50 meters near Coquille Point (Figure 9a), while marine terrace sediments are at sea level on the downthrown side of the fault (McInelly and Kelsey, 1990).

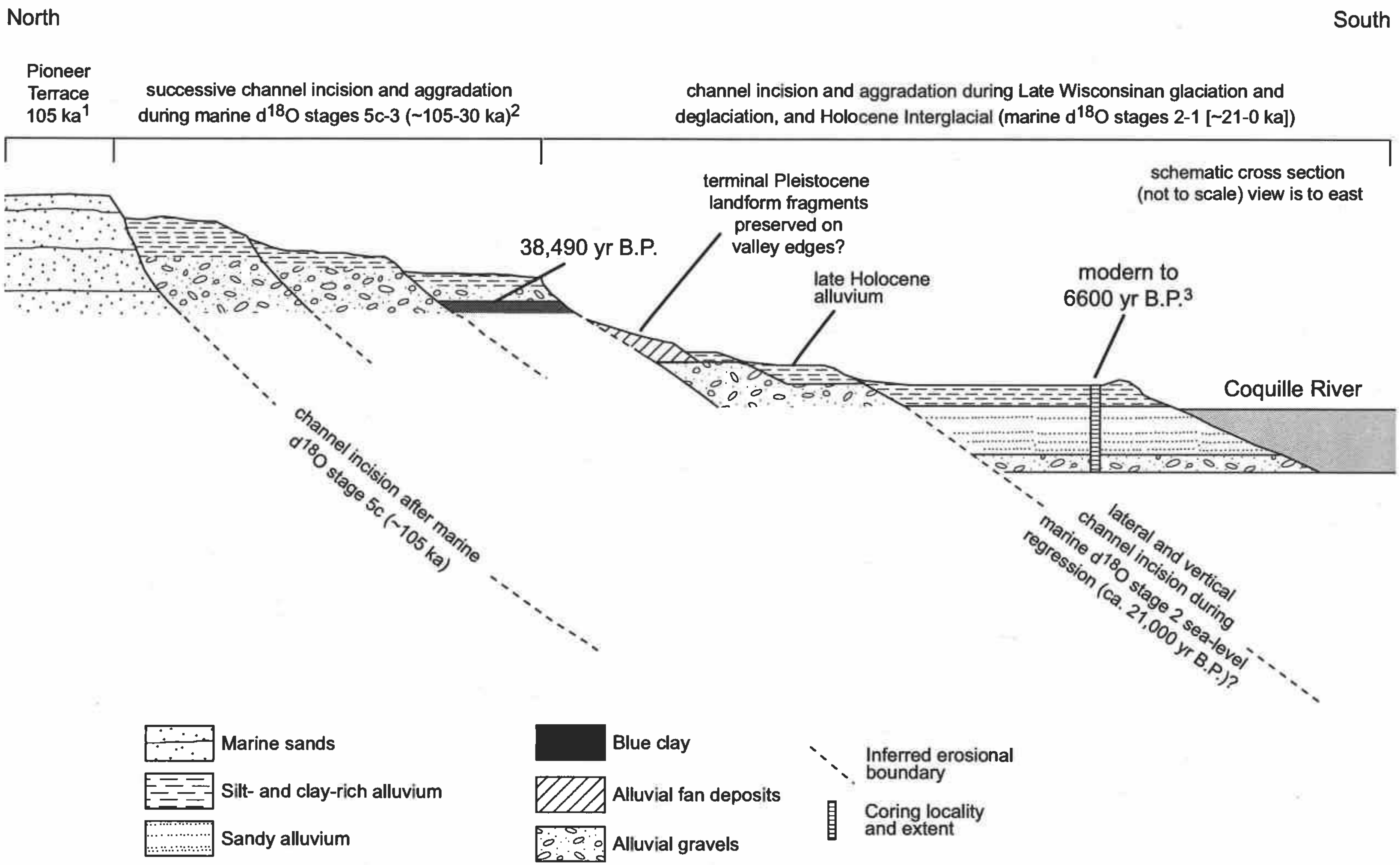
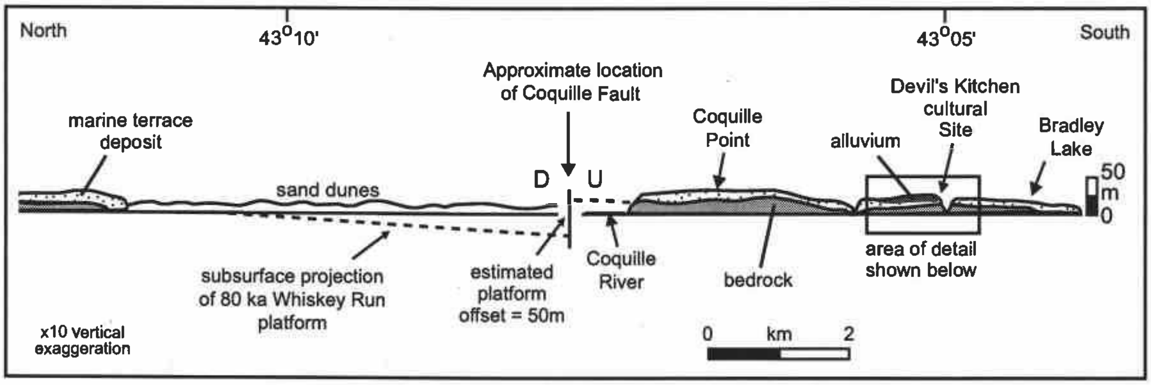


Figure 8. Schematic cross section of the northern portion of the lower Coquille River valley. Cited references include: [1] McInelly & Kelsey (1990); [2] Shackleton & Opdyke (1976); [3] Witter (1999).

Long-term uplift rate estimates for the upthrown side of the Coquille fault (up to 0.8 m per thousand years) are higher than uplift rates for the coast north and south of the Coquille estuary, which are at a more modest 0.3-0.6 m of uplift per thousand years (McInelly and Kelsey, 1990). Contemporary interseismic uplift rates for Coquille Point exceed 4 mm per year (Mitchell et al., 1994), which is five to thirteen times higher than the long-term regional rate (McInelly and Kelsey, 1990; Witter et al, 2003). As seen in Figure 7, the topographically higher south limb of the Coquille fault has differentially uplifted 80 ka marine terrace sediments from the axis just north of Coquille point, descending in amount of uplift to near sea level at Bradley Lake to the south (McInelly and Kelsey, 1990; McNeill et al., 1998; Witter et al., 2003). Although there is no unequivocal evidence of Holocene slip on the Coquille fault, there are indications that continued tectonic uplift of the southern limb of the fault has occurred during the Holocene (Witter et al., 2003).

Evidence for Holocene movement along the Coquille fault may be seen at the Devils Kitchen site, located on the southern edge of Bandon, immediately north of Crooked Creek (Figure 9a). The Crooked Creek drainage is located on the uplifted, southern limb of the Coquille fault, and flows into the ocean ca. 3.5 km south of Coquille Point. On the north side of the creek mouth, marine, alluvial, and aeolian deposits overlying uplifted bedrock contain a stratified series of cultural occupations beginning some time between approximately 11,000 yr B.P. and 6000 yr B.P. and ending at ca. 3000 yr B.P. Today, Crooked Creek lies approximately 12 meters below its northern bank Figure 9b); however, site stratigraphy and topographic contouring of the landscape near the stream suggests that between 11,000 yr B.P. and 3000 yr B.P. the stream flowed north of the Devils Kitchen site. After ca. 3000 yr B.P., alluvial facies are buried beneath extensive dune deposits. Continual positive vertical displacement on the Coquille fault may have diverted the course of the stream further south when sea level rise slowed (Witter et al., 2003), followed by downcutting of the stream through its banks to reach its present position.

Alternatively, Crooked Creek's change of course and cessation of alluvial deposition at the Devils Kitchen site may have been caused by abrupt, coseismic deformation of the Coquille fault. If the fold tightened coseismically, northern areas nearer to the axis of the fold may have risen higher relative to southern areas away from the fold axis. Witter et al. (2003) postulate seismic activity around 3300 yr B.P., 2900 yr B.P., and 1700 yr B.P. based on evidence recovered from sediment cores extracted from the Coquille River basin. Slip on this a.



b.

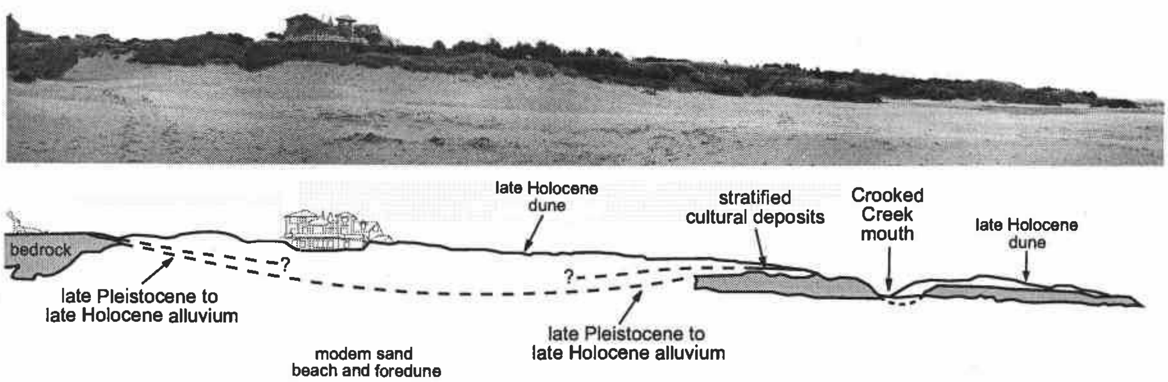


Figure 9. a. Coast-parallel profile along the region north and south of the Coquille River showing offset of 80,000 year old wave-cut platform sediments (McInelly and Kelsey, 1990) used to infer location of Coquille fault axis (Witter et al., 2003). Greatest amount of vertical deformation occurs on southern, up-thrown side of fault. Modified from Witter et al. (2003:Fig.3).
b. Detail of coast-parallel profile showing the modern-day location of Crooked Creek and cultural site in relation to late Pleistocene and early Holocene alluvial deposits.

upper plate structure may have occurred independently or in association with a larger, Cascadia subduction zone earthquake. In either case, uplift along the axis of the Coquille fault to the north may have driven Crooked Creek south. In the process, stream-side sediments were left untouched by the erosional action of the creek and cultural deposits within this alluvium were preserved.

Conclusion

Geoarchaeological study along the Northwest Coast, and in other New World areas with tectonically-active continental margins, must consider the cumulative effects of subduction zone tectonism, styles of upper plate deformation, and their geomorphic influence on coastal landscapes during a period of post-glacial marine transgression. Our research along the Oregon coast reveals some repetitive themes in how certain modes of upper plate deformation can influence fluvial systems to preserve, obscure, or destroy late Pleistocene-age deposits during post-glacial marine transgression. Through this work, we show that the differential preservation of late Pleistocene-age terrestrial deposits in Oregon's coastal landscape, and the early cultural sites they may contain, is not random but can be closely related to larger tectonogeomorphic processes that have been ongoing throughout the late Quaternary. Armed with these geoarchaeological perspectives, archaeologists will be able to focus their efforts on temporally-relevant landscape sections in a search for early coastal sites. This approach meets the call made by Mandryk et al. (2001) that geoarchaeology conducted in the service of testing a late Pleistocene coastal migration hypothesis must concentrate on subregional scales (i.e., 1000 sq. km), such as the Oregon coast.

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CHAPTER 3: THE DEPOSITIONAL EVOLUTION OF A MARINE-RIVERINE INTERFACE ON THE SOUTHERN OREGON COAST REVEALED THROUGH FOSSIL DIATOM AND SEDIMENT STRATIGRAPHY

Introduction

A recent discovery at a rocky headland on the southern coast of Oregon indicates that humans occupied the Northwest Coast by 12,000 years ago (Davis et al. 2004). However, the extent to which the Pacific coast served as a pathway for migration by early humans into North America is debated (Fladmark 1979; Gruhn 1988, 1994; Easton 1992). The viability of coastal Oregon as a migration corridor for the first humans into North America depends in part on whether the coast provided environments suitable to human needs. Research indicates that early, coastally-adapted humans often utilized areas in close proximity to estuaries (Yesner,1980; Maschner and Stein 1995; Draper 1988; Aikens 1993; Minor and Toepel 1986). These areas would have provided close access to potable water, aquatic and terrestrial food resources, water-craft beaching areas, and protection from hazardous coastal climatic events. Such estuarine environments exist all along the Oregon coast today, but the timing of individual estuary development is unknown.

An estuary is defined as "the seaward portion of a drowned river valley system which receives sediment from both fluvial and marine sources and which contains facies influenced by tide, wave and fluvial processes. The estuary is considered to extend from the landward limit of tidal facies at its head to the seaward limit of coastal facies at its mouth." (from Dalrymple et al. 1992:1132). Most of the modern estuaries along the Oregon coast formed during the late Pleistocene and early Holocene as global, eustatic sea level rise flooded incised river valleys (Glenn 1978; Peterson et al. 1984). Estuaries are ephemeral features, their development and life spans dependent upon factors such as rates of eustatic sea level change, sediment supply, tectonic activity, and basin morphology (Boggs and Jones 1976; Peterson et al. 1984; Dalrymple et al. 1992). Dalrymple et al. (1992) argue that estuaries form only under conditions of relative sea level (RSL) rise, and that progradation eventually fills and destroys estuaries under conditions of RSL stillstand or fall.

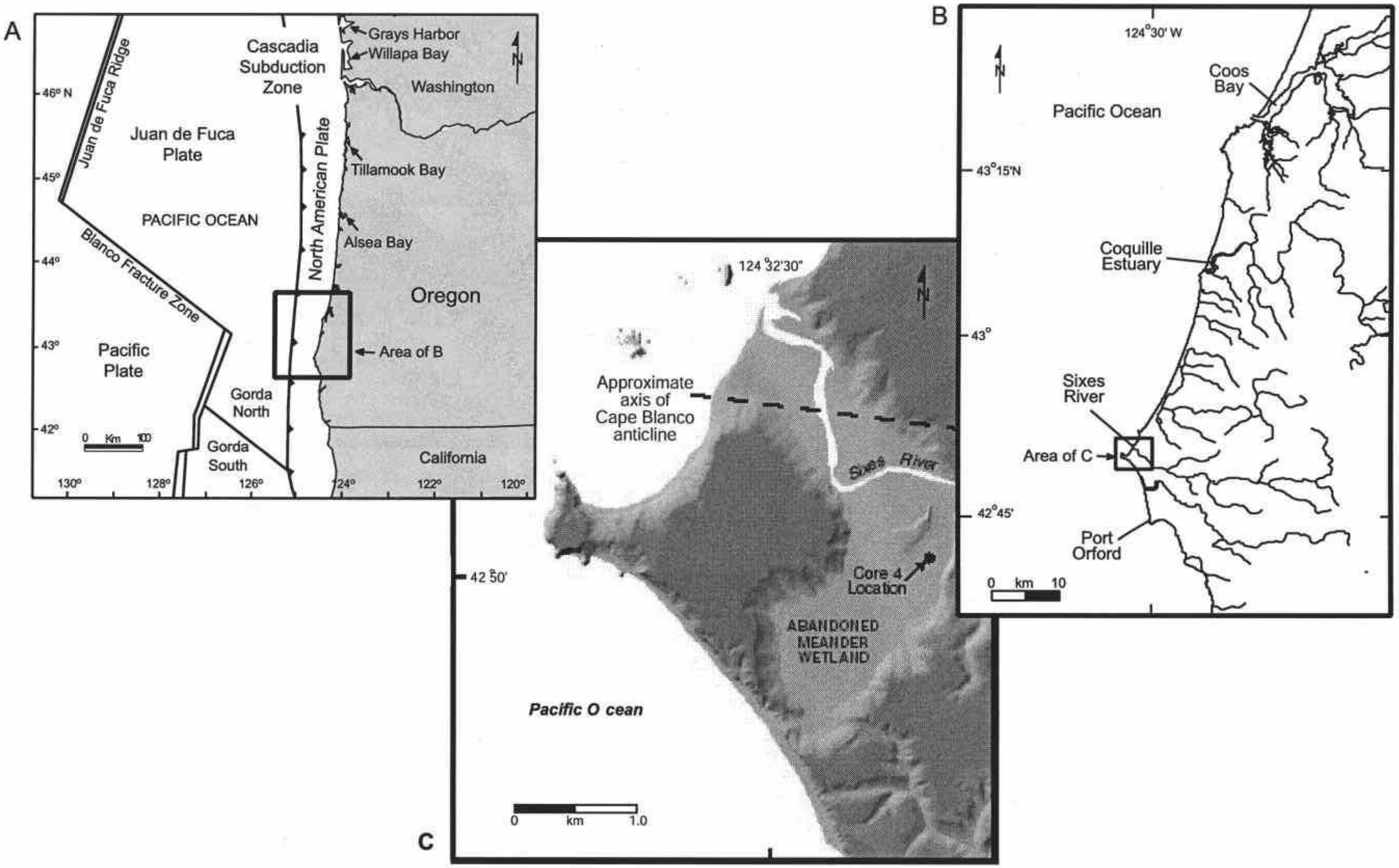


Figure 1. (A) Setting of southern coastal Oregon in relation to major plate boundaries. Locations of regional coastal estuaries discussed in text indicated. (B) Local setting of Sixes River in relation to other local estuaries and the tidal datum at Port Orford. (C) Map of lower Sixes River valley showing location of abandonded meander area, core extraction location, and approximate axis of Cape Blanco anticline (Kelsey 1990).

This study explores depositional environment change through time at an active margin, coastal estuary and wetland locality (Figure 1). A depositional environment is a geomorphic setting in which a characteristic set of physical, chemical, and biological processes operate (Boggs 2001:257). Specific depositional environments produce identifiable sedimentary facies that display evidence of these physical, chemical, and biological activities. Interpretation of sedimentary facies preserved in a long sediment core recovered from the lower Sixes River valley on the southern Oregon coast (Figure 1) relies on investigations of multiple, independent lines of biologic and lithologic evidence from sediments dating to as early as the late Pleistocene.

Radiocarbon dates on organic materials from identifiable intertidal settings provide age estimates for rates of relative sea level rise (through the production of a relative sea level curve), sedimentary facies development, and depositional zone transitions. Once the history of development of the Sixes River estuary and wetland is produced, it is evaluated in terms of an idealized transgressive estuary evolution and compared to other estuarine life histories from the Oregon and Washington coasts. Variables affecting estuary evolution, such as eustatic sea level change, sedimentation, tectonic activity, and basin morphology are assessed to determine their influence on the study locality. The results of these comparisons and evaluations are discussed in terms of their impact on early humans entering the New World via a coastal route.

Conceptual Approach

The litho- and biostratigraphic investigations employed by this study pertain to three primary topics which aid in the identification of depositional environment type: 1) depositional energies; 2) relative influences of marine, estuarine, and fluvial sediment deposition; and 3) intertidal settings. Information regarding depositional energy addresses the physical activities impinging upon the depositional environment. Data pertaining to the influences of marine, estuarine, and fluvial forces of sediment deposition (sediment source) address both physical and chemical aspects of depositional environments. Physically, information regarding sediment source can help elucidate what processes are active at a site through time. Chemically, salinity associations are useful in placing a depositional environment within the elevation range of the tidal spectrum and in determining the relative influence of marine versus freshwater depositional forces. Additionally, intertidal setting identification allows inferences pertaining to the physical location of the depositional environment relative to the estuary and relative to tidal influence/salinity gradients to be made. Finally, intertidal settings are associated with varying amounts of biological activity, so that relative amounts of organic matter association can be expected depending on identified setting.

Whereas these three primary topics do not address the complete range of physical, chemical, and biological activities associated with depositional environments, they do provide a basis from which differentiation of depositional environments can be made. Most important for this study, evidence pertaining to each of these topics is preserved in the sedimentary record and can be studied using litho- and biostratigraphic analyses.

Lithostratigraphic investigations employed by this study include average grain size measurements, magnetic susceptibility, gamma density, and loss on ignition (LOI). Average grain size distributions are used to infer depositional energy, with larger grain sizes being transported by higher energy depositional forces. Research conducted by Boggs (1969) from the headwaters of the Sixes River down to the estuary and surrounding beach suggests that higher-density, magnetic minerals are more prevalent in the sand-sized fraction of river deposits than in the sand-sized fraction of beach or estuary deposits. This study utilizes magnetic susceptibility and gamma density of sediments to determine sediment source, with higher magnetic susceptibility readings and higher sediment densities expected to correlate with sediments from an upriver, freshwater source. Loss on ignition is used as a proxy for organic carbon content, with higher relative LOI readings expected to be associated with more productive, higher elevation intertidal settings (Pizzuto and Rogers 1992).

Biostratigraphic investigations involve the identification and classification of fossil diatoms that are incorporated into stratigraphic sections. Information regarding salinity tolerances can be used to infer dominant depositional contexts, including sediment source, with higher percentages of freshwater diatoms expected to be associated with fluvial sediment deposition and higher marine-diatom percentages associated with marine or marine/estuarine sediment deposition. Researchers have also used diatom assemblage interpretations to infer intertidal setting through the analysis of species intertidal zone association, life form, and substrate preferences (Hemphill-Haley 1995; Nelson and Kashima 1993).

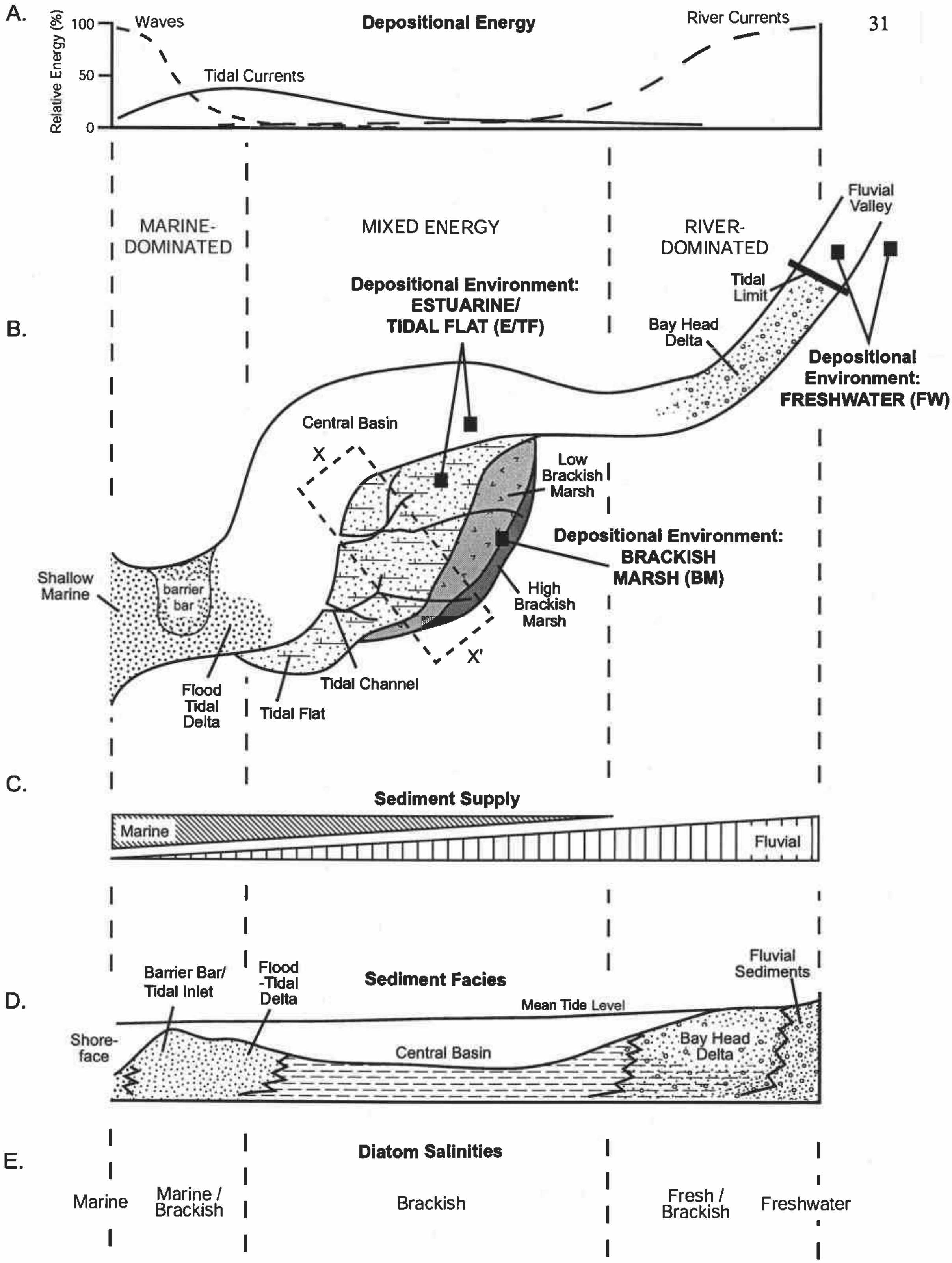


Figure 2. Schematic representation of an estuary setting including: (A) relative depositional energies; (B) landforms and intertidal settings; (C) typical facies assemblages; (D) dominant sediment supplies; and (E) typical diatom salinity associations. Rectangular transect X to X' depicted in detail in Figure 3. Modified from Dalrymple et al. (1992: Figure 4) and Nichols and Biggs (1985:Figure 2-48).

Estuaries are complex systems encompassing a number of depositional environments (Nichols and Biggs 1985; Perillo 1995). Both fluvial and marine processes interact in an estuary setting. Depositional energies vary in strength and source of influence in both landward and seaward directions (Figure 2a) as well as laterally from channel margins (Figures 2b and 3). Sediment sources are marine and fluvial, while mixed sediments deposited in central areas are often recycled back into the system for subsequent redeposition (Figures 2c and 3).

Sediment deposition occurs within all parts of the estuary and along the estuary margins (Figures 2d and 3), although not all of this sediment is preserved in the stratigraphic section. Fluvial sediment is emplaced along river channels as overbank deposition or lateral accretion. Sediments carried within the fluvial water column, including bedload, saltation load, and suspended sediment, are often deposited as a bay head delta when the relatively shallow stream channel enters the deeper estuary basin. Some suspended sediment is carried further seaward into the estuary and deposited, or it may be flushed out of the system completely, depending on the energy of the fluvial system relative to marine tides and wave power.

Tidal currents and wave energy bring marine sediment into the system from the seaward end, with a flood tidal delta produced just inside the mouth of the estuary where water depth increases and sediment transport energy decreases (Figure 2a and d). Marine and estuarine sediments are carried upstream by tidal currents, with the landward distance of transport dependent upon the relative energies of the marine tidal versus the fluvial system. Marine and estuarine sediment is deposited laterally on tidal flats and brackish marshes (Figures 2b and 3). Wave energies are most influential in the lowest elevation tidal flats and channels, while tidal currents bring sediments into the upper elevations of the tidal flats and onto the low and high brackish marshes. Water salinity within estuary systems decreases upstream and laterally with elevation relative to tidal encroachment (Figures 2e and 3). Freshwater uplands occur at elevations above any tidal influence, with sediment influx occurring in association with extreme flood events or erosion of surrounding landscapes (such as bluffs).

These descriptions of depositional variables within an estuary setting are necessarily simplified for the purposes of this study. A typical sedimentary facies produced by specific depositional environments can be proposed based on the information presented above, with the understanding that deviances from the norm are to be expected. With this in mind, this

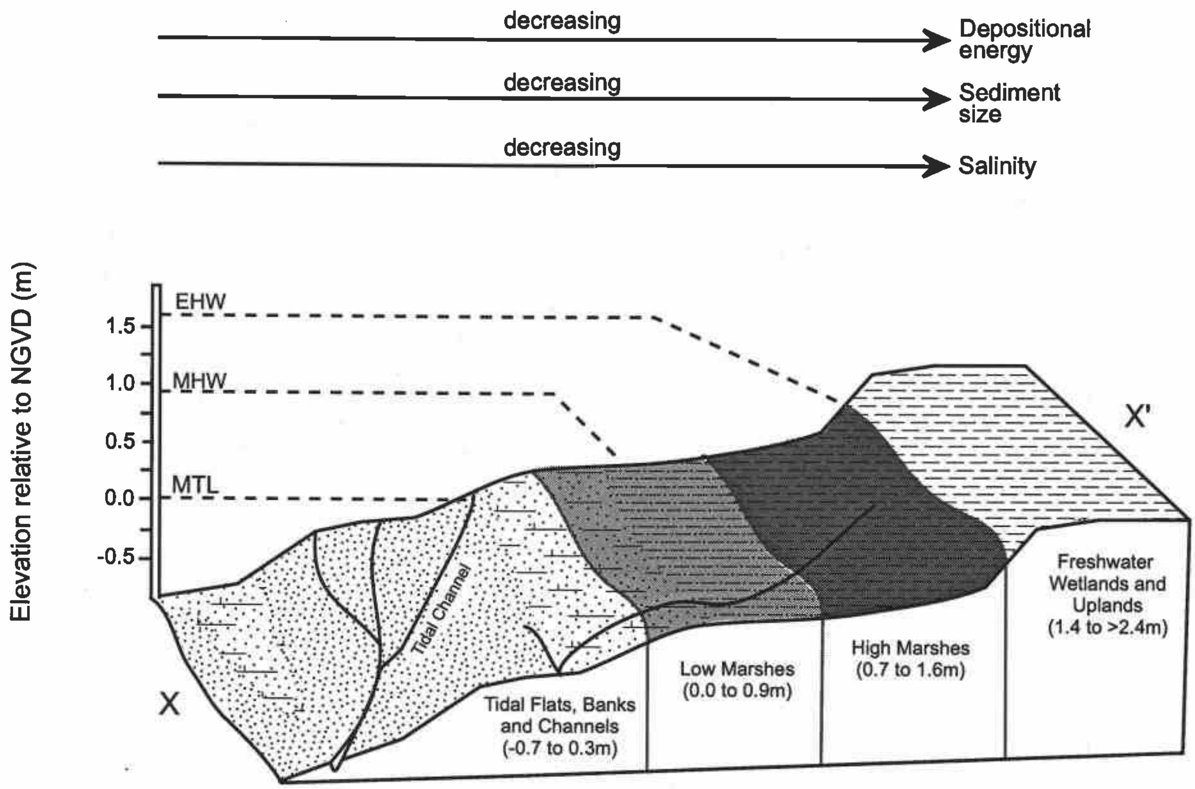


Figure 3. Elevation ranges for intertidal zones at the Sixes River Estuary based on information from Jennings and Nelson (1992), Nelson and Kashima (1993), and Hemphill-Haley (1995a). Tidal information from the National Ocean Service (1992). EHW, extreme high water; MHW, mean high water; MTL, mean tide level. Intertidal zones overlap by 20-30cm, reflecting variations in vertical zone boundaries (Nelson and Kashima1993).
X to X' transect shown on Figure 2.

study identifies three different depositional environments within an estuary setting that have high preservation potential and that can be identified using litho- and biostratigraphic facies analysis designed to address the three primary topics listed above (depositional energy, sediment source, and intertidal setting). The three depositional environments are presented below, with hypothesized stratigraphic characteristics.

The first depositional environment is a Freshwater setting (FW) (Figure 2b). This setting includes those areas along the river margins and in the freshwater wetlands and uplands surrounding the coastal marsh areas. This environment occurs at an elevation above the influence of brackish-water tides or upriver from tidal influence and is expected to be associated with high percentages of freshwater diatoms and freshwater wetland intertidal settings. Sediment densities and magnetic susceptibility will also be high, as most of the sediment deposited in freshwater settings is fluvially-derived. Depositional energies associated with this environment are expected to vary—those deposits associated with river deposition will range from fine to coarse grained, while deposits associated with freshwater uplands will be fine-grained. Freshwater settings support extensive plant life, and will therefore display high LOI readings.

The second depositional environment is the Brackish Marsh (BM) (Figure 2B). Considerable variation in grain size is expected as these localities are frequently inundated by river flood waters and normal tidal cycles. Magnetic susceptibility readings and sediment densities will be moderate due to the combined influence of freshwater and brackish sediment deposition on the site. Diatom salinities are expected to range from freshwater or fresh-brackish, indicating a freshwater source, to brackish and brackish-marine due to tidal activities. Diatoms assemblages will be indicative of high brackish marsh or low brackish marsh intertidal settings. Extensive plant communities are supported in high and low intertidal marsh areas, so LOI readings will be moderate to high.

The final depositional environment is the Estuarine/Tidal Flat setting (E/TF) (Figure 2b). This environment includes areas within the tidal flat and channels, as well as the area within the bounds of the estuary itself. E/TF sediments may be silt and clay or sands depending on their position relative to high energy tidal channels and wave activity. Sediments from the estuary's central basin will be fine-grained. Sediment density and magnetic susceptibility readings are expected to be very low in comparison to the other depositional environments, indicating a primarily marine/estuarine sediment source. Diatom salinities will be predominantly marine and brackish and intertidal setting reconstructions will indicate tidal flats, tidal channels, or estuarine basins. LOI readings will be the lowest of all the depositional environments.

While a fourth depositional environment representative of a shallow marine setting is seen in the sedimentary records of some estuaries, the coring location of this study is probably too far inland to have been near enough to the shoreline to retain such a depositional facies at this particular spot.

By inferring the depositional energy, sediment source, and intertidal environment associated with each sedimentary facies recorded at the study location, this project aims to establish not only what depositional environments existed at the site through time, but also what contextual influences caused the setting to change from one depositional environment to another.

Study Site

This study was conducted in lower Sixes River valley, located ~11 km north of Port Orford on the southern Oregon coast (Figure 1). This location was chosen because previous work in the area has established the existence of early human activity in the region (Minor 1993; Davis et al. 2004). Additionally, the area has undergone extensive shallow coring resulting in evidence of estuary establishment and transition, as well as earthquake activity dating to as early as the mid-Holocene (Kelsey et al. 2002).

The modern Sixes River estuary is confined within the active river channel, with head of tide reaching approximately three river kilometers upstream (Kelsey et al. 1998). The coastal lowland surrounding the river is currently higher than mean higher high water (MHHW), which is 0.98 m relative to the National Geodetic Vertical Datum (NGVD). All elevations reported in this paper will be relative to NGVD and are tied to the Port Orford tide gauge located 11 km to the south of Cape Blanco (Figure 1). Much of the lower Sixes valley is an abandoned meander wetland cut into surrounding Pleistocene marine terrace deposits (Figure 1). It is thought that the meander was cut sometime during the last glacial period and filled in with marine, estuarine, and fluvial (riverine) sediments as sea level rose in the late Pleistocene and early Holocene periods (Kelsey et al. 2002).

The lower Sixes River valley is impacted by local and regional tectonic activity. Coastal Oregon lies within the central portion of the Cascadia subduction zone (CSZ), a shallow reverse fault extending from northern California to southern British Columbia

(Figure 1). This regional zone has been subjected to significant tectonic deformation during the Quaternary through slow, interseismic uplift and periodic, abrupt coseismic subsidence (Atwater 1987; Mitchell et al. 1994; Muhs et al. 1990; Kelsey 1990; Kelsey et al. 1996). Locally, the Cape Blanco anticline (Figure 2), an east-trending, east plunging fold, has caused the river basin to uplift during the late Quaternary, as evidenced by nearby warped marine terrace platforms (Kelsey, 1990).

We recovered four long cores from the lower Sixes River valley, with the longest and most complete core, Core 4, extracted from a freshwater wetland within the abandoned meander 3.5 km from the modern channel mouth (Figure 1). Previous work within the abandoned meander conducted by Kelsey et al. (2002) focused on the southern and northwestern freshwater wetland and swamp portions of the area. Using hand-operated gouge cores, their efforts recovered sediments to a maximum depth of just over -3 m NGVD. Our team utilized an alternative coring technology, a hydraulically powered, truck-mounted Geoprobe, to recover sediments to a maximum depth of -21.2 m NGVD in Core 4. AMS radiocarbon dating of seeds from near the bottom of the core resulted in a date of ~10,000 cal yr BP for sediments buried -20.6 m NGVD.

Methods

Following recovery of sediment cores, a number of litho-, bio-, and chronostratigraphic analyses were employed to reconstruct the evolution of depositional environments at the site. Our aim was to determine general trends in relative sea level (RSL) rise and fall at the site, as well as to differentiate between dominant depositional forces operating through time. Analysis efforts were concentrated on the longest of four cores recovered from the area, Core 4. This core was extracted in 22 sections, measuring 1.22 m each, to a depth of 26.78m below the surface (-21.2m NGVD). In order to minimize mixing of sediments between sections, the Geoprobe corer was lowered to the appropriate depth within the core hole before the probe barrel was opened for sediment retrieval. In this way, only those sediments encountered between a known range of depths spanning 1.22 m were recovered and compaction amounts could be determined on a section-by-section basis. Unfortunately, due to the nature of the coring device, portions of core Sections 1, 3, and 4 were lost during the coring process. All sections below Section 4 (below 0.67 m) were recovered intact with minimal amounts of compaction or sediment loss.

Lithostratigraphic Investigations:

Four types of lithostratigraphic analyses were performed on the ~27 meter length of Core 4, including average grain size, magnetic susceptibility, gamma density, and loss on ignition (LOI). Grain size, magnetic susceptibility, and gamma density readings were taken at 2cm intervals, while LOI analyses were performed on 132 samples extracted from the core at intervals no greater than 40cm. Grain size analysis is used to infer depositional energy; magnetic susceptibility and gamma density help determine sediment source; and LOI is used to deduce intertidal setting.

Prior to splitting, each core section was passed through the Geotek multi-sensor core logger at Oregon State University's Department of Oceanography and Atmospheric Sciences core analysis and storage facility to determine downcore magnetic susceptibility and gamma density of sediments. The magnetic susceptibility meter attached to the core logger exposes sediments to an external magnetic field at intervals of two centimeters. This field magnetizes sediments in proportion to the amount of iron-bearing minerals within the sediment sample and then measures the ease with which the sediments are magnetized. Those sediments with higher proportions of magnetic minerals give higher susceptibility readings (Geotek 2000).

Gamma density is determined by measuring the number of unscattered gamma photons that pass through the core sections. A narrow beam of gamma rays is emitted by a source and these photons passing through the core are detected on the other side. Attenuation, or reduction of gamma energy, occurs when gamma rays encounter electrons within the core and are scattered. The thicker the electron density is within the core, the more attenuation of gamma photons that occurs. Therefore, higher relative gamma density readings (high counts per second (cps)) correlate with core sediments of lower density. Gamma density readings were taken every 2cm throughout the length of the core,

Cores were split into halves, digitally and x-ray photographed, and described with special attention to sediment and stratigraphic morphology, including color, grain size, sorting, bedding, inclusions, and boundaries. Average physical grain size was estimated by visual inspection and manual measurement of the sediments. Based on these initial investigations, sediments for more detailed analyses of diatoms and loss on ignition (LOI) were chosen. Samples were extracted at obvious shifts in sediment or stratigraphic morphology or within areas of relatively high or low magnetic susceptibility or density readings, determined on a section-by-section basis. In relatively homogeneous core sections, samples were selected at intervals no greater than 40 cm. A total of 132 sediment samples were extracted from the 22 core sections for further analysis.

Loss on ignition (LOI) was performed on all 132 samples extracted from the core sections. LOI is used as a measure of relative organic carbon content within a sediment sample, with LOI values approximately two times higher than organic carbon content (Ball 1964). Approximately 2cc of sediment from each extracted sample was heated to 105^0C for a minimum of 16 hours to remove moisture and to determine oven-dry weight. The samples were then heated to a temperature of 375^0C for a minimum of 16 hours and weighed again. The difference in weight represents the loss of organic material. From this, the percent of original sample lost on ignition was determined.

Biostratigraphic Investigations:

Biostratigraphic investigations involved the identification and analysis of fossil diatoms from 132 samples extracted at intervals of no greater than 40cm from the ~27m of core sediments, following the methodology of Patrick and Reimer (1966), Nelson and Kashima (1993), and Hemphill-Haley (1995). Diatom analyses are an independent test of sediment source and intertidal setting that can be compared to the lithostratigraphic analyses described above.

Approximately 1-2cc of sediment was extracted for each of the 132 samples taken for diatom analysis. Sediment samples were cleaned by oxidizing in 30% H_2O_2 and rinsing with distilled water. Silica was separated from heavy mineral sediments by flotation in a sodium polytungstate solution with a specific gravity of 2.56, transferred to a separate centrifuge tube, and repeatedly rinsed using distilled water. An aliquot of approximately 0.05 to 0.10 ml of the cleaned water-silica solution was transferred to a cover slip, allowed it to dry, and permanently mounted on a glass slide using Hyrax.

Diatom preservation throughout the core was variable, with the best preservation occurring in the upper eight core sections (to approximately -4.00 m NGVD). Where possible, 100+ diatoms were identified per slide to the species level and counted at a magnification of 1000x. In cases where <100 diatoms were counted, paleosalinity and paleoenvironmental inferences were based on those diatoms valves that could be identified. Salinity tolerances for each species and variety were compiled from a number of sources, including Patrick and Reimer (1966; 1975); Nelson and Kashima (1993); Hemphill-Haley

(1993); Hemphill-Haley and Lewis (1995); Laws (1988); John (1983); Foged (1981); Pankow (1990); and Krammer and Lange-Bertalot (1986-1991).

Salinity tolerances:

The relative influence of marine, estuarine, and fluvial forces on sediment deposition can be inferred through an analysis of fossil biological material incorporated into the sediment. Because diatoms are incorporated into the sediment as silt-sized particles when they die, they represent tracers of the salinity influence upon a given sediment deposit. Diatom counts for each sample extracted from the core sections were organized based on salinity preference, as delineated in the texts cited above (diatom counts appear in Appendix A). Salinity organizational groups included freshwater species (do not tolerate any amount of salt), freshwater-brackish species (salinity tolerance range from 0 to <0.2 $^{o}/_{oo}$), brackish (0.2-10 $^{o}/_{oo}$), brackish-marine (10-30 $^{o}/_{oo}$), marine (>30 $^{o}/_{oo}$), and euryhaline (tolerate a range of salinity). Those diatom valves which could not be identified to species level or for which no salinity preference information was available were classified as "unknown". For each sediment sample, the percentage of the total diatoms counted per slide each salinity group represented was computed. These results can be used to infer dominant sources of sediment deposition throughout the length of the core.

Intertidal Zone Identification:

Diatom assemblage analysis, involving consideration of salinity percentages, dominant species type, and valve preservation, was also conducted on each of the 132 samples in order to determine intertidal environmental setting and to aid in the construction of a relative sea level curve for the site. In addition to differing salinity tolerances and exposure preferences, diatoms are associated with specific habitats and can be identified as planktonic (diatoms which inhabit the water column) or benthic (diatoms associated with a specific substrate, such as sand, mud, or vegetation). Groups of diatoms that inhabit defined elevation ranges relative to mean tide level have been identified in modern coastal settings in Washington (Hemphill-Haley 1995) and Oregon (Nelson and Kashima 1993). These researchers grouped diatom taxa into typical intertidal zone assemblages based on Q-factor and discriminant function analyses of the distributions of modern species. Identifiable intertidal zones include freshwater uplands, brackish high marshes, brackish low marshes, and intertidal flats/channels (Figure 3). Ancient zones of intertidal deposition recorded in the sediment record are determined through comparison of fossil diatom assemblages with these modern intertidal distributions (Atwater and Hemphill-Haley 1997; Nelson et al. 1996b; Kelsey et al. 2002; Witter et al. 2003).

Statistical Investigations:

Intertidal environments and the relative influences of marine, estuarine, and fluvial forces on sediment deposition can be inferred using diatom biostratigraphy, as outlined above. However, biostratigraphic analysis represents a very time consuming exercise. Thus, analysis of sediments in the ~27m long core at intervals of 2cm (the interval used for grain size, magnetic susceptibility, and gamma density) was well beyond the scope of this project. Instead, diatom samples taken at maximum intervals of 40cm were statistically compared to higher resolution, lithostratigraphic data sets in order to establish relationships between bio- and lithostratigraphic variables. In this way, those sediments for which little or no diatom data were available (due to sampling interval or preservation issues) could still be classified according to sediment source and intertidal environment through analysis of high-resolution lithostratigraphic data that have statistically significant relationships to biostratigraphic data.

The statistical portion of this study seeks to answer the following question: what are the relationships between the lithostratigraphic variables measured (grain size, magnetic susceptibility, gamma density, LOI) and the intertidal setting components that we want to decipher (depositional energy, sediment source/salinity, and intertidal zone)? In other words, is there a statistically significant relationship between the variables we measured and the environments we are trying to reconstruct?

The statistical investigations are designed to identify and quantify meaningful relationships between the lithostratigraphic variables and intertidal setting components in order to infer environmental conditions for those portions of the core lacking diatom assemblage interpretations. For statistical operations, intertidal zones were assigned numerical values as follows: freshwater (1), brackish high marsh (2), brackish low marsh (3), and tidal flat/channel (4), ordered according to their relative elevations and salinity influences (Figure 3). Average grain sizes were grouped into silt/clay (grain size <0.062mm), sand (grain size $\geq$ 0.062 and <1.99mm) and pebbles (grain size $\geq$ 1.99mm).

Regression analysis was performed on litho- and biostratigraphic data sets to determine the strength and nature of relationships between variables following techniques outlined by Madrigal (1998). In certain cases where regression analyses did not return statistically meaningful values, variables for comparison were separated according to grain size or core depth in order to further define the relationships between variables. Additionally, polynomial trendlines (6th order) were applied to the magnetic susceptibility, gamma density, and LOI data sets in order to illustrate general trends in the data and to identify significant deviations from these trends.

Chronostratigraphic Investigations:

Plant macrofossils from within the cores were carefully selected, cleaned, and identified. Samples for radiocarbon dating were chosen based on their association with changes in litho- and bio-stratigraphy. Each sample was mixed with 30 ml of distilled water and sodium metahexaphoshate to allow botanical and charcoal remains to deflocculate from clays and float to the surface. These samples were then filtered through a fine mesh and allowed to dry. When present, specimens of identifiable seeds or woody detritus, botanical fossils considered most reliable for dating (Nelson 1992; Kelsey et al. 2002), were picked using a dissecting microscope and submitted for accelerator mass spectrometry (AMS) radiocarbon dating. Charcoal fragments were selected for dating when other biological remains were absent. In these cases, care was taken to choose angular rather than rounded specimens to avoid redeposited samples. Due to budget constraints, only seven AMS radiocarbon samples were submitted to Beta Analytic, Inc. for dating.

Relative Sea Level Curve Construction:

Once intertidal zones associated with diatom assemblages are determined, a relative sea level curve (elevation of mean tide level (MTL) over time) for the site can be constructed. Intertidal zones are found within defined elevation ranges relative to MTL along the coast of Oregon (Nelson and Kashima 1993). By determining the intertidal zone represented by sediments extracted from a certain depth relative to NGVD, local sea level at the time those sediments were deposited can be estimated. Following this methodology, paleo-MTL

Table 1. Radiocarbon Ages and Estimated Sedimentation Rates, Lower Sixes River Valley

Dated Sample Number	Core : Section	Elevation relative to NGVD (m)	Depth below surface (m)	Material dated	Beta Analytic Lab Number	Conventional radiocarbon age and reported error (C14 yr BP)*	Calibrated age (2 sigma)	Estimated Rate of Sediment Deposition (mm/yr)
B	4 : 2	4.18 to 4.16	1.38	small woody debris	Beta-203257	2300+/-40 BP	Cal BP 2350 to 2300 and Cal BP 2260 to 2160	<1
G	4 : 7	-2.125 to -2.135	7.68	small, woody detritus	Beta-203256	5600+/-40 BP	Cal BP 6450 to 6300	2
H	4 : 7	-2.51 to -2.50	8.06	small woody debris, sharp edged	Beta-203255	5860+/-40 BP	Cal BP 6690 to 6500	2
I	4 : 9	-4.42	9.96	Seeds	Beta-199710	5970+/-40 BP	Cal BP 6890 to 6690	10
J	4 : 15	-11.63 to -11.66	17.18	Wood	Beta-199712	8280+/-50 BP	Cal BP 9440 to 9120	3
K	4 : 18	-16.25	21.80	Plant material	Beta-199709	8900+/-50 BP	Cal BP 10190 to 9880	7
M	4 : 22	-20.62 to -20.64	26.18	Seeds	Beta-199715	8980+/-40 BP	Cal BP 10220 and 10140 and Cal BP 10000 to 9960	40

* Lab-reported ages represent radiocarbon years before present (C-14 yr BP) where present is equivalent to AD 1950. Radiocarbon ages were calibrated using the INTCAL98 calibration data set of Stuiver et al. (1998) and are reported in the text and in Tables 1 and 2 as calibrated (solar) years before AD 1950 (cal yr BP).

elevation ranges for each of the dated sediment horizons were calculated and plotted on a graph comparing elevation (NGVD) to time before present to produce a relative sea level curve for the site.

Results

Chronostratigraphic Investigations:

The material dated, its context, and the results are outlined in Table 1. Radiocarbon dates returned on organic materials ranged from 2300+/-40 BP (Cal BP 2350 to 2300 and Cal BP 2260 to 2160) at a depth of 1.38m (4.17m NGVD) to 8980+/-40 BP (Cal BP 10220 and 10140) and Cal BP 10000 to 9960) at a depth of 26.17m (-21.63m NGVD) (Tables 1 and 2). Implied rates of sediment deposition range from 40mm/yr to <1mm/yr (Table 1).

Lithostratigraphic Investigations:

General trends in grain size distribution can be seen in Figure 4a. The upper six meters of the core are relatively fine grained, with grain size in the silt to clay range. From -0.55m to -17.63m (all elevations reported in the results section are in meters relative to NGVD) grain size varies considerably with the largest sediments deposited between -8.7 and -9.0m and between -16.4 and -16.9m. Below Section 20 grain size again fines with the lowest 3.5 meters of the core dominated by silt/clay.

Magnetic susceptibility readings (Figure 4b) are charted for the sand-sized fraction of sediments only, following Boggs (1969). Susceptibility is relatively low in the uppermost two meters of the core. Peaks and lows occur throughout the rest of the core, but notable relative trends include the following: between 4.0m and 3.5m magnetic susceptibility is high, followed by half-meter intervals of highs and lows to around -5.5m; from approximately

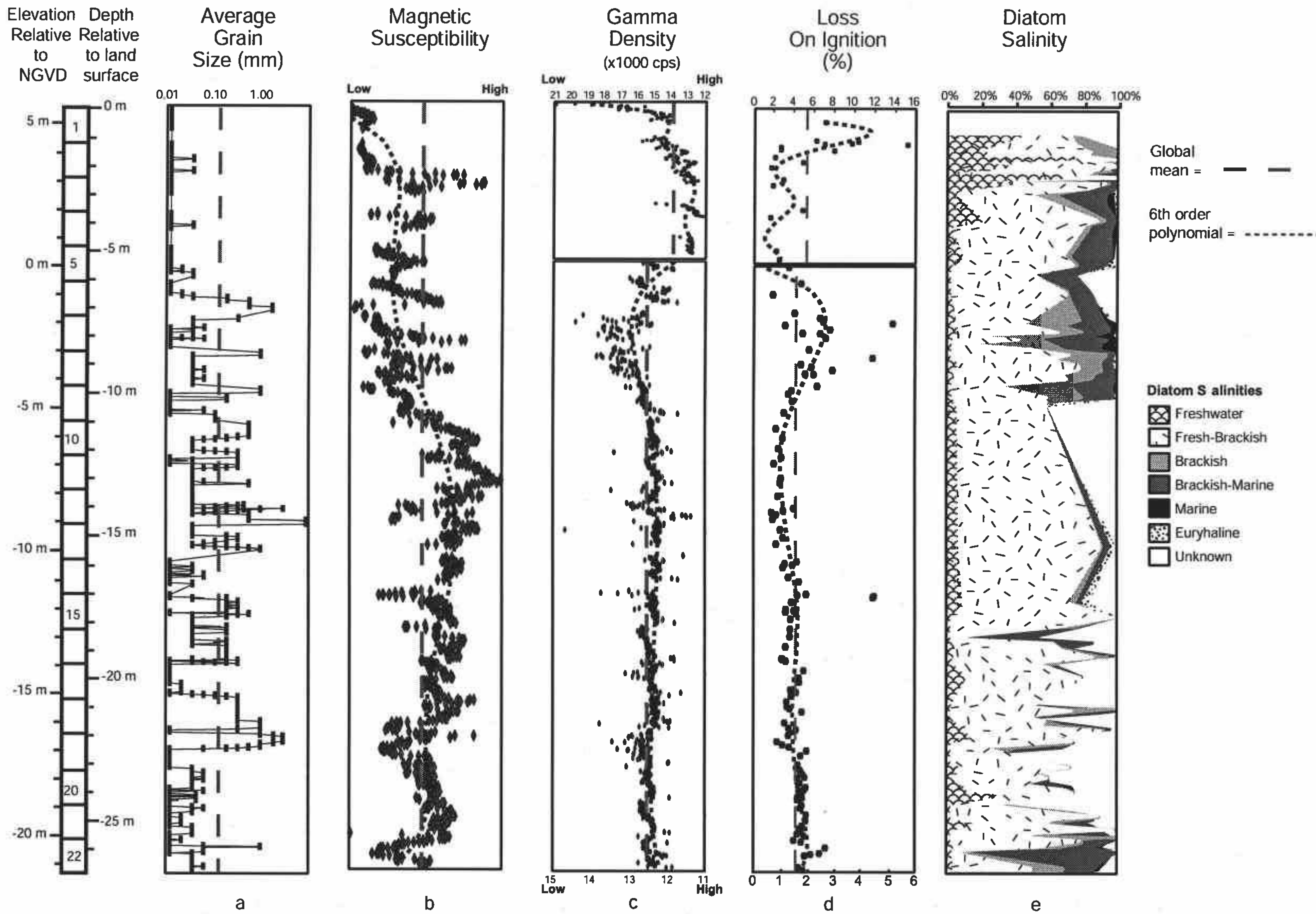


Figure 4. Summary of downcore results for litho- and biostratigraphic analyses. Note difference in scale between upper and lower portions of Gamma Density and Loss on Ignition

Table 2. Diatom Salinity Percentages for Each Sample, Number in Sample, and Intertidal Setting Assignments

Core Section	Sample Number	Elevation relative to NGVD (m)	Core Depth (m)	Percent of Total (%) Fresh-water	Fresh/ Brackish	Brackish	Marine/ Brackish	Marine	Eury-haline	Unknown	Number of diatoms counted	Inferred intertidal setting
4:0-4/1	SS-18	4.93	0.61	42.7	29.1	4.5	0.0	0.0	0.9	22.7	110	FW
4:4-8/2	SS-19	4.29	1.25	16.5	59.6	16.5	0.9	0.0	0.0	6.4	109	BHM
4:4-8/2	SS-20	4.25	1.29	18.9	56.8	12.6	0.0	0.0	0.9	10.8	111	BHM
4:4-8/2	SS-21	4.19	1.35	18.0	54.1	15.6	0.0	0.0	0.0	12.3	122	BHM
4:4-8/2	SS-22	4.18	1.37	15.0	70.0	7.7	3.5	0.0	0.0	4.2	143	BLM
4:4-8/2	SS-23	4.15	1.39	72.7	25.6	0.0	0.0	0.0	0.0	1.7	121	FW
4:4-8/2	SS-24	4.06	1.48	12.4	49.5	11.4	1.0	0.0	0.0	25.7	105	BLM
4:4-8/2	SS-154	4.03	1.51	16.4	81.1	0.0	2.5	0.0	0.0	0.0	122	FW
4:4-8/2	SS-25	3.98	1.56	30.0	57.0	0.0	0.0	0.0	0.0	13.0	23	FW
4:4-8/2	SS-155	3.96	1.58	18.8	74.1	0.0	6.3	0.0	0.0	0.9	112	BLM
4:4-8/2	SS-26	3.94	1.60	6.3	63.8	16.5	2.4	0.0	0.0	11.0	127	BHM
4:4-8/2	SS-156	3.91	1.63	0.7	59.9	22.4	12.9	2.0	2.0	0.0	147	BLM
4:4-8/2	SS-157	3.90	1.64	13.2	62.3	15.8	8.8	0.0	0.0	0.0	114	BHM
4:4-8/2	SS-27	3.71	1.83	66.7	33.3	0.0	0.0	0.0	0.0	0.0	3	FW
4:4-8/2	SS-158	3.55	1.99	2.7	6.3	17.0	71.4	2.7	0.0	0.0	112	TF
4:4-8/2	SS-28	3.53	2.01	37.4	56.5	2.3	3.8	0.0	0.0	0.0	131	BHM
4:8-12/3	SS-132	2.90	2.64	5.6	77.8	0.0	16.7	0.0	0.0	0.0	18	BHM
4:8-12/3	SS-131	2.70	2.84	2.3	45.0	17.6	29.0	3.8	2.3	0.0	131	BLM
4:12-16/4	SS-130	1.84	3.70	20.0	69.6	4.4	5.9	0.0	0.0	0.0	135	BHM
4:12-16/4	SS-129	1.58	3.96	0.0	81.2	3.1	12.5	3.1	0.0	0.0	32	BHM
4:16-20/5	SS-128	0.41	5.13	7.6	60.4	3.8	26.4	0.0	0.0	1.9	53	BHM
4:16-20/5	SS-127	0.12	5.42	0.0	75.2	2.4	15.2	0.0	7.2	0.0	125	BHM
4:16-20/5	SS-126	-0.20	5.74	0.0	50.0	0.0	25.0	0.0	0.0	25.0	4	BHM
4:20-24/6	SS-125	-0.76	6.30	0.0	71.4	0.0	14.3	0.0	0.0	14.3	14	BHM
4:24-28/7	SS-122	-1.98	7.52	3.4	44.9	31.4	12.7	2.5	3.4	1.7	118	TF
4:24-28/7	SS-121	-2.11	7.65	0.0	44.4	23.9	27.4	3.4	0.0	0.9	117	TF
4:24-28/7	SS-120	-2.16	7.70	7.5	59.6	13.7	15.8	2.7	0.7	0.0	146	BLM
4:24-28/7	SS-119	-2.23	7.77	0.0	12.8	31.1	41.2	12.8	0.0	2.0	148	TF
4:24-28/7	SS-118	-2.38	7.92	0.7	43.0	9.7	42.0	4.8	0.0	0.0	145	TF
4:24-28/7	SS-117	-2.50	8.04	0.6	7.5	55.0	28.0	7.5	1.3	0.0	160	TF
4:24-28/7	SS-116	-2.52	8.06	0.6	47.0	21.7	21.0	8.6	0.6	0.0	175	BLM

Table 2. Continued

Core Section	Sample Number	Elevation relative to NGVD (m)	Core Depth (m)	Percent of Total (%) Fresh-water	Fresh/ Brackish	Brackish	Marine/ Brackish	Marine	Eury-haline	Unknown	Number of diatoms counted	Inferred intertidal setting
4:24-28/7	SS-115	-2.68	8.22	0.0	73.0	22.1	4.9	0.0	0.0	0.0	122	BHM
4:28-32/8	SS-113	-3.36	8.90	0.0	61.8	30.3	5.3	0.0	2.0	0.7	152	BHM
4:28-32/8	SS-112	-3.59	9.13	5.7	71.7	13.2	6.6	0.0	1.9	0.9	106	BHM
4:28-32/8	SS-111	-3.68	9.22	0.0	78.4	14.2	6.4	0.5	0.5	0.0	204	BHM
4:28-32/8	SS-110	-3.80	9.34	1.6	65.8	20.1	12.0	0.0	0.5	0.0	184	BLM
4:28-32/8	SS-109	-3.92	9.46	2.5	68.9	14.8	13.9	0.0	0.0	0.0	122	BLM
4:28-32/8	SS-108	-3.94	9.48	0.0	28.8	41.8	27.1	2.4	0.0	0.0	170	BLM
4:32-36/9	SS-107	-4.34	9.88	0.8	59.0	21.0	19.0	0.0	0.8	0.0	131	TF
4:32-36/9	SS-106	-4.50	10.04	3.8	54.0	0.0	0.0	0.0	0.0	42.0	26	BHM
4:48-52/13	SS-87	-9.62	15.16	4.4	86.8	1.1	4.4	0.0	2.2	1.1	91	BHM
4:56-60/15	SS-78	-11.63	17.17	7.3	63.4	4.9	2.4	0.0	4.9	17.1	83	BLM
4:56-60/15	SS-77	-11.65	17.19	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0	FW
4:56-60/15	SS-73	-12.16	17.70	0.0	0.0	0.0	0.0	0.0	0.0	100.0	2	FW
4:56-60/15	SS-72	-12.21	17.75	0.0	100.0	0.0	0.0	0.0	0.0	0.0	1	FW
4:56-60/15	SS-71	-12.26	17.80	0.0	0.0	0.0	0.0	0.0	0.0	100.0	2	FW
4:56-60/15	SS-70	-12.46	18.00	0.0	66.7	0.0	11.1	0.0	0.0	22.2	9	BHM
4:60-64/16	SS-68	-13.06	18.60	0.0	0.0	0.0	50.0	0.0	0.0	50.0	2	BLM
4:60-64/16	SS-67	-13.41	18.95	0.0	62.5	0.0	25.0	0.0	0.0	12.5	8	BLM
4:60-64/16	SS-66	-13.83	19.37	4.8	90.0	0.0	4.8	0.0	0.0	41.7	42	BHM
4:60-64/16	SS-65	-13.85	19.39	2.1	85.0	8.3	4.2	0.0	0.0	0.0	48	BHM
4:60-64/16	SS-64	-13.91	19.45	0.0	52.9	11.8	0.0	0.0	0.0	35.3	17	BHM
4:64-68/17	SS-63	-14.23	19.77	10.0	70.0	0.0	0.0	0.0	0.0	20.0	10	BHM
4:68-72/18	SS-57	-15.32	20.86	0.0	50.0	0.0	0.0	0.0	0.0	50.0	4	BHM
4:68-72/18	SS-56	-15.48	21.02	0.0	66.7	22.2	0.0	0.0	0.0	0.0	9	BHM
4:68-72/18	SS-55	-15.56	21.10	0.0	45.5	0.0	0.0	0.0	0.0	54.5	11	BHM
4:68-72/18	SS-54	-15.67	21.21	0.0	58.3	0.0	0.0	0.0	0.0	41.7	12	BHM
4:68-72/18	SS-53	-16.05	21.59	10.0	45.0	15.0	0.0	0.0	0.0	30.0	20	BLM
4:68-72/18	SS-52	-16.23	21.77	3.6	89.0	1.8	3.6	0.0	0.0	1.8	55	BHM

Table 2. Continued

Core Section	Sample Number	Elevation relative to NGVD (m)	Core Depth (m)	Percent of Total (%) Fresh-water	Fresh/ Brackish	Brackish	Marine/ Brackish	Marine	Eury-haline	Unknown	Number of diatoms counted	Inferred intertidal setting
4:68-72/18	SS-51	-16.29	21.83	14.0	50.0	0.0	0.0	0.0	0.0	36.0	14	BHM
4:72-76/19	SS-50	-16.49	22.03	0.0	75.0	0.0	0.0	0.0	0.0	25.0	4	FW
4:72-76/19	SS-49	-16.70	22.24	0.0	20.0	20.0	30.0	0.0	0.0	30.0	10	BHM
4:72-76/19	SS-48	-16.81	22.35	0.0	33.3	0.0	0.0	0.0	0.0	66.7	3	BHM
4:72-76/19	SS-47	-16.89	22.43	0.0	40.0	0.0	0.0	0.0	0.0	60.0	5	BHM
4:72-76/19	SS-46	-17.02	22.56	0.0	62.5	0.0	0.0	0.0	0.0	37.5	8	BHM
4:72-76/19	SS-45	-17.19	22.73	6.1	66.7	0.0	0.0	0.0	0.0	27.3	33	BHM
4:72-76/19	SS-44	-17.51	23.05	0.0	50.0	0.0	0.0	0.0	0.0	50.0	16	BHM
4:76-80/20	SS-43	-17.70	23.24	0.0	60.0	0.0	0.0	0.0	0.0	40.0	5	BHM
4:76-80/20	SS-41	-17.94	23.48	6.3	58.0	8.3	19.0	0.0	0.0	60.0	48	TF
4:76-80/20	SS-40	-17.96	23.50	14.0	76.0	3.0	0.0	3.0	0.0	35.7	29	BHM
4:76-80/20	SS-39	-18.14	23.68	0.0	75.0	0.0	0.0	0.0	0.0	25.0	12	BHM
4:76-80/20	SS-38	-18.29	23.83	29.4	41.2	0.0	0.0	0.0	0.0	29.4	17	BHM
4:76-80/20	SS-37	-18.38	23.92	0.0	25.0	0.0	0.0	0.0	0.0	75.0	4	BHM
4:76-80/20	SS-35	-18.44	23.98	0.0	75.0	0.0	0.0	0.0	0.0	25.0	4	FW
4:80-84/21	SS-17	-18.92	24.46	0.0	90.9	0.0	0.0	0.0	0.0	9.1	11	FW
4:80-84/21	SS-16	-19.02	24.56	0.0	62.5	0.0	25.0	0.0	0.0	12.5	8	BLM
4:80-84/21	SS-15	-19.25	24.79	10.0	50.0	10.0	10.0	0.0	0.0	20.0	10	BLM
4:80-84/21	SS-14	-19.46	25.00	14.3	42.9	7.1	21.4	0.0	0.0	14.3	14	BLM
4:80-84/21	SS-13	-19.64	25.18	0.0	100.0	0.0	0.0	0.0	0.0	0.0	4	BHM
4:80-84/21	SS-12	-19.74	25.28	0.0	50.0	0.0	0.0	0.0	0.0	50.0	2	FW
4:80-84/21	SS-11	-19.85	25.39	0.0	50.0	50.0	0.0	0.0	0.0	0.0	2	BHM
4:80-84/21	SS-10	-19.92	25.46	0.0	80.0	0.0	20.0	0.0	0.0	0.0	5	BHM
4:84-88/22	SS-8	-20.14	25.68	2.7	50.5	15.3	17.1	1.8	1.8	10.8	111	BLM
4:84-88/22	SS-7	-20.20	25.74	0.0	0.0	0.0	100.0	0.0	0.0	0.0	2	TF
4:84-88/22	SS-4	-20.63	26.17	2.6	47.0	19.1	18.3	1.7	3.5	7.8	115	TF

-5.5m to -7.5m magnetic susceptibility slowly rises, peaks, and then gradually falls to a low at around -17.0m; susceptibility gradually rises again until -20.0m where it takes a significant drop followed by another rise at around -20.5m. A smoothed, 6th order polynomial trendline (Figure 4b, fine dashed line) reveals a pattern of lower than average susceptibility in the upper portion of the core, higher than average readings in the central portion of the core, and near average to below average readings in the lowest portion.

Gamma density (Figure 4c) is relatively low (higher cps = lower density) in the uppermost portion of the core compared to the rest of the core (note difference in scale between upper and lower sections of chart; average gamma reading in upper section is ~14000cps, lower section is ~12,500cps). At 4.0m the sediments rise in density to around – 0.0m when density begins to drop. Lower than average density is recorded from –1.0 to – 4.0m. By -5.5m density reaches and maintains a moderately high, above-average reading throughout the rest of the core, with small peaks and troughs apparent within each section. Noteworthy troughs appear in the density readings from approximately –1.5m to -4m and from -16m to -18m. A smoothed, 6th order polynomial trendline of gamma density (Figure 4c, dashed line) reveals a pattern of low density in the upper portion of the core (when related to the core as a whole), followed by a gentle rise in density to above average in the core's midsection. Readings slowly fall to below average or average density in the lower two-thirds of the core.

LOI readings are highest in the upper 3.5 meters of the core (note difference in scale in upper and lower sections of chart; average LOI for upper section is nearly 6% versus and average of around 2% in the lower section). Peaks and lows occur within both the highly organic upper section and the less organic lower section. The 6th order polynomial trendline for LOI (Figure 4d, dashed line) reveals general trends in LOI readings for the upper and lower sections. In the upper section, LOI is above average to around 4.0m, whereupon it drops below average with a only one notable small peak at 2.5m. Organic content in the lower section peaks at -1.5m. Below this, LOI readings are below average until they rise to just over average at -11.5m. Above average to average readings are maintained throughout the rest of the core except for a small trough from -14.0m to -17.0m.

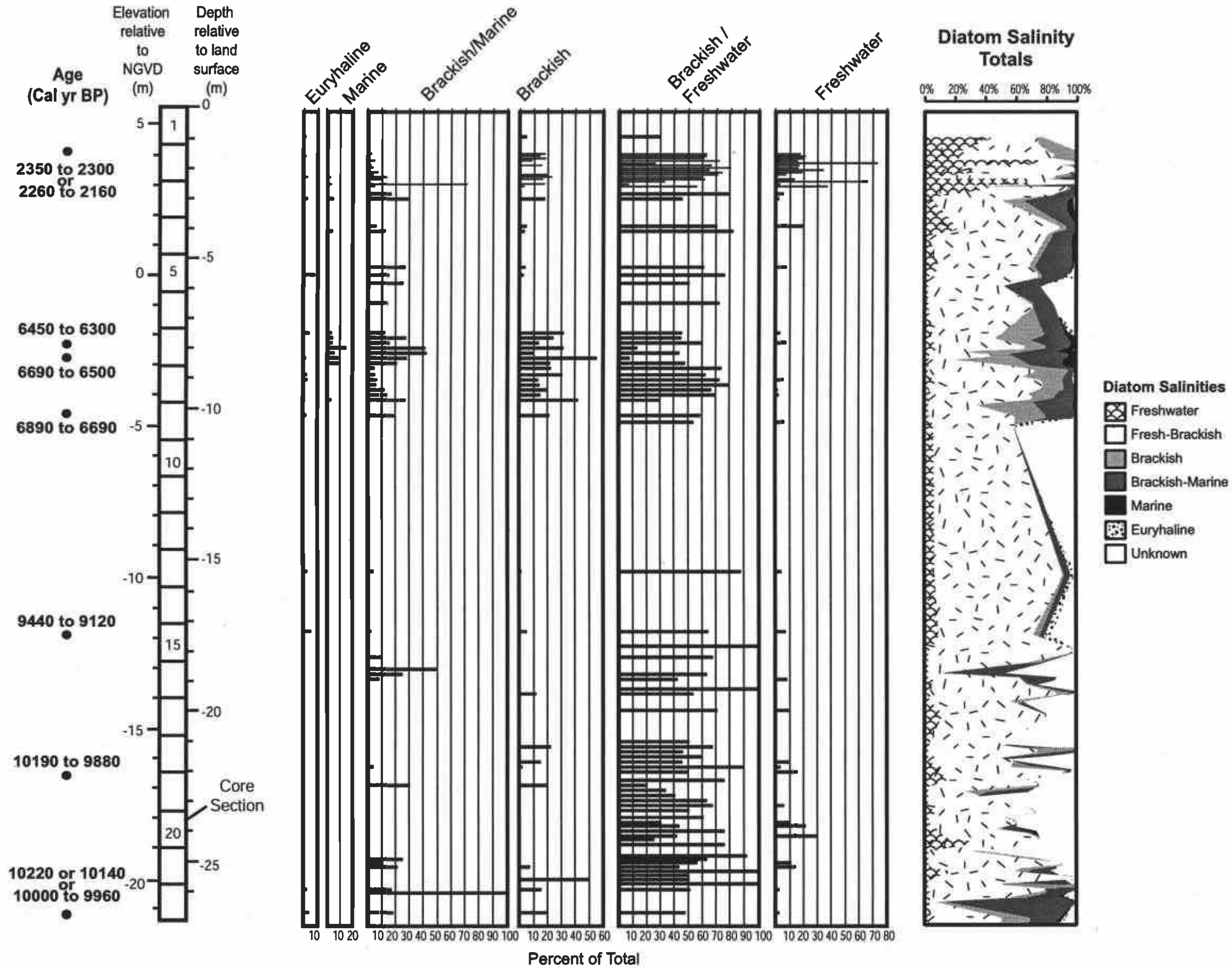


Figure 5. Diatom percents by salinity tolerance catagories.

Biostratigraphic Investigations:

Salinity tolerances:

Freshwater and fresh-brackish diatoms are most dominant in the upper two meters of the core. From 3.0m to –5.0m, diatom assemblages are mixed, with spikes in lower salinity-tolerant species interspersed with more saline species assemblages. The sediments of the center section of the core, from -5m to –11.5m, were extremely diatom poor, with only one slide containing any significant diatom assemblage (Sample 87 at -9.62m) dominated by fresh-brackish species. From -12.5m to -18.5m, salinity assemblages were predominantly fresh-brackish, with punctuated episodes of more highly saline-tolerant assemblages. The lowest 2.5 meters of core sediments are characterized by mixed assemblages, with numerous fresh-brackish, brackish and brackish-marine species identified. Table 2 and Figures 4e and 5 show the relative percentages of each salinity for each sediment sample through the core.

Intertidal Zone Identification:

Diatom assemblage data for Core 4 are compiled in Appendix B, where diatom-derived estimates of tidal zonation are listed for each sample. Intertidal zones and their relationships to tide level elevations and diatom assemblages are shown in Figure 3. Assemblages are divided into four groups: 1) freshwater wetland (elevation range of 1.4m NGVD and up, with the upper bounding elevation set at 2.4m for purposes of estimating paleo-MTL); 2) brackish high marsh (elevation range of 0.7 to 1.6m NGVD); brackish low marsh (elevation range of 0.0 to 0.9m NGVD); and tidal flats/channels (incorporating intertidal mud and sand flats, tidal channel banks, *Zostera* (eelgrass) beds, and shallow subtidal channels with an elevation range of -0.7 to 0.3m NGVD) (from Nelson and Kashima (1993) and Hemphill-Haley (1995)).

The intertidal setting at the study site shifted numerous times, as evidenced through intertidal zone assignments on 85 diatom assemblages and shown in Figure 4f. Although a total of 132 diatoms samples were originally taken for analysis, those samples with no identifiable diatom valves were not included in the study. Freshwater wetland assemblages dominate in the upper two meters of the core, with punctuated drops to brackish zones interspersed. From 3.0m to –1.0m brackish high to low marsh assemblages are most prevalent. Brackish low marsh to tidal flat/channel deposits predominate to ~ -4.5m, with occasional brackish high marsh assemblages apparent. From –5.0 to –10.0m, few diatom assemblages were available for analysis. Those diatoms which could be identified were mostly indicative of freshwater marsh or brackish high marsh conditions. Below –10.0m, to around –19.0m, inferred intertidal setting fluctuates around brackish high marsh assemblages, with some low marsh and some freshwater marsh environments evident. Below -19.0m, assemblages become more saline, with brackish low marsh and intertidal flat/channel assemblages common.

Statistical Investigations:

Magnetic susceptibility is an accurate predictor of intertidal zone when only the sand-sized fraction is considered. Figure 6a displays a linear regression analysis of magnetic susceptibility versus intertidal environment, with samples separated into two groups by average grain size. For the sand-sized fraction, highest magnetic susceptibility readings are associated with freshwater environments, brackish marshes are associated with intermediate susceptibility readings, and lowest values are associated with tidal flats/channels. The p value for the sand sized fraction is <0.001 and is therefore statistically significant. The R^2 value is 0.24, indicating that magnetic susceptibility explains 24% of the variation in intertidal environment. For silt/clay-sized particles the relationship is not statistically significant ($p>0.05$).

Magnetic susceptibility is not a statistically significant predictor of diatom salinity percentages in the sand-sized fraction for any of the salinity groupings. However, there is a stronger relationship between low magnetic susceptibility readings and brackish or marine salinities than freshwater (Figure 6b). There is a statistically significant relationship between the magnetic susceptibility of silt-sized particles and freshwater diatom percentages (Figure 6c), in that high numbers of freshwater species correlate with low magnetic susceptibility ($p < 0.04$). However, none of the R^2 values involving salinities are over 0.10, indicating that very little of the variation in salinity is explained by the magnetic susceptibility readings.

Gamma density is an accurate predictor of intertidal setting in the portion of the core below the elevation 0.00m NGVD (Figure 7a). Regression analysis reveals a statistically significant relationship between gamma density and intertidal setting, in that higher density sediments (lower gamma readings) are associated with higher elevation intertidal settings,

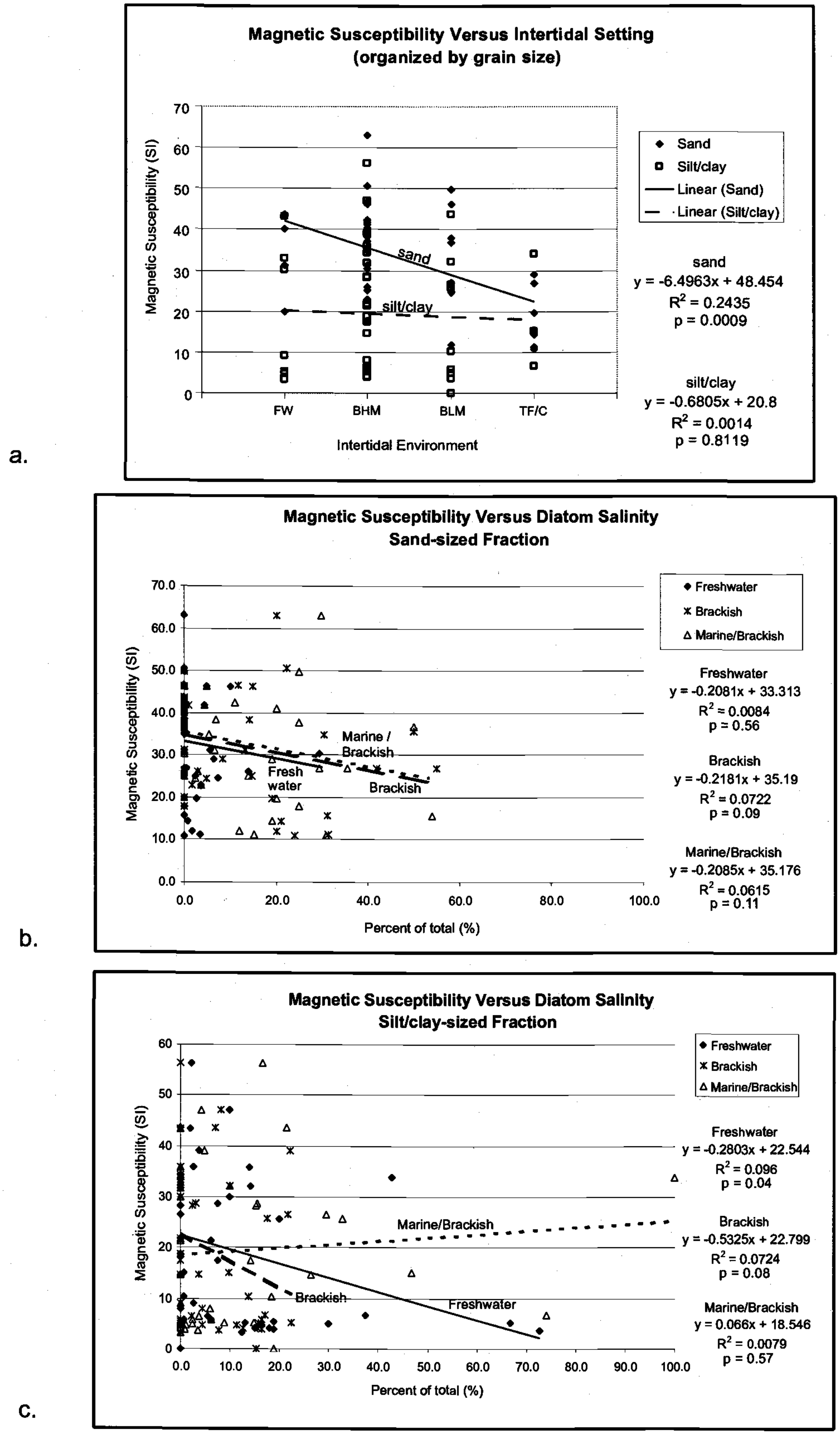
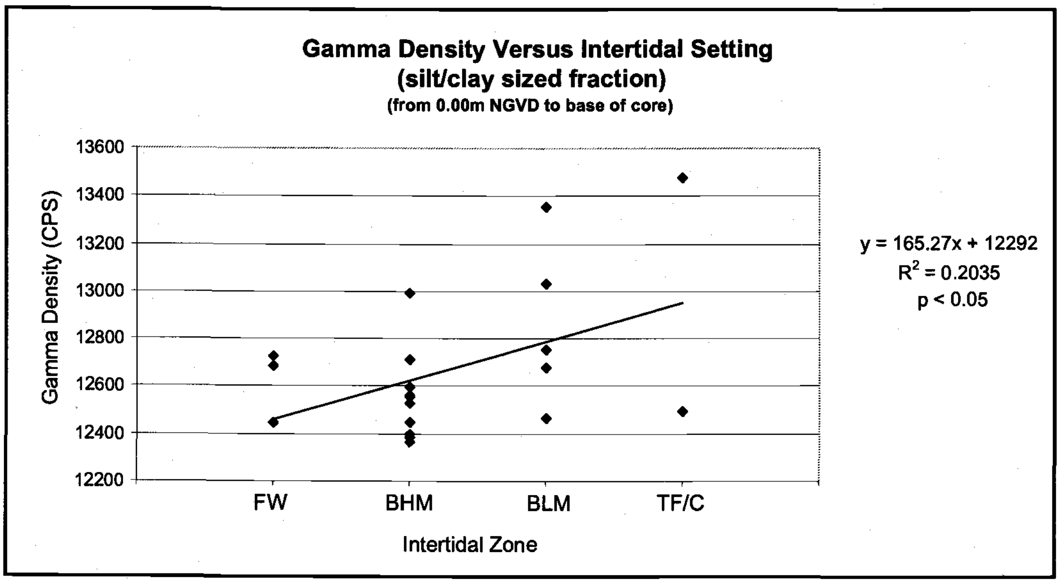
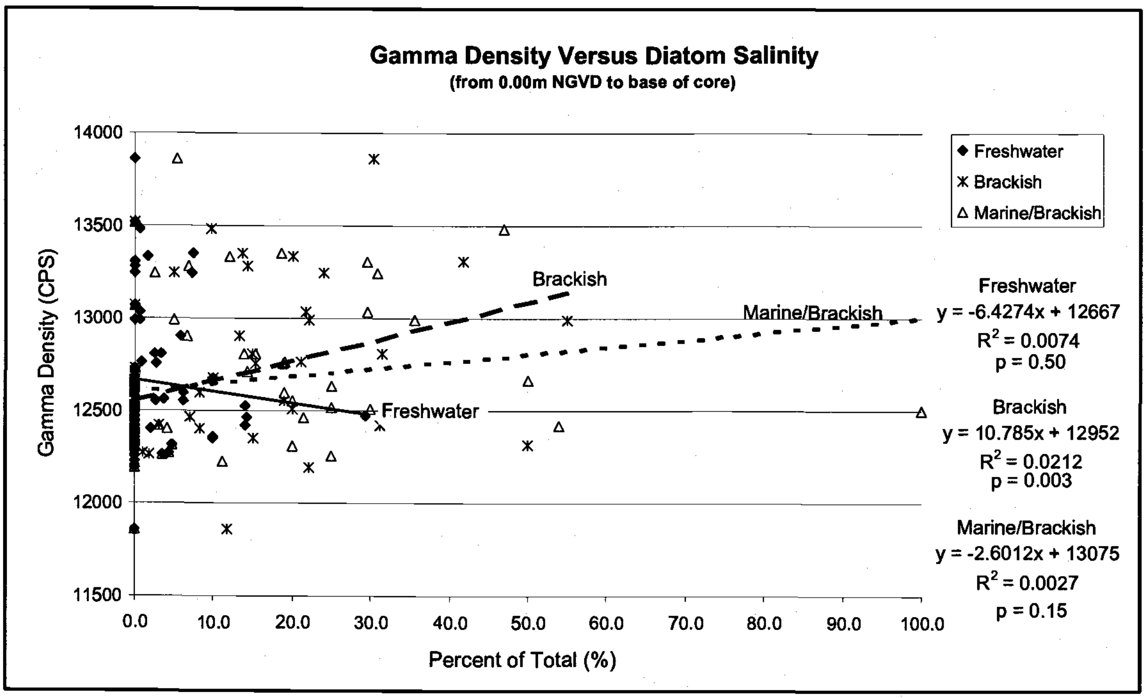


Figure 6. (a) Linear regression analysis of magnetic susceptibility versus intertidal setting separated by grain size. FW= Freshwater; BHM= Brackish High Marsh; BLM= Brackish Low Marsh; TF/C= Tidal Flat/Channel (b,c) Regression analysis between magnetic susceptibility and diatom salinity percentages, separated by grain size.

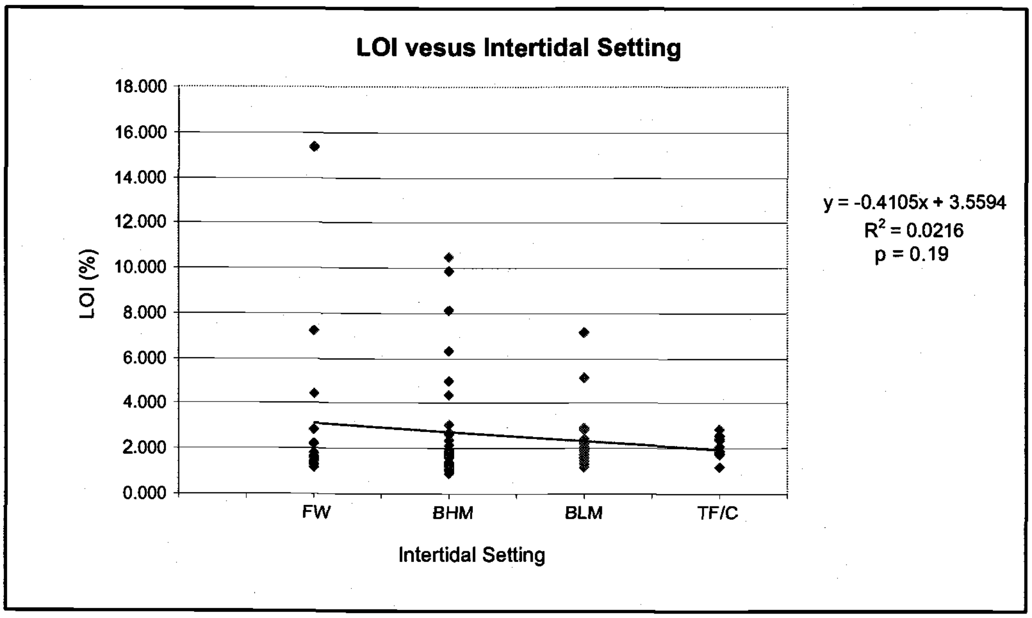


a.

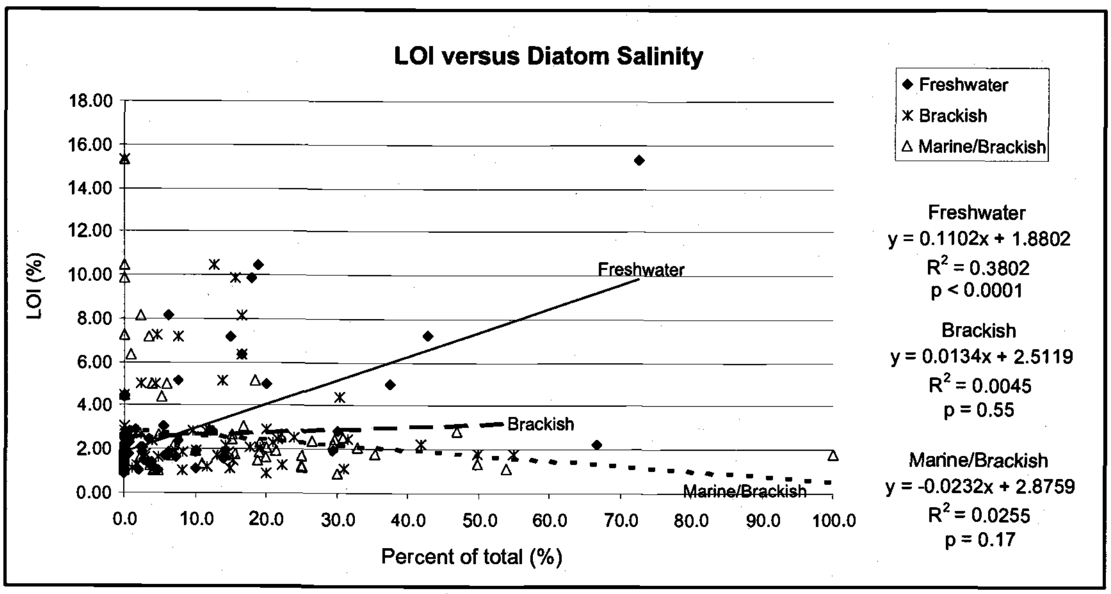


b.

Figure 7. Gamma density relationships for the portion of the core from 0.00m NGVD to core base (a) Linear regression analysis of gamma density versus intertidal setting for the silt/clay sized fraction FW= Freshwater; BHM= Brackish High Marsh; BLM= Brackish Low Marsh; TF/C= Tidal Flat/Channel (b) Regression analysis bewteen gamma density and diatom salinity percentages, for all grain sizes.



a.



b.

Figure 8. (a) Linear regression analysis of loss on ignition (LOI) versus intertidal setting. FW= Freshwater; BHM= Brackish High Marsh; BLM= Brackish Low Marsh; TF/C= Tidal Flat/Channel(b) Regression analysis bewteen loss on ignition (LOI) and diatom salinity percentages.

and lower density sediments (higher gamma readings) with lower intertidal settings. The relationship between gamma density and diatom salinity is not statistically significant when the analysis is performed on the entire length of the core. There is a strong relationship between gamma density and brackish diatom abundance in the lower core sections (Figure 7b). Low gamma density readings (high sediment density) are correlated with low percentages of brackish diatoms ($p=0.003$). However, the R^2 value for this relationship is only 0.02, indicating that very little of the variation in brackish diatom abundance is explained by sediment density.

The relationship between LOI values and intertidal setting is not statistically significant; however, LOI percentages are in general lower in the lower intertidal zones (Figure 8a). LOI is strongly associated with freshwater diatom abundance (Figure 8b). The highest percentages of freshwater diatoms from samples are correlated with the highest LOI values ($p<0.0001$; R^2 value= 0.38). Although neither brackish nor marine/brackish percentages have statistically significant relationships with LOI values, low marine diatom percentages do correlate with low LOI values to a limited degree ($p= 0.17$).

Relative Sea Level Curve Construction:

Based on the information presented above regarding intertidal environmental setting in reference to core depth, estimates of mean tide level (MTL) paleoelevations relative to NGVD and the range of elevation associated with each zone were determined (Table 3). By associating these MTL estimations with the radiocarbon dates, a relative sea level curve for the site was constructed. Presented below is detailed biostratigraphic evidence of relative sea level pertaining to each dated stratigraphic section (see also Appendix B). These results are summarized in Table 3 and portrayed in graphic form in Figure 9. The rectangles associated with each date and paleo-MTL elevation incorporate error margins related to ranges in intertidal elevation for each diatom assemblage (Table 3) as rectangle height and errors in age estimates for each radiocarbon sample (Table 1) as rectangle width. A detailed description of RSL curve construction is presented in Appendix C.

The resulting curve portrays a general history of relative sea level change for the site (Figure 9). The rate of relative sea level rise at the site is fastest from 10,000 to 9000 cal yr BP (7 m/1000yrs), when the rate slows slightly. From 9000 to 7000 cal yr BP the average

Table 3. Paleo-Mean Tide Level for Dated Portions of Core

Sea Level Curve Label (see Figure 9)	Diatom Sample Numbers	Elevation (NGVD) diatom samples (m)	Paleo-environment of diatom sample*	Vertical position of diatom sample relative to paleo-MTL (m)**	Elevation (NGVD), paleo-MTL (m)	Age (cal yr BP) Calibrated 2-sigma***	Estimated Rate of Sediment Deposition (mm/yr)
B	23	4.15	Freshwater wetland	1.4 to 2.4	2.8 to 1.8	ca. 2160 to 2350	0.7
G	120	'-2.16	High to low marsh?	0.0 to 1.6	-2.2 to -3.8	6300-6450	1.6
H	116	-2.49	Low Marsh	0.0 to 0.9	-2.5 to -3.4	6500-6690	2.0
I	106	-4.50	High Marsh	0.7 to 1.6	-5.2 to -6.1	6690-6890	10.0
J	77	-11.65	Freshwater wetland	1.4 to 2.4	-13.1 to -14.1	9120-9440	3.0
K	51	-16.29	High Marsh to freshwater wetland	0.7 to 2.4	-17.0 to -18.7	9880 to 10190	7.0
M	4	-20.63	Estuarine tidal flat or channel	-0.7 to 0.3	-19.9 to -20.9	ca. 9960 to 10220	40.0

*See Appendix B

**Elevation ranges for marsh and tidal flat environments, relative to Mean Tide Level (MTL), from Nelson and Kashima (1993) and Hemphill-Haley (1995)

***ca. ages incorporate error range due to multiple intercepts on radiocarbon calibration curve

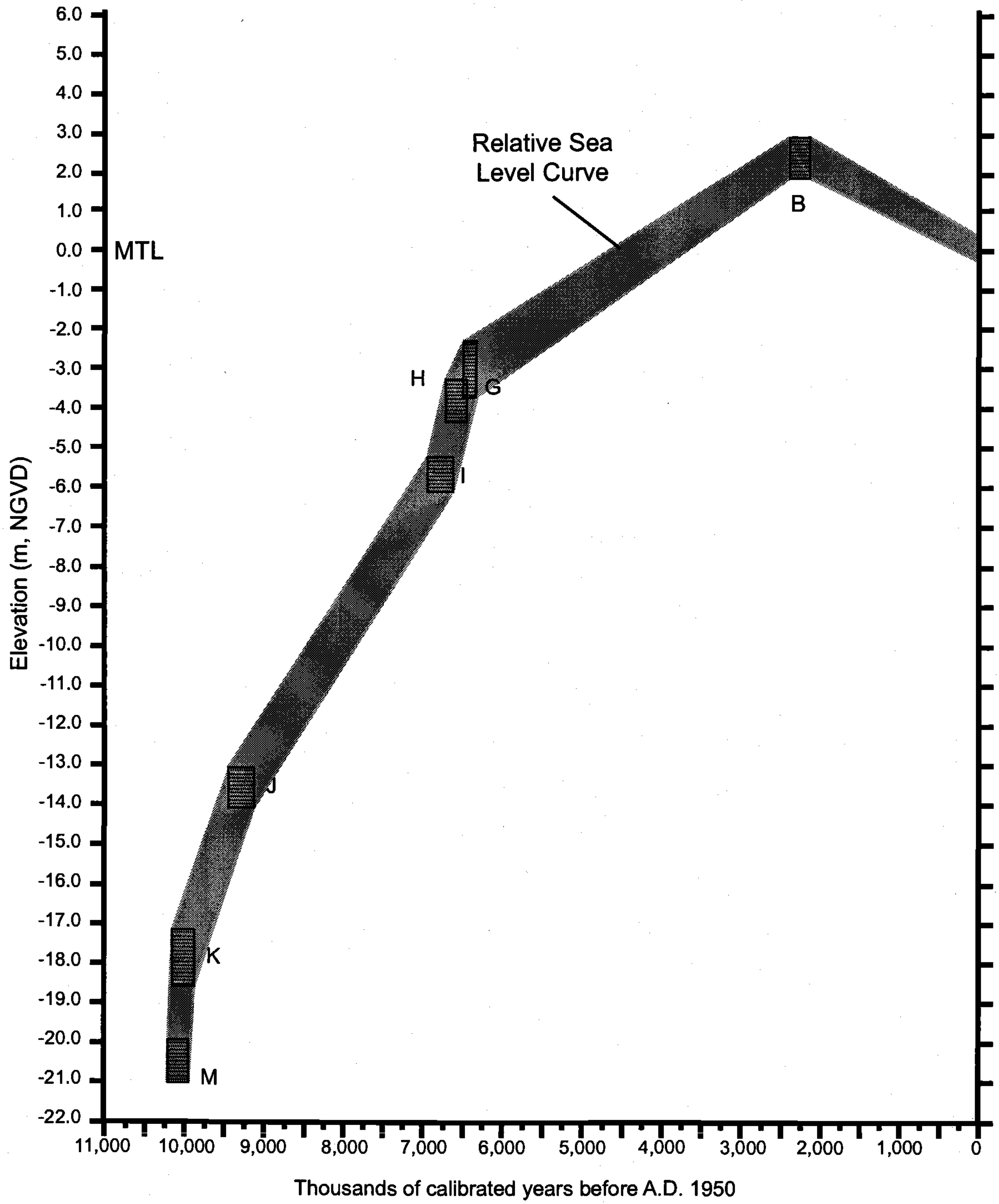


Figure 9. Relative sea level curve for lower Sixes River study site. Intertidal elevation error margin incorporated as rectangle height; AMS radiocarbon dating errors incorporated as rectangle width. See Appendix C for sea level curve construction details.

rate is 3.5m/1000yrs, followed by another jump in relative sea level rise rate from 7000 to 6500 cal yr BP (8m/1000yrs). The curve levels out after 6500 cal yr BP to the present with average cumulative relative sea level rise around 0.3m/1000yrs.

Discussion

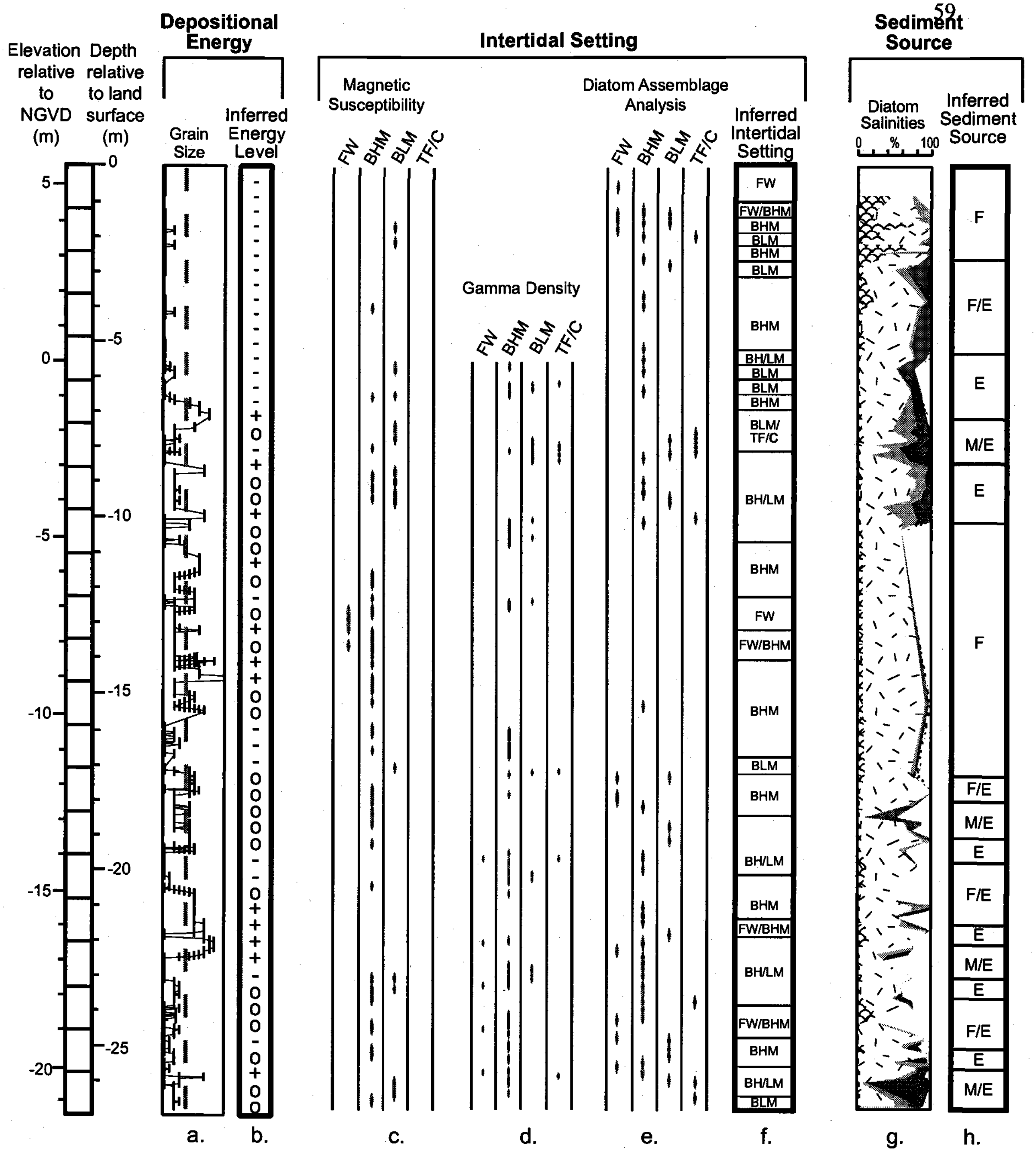
The results of this study show that three aspects of depositional environments, depositional energy, sediment source, and intertidal setting, can be inferred through litho- and biostratigraphic investigations. Using on the data presented here and the statistical relationships established between data sets, we construct charts predicting down-core conditions for each variable involved in the reconstruction of depositional environments.

Depositional energy

Average sediment grain size can be used as a proxy for depositional energy, in that higher energy depositional forces are required to transport and deposit larger grain sizes. Although other variables may inhibit or promote grain transport in individual situations (Knighton 1998), in general the relationship between larger grain sizes requiring greater depositional forces hold true. Therefore, we construct a simplified, downcore interpretation of depositional energy that characterizes relative energy amounts as high, moderate, and low based on average grain size information (Figure 10a, b).

Depositional energies do not appear to correlate directly with any one intertidal setting or inferred sediment source. In general, lower energy deposition occurred in association with brackish marsh intertidal settings in the lowest portion of the core and with brackish marsh and freshwater intertidal settings in the upper portion of the core. Deposition of fine-grained sediment in association with brackish and freshwater marsh settings is consistent with the depositional model shown in Figure 3.

Higher energy deposition occurred in the central portion of the core, in association with both freshwater and brackish sediment deposition. Higher energy deposition between 9000 and 6500 cal yr BP is consistent with reports from other regional estuary settings for this time period (Peterson et al. 1983; Peterson and Phipps 1992).



Inferred Depositional Energy

- = low
o = moderate
+ = high

Inferred Intertidal Setting

FW = freshwater wetland, upland, or river deposit
BHM = brackish high marsh
BLM = brackish low marsh
TFC = tidal flat or channel
BH/LM = brackish high or low marsh

Inferred Sediment Source

F = Freshwater
E = Estuarine
M/E = Marine / Estuarine

Diatom Salinities

Freshwater
Fresh-Brackish
Brackish
Brackish-Marine
Marine
Euryhaline
Unknown

Figure 10. Factors used to reconstruct depositional environments (Depositional Energy, Intertidal Setting, and Sediment Source) inferred from relationship to litho- and biostratigraphic data sets.

Intertidal Setting

Statistical analysis of relationships between measured variables reveals that magnetic susceptibility is a strong predictor of intertidal setting in the sand-sized fraction (Figure 6a). As expected, highest magnetic susceptibility readings correlated with freshwater/upland intertidal settings and lowest readings with tidal flat/channel deposits. These results corroborate a study conducted by Boggs (1969) in the Sixes River drainage basin. Boggs (1969) determined the distribution of sand-sized (0.177-0.125mm) heavy minerals from sample locations in tributaries near the headwaters, along the main trunk of the river, within the estuary, and west to the beach surrounding the outlet of the river to the Pacific Ocean. Opaque, magnetic heavy minerals included primarily magnetite and some magnetic ilmenite. Boggs found that magnetite content decreased significantly in the downstream direction, making up less than three-tenths of a percent of the total sand-sized fraction in the Sixes River estuary and beach samples (Boggs 1969:144). The beach sample, especially, contained markedly lower magnetite content than the river samples. Because of the strong relationship revealed between magnetic susceptibility and intertidal setting, we infer that intertidal zone can be predicted throughout the length of the core using the susceptibility readings on sand-sized particles. The intertidal zone predictions are shown in Figure 10c.

Gamma density readings can be used to predict intertidal setting when silt/clay-sized particles are considered (Figure 7a). Higher sediment density (lower gamma readings) will correlate with freshwater intertidal settings, whereas lower density sediments (higher gamma readings) will predict lower intertidal settings. These findings hold true for the sediments located at 0.0m NGVD and below, and are used to predict intertidal setting for the lower portion of the core (Figure 10d)

The upper five meters of sediment is markedly less dense than any other section of the core (Figure 4c). The inconsistent nature of the gamma density record in the upper versus the lower portion of the core is due to issues associated with all gamma density studies, including sediment compaction, organic content, and saturation levels (Geotek 2000; Brady 1990). Low density readings in the upper section of the core may be due to less sediment loading, and thus a lower amount of compaction. Alternatively, the upper portions of the core may be highly affected by their high organic content. The LOI readings on the upper five meters of the core reveal markedly higher amounts of organic material than in the lower core (Figure 4d). Organic sediments have a lower density than an equal volume of low-organic, mineral sediments. Sediment moisture levels also can cause significant changes in the gamma density readings because the gamma signal will have a different return time in wet sediment versus dry sediment. The top ~5 meters of core section were recovered in a relatively dry state, while those sections below 0.0m NGVD were saturated when extracted from the ground. This may be an additional cause of the extremely low density values in the upper portion of the readings because the gamma rays travel more slowly in the lower, saturated core sections. These issues are taken into account by statistically analyzing (Figure 7) and making intertidal setting predictions (Figure 10d) for only the lower portion of the core.

Although there is no statistically significant relationship between LOI and intertidal setting (Figure 8a), it is visually apparent that higher LOI readings are associated with the upper elevation intertidal zones and lower LOI with the lower intertidal areas, especially the tidal flat/channel zone. These visual findings are supported by research in other coastal settings pertaining to the relationship between organic carbon and intertidal setting. The total organic carbon content in sediments has been measured in studies on the coasts of Louisiana and Delaware to aid in the determination of paleo-depositional environments at tidally-influenced settings (Hart 1988; Pizzuto and Rogers 1992).

The lack of a statistically significant relationship between LOI and intertidal setting is probably due to preservation issues. Preservation of high concentrations of organic content in buried sediments is achieved only when the original environment promoted high productivity and conditions were predominantly reducing. Within coastal estuary systems, areas of highest primary productivity and LOI values include tidal and non-tidal wetlands which occur along river or estuary channel margins (Pizzuto and Rogers 1992). These areas correspond with the high brackish marshes and freshwater wetlands discussed in the study presented here. However, it is apparent that in some cases, even when high productivity conditions existed, organic content preservation did not necessarily occur (i.e. in the lowest portion of the core where freshwater wetlands or high brackish marshes are indicated by the fossil diatom assemblages, but LOI content is low). Because of this issue of preservation, we do not use LOI as a predictor of intertidal setting.

Figure 10e displays intertidal setting assignments based on the fossil diatom assemblage interpretations listed in Appendix B. By combining these results with the predictions from the magnetic susceptibility and gamma density information, a finer-scale picture of down-core intertidal setting can be hypothesized (Figure 10f).

Sediment Source

Magnetic susceptibility is an accurate predictor of freshwater diatom abundance in the silt/clay sized fraction, but has no significant relationship with either brackish or marine/brackish diatoms. There is a statistically significant relationship between gamma density and brackish water diatoms, but no significant relationship between freshwater or marine/brackish diatoms and gamma density is apparent. LOI values are an accurate predictor of freshwater sediments, as revealed by the clear relationship between high percentages of freshwater diatoms and high LOI values (Figure 8b). However, there is no significant relationship between LOI and brackish or marine/brackish diatoms. Because not one of the lithostratigraphic variables was found to be a statistically significant predictor of diatom abundance in the three salinities of interest (freshwater, brackish, and marine/brackish), these data cannot be used as proxy indicators sediment source for this study. Instead, we use the more coarsely-spaced diatoms sample data to infer general trends in sediment source through the core (Figure 10g,h).

Reconstruction of Depositional Environments at the Lower Sixes River Study Site

Based on the depositional energy, intertidal setting, and sediment source predictions displayed in Figure 10, we propose a depositional environment reconstruction for the lower Sixes River site through the last 10,000 years (Figure 11). From ~10,000 to ~9,300 cal yr BP, the location was primarily a Brackish Marsh depositional environment. Higher energy deposition accompanied episodes of marine/estuarine sediment incursion, possibly representing tidal channels or shoals, or intertidal flats associated with a Tidal Flat/Estuarine depositional environment (Nichols and Biggs 1985). Lower energy deposition occurred in association with Freshwater depositional environment emplacement. These low energy freshwater facies are associated with overbank deposition, alongshore drift, upland erosion and sediment entrapment which occurs in brackish to freshwater marshes and freshwater wetlands that border estuaries (Frey and Basan 1985).

A notable period of high energy deposition is associated with all three depositional environments at ca. 10,000 cal yr BP. Higher energy depositional forces in Tidal Flat/Estuarine settings would have resulted in sand flats or shoals. In a Brackish Marsh setting, powerful wave activity or extreme high tides would have deposited larger grained

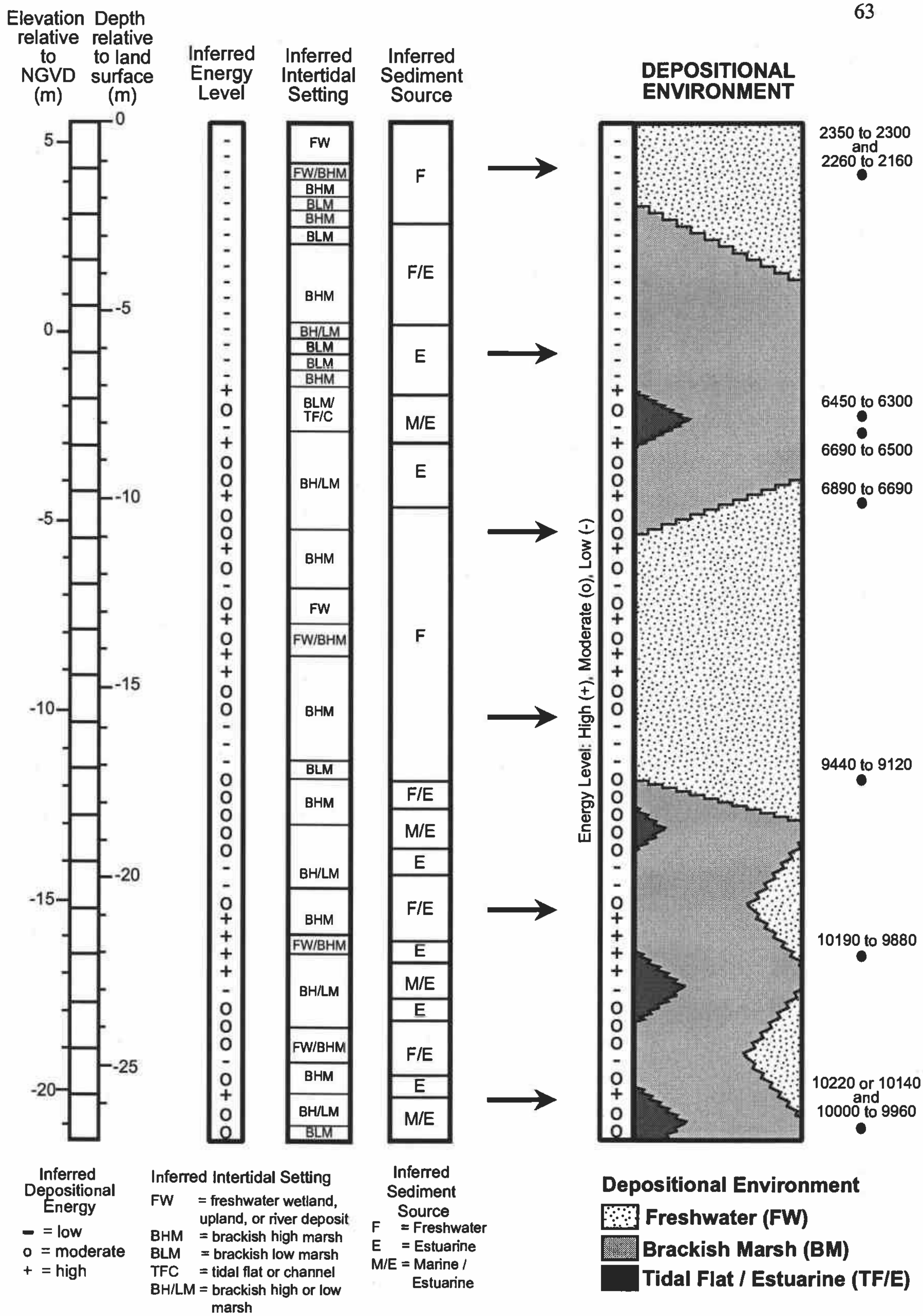


Figure 11. Depositional environment evolution for the lower Sixes River study site for the last 10,000 years reconstructed from information pertaining to depositional energy levels, intertidal setting and sediment source.

sediments, while in Freshwater depositional environments, overbank deposition associated with river flood events may have brought in sediments indicative of higher depositional energies.

Beginning around 9,300 cal yr BP and continuing until around 6800 cal yr BP, the depositional environment of the site is Freshwater. Freshwater sediments requiring moderate to high depositional energy are very abundant during this time and are associated with alluviation within or along active river channel margins. By around 6,500 cal yr BP, the location had reverted back to a predominantly Brackish Marsh environment, with periods of high, moderate and low energy deposition. These fluctuating energies may be associated with fluvial channel migration, meander formation, and channel abandonment followed by intertidal channel and marsh environment establishment and migration.

This study does not possess any age data to constrain the time period during which the intertidal setting evolved from a predominantly Brackish Marsh to a Freshwater depositional environment. Data from the same general locality presented in Kelsey et al. (2002) indicates that a freshwater marsh had been established in the lower Sixes River valley by 5,000 cal yr BP. After that time, punctuated deposition of intertidal marsh, flat, and channel sediments occurred in association with tectonic subsidence, but the dominant depositional setting remained a freshwater marsh or wetland (Kelsey et al. 2002). Data from this study support that contention with Freshwater depositional environment conditions firmly established by ~2,300 cal yr BP, a time when eustatic sea level had reached near its current position. The combined effects of eustatic sea level stasis, continued regional tectonic uplift, and continued overbank sediment aggradation allowed the site to emerge completely from tidal influence from this time to the present day.

One of the dominant drivers of coastal depositional environmental change is eustatic sea level rise (Boggs 2001). Dalrymple et al. (1992) suggest that post-glacial sea level rise and subsequent leveling will result in a predictable facies assemblage discernible in the lithostratigraphic record. This schematic transgressive section is depicted in Figure 12. During sea level lowstand, base level is lowest, the shoreline is furthest from the coast, and the dominant depositional environment is freshwater fluvial sedimentation (alluvial deposits in Figure 12). These fluvial deposits overlie bedrock or pre-glacial period sediments. As sea level begins to rise at the end of the Pleistocene, depositional facies move onshore. The flooding surface in Figure 12 represents the boundary between the lowstand deposition of alluvial sediments and landward-migrating transgressive facies. Continued sea level rise and

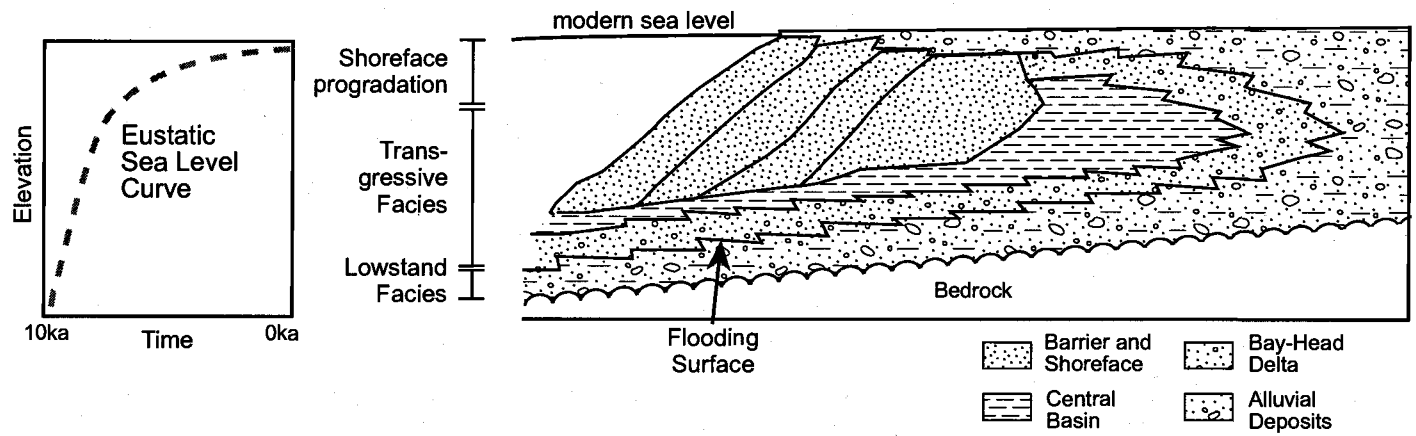


Figure 12. Schematic section along the axis of an estuary showing the distribution of lithofacies resulting from eustatic sea level rise and transgression of the estuary. Modified from Dalrymple et al. (1992: Figure 13)

shoreline transgression move depositional facies further inland. As sea level rise slows, sedimentation along the coast equals or outpaces rates of water-level rise, resulting in progradation of the shoreface (i.e. seaward migration of facies.)

Examples of transgressive depositional facies representing coastal evolution during the last 10,000 years have been found preserved in sediments from intertidal wetlands along the coasts of Washington and Oregon (Glenn 1978; Peterson et al. 1984; Peterson and Phipps 1992; Peterson and Darienzo 1996; Byram and Witter 2000; Kelsey et al. 2002; Witter et al. 2003). Research on these active-margin embayments and estuaries indicates that depositional environments have shifted through time in response to sea level fluctuations, as well as tectonic uplift and sediment infilling of coastal river basins.

In Alsea Bay on the central Oregon coast (Peterson et al. 1984), a shallow, fluvial, freshwater environment is represented in the sedimentary and paleontological depositional record from around 12,000 to 8,500 cal yr BP. A shift to deep-water, estuary-type conditions follows as sea level rises and river valleys are drowned between 8,500 and 6,000 yr BP. Finally, slowed sea level rise, sediment infilling, and continued localized tectonic uplift after around 6,000 yr BP modify the depositional environment once again. Shallow-water estuaries, tidal flats, and salt- and fresh-water marshes are recorded in the litho-stratigraphic record dating to after 6,000 yr BP.

Studies on the Coquille Estuary along the southern Oregon coast have postulated a similar depositional history to that of Alsea Bay (Byram and Witter 2000), although data pertaining directly to the late Pleistocene were not analyzed. A similar history of depositional setting evolution occurred in Tillamook Bay on the Northern Oregon coast (Glenn 1978). However, no basal facies below the ~9000 year estuary sediments is recorded in any of the cores recovered from the bay.

In Grays Harbor on the southwestern coast of Washington, varying sedimentation patterns are recorded at different regions within the bay. In those areas nearest to the rivers and streams that feed the estuary, sediments from core samples display a fining upwards stratigraphy (Peterson and Phipps 1992). Basal sandy gravel is overlain by sands which give way to muddy sands, sandy muds, and finally mud. Peterson and Phipps (1992) suggest that this facies evolution is indicative of deposition of larger-grained river deposits during the late Pleistocene/early Holocene, followed by landward migration and vertical accretion of lower-energy, protected bay and tidal deposits. A coarsening upward sequence is seen in the lower-bay reaches. Peterson and Phipps (1992) argue that these deposits are suggestive of low-energy, fine-grained, protected bay deposits being overlain by larger-grained, landward-migrating and vertically accreting tidal-inlet deposits.

The late Pleistocene/early Holocene history of deposition at the Sixes River coring site is markedly different from the estuaries discussed above and the conceptual model created by Dalrymple et al. (1992). The late Pleistocene is represented in this study by fine-grained, Tidal Flat/Estuarine and Brackish Marsh deposits. Stratigraphically, the core sediments coarsen upwards into sands and gravels by ~9400 cal yr BP. However, the coarser overlying facies is not that of a higher-energy tidal inlet, as seen in the coarsening upwards record at Grays Harbor, but that of a freshwater, fluvial environment. This implies a seaward migration of facies, such as might accompany a sea level regression (caused by eustatic sea level fall). However, because global eustatic sea level rises during this time, a regressive sequence is unexpected, thus implying that some other mechanism must influence the depositional setting evolution at the site other than, or in addition to, eustatic sea level change.

The depositional sequence from ~9400 cal yr BP to the present appears as predicted by the conceptual model (Dalrymple et al. 1992) and correlates with transgressive depositional facies seen in sediments from other coastal study sites in the Pacific Northwest (Glenn 1978; Peterson et al. 1984; Peterson and Phipps 1992; Peterson and Darienzo 1996; Byram and Witter 2000; Kelsey et al. 2002; Witter et al. 2003). It is only the record from the oldest depositional facies at our study site that differ markedly from the expected (Figure 11). The lowest section of the core contains sediments of a generally brackish marsh origin, with occasional shifts to more fresh or more saline depositional conditions, rather than the expected freshwater fluvial facies.

It is possible that the brackish facies represented in the lowest portion of the core is simply a deposit located on the lateral margins of the primary depositional channel (Figure 2b). Because estuaries contain spatially variable depositional environments in both downstream and lateral directions, it is difficult to discern the evolution of an entire basin from a single subsurface core. Therefore, it is possible that sediments recovered from other locations within the estuary will produce the type of freshwater facies assemblages expected for this time period. However, the presence of brackish-water facies this far inland at this time period is still rather unusual considering that other, more well-cored estuaries along the west coast do not contain brackish facies dating to this time period that underlie freshwater sediments (Glenn 1978; Peterson et al. 1983; Peterson and Phipps 1992).

As mentioned above, eustatic sea level rise played a major role in the infilling of incised coastal river valleys during the late Pleistocene/early Holocene. However, all of the Northwest Coast estuaries experienced the same rate of eustatic sea level rise during this time period. Therefore, for brackish-water sedimentation to have occurred during the early Holocene at a location well inland from the coast, some other variable must have affected the depositional evolution of the Sixes River estuary. Factors such as tectonic activity, sedimentation rates, or valley morphology may have influenced depositional setting evolution (e.g. Dalrymple et al. 1994; Fletcher and Wehmiller 1992).

The Cape Blanco area has one of the fastest average uplift rates on the northwest coast (Muhs et al. 1990; Kelsey 1990), but was there enough uplift over a relatively short period of time to outrun global sea level rise and cause local, relative sea level to stagnate? Long term, permanent uplift rates based on marine-terrace data indicate ca. 0.85 to 1.25 m of net uplift per thousand years (Muhs et al. 1990; Kelsey 1990). The rate of global sea level rise from ~11,000 to ~9,000 yr BP was around 8-10 m/ka (Bloom 1980; Fairbanks 1989). Based on the sea level curve constructed for this locality, relative sea level rise during this time at the Sixes River was around 7-8 m/ka (Figure 9). Clearly, tectonic uplift was significantly outpaced by sea level rise (~1m/ka vs 7-10m/ka) and therefore was probably not a major factor in depositional setting change.

It is possible that the freshwater depositional sequence we see in middle of the core section does not represent the basal, flooding surface alluvium that is seen in the model sequence in Figure 12. During initial core extraction activities, Core 4 was extracted to a depth of over 27m. Core extraction ceased at that depth because of mechanical limitations, not because basal fluvial gravels or bedrock were reached. It is possible that the basal flooding surface and overlying alluvial deposits are located at a depth below our extraction depth. If this is the case, then the intertidal Brackish Marsh and Tidal Flat/Estuarine sediments seen in the bottom 10m of the core may represent the bay-head delta and central basin deposits that just overlie the flooding surface in the model transgressive sequence.

An abrupt episode of freshwater sediment incursion may have occurred around 9,400 due to increased sediment input from a fluvial source, resulting in a prograding fluvial facies despite continued eustatic sea level rise. This period of time is associated with increased sediment input into coastal river systems, possibly due to an increase in regional precipitation and upland colluvial hollow evacuation (Personius et al. 1993; Reneau and Dietrich 1990). If this is the case, then fluvial energy and sediment availability would have increased significantly, resulting in a record of fluvial dominance in the stratigraphic record. Unfortunately, this does not address the question as to why the record at the Sixes River valley looks different from other coastal records if increased sediment input occurred all along the coast during the early Holocene (Personius et al. 1993; Reneau and Dietrich 1990), unless the history of sediment storage and subsequent influx into the system varies considerably between coastal river basins.

In addition to local tectonics and sedimentation, the interaction between eustatic sea level rise and basin morphology can play a role in the depositional evolution of a coastal estuary. The general slope of the relative sea level curve constructed for the Sixes River site (Figure 9) agrees well with global eustatic sea level curve estimates through the Pleistocene and Holocene (Bloom 1980; Fairbanks 1989) (Figure 13). However, the oldest portion of the relative sea level curve (~10,000 to 9000 cal yr BP) appears to have a steeper slope than the global eustatic curve.

Relative sea level at ~10,000 ago was approximately –22 meters NGVD (Figure 9). The time period from 10,000 to 9000 cal yr BP represents an interval of high rates of global sea level rise (Bloom 1980; Fairbanks 1989), and very rapid local relative sea level rise (Figures 9 and 13) accompanied by high rates of sedimentation (Table 1). When relative sea level rise outpaces tectonic uplift of the landscape and sediment input from river and marine sources, conditions become favorable for an estuary to form (Dalrymple et al. 1992). Rapid sea level rise and marine inundation of the coastal plain during this time period may have allowed tidal waters to encroach further inland at the Sixes River, especially if river power or sediment availability from a fluvial source was at a low. Additionally, the lower Sixes River basin is highly constricted relative to other basins in the area. Rapid sea level rise and flooding of an incised river channel in a constricted basin would result in increased inland tidal encroachment and brackish water sedimentation (Roy 1994).

Although it is impossible to reconstruct the depositional evolution of an entire estuary/river basin on the basis of one subsurface core, inferences regarding fluctuating depositional environments at a particular site can be made. The results of this study indicate that freshwater, fluvial environments did not dominate the lower Sixes River valley until at least 9400 cal yr BP. Instead, a tidally influenced estuarine setting or intertidal wetland occupied the site during the late Pleistocene and early Holocene.

It is not immediately apparent why the Sixes River valley maintained tidal influence well into the Holocene unlike other estuaries along the coast. It is possible that local features,

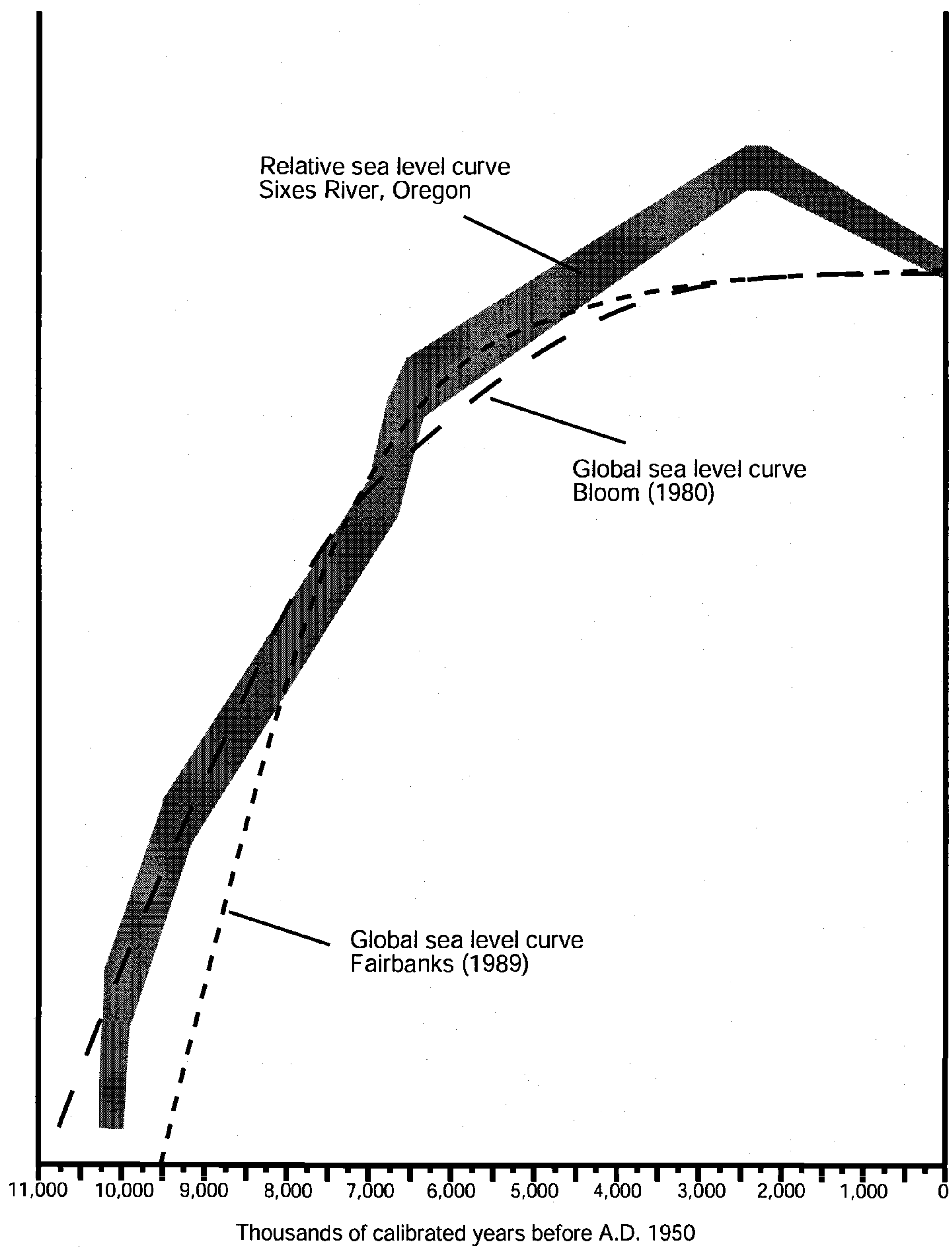


Figure 13. Relative sea level curve for lower Sixes River study site compared to global estimates of eustatic sea level change.

such as the river valley width, local uplift rates, or higher rates of sedimentation may have had a significant effect on the timing of estuary and tidal wetland existence at the site. If this is the case, then the exact location of early human use of highly productive coastal landscapes, such as estuaries and tidal wetlands, would depend upon the interactions of coastal tectonics, geomorphology, and local, relative sea level rise. A search for evidence of late Pleistocene occupation of coastal river valleys, then, will have to be considered on a case-by-case basis.

Conclusion

Litho-,bio-, and chronostratigraphic investigations on a long core recovered from a small estuary on the southern Oregon coast reveal patterns of fluctuating depositional energies, sediment sources, and intertidal settings since the late Pleistocene. From ~10,000 to 9400 cal yr BP, the Sixes River coring site maintained a dominantly brackish marsh depositional environment, with occasional incursions of more tidal flat/estuarine or freshwater depositional facies. Depositional energies were predominantly moderate to high from fluvial, estuarine, and marine sediment sources.

By ~9400 cal yr BP, the site became a freshwater depositional environment, with varying depositional energies. Freshwater alluvial overbank deposition and upland sedimentation predominate, along with some fresh-brackish bay-head delta accumulations. Freshwater deposition tapers off by around 6700 cal yr BP, when the site returns to a brackish marsh depositional environment. A shift to more tidal flat/estuarine conditions accompanied an increase in depositional energy and increased marine and estuarine sediment input around 6500 cal yr BP. A return to a freshwater depositional environment by ~2300 cal yr BP is indicated by low sedimentation energies, brackish high marsh and freshwater intertidal settings, and a dominantly freshwater sediment source.

The depositional environment reconstruction for the site indicates a transgressive evolution from the late Pleistocene to the present that differs from models of transgressive coastal facies as well as studied estuarine life histories from other locations along the Northwest Coast. Additional cores recovered and analyzed from the same lower Sixes River basin would aid in the identification of variables affecting the estuary's depositional history, as well as lead to a better understanding of transgressive sedimentary facies development along active margins. Such efforts in paleoenvironmental reconstruction will help researchers to better understand the environmental setting that early human migrants along the Northwest Coast would have encountered.

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CHAPTER 4: INVESTIGATION OF A 10,000-YR ESTUARINE RECORD OF CASCADIA COASTAL SUBSIDENCE AND TSUNAMIS IN OREGON

Introduction

On the evening of January 26, 1700 a large earthquake shook the length of the Cascadia subduction zone (CSZ), producing a tsunami and causing much of the Pacific Northwest coastline to subside below sea level (Satake et al. 1996). Geological evidence from coastal marsh and lake sites along the length of Washington and Oregon (summarized in Atwater et al. 1995; Kelsey et al. 1998), as well as from localities in northern California (Garrison-Laney 1998) and southern British Columbia (Clague et al. 2000), indicates rapid changes in relative sea level and/or tsunami inundation associated with this event. This AD1700 year event is also recorded off-shore in the form of turbidites, submarine landslides on the continental margin triggered by seismic movement along the CSZ (Goldfinger et al. 2003).

Turbidites, marshes, and lakes provide records of plate-boundary rupture events dating to before 300 years ago (Darienzo and Peterson 1990; Clague 1996; Nelson et al. 1996a; Atwater and Hemphill-Haley 1997; Garrison-Laney 1998; Kelsey et al. 2002; Witter et al. 2003; Kelsey et al. 2005). The longest record of great (magnitude >8) earthquakes on the CSZ is derived from offshore turbidite stratigraphy, which indicates that 18 events have occurred along the entire length of the subduction zone offshore from Washington and Oregon during the last ~9800 years (Goldfinger et al. 2003). An onshore record from Bradley Lake, Oregon, yields a 7300-year history of tsunami inundation resulting from rupture of the CSZ plate boundary (Ollerhead et al. 2001; Kelsey et al. 2005). Research on early marsh deposits from the Coquille and Sixes rivers on the southern Oregon coast has provided evidence of coseismic subsidence associated with great earthquakes dating back nearly 7000 and 5500 years before present, respectively (Witter et al. 2003, Kelsey et al. 2002). Further north, evidence from Coos Bay provides an almost 5000 year history of earthquake-associated subsidence (Nelson et al. 1996a, 1998), and work in the areas of Willapa Bay and Grays Harbor, Washington, has resulted in earthquake records dating to as early as 5000 years ago (Atwater and Hemphill-Haley 1997; Shennan et al. 1996).

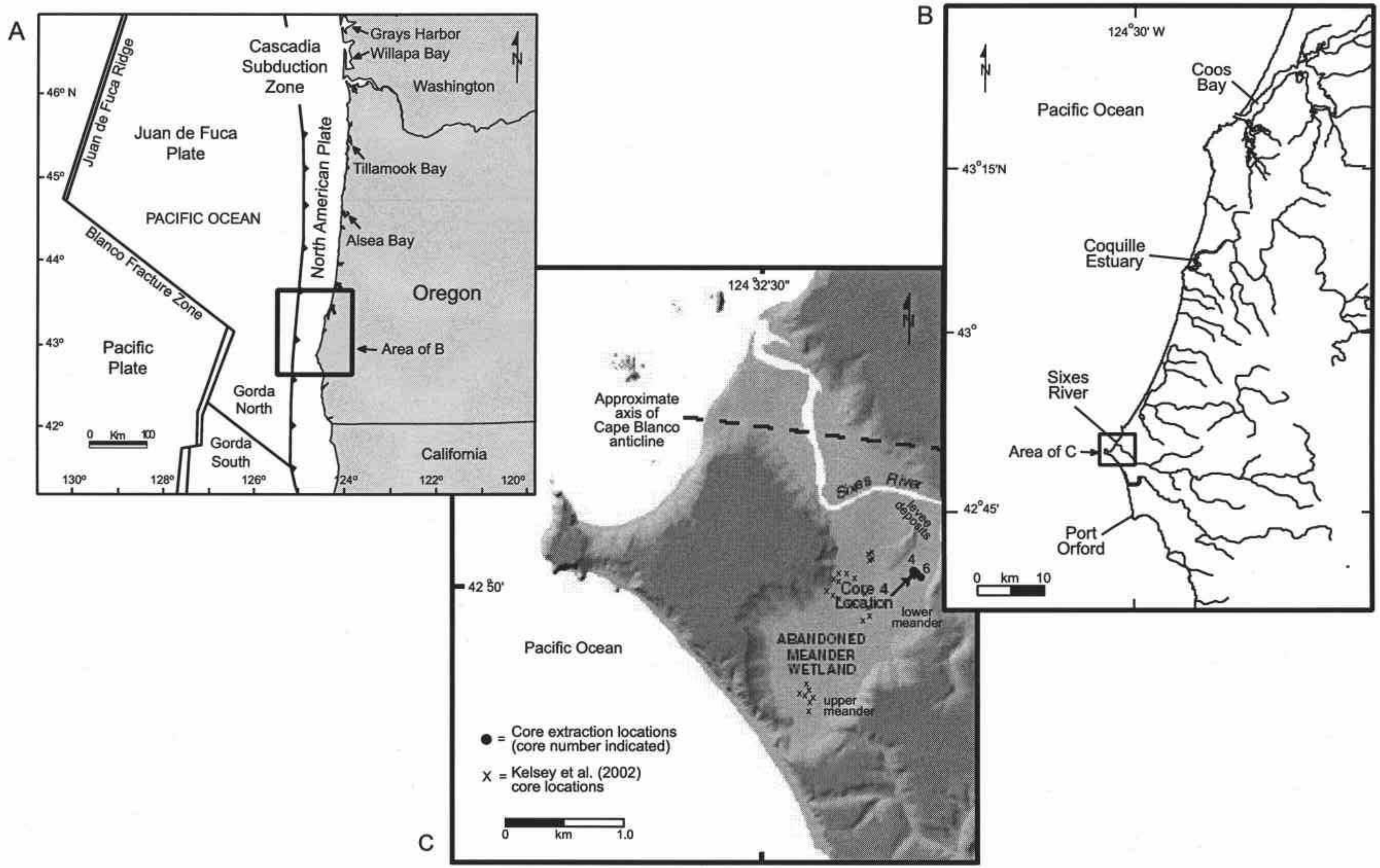


Figure 1. (A) Setting of southern coastal Oregon in relation to major plate boundaries. Locations of regional coastal estuaries discussed in text indicated. (B) Local setting of Sixes River in relation to other local estuaries and the tidal datum at Port Orford. (C) Map of lower Sixes River valley showing location of abandonded meander area, core extraction location, and approximate axis of Cape Blanco anticline (Kelsey 1990).

Long records of plate-boundary earthquake events from locations along the length of the CSZ are necessary for determining the nature of CSZ fault rupture. Not only are long records vital to the production of conditional probability estimations for earthquake recurrence intervals (Biasi et al. 2002) and the possibility of interval patterning (Goldfinger et al. 2003; Kelsey et al. 2005), they also address issues of earthquake size and fault segmentation. It is still unclear what role upper-plate structures play in the segmentation of the Cascadia fault zone, or how these structures operate in association with slip on the plate-boundary margin. Longer records of CSZ seismic activity are needed to address these issues.

This paper represents an investigative study of a coastal marsh setting on the lower Sixes River, southern Oregon (Figure 1), within which records of late to middle Holocene coseismic subsidence are well represented (Kelsey et al. 1998; 2002). The goal of this study is to reconstruct the depositional history of the estuary and to determine if deposits indicative of earthquake-generated subsidence or tsunami inundation dating to the early Holocene or late Pleistocene are preserved at the site. If such deposits are present, we aim to determine whether they preserve a record of coseismic subsidence in a manner similar to younger event records from the same area (Kelsey et al. 2002). In order to accomplish this goal, we collected and analyzed litho-, bio-, and chronostratigraphic data from a 27 m long sediment core recovered from the lower Sixes River valley near the area of work by Kelsey et al. (2002). These data allow us to determine the depositional evolution of the location through time and highlight sudden changes within the depositional record that we may then evaluate for a coseismic origin following criteria outlined by Nelson et al. (1996b) and Hemphill-Haley (1995a).

The criteria proposed by Nelson et al. (1996) and Hemphill-Haley (1995a) utilized by this study to evaluate the depositional record for a coseismic origin include the following: the suddenness of submergence, as evidenced by an abrupt rise in relative sea level and a sharp upper soil contact; a laterally expansive record of submergence; lasting relative sea level rise of >0.5m; tsunami deposition concurrent with soil burial; and synchronous submergence with events recorded at other CSZ sites. We expect to see stratigraphic evidence that meets some of the criteria outlined above for determining a coseismic origin of events in the lower, older sections of our core. However, we also understand that the stratigraphic record of older events may be different from records dating to the mid or late Holocene. Because we have a depositional record that dates to as early as the late Pleistocene, we have the opportunity to assess the threshold for earthquake and tsunami detection in coastal marsh settings.

Setting and Core Recovery

The Sixes River valley is located nearly 60 km from the seaward edge of the CSZ (Figure 1). Modern rates of uplift for the area are estimated between 4-5 mm/yr (Mitchell et al. 1994) based on repeated leveling surveys of US Highway 101, located 6 km to the east of the valley. Long term, permanent uplift rates based on marine-terrace data indicate ca. 0.85 to 1.25 m of net uplift per thousand years (Muhs et al. 1990; Kelsey 1990). Both long- and short-term rates of uplift are relatively high compared with most of the CSZ (cf. Kelsey and Bockheim 1994:Fig.7), and may be due to the effects of regional uplift coupled with uplift on the Cape Blanco anticline, a local, upper-plate tectonic structure (Kelsey 1990; Kelsey et al. 1996; 2002). The Cape Blanco anticline is an east-striking, eastward plunging fold formed during ongoing compression of the forearc region of CSZ (Kelsey 1990). This upper plate structure is an onshore extension of the Cascadia fold-and-thrust belt, mapped by Goldfinger et al. (1992) and McNeill et al. (1998), that Kelsey et al. (2002) argue ruptures coseismically in association with some larger, plate-boundary earthquakes along the CSZ.

The Sixes River estuary is confined within the active river channel, with head of tide reaching approximately three river kilometers upstream (Kelsey et al. 1996). The coastal lowland surrounding the river is currently higher than mean higher high water (MHHW), which is 0.98m relative to the National Geodetic Vertical Datum (NGVD). All elevations reported in this paper are relative to NGVD and are tied to the Port Orford tidal gauge located 11 km to the south of Cape Blanco (Figure 1). All ground surface elevations were determined by Total Station survey and referenced by benchmark to NGVD. Accuracy is to the nearest 0.01m.

Much of the lower Sixes valley is an abandoned meander wetland cut into surrounding Pleistocene marine terrace deposits (Figure 1). It is thought that the meander was cut sometime during the last sea level low stand and filled in with fine-grained estuarine, tidal marsh, and freshwater marsh sediments as sea level rose in the late Pleistocene and early Holocene periods (Kelsey et al. 2002). We recovered four long cores in the lower Sixes River valley, with the two longest and most complete cores, Cores 4 and 6, extracted from a dry pasture area within the abandoned meander located to the south of the river within 3.5 km of

Table 1. Radiocarbon Ages, Lower Sixes River Valley

Stratigraphic Discontinuity (SD)	Core : Section	Elevation relative to NGVD (m)	Material dated	Beta Analytic Lab Number	Conventional radiocarbon age and reported error (C14 yr BP)	Calibrated age (2 sigma)
B	4 : 2	4.18 to 4.16	small woody debris	Beta-203257	2300+/-40 BP	Cal BP 2350 to 2300 and Cal BP 2260 to 2160
G	4 : 7	-2.125 to -2.135	small, woody detritus	Beta-203256	5600+/-40 BP	Cal BP 6450 to 6300
H	4 : 7	-2.51 to -2.50	small woody debris, sharp edged	Beta-203255	5860+/-40 BP	Cal BP 6690 to 6500
I	4 : 9	-4.42	Seeds	Beta-199710	5970+/-40 BP	Cal BP 6890 to 6690
J	4 : 15	-11.63 to -11.66	Wood	Beta-199712	8280+/-50 BP	Cal BP 9440 to 9120
K	4 : 18	-16.25	Plant material	Beta-199709	8900+/-50 BP	Cal BP 10190 to 9880
No event associated	4 : 22	-20.62 to -20.64	Seeds	Beta-199715	8980+/-40 BP	Cal BP 10220 and 10140 and Cal BP 10000 to 9960

the modern channel mouth (Figure 1). Previous work within the abandoned meander conducted by Kelsey et al. (2002) focused on the southern and northwestern upper and lower meander areas (Figure 1). Using hand-operated gouge cores, their efforts recovered sediments to a maximum depth of just over -3 m NGVD. Our team utilized an alternative coring technology, a hydraulically powered, truck-mounted Geoprobe, to recover sediments to a maximum depth of -21.2 m NGVD in Core 4. AMS radiocarbon dating of seeds from near the bottom of the longest core resulted in a date of 10220 and 10140 cal yr BP or 10000 to 9960 cal yr BP (Table 1) for sediments buried -20.6 m NGVD (uncertainty in calibrated date due to the nature of the radiocarbon calibration curve during this time period). The two other cores extracted during this reconnaissance also reached depths below those attained by previous researchers in the area and remain at the core storage facility at Oregon State University for future research.

Methods

Lithostratigraphic investigations included magnetic susceptibility, gamma density, and loss on ignition (LOI) analyses, as well as detailed description of coastal wetland stratigraphy as revealed in core sections. Diatom biostratigraphic analyses were designed to assess general trends in depositional setting evolution and to determine whether significant changes in salinity accompanied the abrupt changes in lithostratigraphy. Diatom assemblage investigations were also used to estimate the magnitude of vertical relative sea level change associated with each wetland soil burial event (Hemphill-Haley 1995b). Elevation ranges of intertidal zones are estimated from modern ecological transect studies conducted in marshes on the Oregon and Washington coasts by Nelson and Kashima (1993) and Hemphill-Haley (1995a). Elevation of intertidal zones relative to mean tide level (MTL) used for this study are as follows: tidal flats and shallow subtidal channels (0.3 to -0.7m); low marsh (0.0 to 0.9m); high marsh (0.7 to 1.6m); and freshwater wetland (1.4 to 2.4m). Overlap in elevation ranges of 20-30cm reflects vertical variation in zone elevation and is included in estimations of diatom assemblages' paleo-mean tide levels (Figure 2, Table 2).

Chronostratigraphic investigations entailed the AMS radiocarbon dating of organic materials associated with abrupt burial of tidal wetland soils. Event ages were used for correlation of core stratigraphy between this study and prior work in the area (Kelsey et al. 2002), as well as for comparison with CSZ earthquake events recorded at locations along the

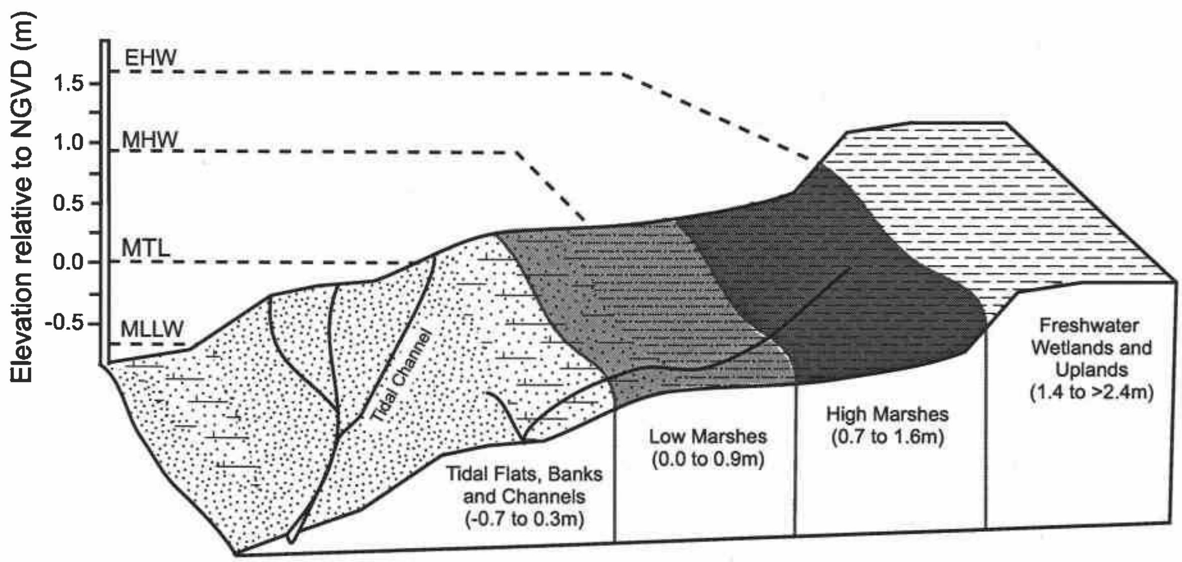


Figure 2. Elevation ranges for intertidal zones at the Sixes River Estuary based on information from Jennings and Nelson (1992), Nelson and Kashima (1993), and Hemphill-Haley (1995a). Tidal information from the National Ocean Service (1992). EHW, extreme high water; MHW, mean high water; MTL, mean tide level. Intertidal zones overlap by 20-30cm, reflecting variations in vertical zone boundaries (Nelson and Kashima 1993)

Table 2. Paleo-Mean Tide Levels Before and After Submergence for Events Recorded in Cores 4 and 6

Stratigraphic Discontinuity	Kelsey et al. (2002) Event Number	Diatom Sample Numbers	Elevation (NGVD) diatom samples (m)	Paleo-environment of diatom sample After submergence, before submergence	Vertical position of diatom sample relative to paleo-MTL (m)[1]	Elevation (NGVD), paleo-MTL (m)	Range of Submergence (m)[2]	Age (cal yr BP) Calibrated 2-sigma[3]
CORE 4								
			4.26	High Marsh,	0.7 to 1.6	3.6 to 2.7		
A	III	21,20	4.20	High Marsh	0.7 to 1.6	3.5 to 2.6	0 to 1.0	
			4.18	High to low marsh,	0.0 to 1.6	4.2 to 2.6		
B	IV	22, 23	4.15	Freshwater wetland	1.4 to 2.4	2.8 to 1.8	0 to 2.4	ca. 2160-2350
			4.07	Low Marsh,	0.0 to 0.9	4.1 to 3.2		
C	V	154, 24	4.03	Frashwater Wetland	1.4 to 2.4	2.6 to 1.6	0.6 to 2.5	
			3.96	Low Marsh,	0.0 to 0.9	4.0 to 3.1		
D	VI	155, 26	3.95	High Marsh	0.7 to 1.6	3.3 to 2.4	0 to 1.6	
			3.91	Low Marsh,	0.0 to 0.9	3.9 to 3.0		
E	VII	156, 157	3.90	High Marsh	0.7 to 1.6	3.2 to 2.3	0 to 1.6	
			3.55	Tidal flat,	-0.7 to 0.3	4.3 to 3.3		
F	VIII	158, 28	3.54	High marsh	0.7 to 1.6	2.8 to 1.9	0.5 to 2.4	
			-2.11	Tidal flat?,	-0.7 to 0.3	-1.4 to -2.4		
G		120,121	-2.16	High to low marsh?	0.0 to 1.6	-2.2 to -3.8	0 to 2.4	6300-6450
			-2.51	Tidal Flat,	-0.7 to 0.3	-1.8 to -2.8		
H		116,117	-2.49	Low Marsh	0.0 to 0.9	-2.5 to -3.4	0 to 1.6	6500-6690
			-4.33	Tidal Flat,	-0.7 to 0.3	-3.6 to -4.6		
I		107,106	-4.50	High Marsh	0.7 to 1.6	-5.2 to -6.1	0.6 to 2.5	6690-6890
			-11.63	High to low marsh?,	0.0 to 1.6	-11.6 to -13.2		
J		77,78	-11.65	Freshwater wetland	1.4 to 2.4	-13.1 to -14.1	0 to 2.5	9120-9440
			-16.23	High to low marsh, High Marsh to	0.0 to 1.6	-16.2 to -17.8		
K		51,52	-16.29	freshwater wetland	0.7 to 2.4	-17.0 to -18.7	0 to 2.5	9880 to 10190
			-17.93	Low Marsh or intertidal flat,	-0.7 to 0.9	-17.2 to -18.8		>9880 and
L		40,41	-17.95	High Marsh	0.7 to 1.6	-18.7 to -19.6	0 to 2.4	<10220
No event associated		4	-20.63	Estuarine tidal flat or channel	-0.7 to 0.3	-19.9 to -20.9		ca. 9960 to 10220
CORE 6								
			-4.36	Tidal Flat or Channel,	-0.7 to 0.3	-3.7 to -4.7		
G		20,21	-4.40	High to Low Marsh	0.0 to 1.6	-4.4 to -6.0	0 to 2.3	
			-4.90	Tidal Flat, High Marsh to	-0.7 to 0.3	-4.2 to -5.2		
H		15,16	-4.96	Freshwater Wetland	0.7 to 2.4	-5.7 to -7.4	0.5 to 3.2	

[1] Elevation ranges for marsh and tidal flat environments, relative to Mean Tide Level (MTL), from Nelson and Kashima (1993) and Hemphill-Haley (1995)

[2] We infer that negative minimum values are invalid estimates of submergence because, in each case, the diatom assemblage data indicate a change from a higher to a lower intertidal zone across the buried soil horizon.

[3] ca. ages incorporate error range due to multiple intercepts on radiocarbon calibration curve

coasts of Washington (Atwater and Hemphill-Haley 1997), Oregon (Nelson et al. 1996a, 1998; Witter et al. 2003; Kelsey et al. 2005), northern California (Abramson 1998; Garrison-Laney 1998), and with events recorded from offshore turbidite records (Goldfinger et al. 2003). Age data also helped to constrain the timing and evolution of depositional systems at the site. For more details on the litho-, bio-, and chronostratigraphic methods employed, see Appendix C.

Unlike stratigraphic records from other Cascadia marsh sequences, buried peats (organic content >40%) or O horizons of Histosols (>50% organic content; Soil Survey Staff 1998) did not appear in Core 4 below 2.44m below the land surface. Buried soils in many of the core sections, especially in the lowest elevations, were identified using the definition of an A horizon: "Mineral horizons that have formed at the surface or below an O horizon. They exhibit obliteration of all or much of the original rock structure and show. . . an accumulation of humified organic matter closely mixed with the mineral fraction" (USDA 1998). We identified buried surface layers based on a slight darkening of sediment color, often a change in sediment texture, an accumulation of humic matter or elevated organic content relative to surrounding sediments, and a diatom assemblage indicative of a marsh or upland surface. The term "mud" is used in this paper to indicate a non-organic silty-clay loam or silty clay.

Results

Core 4 Stratigraphy

Core 4 records a total of 12 stratigraphic discontinuities (SDs), spanning ~10,000 years of depositional history. We present stratigraphic evidence pertaining to these 12 SDs in two sections. The first section presents data pertaining to the youngest six SDs (A through F). These younger SDs either dated to within the time range of events reported by Kelsey et al. (2002) or were inferred to be younger than our second youngest dated SD (~6300 cal yr BP) based on stratigraphic position. The second section presents data concerning our oldest six SDs (G through L), that all returned dates older than the oldest event date reported by Kelsey et al. (2002), of ~6200 cal yr BP.

An idealized model of a stratigraphic section showing both litho- and biostratigraphic discontinuities that are consistent with the types of changes associated with coseismic

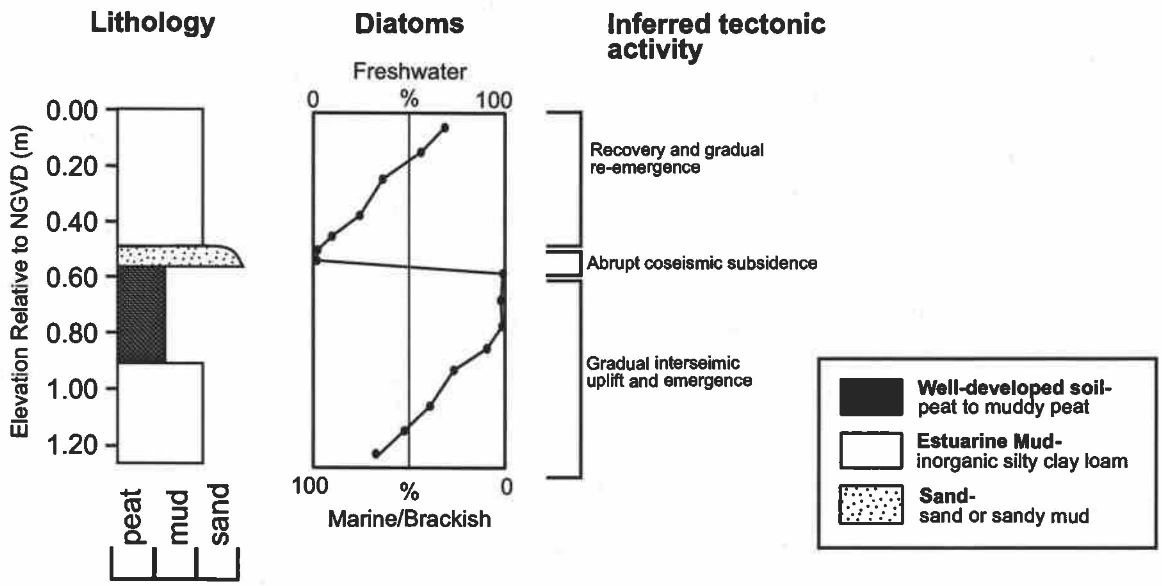


Figure 3. Idealized stratigraphic sediment section displaying litho- and biostratigraphic evidence of tectonic alteration of the landscape, as might result from a subduction zone earthquake. Interseismic uplift causes gradual emergence and a change from estuarine muds to a peaty soil. This is accompanied by an increase in relative percentage of freshwater diatoms. Abrupt subsidence of the landscape results in inundation by tsunami waters and associated sand deposition. The sudden rise in sea level relative to the land causes infilling by intertidal muds. Diatom biostratigraphy displays a sudden drop in freshwater diatom percentage and an influx of marine/brackish diatoms in association with the tsunami deposit and influx of intertidal mud.

subsidence of the landscape and relative sea level rise is shown in Figure 3. For each of the 12 stratigraphic discontinuities (SDs) described below, we have constructed representative litho- and biostratigraphic sections for comparison to the model (Figure 4).

Stratigraphic Discontinuities (SDs) Younger than 6200 yr BP

Buried soils

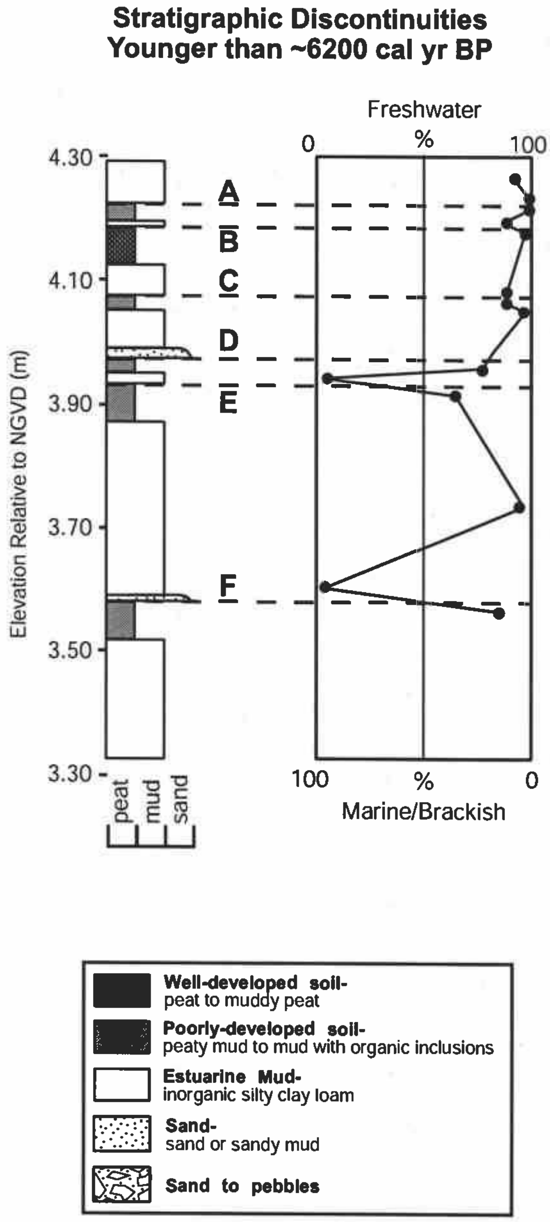
In all cases, well-developed or incipient soils, identified based on sediment structure, aggregation of organic materials, or higher relative LOI readings, are associated with the SDs (Figure 4). Contact abruptness between buried soils and overlying sediments is one indication of the sudden submergence of a soil (Nelson et al. 1996b). For almost every younger SD recorded in our core, an abrupt (<1mm) to sharp (1-3mm) boundary between units is noted. Only SD C displays a gradational (4-10mm) boundary.

Sandy Deposits Overlying Buried Soils

Sediment deposits with significantly higher percentages of sand than the units directly underlying them occurs in association with SD D and F (Figure 4, Table 3). Texture of the overlying sediments are massive sandy clay loams and are <2cm thick, sharply overlying the soils below. Events A, B, C, and E have no notable layers of sand associated, or experience a drop in relative sand percentage across the event boundary. Because the boundaries between each of the buried soils and overlying sandy units associated with Events D and F are abrupt, and because no soil development is noted to occur within the top portions of these sandy units, we infer that the sandy beds were deposited rapidly and subsequently buried by intertidal mud deposits.

Diatom Biostratigraphy

On the basis of relative percentages of diatoms with freshwater, fresh-brackish, brackish, marine-brackish, and marine salinity preferences, the general environmental setting of the lower meander site for the past 10,000 years can be characterized (Figure 5). Within this general evolution of a fluctuating brackish or freshwater paleoecological setting, sudden shifts in assemblage salinity were apparent. These abrupt changes in salinity are characterized by diatom assemblages indicative of higher intertidal environments shifting suddenly across a lithostratigraphic boundary to assemblages typical of lower intertidal



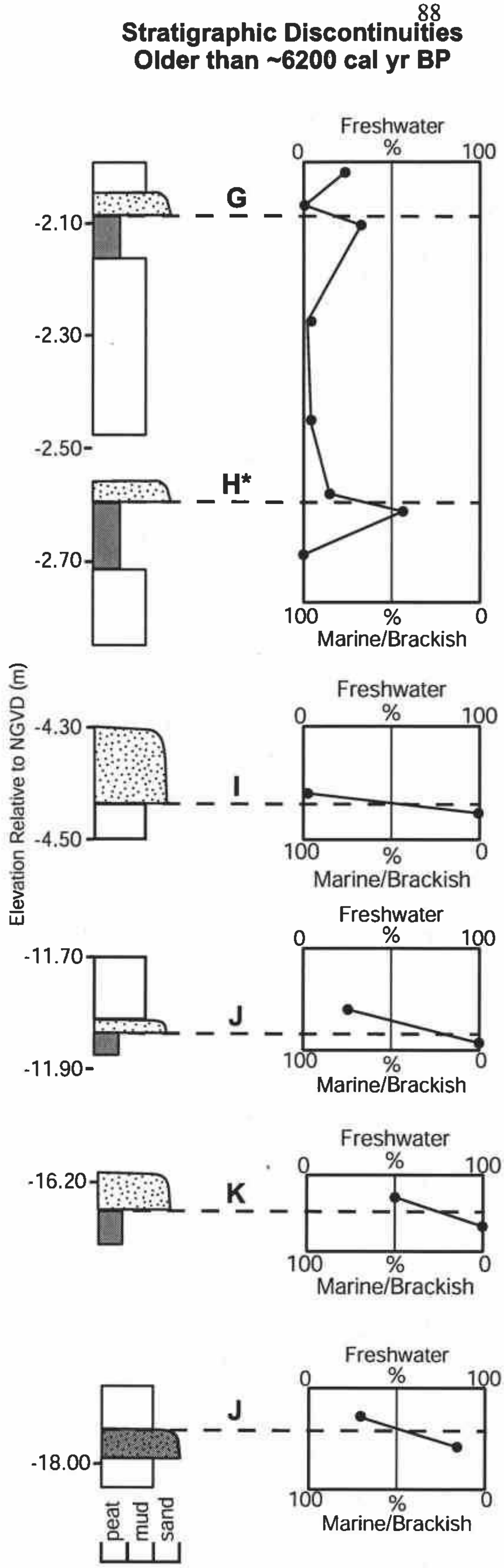


Figure 4. Litho- and biostratigraphic evidence associated with stratigraphic discontinuities (SDs) recorded in Core 4.
* Biostratigraphic evidence for SD H recovered from Core 6.

Table 3. Attributes of Stratigraphic Discontinuities (SDs) from Cores at Lower Sixes River Valley.

Stratigraphic Discontinuity (SD)[1]	Correlative with Kelsey et al. (2002) Buried Soil number:	Depth to SD (m)[2]	Number of cores that sample SD[3]	Abruptness of contact[4]	Sandy deposit overlying buried horizon?	Thickness of sand overlying buried horizon (cm)	Stratigraphic separation between SDs (m)[5]
A	III	1.34	1 (11)	Sharp	No	N.A.	N.A.
B	IV	1.38	1 (11)	Abrupt	No	N.A.	0.04
C	V	1.50	1 (20)	Gradational	No	N.A.	0.12
D	VI	1.59	1 (10)	Sharp	Yes	2.0	0.09
E	VII	1.64	1 (10)	Sharp	No	N.A.	0.05
F	VIII	2.00	1 (10)	Sharp	Yes	1.0	0.36
G		7.68	2	Sharp	Yes	3.0	N.A.
H		8.06	2	Abrupt	Yes	4.5	0.46
I		9.96	1	Sharp	Yes	10.0	0.74
J		17.18	1	Sharp	Yes	3.0	N.A.
K		21.80	1	Sharp	Yes	4.0	N.A.
L		23.49	1	Sharp	No	N.A.	N.A.

, [1] We use the term "Stratigraphic Discontinuity (SD)" rather than "Buried Soil" because in the case of Events I and L. no buried soil is associated with the burial event.

[2] Depth to event is averaged for events G and H from cores 4 and 6

[3] Parentheses around the second number indicates the minimum number of cores identified by Kelsey et al. (2002) containing evidence of the burial event. See text for discussion of correlation between soil burial events reported by Kelsey et al. (2002) and events identified through this study.

[4] Abrupt = <1mm; Sharp = 1-3mm; Gradational = 4-10mm; Diffuse = >11mm

[5] Stratigraphic separation calcuated for those events between which no sediment was lost during coring activities.

environments. Each of the six younger SDs correlates to such a sudden shift in diatom assemblage (Figure 5; Appendix B). Because the sandy sediment that overlies buried soils D and F contains brackish and/or marine diatoms (Appendix A, B), we infer that each depositional event that transports sand to the site also transports brackish and/or marine diatoms onto the buried marsh soils.

Age assignments for buried soils

An age range of cal BP 2350 to 2300 and cal BP 2260 to 2160 was assigned to SD B based on AMS radiocarbon dating of a sample extracted from the upper 2cm of the buried soil horizon (Table 1).

Correlation with Previously Recorded Events within the Sixes River Wetland

Correlation between SDs recorded in Core 4 and events reported by Kelsey et al. (2002) for the same area is attempted based on stratigraphic signatures such as depth, litho- and biostratigraphy, stratigraphic separation, and radiocarbon information. SDs A through C can be correlated with Kelsey et al.'s (2002) buried soil events III through V based on a date returned on our SD B and associated stratigraphic signatures (Figure 6). A date range of cal BP 2350 to 2300 and cal BP 2260 to 2160 for our SD B (Table 1) falls between the dates for Kelsey et al.'s (2002) soil burial events III and V, thus correlating with their burial event IV. SDs A-C occur at stratigraphic positions consistent with the depth and stratigraphic separation between their events III through V, summarized in their Tables 1 and 3 (Kelsey et al. 2002:302,303). Our SD B is found less than 5cm below SD A in the stratigraphic column, placement which is consistent with the stratigraphic coupling reported by Kelsey et al. for their buried soils III and IV. Our SD C occurs 12cm below SD B, over double the separation between the two upper events, which is consistent with separations between Kelsey et al.'s buried soils III and IV as compared to IV and V. We correlate our SDs D through F with Kelsey et al.'s soil burial events VI through VIII based on the stratigraphic similarities in the positioning of event horizons (Figure 6). As with their events VI and VII, our SDs D and E display little stratigraphic separation (~4cm). This coupling aids in the determination of correlation between cores from the same study area. Kelsey et al.'s (2002) events IX through XII are not preserved in Core 4 due to discontinuous sediment retrieval.

Although the stratigraphic separation between SDs A through F in our core is smaller than that reported by Kelsey et al. (2002:Table 3), this is consistent with their contention that

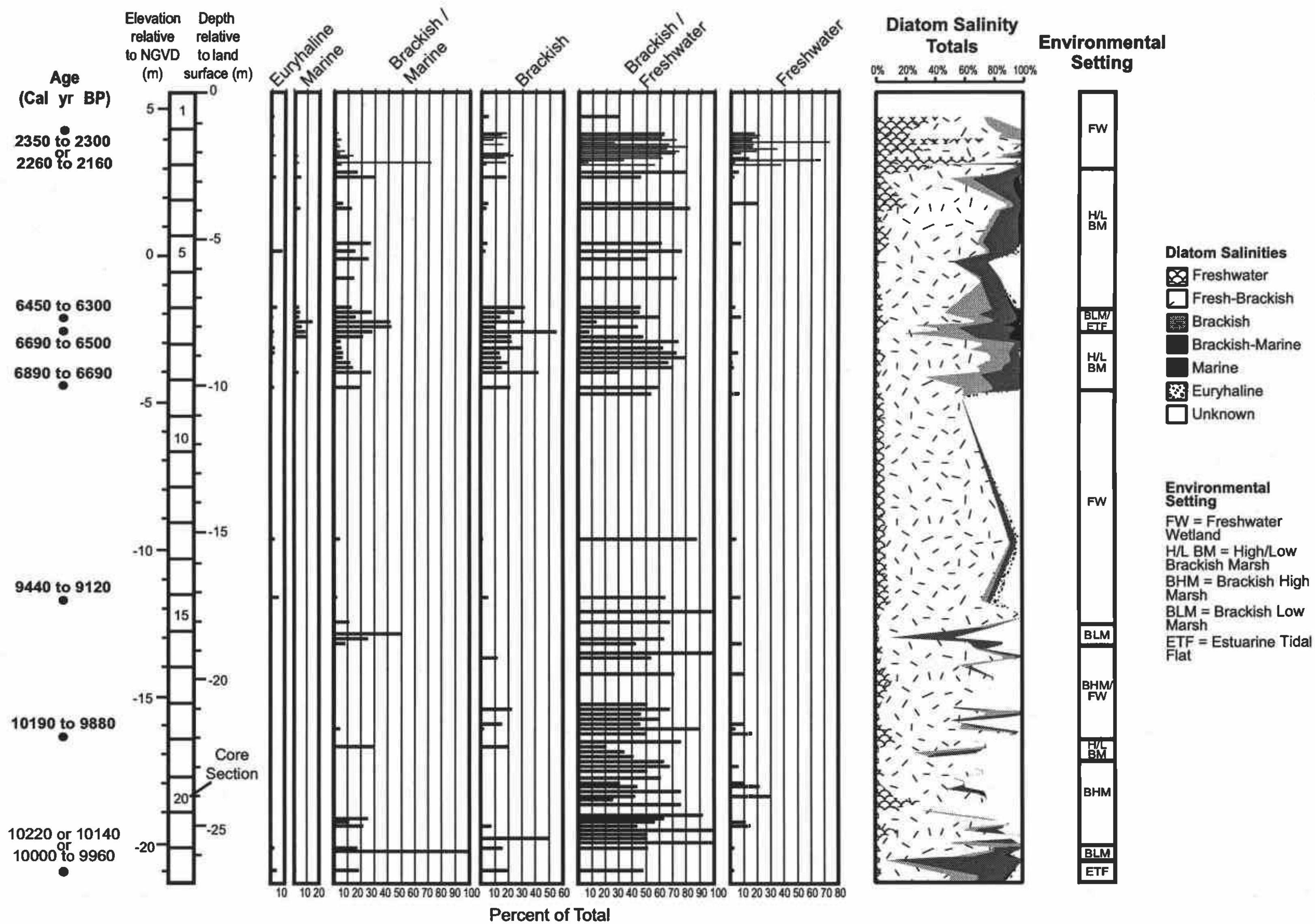


Figure 5. Diatom percentages organized by salinity tolerances used to infer environmental setting.

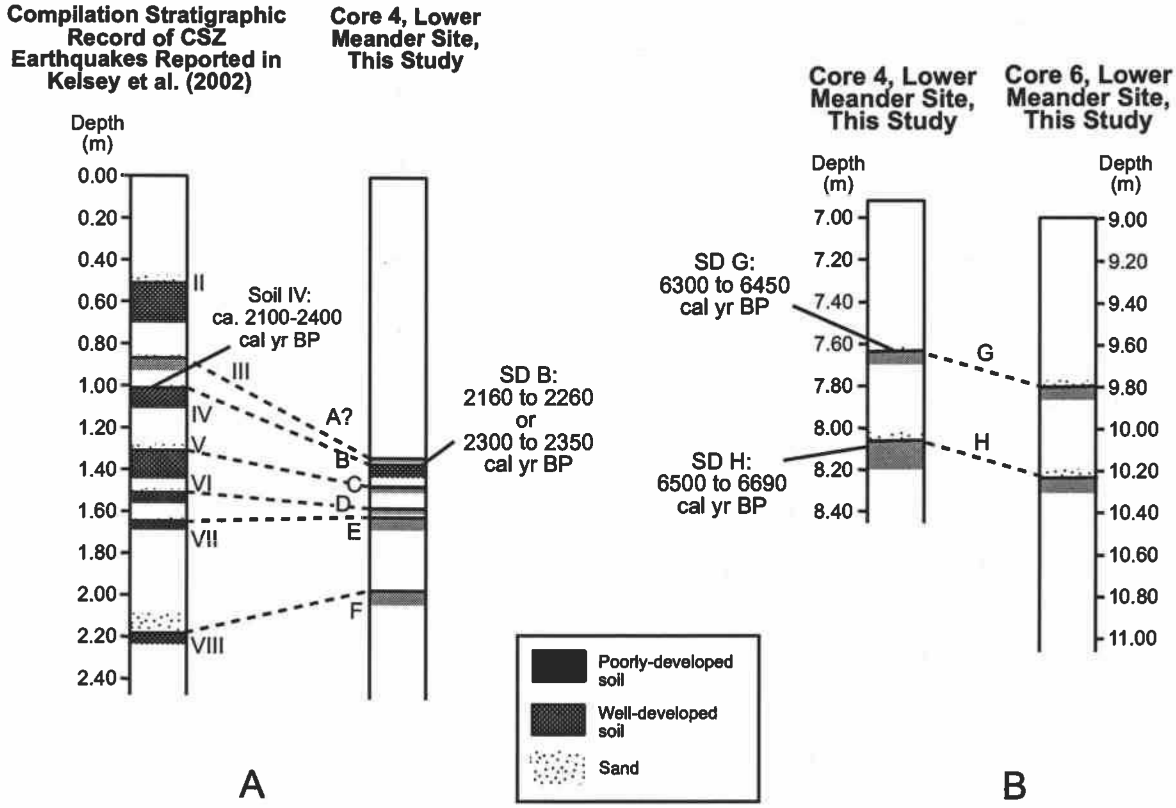


Figure 6. (A) Stratigraphic record correlation between events reported in Kelsey et al. (2002) and six youngest Stratigraphic Discontinuities (SDs) reported in this study. Compilation lower meander sediment core constructed from information included in Kelsey et al. (2002): average depth to buried soil from their Table 3, buried soil characteristics from their Figure 3, and average thickness of sand deposits associated with buried soils from their Table 1. Soil IV estimatebased on their Table 5, their Figure 12 and correlation with Witter et al.'s buried soil number 4 (2003: Table 1). (B) Stratigraphic correlation of SDs G and H between Cores 4 and 6, this study.

core sites located closer to the Cape Blanco anticline will display less net sediment accretion between events than those further away from the anticline axis. They argue that coseismic tightening of the anticline negates in part the total amount of subsidence caused by regional slip on the underlying megathrust (Kelsey et al. 2002:313). Since the location of Core 4 is nearer to the anticline axis than any of the cores retrieved in their study (Figure 1), a smaller amount of stratigraphic separation between events should be expected.

Correlation of our SDs A-F with events III-VIII reported by Kelsey et al. (2002) is substantiated by diatom assemblage analysis (Figures 4, 5; Table 2; Appendix A, B). Diatom assemblages across stratigraphic boundaries B-F shift from a higher to a lower intertidal setting. The diatom assemblage from our SD A shows little change in species dominance, with high brackish marsh settings indicated both above and below the event boundary (Figure 4; Table 2). This lack of change is consistent with the abundance of freshwater diatoms seen above and below Kelsey et al.'s (2002) Event III, as revealed in their Lower-Meander Core V (2002:Figure 6, Core V diatom graph). This same graph also clearly displays a significant change in intertidal setting associated with their Event V, a jump from nearly 100% freshwater diatoms to 100% brackish/marine diatoms across the event boundary. Our correlative SD C shows a similar significant drop in freshwater diatom abundance, indicating a shift from a freshwater wetland to a low marsh (Figure 4; Table 2; Appendix 1).

Ages for buried soils A and C-F (Table 2) were estimated based on correlation with events and ages reported by Kelsey et al. (2002), as shown in Figure 6.

Stratigraphic Discontinuities (SDs) Older than 6200 cal yr BP

Buried soils

In all cases except for SD I and L, well-developed or incipient soils, identified based on sediment structure, aggregation of organic materials, or higher relative LOI readings, are associated with the SDs (Figure 4). In the case of SD I and L, no macroscopically visible buried soil is associated. In these two cases, other lithostratigraphic data, such as contact abruptness and overlying sediment texture, in addition to biostratigraphic data, are used to identify buried former land surfaces. Contact abruptness between buried soils and overlying sediments is one indication of the sudden submergence of a soil (Nelson et al. 1996b). For every older SD recorded in our core, an abrupt (<1mm) to sharp (1-3mm) boundary between units is noted.

Sandy Deposits Overlying Buried Soils

Sediment deposits with significantly higher percentages of sand than the units directly underlying them occur in association with SDs G-K (Figure 4; Table 3). Texture of the sediment ranges from medium to very fine sand with variable amounts of silt/clay. Thicknesses of the sand layers range from ~1.0 to 10.0cm. SD L has no notable layer of sand associated. Buried soils underlie sandy deposits in SDs G, H, J, and K. In each of these cases, the boundary between the buried soil and the overlying sandy unit is sharp or abrupt. No buried soil is apparent in the case of SD I. The underlying unit is a silty clay loam with no apparent organic inclusions. The boundary between this and the overlying lithologic unit is abrupt, slanted in the core section, and appears erosional. The overlying unit is loamy sand, poorly sorted, with some clasts ranging in size from pebbles to fine sand.

Sandy deposits associated with SDs G, J, and K are massive sands to sandy loams with no apparent internal bedding. In the case of SD H, however, a fining upward sequence of medium to fine sand occurs between -2.46 and -2.50 m NGVD, abruptly overlying an organically laminated clay loam. Because the boundaries between each of the buried soils and overlying sandy units associated with SDs G, H, J, and K are abrupt to sharp, and because no soil development is noted to occur within the top portions of these sandy units, we infer that the sandy beds were deposited rapidly and immediately buried by intertidal mud deposits.

Diatom Biostratigraphy

Each of the six older SDs correlates to a sudden shift in fossil diatom salinity percentages (Figures 4, 5), from an assemblage indicative of a higher intertidal environment to an assemblage typical of a lower intertidal environment (Table 2; Appendix B). Because the sandy sediment that overlies SDs G, H, J, and K contains brackish and/or marine diatoms (Appendix A,B), we infer that each depositional event that transports sand to the site also transports brackish and/or marine diatoms onto the buried marsh soils.

Age Assignments for Buried Soils

Ages were assigned to SDs G, I, J, K, and L based on AMS radiocarbon dating of samples extracted from the upper 2cm of each buried soil horizon (Table 1). There is no radiocarbon age for the oldest buried soil, SD L. However, if we use the age ranges from dates recovered above and below this event, a bounding age range for the event can be proposed. The youngest possible age on material associated with SD K from core Section 18 is 9880 cal yr BP. The oldest reliable age from material below SD L is 10,220 cal yr BP, from seeds at -20.63m, core Section 22 (Table 1). Based on the stratigraphic position of SD L lower in the core than SD K and higher than the date from core Section 22, the age range for SD L is >9880 and <10,220 cal yr BP (Table 2).

Correlation with Core 6 Sediments

By matching magnetic susceptibility patterns recorded in Cores 4 and 6, and then closely examining the litho- and biostratigraphies of corresponding sediment units, we correlate SDs G and H between the two cores (Figure 6). Older buried soils recorded in Core 4 were recovered from depths below the lowest section of Core 6, which could not be pushed below a coarse gravel layer at -12.12 m below the surface. Therefore, no correlation within the meander locality of SDs I, J, K, or L was possible with the cores we acquired.

Relative Sea Level Curve Construction

Figure 7 displays a relative sea level curve constructed for the site based on radiocarbon dates and diatom biostratigraphy produced by this study (see Appendix B for a full description of relative sea level curve construction). Superimposed upon the general trend in relative sea level rise since the late Pleistocene are six instances of sudden sea level rise, correlative with our six dated stratigraphic discontinuities. The amounts of submergence and relative sea level rise associated with each radiocarbon dated stratigraphic boundary are estimated using diatom assemblage data from above and below the event boundaries (Table 2). The maximum amount of submergence associated with these events is 3.2m. The minimum amount of submergence incurred is estimated to be ≥0. For some events a negative amount of submergence is estimated based on diatom assemblage elevation ranges, but in each case we reject any negative estimate due to the change in litho- and/or biostratigraphy from a higher to a lower intertidal setting.

Evidence for Coseismic Subsidence and Tsunamis Induced by Great Earthquakes

We present evidence to satisfy criteria proposed by Nelson et al. (1996b) and Hemphill-Haley (1995b) in support of a coseismic origin for soil submergence and burial for the 12 stratigraphic discontinuities/burial events recorded in the lower Sixes River valley (SDs A-L). These criteria include the suddenness of submergence, as evidenced by an abrupt rise in relative sea level and a sharp upper soil contact; a laterally expansive record of submergence; lasting relative sea level rise of >0.5m; tsunami deposition concurrent with soil burial; and synchronous submergence with events recorded at other CSZ sites (Table 4).

Of the 12 candidate paleoseismic events presented here, we believe the first six events (SDs A-F) correlate to events III-VIII presented in Kelsey et al. (2002). This contention is based on the stratigraphic signatures such as depth, litho- and biostratigraphy, stratigraphic separation, and radiocarbon information discussed above (Figure 6). If this correlation is correct, then each of these events satisfy from four to six of the criteria used to assess a coseismic origin for soil submergence and burial, listed in Table 4 (Kelsey et al. 2002:Table 7). Therefore, we will concentrate our discussion on the older, lower six events recorded in our cores, SDs G through L.

Candidate Paleoseismic Events Older than 6,200 cal yr BP

Soil/mud couplets

We have identified six instances of sudden submergence and burial of sediments older than the oldest event reported by Kelsey et al. (2002) for the same abandoned meander wetland. These buried sediments are identified as former freshwater or brackish marsh soils based on incipient soil development and/or diatom assemblage analysis. (Tables 2 and 3, Figure 4, Appendices 1 and 2). In most of these cases, development of buried soil horizons is weak or non-detectable. This poor development may be due to post-burial degradation of the soil due to pedoturbation by plants or animals, microbial activity, or non-reducing conditions (Atwater 1992; Hart 1994). Erosion of the uppermost soil surfaces may have occurred in association with tsunami deposition. Alternatively, marsh soils at this locality may have not developed enough to produce strong pedologic signatures to be preserved. Poor preservation or lack of recognizable marsh soil horizons is not an uncommon occurrence in tidal marsh studies. Both Kelsey et al. (2002) and Witter et al. (2003) have reported degradation of soils in deeper core sections from southern Oregon marshes, and Mathewes and Clague (1994) relied upon paleoecologic studies of fossil assemblages to identify buried marsh soils. In each case in the lower sections of our cores where soil development is poor or lacking, biostratigraphic data provide evidence that the sediment represents freshwater or high brackish marsh deposits (Table 2; Appendix B).

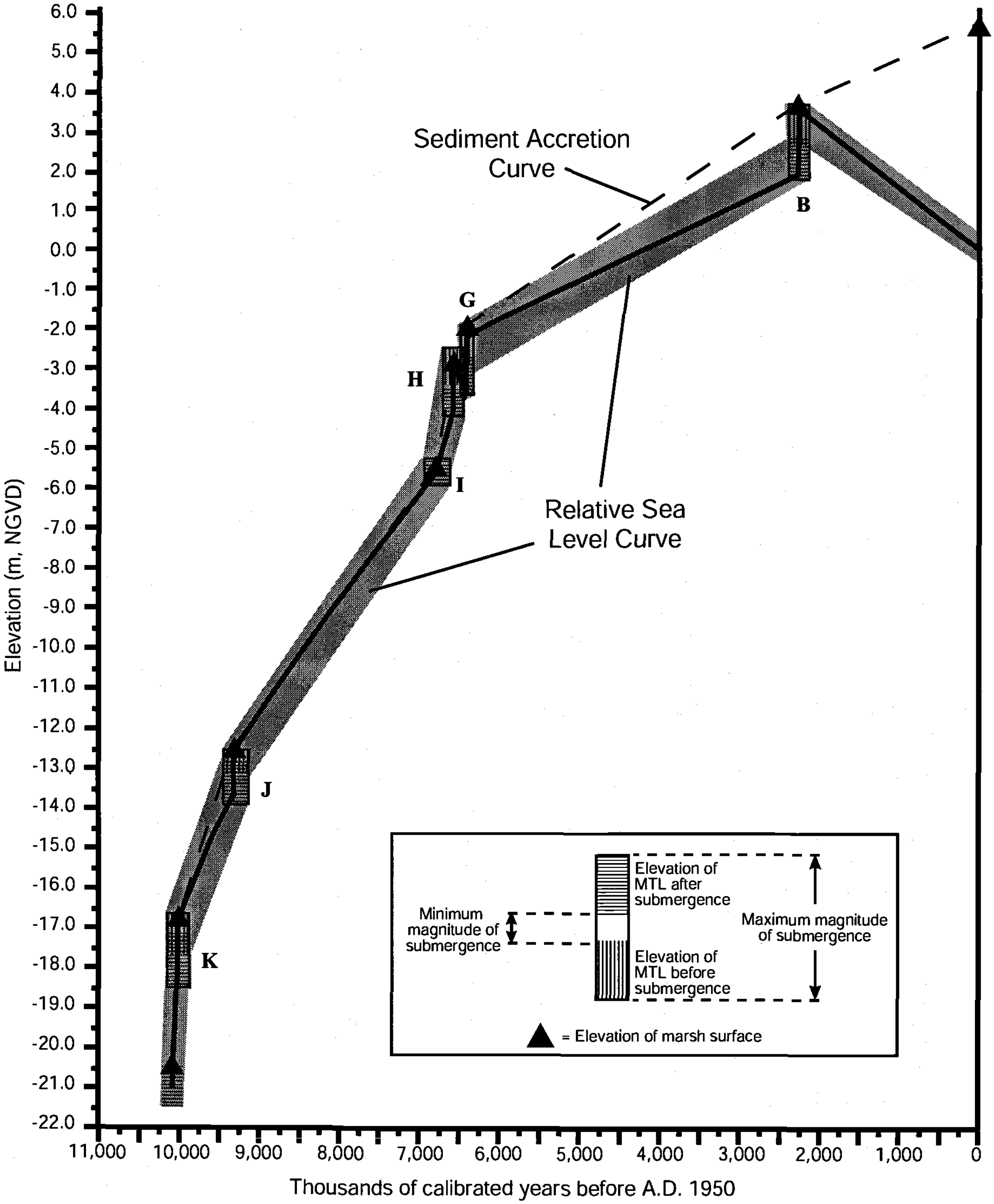


Figure 7. Elevation of mean tidal level (MTL) over time ("Relative Sea Level Curve"). Vertical elevation of mean tide level across each stratigraphic discontinuity (SDs A, G, I, J, K, and L) based on elevation ranges relative to NGVD of intertidal zones inferred from diatom assemblage data (see Table 2 and Appendix B). Rectangle height incorporates error margins related to ranges in elevation for each intertidal zone. Errors in age estimates for each sample are listed in Table 1 and are portrayed as rectangle width. Shaded area represents sea level curve with error margins incorporated. Triangles mark buried surface horizons (i.e. buried wetland soils) and are connected with dashed line that indicates sediment aggradation over time.

Table 4. Summary of Evidence for Coseismic Origin of Stratigraphic Discontinuities, Lower Sixes River Valley

		Evidence for coseismic subsidence							
Candidate Paleo-seismic Event (Same designation as stratigraphic discontinuity)	Age (cal yr BP) Calibrated 2-sigma[1]	Rapid relative sea level rise	Permanence of relative sea level rise (>10cm of tidal mud overlies buried soil)	Lateral extent of event >150,000m^2	Estimated relative sea level rise >0.5m	Tsunami concurrent with submergence	Similar age to regional earthquake events	Relative confidence level (number of criteria met)	Candidate Events Younger than ~6200 cal yr BP
A	1940-2130#	X*	X*	X*		X*		4	
B	ca. 2160-2350	X*	X*	X*	X*	X*	X*	6	
C	2460-2750#	X*	X*	X*	X*	X*	X*	6	
D	2880-3160#	X*	X*	X*	X*	X*	X*	6	
E	3390-3560#	X*	X*	X*	X*	X*	X*	6	
F	4150-4410#	X*	X*	X*	X*	X*	X*	6	
									Candidate Events Older than ~6200 cal yr BP
G	6300-6450	X	X		X	X	X	5	
H	6500-6690	X	X		X	X		4	
I	6690-6890		X		X			2	
J	9120-9440	X			X	X	X	4	
K	ca. 9880-10190	X	X		X		X	4	
L	9880-10220	X	X		X	X	X? (see text)	4	

* Evidence marked with an asterisk is based on data provided by this study and/or correlation of event with evidence from soil burial event reported by Kelsey et al. (2002:Table 7)

1 Ages marked with # are estimated based on correlation with events reported in Kelsey et al. (2002: Tables 4 and 5); ca. ages incorporate error range due to multiple intercepts on radiocarbon calibration curve; age for Event L estimated using bounding ages from radiocarbon dates acquired above and below Event L (see text)

Evidence for Rapid Subsidence

The sharp (<3mm) boundary recorded at all six lower SDs (G-L) indicates a rapid shift from a higher intertidal setting to a lower one (Table 2). If deposition of the overlying sediments had not been rapid, a more gradational boundary would have formed. SDs G, H, and I also exhibit diatom assemblages across these sharp boundaries from non-contiguous intertidal settings. Because diatoms that characterize intermediate intertidal settings are not abundant in these assemblages, we infer that very little time passed between deposition of diatom-associated sediments above and below the lithologic boundaries. In the case of SD I, however, the uneven nature of the boundary and the large grain size of the overlying sediment unit leaves open the possibility that a higher energy event eroded and removed sediments from the location before deposition resumed.

Evidence for Lasting Submergence

The litho- and biostratigraphic data imply a lasting, rather than ephemeral, shift in depositional setting from a higher to a lower intertidal zone for SDs G, H, I and K. Using estimates of marsh accretion rates by Kelsey et al. (2002:Figure 11), 10cm of sediment represents from 70 to 140 years. Because at least 10cm of intertidal mud overlies each buried event horizon, we infer that the change in RSL associated with each event was long-lasting. In the case of SD I, over 65cm of intertidal sands and muds (tidal flats or lower brackish marsh deposits) bury the high brackish marsh deposit. While some of this sediment is coarse-grained and probably indicates rapid deposition, at least 50cm of the overlying deposit is fine-grained silts and clays. Additionally, diatom assemblages from centimeters above SDs G, H, I, and K are all indicative of lower intertidal environments than assemblages from the underlying, buried units associated with each event (Figure 4, Appendix B). This implies a lasting change in environment from a higher to a lower intertidal zone. Such long-term submergence and subsequent sediment accretion argues against more short-term fluctuations in sea level and sediment deposition caused by unusually high tides, storm surges, or El Niño events (Nelson et al. 1996b; Witter et al. 2003).

It is difficult to determine whether the submergence associated with SD J was a long- or short-term episode. While at least 10cm of relatively inorganic, intertidal mud overlies the freshwater marsh material, the diatom samples extracted from this unit and from all sediments of the core section above this were barren of identifiable valves. Additionally, no radiocarbon dates were retrieved from the upper units. Unequivocal evidence, therefore, is lacking to determine the lasting nature of the subsidence. In the case of SD L, it is also difficult to determine the lasting nature of the change in depositional environment, as diatom preservation from overlying sediments is extremely poor. However, the lithology of the overlying sediments continues to be loamy for at least 20cm further upcore before gradually fining into a mud, implying a lasting change in depositional setting.

Lateral Extent of Buried Horizon

As stated above, SDs A-F are correlated with buried soils from throughout the abandoned marsh locality, an area ranging from 150,000m^3 to 220,000m^3. Of the older candidate events, only SDs G and H are correlated with other cores extracted from the same area. These core localities are spaced approximately 90m apart within the same region of the abandoned meander (Figure 1). While this does not rule out the possibility that the recorded burial events were caused by localized, rather than estuary-wide, sedimentation or hydrodynamic events, the spacing does imply wide-spread change. We are able to eliminate local-scale, river flooding events as the cause of the shift in depositional zones for all of the older SDs, G-L, because in each case the rapidly deposited overlying sediment contains higher relative percentages of marine or brackish fossil diatoms, not freshwater diatoms as would be the case if the sediment derived from upriver.

Amount of Coseismic Subsidence

The amount of submergence associated with each SD was estimated based on diatom assemblage analysis relative to intertidal zone elevation ranges from Nelson and Kashima (1993). The maximum amount of submergence associated with any of the lower six SDs is 3.2m (using diatom data from Core 6) and the minimum is $\geq$0 (Table 2). We infer that for each SD some amount of subsidence and relative sea level rise occurred because in each case the overlying diatom assemblage is distinctly different from the underlying assemblage, with a lower percentage of freshwater diatoms and a higher percentage of brackish or marine diatoms relative to the underlying unit.

Evidence for Tsunami Inundation

Based on our litho- and biostratigraphic investigations, evidence suggests that both SDs G and H were accompanied by tsunami inundation. Both SDs have sandy units overlying sharp stratigraphic boundaries (Table 2) and both of these sandy units contain a high proportion of epipsammic, tidal flat fossil diatoms (Appendix B). A bed of coarse to fine sand abruptly overlies a brackish marsh surface in the case of SD I, which implies a surge of sandy sediment concurrent with the sudden subsidence and rise in RSL. The diatom assemblage is characteristic of an intertidal flat or subtidal channel, which suggests an estuary or marine source for the deposit. However, other features of the sandy deposit are not consistent with tsunami deposition, including poor sorting of sediment and no evidence for upward fining.

The overlying unit of SD J is a sandy deposit with numerous planktonic diatoms associated. While the character of the diatom assemblage of the overlying unit could be indicative of standing water within a high marsh environment, the sudden nature of its burial and the sandy texture of the sediment in comparison with the underlying mud makes a moving source for the overlying unit more probable. We attribute the burial of the underlying unit of SD J to a surge of sandy water, such as a tsunami, accompanying sudden subsidence of the landscape.

The sandy nature of the overlying sediment associated with SD K could imply tsunami inundation, but the diatom assemblage includes no tidal flat, shallow subtidal channel, or brackish planktonic forms that would indicate a marine or estuary source of the sands.

Although the overlying loam associated with SD L is slightly sandier (42% sand versus 34% sand in the lower unit), the diatom assemblage is not indicative of a sandy tidal flat. However, the significant change in species' salinity preference and the intertidal nature of many of the valves from the underlying unit suggests that water from an estuary source abruptly buried the high marsh. This may indicate that sand was not available for deposition by a tsunami surge. Rather, diatoms living within tidal flats and on intertidal plants were carried in and deposited by a sudden influx of water, possibly due to tsunami activity.

Synchroneity of Submergence

Event chronologies from an estuary and a freshwater lake on the coast of Oregon (Witter et al. 2003; Kelsey et al. 2005) and from offshore turbidite localities on the continental shelf and slope (Goldfinger et al. 2003), provide age comparisons to the older events recorded in our cores from the lower Sixes River valley (Figure 8). The woody detritus extracted from the upper boundary of the underlying unit of SD G dates to Cal BP 6450 to 6300 (Table 1). While this date is older than any event recorded from within the Sixes River valley (Kelsey et al. 2002), it does overlap, within two standard deviations, the age range reported by Witter et al. (2003:Table 7) for the Coquille River valley (6200 to 6310 cal yr BP). It also falls within the range proposed by Kelsey et al. (2005:Table 4) for their Disturbance Event 16 (6510 to 6310 cal yr BP) from Bradley Lake, just 30km to the north of the Sixes River valley. Additionally, Goldfinger et al. (2003) also report a coseismic offshore turbidite deposit from the Juan de Fuca Channel that dates to this time period, from 6375 to 6507 cal yr BP.

The age ranges for SDs H and I, 6500 to 6690 and 6690 to 6890 cal yr BP, respectively (Table 1), are older than any event previously recorded at the Sixes River or in the Coquille River valley. No events reported from Bradley Lake (Kelsey et al. 2005) or from offshore turbidite studies (Goldfinger et al. 2003) appear to correlate with the dates for SDs H or I.

The AMS radiocarbon date on woody debris extracted from the lower freshwater marsh deposit underlying the sharp stratigraphic boundary of SD J resulted in an age of Cal BP 9440 to 9120 (Table 1). This age is older than any event recorded at an onshore site on the Pacific Northwest coast. It falls directly within the age range reported by Goldfinger et al.'s (2003) event 17 from within the Juan de Fuca channel, which dates from 9011 to 9755 cal yr BP and overlaps with ages on events 31 and 32 from the Noyo channel (8960-9131 and 8981-9749 cal yr BP, respectively).

A date of 9880 to 10190 cal yr BP (Table 1) was obtained on plant material from the underlying unit of burial SD K. This date falls within the age range returned on turbidite buried material from the Noyo Canyon, 9886 to 11098 cal yr BP (Goldfinger et al. 2003).

Not enough datable material was available from the stratigraphic horizons associated with SD L for AMS radiocarbon dating. However, if we use the age ranges from dates recovered above and below this event, a bounding age range BP for the event of >9880 to <10,220 cal yr can be proposed (Table 2). This age range correlates with dates from offshore turbidite-associated event 33 from Noyo Canyon, which is from 9886 to 11098 cal yr BP (Goldfinger et al. 2003).

Criteria Assessment

Of the six oldest burial events recorded in our cores from the lower Sixes River valley, one burial event, SD G, meets five of the criteria proposed by Nelson et al. (1996b) and Hemphill-Haley (1995b) for determining a coseismic origin (Table 4). SDs H, J, K, and L meet four of the criteria, while SD I meets only two of the criteria. We infer, based on the multiple lines of evidence presented in this paper, that SDs G, H, J, K, and L represent stratigraphic indicators of plate boundary earthquakes. SD I does not provide enough evidence to support a coseismic origin. While none of these burial events are correlated laterally throughout the abandoned meander locality, our initial attempts at correlation with sediment extracted from a distance of nearly 100m away (Core 6) were successful for SDs G and H. Unfortunately, we were unable to extract deeper, older sediments at the Core 6 location, so correlation of SDs I, J, K, and L was not possible.

Based on comparison of our radiocarbon age estimates for SDs B, G, H, J, K, and L with events recorded at marsh and lake localities inland, and with offshore turbidite events, we contend that SDs G, H, J, K, and possibly L represent evidence for rupture along much of the length of the CSZ (Figure 8). Correlation of SDs G and H with events seen at Bradley Lake and the Coquille River of coastal Oregon, as well as events recorded in the Juan de Fuca canyon off the coast of northern Washington and southern British Columbia, implies a rupture length of up to 400km for these events. This contention relies upon the assumption that these records are of a single event rather than multiple events at intervals too closely spaced in time to be differentiated by AMS radiocarbon dating . SDs J, K, and L potentially record plate rupture along the length of the fault zone from northern California or southern Oregon up to northern Washington, again assuming a single event. SD B supports the argument put forth by Kelsey et al. (2002) and Witter et al. (2003) that an earthquake rupturing only a portion of the subduction zone affected regions around the Coquille and Sixes rivers around 2200-2300 cal yr BP.

Intervals of Time Between Events

Calculation of average recurrence intervals for a study site requires a continuous stratigraphic record of coseismic subsidence. The record of deposition acquired through this study does not provide sufficient downcore resolution for recurrence interval determination. At onshore estuaries and marshes along the Northwest Coast, the early Holocene is most

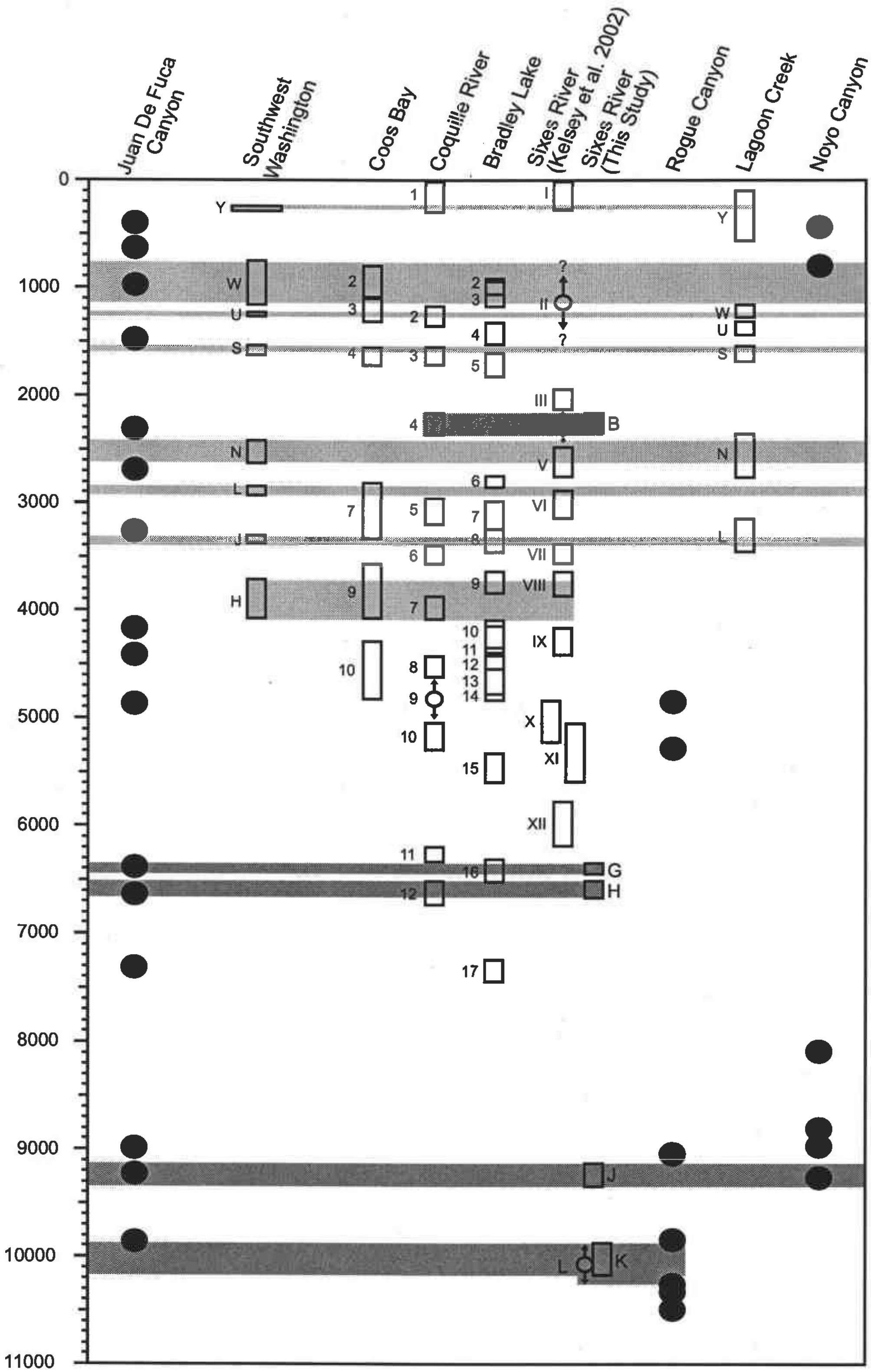


Figure 8. Comparison of radiocarbon age estimates for Cascadia subduction zone earthquakes reported in this study for the lower Sixes River valley with earthquake age estimates from onshore and offshore study sites. Southwestern Washington (Atwater and Hemphill-Haley 1997; Atwater, unpublished data); Coos Bay (Nelson et al. 1996a, 1998); Coquille River (Witter et al. 2003); Bradley Lake (Kelsey et al. 2005); Sixes River (Kelsey et al. 1998, 2002); Lagoon Creek (Abramson 1998; Garrison-Laney 1998); Juan de Fuca, Rogue, and Noyo Canyons (Goldfinger et al. 2001)

often represented in the depositional record by fluvial sediments (Glenn 1978; Peterson et al. 1984; Peterson and Phipps 1992; Peterson and Darienzo 1996; Byram and Witter 2000). These fluvial sediments are poor recorders of sudden land level change relative to sea level, because they show no significant change in diatom assemblage character if relative sea level change is insufficient to cause a change from freshwater conditions. Our Core 4 does contain a dominantly freshwater facies dating from approximately 9000 to 7000 cal yr BP (Figure 4) and during this time no subsidence events are recorded. However, unlike other estuaries along the Northwest Coast, intertidal wetland sediments are preserved in the lower sections of our core, dating to the late Pleistocene/early Holocene. These sediments have the potential to, and indeed do, record sudden changes in land level relative to sea level on a timescale comparable to offshore turbidite records, thousands of years older than other early onshore records.

Conclusion

The lower Sixes River valley preserves over 10,000 years of intertidal wetland deposits capable of recording stratigraphic signatures of subsidence that meet multiple criteria for determining a coseismic origin. Litho- and biostratigraphic evidence of six Cascadia subduction zone earthquakes younger than 4,000 cal yr BP is recorded in a long sediment core extracted from an abandoned meander within the river valley. All six of these events correlate with events previously reported by Kelsey et al. (2002).

At least five plate boundary earthquakes lowered tidal marshes and freshwater wetlands into the lower intertidal zone prior to 6,000 cal yr BP. Each of these subsidence episodes resulted in a stratigraphic record meeting at least four of the six criteria for determining coseismic subsidence, including the following evidence: rapid, lasting relative sea level rise; fossil diatom assemblage changes over lithologic boundaries indicating as much as 3.2m of subsidence; tsunami deposition concurrent with submergence and soil burial; and similarity in age to other earthquake events reported along the Cascadia subduction zone. Future study in the lower Sixes River valley involving the extraction, analysis, and dating of deep sediment cores from localities hundreds of meters apart will provide evidence pertaining to the lateral extent of buried soils.

Comparison of the earthquake record presented here with earthquake records from other onshore and offshore records of Cascadia earthquakes indicates that, like the AD1700 Cascadia earthquake that affected the entire plate boundary from northern California to southern British Columbia, some older earthquakes impacted the length of the margin. Although the record of deposition acquired through this study does not provide the continuous stratigraphic evidence required to determine recurrence interval patterning, this study proves the site's ability to record stratigraphic evidence of coseismic subsidence as early as the late Pleistocene.

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CHAPTER 5: CONCLUSION

This dissertation reconstructed the paleoenvironmental context of the southern Oregon coast within which humans would have lived thousands of years ago. These coastal landscapes have evolved as a result of regional and local tectonic and geomorphic forces operating at variable timescales. Detailed analysis of litho- bio- and chronostratigraphic indicators from river terrace sediments and subsurface cores allows for inferences regarding the geomorphic and tectonic alteration of the landscape to be made. Additionally, a better understanding of landscape change through time within a dynamic, actively evolving coastal river valley setting aids in the evaluation of preservation potential of early Holocene landforms and the archaeological deposits they may contain.

Our research at study sites along the southern Oregon coast examined how certain modes of upper plate deformation can influence fluvial systems to preserve, obscure, or destroy late Pleistocene-age deposits during post-glacial marine transgression. Through this work, we showed that the differential preservation of late Pleistocene-age terrestrial deposits in Oregon's coastal landscape, and the early cultural sites they may contain, is not random but can be closely related to larger tectonogeomorphic processes operating at local and regional scales throughout the Quaternary time period.

Litho-,bio-, and chronostratigraphic investigations on a long core recovered from the lower Sixes River valley revealed the depositional evolution of a marine-riverine interface through time. Detailed diatom assemblage analysis coupled with lithostratigraphic investigations of grain size, magnetic susceptibility, and gamma density were used to infer patterns of fluctuating depositional energies, sediment sources, and intertidal settings since the late Pleistocene. These patterns, or depositional facies sequences, aided in the reconstruction of depositional environment at the site through time. The depositional environment reconstruction for the lower Sixes River site indicates a transgressive evolution from the late Pleistocene to the present that differs from models of transgressive coastal facies as well as studied estuarine life histories from other locations along the Northwest Coast. Factors such as eustatic sea level rise, regional and local tectonic alteration of the landscape, sediment supply, or valley morphology may have played roles in the creation and preservation of this atypical depositional history.

Litho- and biostratigraphic evidence of six Cascadia subduction zone earthquakes younger than 6200 cal yr BP is recorded in a long sediment core extracted from the lower

Sixes River valley study site. All six of these events correlate with earthquake events previously reported by Kelsey et al. (2002). At least five plate boundary earthquakes lowered tidal marshes and freshwater wetlands into the lower intertidal zone prior to 6200 cal yr BP. Each of these subsidence episodes resulted in a stratigraphic record meeting at least four of the six criteria for determining coseismic subsidence (Nelson et al. 1996). Comparison of the earthquake record presented here with earthquake records from other onshore and offshore records of Cascadia earthquakes indicates that, like the AD1700 Cascadia earthquake that affected the entire plate boundary from northern California to southern British Columbia, some older earthquakes impacted the length of the margin. Although the record of deposition acquired through this study does not provide the continuous stratigraphic evidence required to determine recurrence interval patterning, this study proves the site's ability to record stratigraphic evidence of coseismic subsidence as early as the late Pleistocene.

Taken together, these pictures of depositional environment evolution within a setting of local and regional tectonic alteration of the landscape, eustatic sea level change, and variable sedimentation activities depict a complex, dynamically changing environmental context. Importantly, the lower Sixes River valley provides a record of earliest Holocene environmental setting that differs significantly from other similarly dated Northwest coastal sedimentary records. The presence of an intertidal brackish/estuarine depositional facies below a freshwater facies in the lowest, oldest portion of the sedimentary record at the Sixes River study site is inconsistent with models and case studies of post-glacial transgressive estuary development. The implication of this fact for earthquake studies is pivotal—such an environment is conducive to recording stratigraphic evidence of sudden landscape changes consistent with coseismically-originated subsidence. Such an estuarine environment capable of recording Cascadia subduction zone earthquakes dating to the late Pleistocene and early Holocene has not been found anywhere else on the Northwest coast.

Additionally, the presence of a highly productive estuarine setting this far inland has important implications for archaeological research on the Northwest coast. If humans were inhabiting the Oregon coast 10,000 years ago and occupying estuarine settings (as is implied by archaeological and ethnographic data), in most cases those estuaries would have been oceanward of today's coastline because of lowered global sea levels. As sea level rose during the Holocene, evidence of humans occupying these estuarine settings would have been inundated and/or destroyed, making this evidence unavailable for study by archaeologists today. However, the Sixes River study site is three kilometers inland of today's coastline. The evidence presented in this dissertation indicates that if humans had utilized this estuary setting during the early Holocene, evidence of their landscape occupation may be preserved onshore. Further investigation into the lateral extent and relative depth of this early estuarine facies throughout the lower Sixes River valley basin may reveal its existence at shallower, more accessible locations.

Future Work

Additional cores recovered and analyzed from the same lower Sixes River basin would aid in the identification of variables affecting the estuary's depositional history, as well as lead to a better understanding of transgressive sedimentary facies development along active margins. Such efforts in paleoenvironmental reconstruction will help researchers to better understand the environmental setting that early human migrants along the Northwest Coast would have encountered. Additionally, further study in the lower Sixes River valley involving the extraction, analysis, and dating of deep sediment cores from localities hundreds of meters apart will provide evidence pertaining to the lateral extent of buried soils, an important measure for assessing the potential coseismic origin of a depositional facies shift.

A better understanding of the tectonogeomorphic setting of active margin coasts will allow archaeologists testing a coastal migration hypothesis to focus their efforts on landforms of the appropriate age on a subregional scale, such as the Oregon coast. Geoarchaeological study along the Northwest Coast, and in other New World areas with tectonically-active continental margins, must consider the cumulative effects of subduction zone tectonism, styles of upper plate deformation, and their geomorphic influence on coastal landscapes when attempting to understand the paleoenvironmental context within which humans would have lived since the late Pleistocene. Armed with these geoarchaeological perspectives, archaeologists will be able to focus their efforts on temporally-relevant landscape sections in a search for early coastal sites.

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APPENDICES

APPENDIX A: DIATOM COUNTS

Appendix A: Diatom Counts																																			
				Core 22			Core 21								Core20							Core 19							Core 18						
Genus	Species	Variety	**Salinity**	4	7	8	10	11	12	13	14	15	16	17	35	37	38	39	40	41	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Achnanthes	*coarctata*		F								1																								
Achnanthes	*suchlandtii*		F																																
Cymbella	*similis*		F																																
Cymbella	*tumidula*	*lancettula*	F																																
Diatoma	*anceps*		F								1																		1						
Eunotia	*flexuosa*		F																																
Eunotia	*incisa*		F																																
Eunotia	*maior*		F									1					1																		
Eunotia	*monodon*		F																																
Eunotia	*naegelii*		F																																
Eunotia	*parallela*		F																																
Eunotia	*pectinalis*		F	1													2		1										1		1				
Eunotia	*praerupta*	*bidens*	F	1																2										2					
Eunotia	*van heurckii*		F																																
Eunotia	*van heurckii*	*intermedia*	F																																
Eunotia	*valida*		F																																
Eunotia	*spp.*		F														2		1	1			1												
Fragilaria	*exigua*		F																																
Frustulia	*rhomboids*		F																																
Gomphonema	*truncatum*		F																																
Navicula	*digitulus*		F																																
Navicula	*leptostriata*		F																																
Navicula	*pupula*	*elliptica*	F																																
Nedium	*hercynicum*		F																												1				
Nedium	*iridis*	*iridis*	F																																
Nitzschia	*angustulata*		F																																
Opephora	*martyii*		F	1																															
Pinnularia	*acrosphaeria*		F			1																													
Pinnularia	*bogotensis*		F																																
Pinnularia	*divergentissima*		F																																
Pinnularia	*gibba*	*linearis*	F																1				1												
Pinnularia	*krockii*		F																																
Pinnularia	*maior*		F																																
Pinnularia	*microstauron*		F																																
Pinnularia	*nodosa*		F																																
Pinnularia	*stomataphora*		F																																
Pinnularia	*subcapitata*	*paucistriata*	F																																
Pinnularia	*subgibba*		F			2																													
Stauroneis	*phoenicenteron*	*brunii*	F																																
Stauroneis	*smithii*	*incisa*	F																																
Synedra	*rumpens*		F																1																
Total				3	0	3	0	0	0	0	2	1	0	0	0	0	5	0	4	3	0	0	2	0	0	0	0	0	2	2	2	0	0	0	0
% of Slide Total				2.6	0	2.7	0	0	0	0	14	10	0	0	0	0	29	0	14	6.3	0	0	6.1	0	0	0	0	0	14	3.6	10	0	0	0	0
Achnanthes	*hustedtii*		F/B	2																															
Achnanthes	*lanceolata*	*dubia*	F/B	1																										3					
Achnanthes	*lanceolata*	*ssp.*	F/B																																
Achnanthes	*lanceolata*	*lanceolata*	F/B	2		1								1																		1			
Achnanthes	*minutissima*		F/B																																
Amphora	*coffeiformis*		F/B																																
Amphora	*ovalis*		F/B																																
Amphora	*ovalis*	*affinis*	F/B																	1				1											
Amphora	*perpusilla*		F/B	1																															
Aulacosira	*granulata*		F/B			1	1	1			1	1																							
Aulacosira	*islandica*		F/B	1										1														1							

				Core 22			Core 21								Core20							Core 19							Core 18						
Genus	Species	Variety	**Salinity**	4	7	8	10	11	12	13	14	15	16	17	35	37	38	39	40	41	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Aulacosira	*italica*		F/B	1																															
Calonesis	*bacillum*		F/B			2																													
Cocconeis	*diminuta*		F/B									1								1					1					1			1		
Cocconeis	*placentula*		F/B	1		1																								2	1	2			
Cocconeis	*placentula*	*euglypta*	F/B	1						2				1		1	1	1	5	2	1	2	6	1			1	2		4	3	1	2	1	
Cyclotella	*meneghiniana*		F/B																																
Cyclotella	*compta*		F/B																																
Cyclotella	*ocellata*		F/B																																
Cyclotella	*stelligera*		F/B																																
Cymbella	*aspera*		F/B																																
Cymbella	*cistula*		F/B									1																							
Cymbella	*minuta*		F/B																											1					
Cymbella	*sinuata*		F/B															1	1				1							1					
Cymbella	*tumida*		F/B																																
Diatoma	*mesodon*		F/B			1													1																
Diploneis	*pseudovalis*		F/B																																
Epithemia	*sorex*		F/B															1					1						1						
Epithemia	*turgida*		F/B	1									2																						
Epithemia	*turgida*	*westermannii*	F/B														1	1	1	1										4	1	1		1	
Epithemia	*zebra*		F/B																				1											1	
Eunotia	*pectinalis*	*minor*	F/B																																
Fragilaria	*brevistriata*		F/B																				1												
Fragilaria	*capucina*	*vaucheriae*	F/B																															1	
Fragilaria	*construens*		F/B																																
Fragilaria	*construens*	*pumila*	F/B	1																															
Fragilaria	*construens*	*venter*	F/B			1																													
Fragilaria	*leptostauron*		F/B																																
Fragilaria	*parasitica*		F/B																																
Fragilaria	*pinnata*		F/B	1																															
Fragilaria	*virescens*		F/B																																
Frustulia	*vulgaris*		F/B																																
Gomphoneis	*herculeana*		F/B																																
Gomphonema	*acutiusculum*		F/B																																
Gomphonema	*angustatum*		F/B																																
Gomphonema	*gracile*		F/B																																
Gomphonema	*parvulum*		F/B			1												2												2				1	1
Hantzschia	*amphioxys*		F/B			1																								3					
Melosira	*roeseana*		F/B																1											1					
Meridion	*circulare*	*constricta*	F/B																												1				
Navicula	*accomoda*		F/B																																
Navicula	*cari*		F/B																																
Navicula	*contenta*		F/B	2										1					1																
Navicula	*cryptotenella*		F/B																																
Navicula	*elegans*		F/B																										1						
Navicula	*elginensis*		F/B																																
Navicula	*elginensis*	*cuneata*	F/B																																
Navicula	*gallica*	*perpusilla*	F/B											1					1			1											1		
Navicula	*lanceolata*		F/B																																
Navicula	*minima*		F/B																																
Navicula	*mutica*		F/B	29		15												2	1	1	1	1	4	1		1			1	9	1			1	
Navicula	*mutica*	*undulata*	F/B																				1												
Navicula	*muticoides*		F/B																																
Navicula	*placentula*		F/B																																
Navicula	*pupula*		F/B																	1															
Navicula	*pusilla*		F/B	3		21																								1					
Navicula	*pusilla*	*1*	F/B																								1								
Navicula	*radiosa*		F/B			1																													
Navicula	*stankovicii*		F/B																																
Navicula	*tenelloides*		F/B																																

				Core 22			Core 21								Core20							Core 19							Core 18						
Genus	Species	Variety	**Salinity**	4	7	8	10	11	12	13	14	15	16	17	35	37	38	39	40	41	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Navicula	*tripuctata*		F/B	1																															
Nitzschia	*brevissima*		F/B																																
Nitzschia	*capitellata*		F/B																																
Nitzschia	*commutata*		F/B																	2										1					
Nitzschia	*dissipata*		F/B			1																							1	1					
Nitzschia	*inconspicua*		F/B	1																1															
Nitzschia	*nana*		F/B				1																												
Nitzschia	*palea*		F/B	2																												1			
Nitzschia	*parvula*		F/B																																
Nitzschia	*pellucida*		F/B																																
Nitzschia	*perminuta*		F/B																																
Nitzschia	*pusilla*		F/B																																
Nitzschia	*scapelliformis*		F/B			2																								2					
Nitzschia	*terrestris*		F/B																			2													
Nitzschia	*trybilonella*		F/B																																
Pinnularia	*appendiculata*		F/B																																
Pinnularia	*borealis*		F/B											1	1						1	1	3							2					
Pinnularia	*intermedia*		F/B																																
Pinnularia	*lagerstedtii*		F/B	1		5																													
Pinnularia	*similiformis*		F/B	1							2														1										
Pinnularia	*subcapitata*		F/B																2	5										1					
Pinnularia	*viridis*		F/B																	3															
Pinnularia	*viridis*	*minor*	F/B			1																													
Rhoicosphenia	*curvata*		F/B																3	2			1	1					2	2					
Rhopalodia	*gibba*		F/B																																
Rhopalodia	*gibberula*		F/B																																
Stauroneis	*anceps*		F/B																	3													1		
Stauroneis	*kriegerii*		F/B												1																				
Stauroneis	*phoenicenteron*		F/B																													1			
Stephanodiscus	*astrea*		F/B																																
Surirella	*brebissonii*		F/B																																
Synedra	*ulna*		F/B			1	2		1	2	3	2	3	4	1		5	1	5	5		1	3	1					1	8	2				1
Tabellaria	*fenestrata*		F/B																																
Thalassiosira	*westflogii*		F/B	1																															
Total				54	0	56	4	1	1	4	6	5	5	10	3	1	7	9	22	28	3	8	22	5	2	1	2	3	7	49	9	7	5	6	2
% of Slide Total				47	0	50	80	50	50	100	43	50	63	91	75	25	41	75	76	58	60	50	67	63	40	33	20	75	50	89	45	58	45	67	50
Achnanthes	*brevipes*		B																																
Achnanthes	*brevipes*	*intermedia*	B								1									1															
Achnanthes	*exigua*		B																																
Achnanthes	*hauckina*		B	7		4																													
Achnanthes	*hauckina*	*rostrata*	B																																
Amphora	*mexicana*		B																																
Amphora	*ovalis*	*pediculus*	B																																
Calonesis	*westii*		B	1		1																													
Cocconeis	*disculus*		B					1																										1	
Cyclotella	*striata*		B																																
Denticula	*subtilis*		B																																
Diploneis	*didyma*		B																																
Diploneis	*interrupta*		B																								1								
Diploneis	*ovalis*		B																																
Frustulia	*linkei*		B																																
Gomphonema	*pseudexigum*		B																																
Gyrosigma	*balticum*		B																																
Gyrosigma	*eximium*		B									1																							
Mastogloia	*exigua*		B																																
Melosira	*nummuloides*		B																																
Navicula	*cincta*		B	10		5													1								1			1	3			1	
Navicula	*cryptolyra*		B																																

				Core 22			Core 21								Core20							Core 19							Core 18						
Genus	Species	Variety	**Salinity**	4	7	8	10	11	12	13	14	15	16	17	35	37	38	39	40	41	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Navicula	*peregrina*		B	1		2																													
Navicula	*pygmaea*		B	1																															
Navicula	*salinarum*		B																																
Nitzschia	*aerophila*		B																																
Nitzschia	*debilis*		B																																
Nitzschia	*fasciculata*		B																																
Nitzschia	*levidensis*		B																																
Nitzschia	*levidensis*	*victoriae*	B																																
Nitzschia	*littoralis*		B																																
Nitzschia	*longissima*		B																																
Nitzschia	*navicularis*		B																																
Nitzschia	*plana*		B																																
Nitzschia	*sigma*		B																																
Nitzschia	*vitrea*		B																																
Rhopalodia	*musculus*		B			1														1															
Synedra	*fasciculata*		B	2		4														2															
Synedra	*gaillonii*		B																																
Total				22	0	17	0	1	0	0	1	1	0	0	0	0	0	0	1	4	0	0	0	0	0	0	2	0	0	1	3	0	0	2	0
% of Slide Total				19	0	15	0	50	0	0	7.1	10	0	0	0	0	0	0	3.4	8.3	0	0	0	0	0	0	20	0	0	1.8	15	0	0	22	0
Achnanthes	*delicatula*		M/B																																
Actinocyclus	*spp.*		M/B																	1															
Actinoptychus	*senarius*		M/B																																
Amphora	*proteus*		M/B																											1					
Amphora	*ventricosa*		M/B																																
Bacillaria	*paradoxa*		M/B																																
Camplyodiscus	*echineis*		M/B																																
Catentula	*adherens*		M/B																																
Cerataulus	*turgidus*		M/B																																
Cocconeis	*scutellum*		M/B	3									1							8															
Cocconeis	*scutellum*	*parva*	M/B	1		1						1																							
Delphineis	*surirella*		M/B			7																													
Dimeregramma	*minor*		M/B	3	1																														
Diploneis	*smithii*		M/B																																
Grammatophora	*oceanica*		M/B																																
Gyrosigma	*spencerii*		M/B																																
Hantzschia	*virgata*		M/B																																
Hyalodiscus	*scoticus*		M/B																																
Melosira	*moniliformis*		M/B																																
Navicula	*digitoradiata*		M/B																																
Navicula	*granulata*		M/B																																
Navicula	*lyra*		M/B																																
Navicula	*lyra*	*elliptica*	M/B	1																															
Navicula	*perminuta*		M/B																											1					
Navicula	*phyllepta*		M/B																																
Navicula	*rhyncocephala*		M/B																																
Nitzschia	*acuminata*		M/B			1																													
Nitzschia	*bilobata*		M/B																																
Nitzschia	*compressa*		M/B								1																								
Nitzschia	*constricta*		M/B			1																					1								
Nitzschia	*granulata*		M/B			1																					1								
Nitzschia	*lanceola*		M/B																																
Nitzschia	*obtusa*		M/B	2																															
Nitzschia	*punctata*		M/B																																
Opephora	*pacifica*		M/B																																
Opephora	*parva*		M/B	6																															
Paralia	*sulcata*		M/B	4	1	7	1																				1								
Plagiogramma	*staurophorum*		M/B																																
Rhabdonema	*arcuatum*		M/B																																

				Core 22			Core 21								Core20							Core 19							Core 18						
Genus	Species	Variety	**Salinity**	4	7	8	10	11	12	13	14	15	16	17	35	37	38	39	40	41	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Rhaphoneis	*amphiceros*		M/B																																
Rhaphoneis	*psammicola*		M/B	1																															
Rhaphoneis	*surirella*		M/B			1																													
Scoliopleura	*tumida*		M/B																																
Surirella	*fastuosa*		M/B																																
Thalassiosira	*discepens*		M/B										1																						
Thalassiosira	*lacustris*		M/B								2																								
Total				21	2	19	1	0	0	0	3	1	2	0	0	0	0	0	0	9	0	0	0	0	0	0	3	0	0	2	0	0	0	0	0
% of Slide Total				18	100	17	20	0	0	0	21	10	25	0	0	0	0	0	0	19	0	0	0	0	0	0	30	0	0	3.6	0	0	0	0	0
Amphora	*angusta*		M																																
Amphora	*granulata*		M	1																															
Bidduluphia	*aurita*		M																																
Calonesis	*brevis*		M																																
Coscinodiscus	*radiatus*	*f. obscurus*	M																																
Cyclotella	*styrolum*		M																																
Diploneis	*smithii*	*rhombica*	M																1																
Endictya	*sp.1*		M																																
Nitzschia	*compressa*	*vexans*	M	1																															
Odontella	*obtusa*		M																																
Opephora	*marina*		M																																
Rhaphoneis	*margaritalimbata*		M																																
Thalassionema	*nitzschioides*		M																																
Thalassiosira	*eccentrica*		M																																
Thalassiosira	*pacifica*		M			1																													
Trachyneis	*aspera*		M																																
Trachysphenia	*australis*		M																																
Actinoptychus	*vulgaris*		M			1																													
Nitzschia	*coarctata*		M																																
Total				2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% of Slide Total				1.7	0	1.8	0	0	0	0	0	0	0	0	0	0	0	0	3.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Navicula	*capitata*		E	1																															
Navicula	*capitata*	*hungarica*	E																																
Navicula	*cryptocephala*		E	3		2																													
Tabellaria	*flocculosa*		E																																
Total				4	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% of Slide Total				3.5	0	1.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Achnanthes	*spp.*		Unknown																																
Amphora	*spp.*		Unknown								1																						1		
Calonesis	*spp.*		Unknown			1																													
Cocconeis	*klamathensis*		Unknown																																
Cocconeis	*spp.*		Unknown																		1	1	1								1			1	
Cyclotella	*caspia*		Unknown																																
Cyclotella	*spp.*		Unknown																																
Cymbella	*spp.*		Unknown			1							1																						
Diploneis	*spp.*		Unknown																			1			1	1									
Epithemia	*spp.*		Unknown			2					1	2		1			2					3	1	2					1	1	3	2	3		
Fragilaria	*spp.*		Unknown																																
Gomphonema	*bipunctum*		Unknown																																
Gomphonema	*spp.*		Unknown																			1													
Gyrosigma	*spp.*		Unknown																																
Hantzschia	*spp.*		Unknown																																
Mastogloia	*spp.*		Unknown																																
Melosira	*spp.*		Unknown																																
Navicula	*lapidosa*		Unknown																																
Navicula	*stroemii*		Unknown																																
Navicula	*sublucidula*		Unknown																																

				Core 22			Core 21								Core20							Core 19							Core 18						
Genus	Species	Variety	**Salinity**	4	7	8	10	11	12	13	14	15	16	17	35	37	38	39	40	41	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57
Navicula	*spp.*		Unknown															1					1				1								
Nedium	*spp.*		Unknown																																
Nitzschia	*palustris*		Unknown																																
Nitzschia	*spp.*		Unknown	8		5																1			1	1	2				1	2	1		
Pinnularia	*spp.*		Unknown																1	1			2						1						
Pleurosigma	*spp.*		Unknown																																
Rhopalodia	*spp.*		Unknown																																
Stauroneis	*spp.*		Unknown															4		3															
Surirella	*spp.*		Unknown																																
Synedra	*spp.*		Unknown	1											1	3	3	2			1	1	4	1	1			1	3		1	1	1		2
Tabellaria	*spp.*		Unknown						1																										
Thalassiosira	*spp.*		Unknown			3																													
Total				9	0	12	0	0	1	0	2	2	1	1	1	3	5	7	1	4	2	8	9	3	3	2	3	1	5	1	6	5	6	1	2
% of Slide Total				7.8	0	11	0	0	50	0	14	20	13	9.1	25	75	29	58	3.4	8.3	40	50	27	38	60	67	30	25	36	1.8	30	42	55	11	50
Total # of valves counted on slide				115	2	111	5	2	2	4	14	10	8	11	4	4	17	12	29	48	5	16	33	8	5	3	10	4	14	55	20	12	11	9	4

Appendix A: Diatom Counts

Genus	Species	Variety	Salinity	59	63	64	65	66	67	68	70	71	72	73	77	78	87	106	107	108	109	110	111	112	113	115	116	117	118	119	120	121	122	125
				C17		Core 16					Core 15						C13	Core7		Core 8						Core 7								Core6
Achnanthes	*coarctata*		F																															
Achnanthes	*suchlandtii*		F																														1	
Cymbella	*similis*		F																			1												
Cymbella	*tumidula*	*lancettula*	F																															
Diatoma	*anceps*		F					1																										
Eunotia	*flexuosa*		F																					1									1	
Eunotia	*incisa*		F														2																	
Eunotia	*maior*		F																					1										
Eunotia	*monodon*		F		1											1								2										
Eunotia	*naegelii*		F																															
Eunotia	*parallela*		F																															
Eunotia	*pectinalis*		F														1										1				1			
Eunotia	*praerupta*	*bidens*	F																		1													
Eunotia	*van heurckii*		F																															
Eunotia	*van heurckii*	*intermedia*	F																1															
Eunotia	*valida*		F																															
Eunotia	*spp.*		F				1	1								2					2								1		1			
Fragilaria	*exigua*		F																															
Frustulia	*rhomboids*		F																					1										
Gomphonema	*truncatum*		F																															
Navicula	*digitulus*		F													1															2			
Navicula	*leptostriata*		F																												3		1	
Navicula	*pupula*	*elliptica*	F																															
Nedium	*hercynicum*		F																															
Nedium	*iridis*	*iridis*	F																															
Nitzschia	*angustulata*		F																			1						1						
Opephora	*martyii*		F																															
Pinnularia	*acrosphaeria*		F																												1			
Pinnularia	*bogotensis*		F																															
Pinnularia	*divergentissima*		F																															
Pinnularia	*gibba*	*linearis*	F																					1							1			
Pinnularia	*krockii*		F																												2			
Pinnularia	*maior*		F																															
Pinnularia	*microstauron*		F													1																		
Pinnularia	*nodosa*		F																															
Pinnularia	*stomataphora*		F														1																	
Pinnularia	*subcapitata*	*paucistriata*	F																															
Pinnularia	*subgibba*		F																			1												
Stauroneis	*phoenicenteron*	*brunii*	F																															
Stauroneis	*smithii*	*incisa*	F																														1	
Synedra	*rumpens*		F															1																
Total				0	1	0	1	2	0	0	0	0	0	0	0	5	4	1	1	0	3	3	0	6	0	0	1	1	1	0	11	0	4	0
% of Slide Total				0	10	0	2.1	4.8	0	0	0	0	0	0	0	6	4.4	3.8	0.8	0	2.5	1.6	0	5.7	0	0	0.6	0.6	0.7	0	7.5	0	3.4	0
Achnanthes	*hustedtii*		F/B																														1	
Achnanthes	*lanceolata*	*dubia*	F/B																												2		1	
Achnanthes	*lanceolata*	*ssp.*	F/B													1																		
Achnanthes	*lanceolata*	*lanceolata*	F/B				2	2													4	1	1	3				3		3	15	11	6	
Achnanthes	*minutissima*		F/B																							2	5	3				8	4	
Amphora	*coffeiformis*		F/B																											3		1		
Amphora	*ovalis*		F/B																															
Amphora	*ovalis*	*affinis*	F/B					1																								1		
Amphora	*perpusilla*		F/B																															
Aulacosira	*granulata*		F/B													10	4				2													
Aulacosira	*islandica*		F/B													17	32																	

				C17		Core 16					Core 15						C13	Core7		Core 8						Core 7								Core6
Genus	Species	Variety	**Salinity**	59	63	64	65	66	67	68	70	71	72	73	77	78	87	106	107	108	109	110	111	112	113	115	116	117	118	119	120	121	122	125
Aulacosira	*italica*		F/B													5																	1	
Calonesis	*bacillum*		F/B																		2	4	3	1	5	1	12							
Cocconeis	*diminuta*		F/B				2										2		1	1	1	1										1	1	
Cocconeis	*placentula*		F/B			1	1	4	1														3	1		1					3	1	4	1
Cocconeis	*placentula*	*euglypta*	F/B			3	3	6										2		1	5	2					1			3	4	2	5	
Cyclotella	*meneghiniana*		F/B																															
Cyclotella	*compta*		F/B													1																		
Cyclotella	*ocellata*		F/B																															
Cyclotella	*stelligera*		F/B													3																		
Cymbella	*aspera*		F/B																															
Cymbella	*cistula*		F/B																															
Cymbella	*minuta*		F/B					1																							1			
Cymbella	*sinuata*		F/B				3	6			1								1		2						2				2		1	
Cymbella	*tumida*		F/B																															
Diatoma	*mesodon*		F/B					1															1	1							3		1	
Diploneis	*pseudovalis*		F/B																		1	2	6											1
Epithemia	*sorex*		F/B				3														1			1							2			
Epithemia	*turgida*		F/B															2			2	1		3								1		
Epithemia	*turgida*	*westermannii*	F/B				2	1	1											3	6		1	2						1	4	1		1
Epithemia	*zebra*		F/B																		1		1											
Eunotia	*pectinalis*	*minor*	F/B																															
Fragilaria	*brevistriata*		F/B													1	4																	
Fragilaria	*capucina*	*vaucheriae*	F/B																															
Fragilaria	*construens*		F/B														3																	
Fragilaria	*construens*	*pumila*	F/B													3	3																	
Fragilaria	*construens*	*venter*	F/B					1								1	6										1						1	
Fragilaria	*leptostauron*		F/B				1									1	3																	
Fragilaria	*parasitica*		F/B													3	5																	
Fragilaria	*pinnata*		F/B													1	3												1	2	1			
Fragilaria	*virescens*		F/B				1																	1										
Frustulia	*vulgaris*		F/B					1														2		1	2	4		1						
Gomphoneis	*herculeana*		F/B																												1			
Gomphonema	*acutiusculum*		F/B																															
Gomphonema	*angustatum*		F/B																															
Gomphonema	*gracile*		F/B																		1							2						
Gomphonema	*parvulum*		F/B		1		2	1													2			4				1	1		6	1	1	
Hantzschia	*amphioxys*		F/B															2			1		1											1
Melosira	*roeseana*		F/B					1								4													1					
Meridion	*circulare*	*constricta*	F/B																1														1	
Navicula	*accomoda*		F/B																													1		
Navicula	*cari*		F/B																										1	1				
Navicula	*contenta*		F/B		1	1	1										1		1		1				1	11	1						1	
Navicula	*cryptotenella*		F/B																											1	3		2	
Navicula	*elegans*		F/B															1	1						2						1			
Navicula	*elginensis*		F/B																	1														
Navicula	*elginensis*	*cuneata*	F/B													1													1					
Navicula	*gallica*	*perpusilla*	F/B																					1								1		
Navicula	*lanceolata*		F/B					1											1			1												
Navicula	*minima*		F/B													1										1					1			
Navicula	*mutica*		F/B		1	1		3	1		1						6		12	13	18	28	39	3	27	33	37	1	26		2	1	4	
Navicula	*mutica*	*undulata*	F/B																															
Navicula	*muticoides*		F/B																								5							
Navicula	*placentula*		F/B																															
Navicula	*pupula*		F/B				1																									1	1	
Navicula	*pusilla*		F/B															1	43	6	8	47	70	35	12	13	7		21		1		2	2
Navicula	*pusilla*	*1*	F/B																			1	5											
Navicula	*radiosa*		F/B																							1					1			
Navicula	*stankovicii*		F/B														1									3								
Navicula	*tenelloides*		F/B																												3			

				C17		Core 16					Core 15						C13	Core7		Core 8						Core 7								Core6
Genus	Species	Variety	**Salinity**	59	63	64	65	66	67	68	70	71	72	73	77	78	87	106	107	108	109	110	111	112	113	115	116	117	118	119	120	121	122	125
Navicula	*tripuctata*		F/B																												1	1		
Nitzschia	*brevissima*		F/B										1																					2
Nitzschia	*capitellata*		F/B																															
Nitzschia	*commutata*		F/B				1	1											1	7	1	1	1	1	4		2		3		2			
Nitzschia	*dissipata*		F/B																												1			
Nitzschia	*inconspicua*		F/B																	1						1	1				5			
Nitzschia	*nana*		F/B																1	2	9	6	5		10	7	3		1					
Nitzschia	*palea*		F/B				1									1				5		2	2		8	1			1		2	1		
Nitzschia	*parvula*		F/B																								1							
Nitzschia	*pellucida*		F/B				1									1				1					1	2	1				1		1	
Nitzschia	*perminuta*		F/B																											3				
Nitzschia	*pusilla*		F/B														1			1			3		3	1					2	2	4	
Nitzschia	*scapelliformis*		F/B																6	4		1	1		2		1	1						
Nitzschia	*terrestris*		F/B																										1					
Nitzschia	*trybilonella*		F/B																															
Pinnularia	*appendiculata*		F/B																												1			
Pinnularia	*borealis*		F/B					1			1							4			4			2										
Pinnularia	*intermedia*		F/B																										1	1		12		
Pinnularia	*lagerstedtii*		F/B															1	6			18	13	5	15	5			2			1	1	
Pinnularia	*similiformis*		F/B															1			5			1		1	1							1
Pinnularia	*subcapitata*		F/B																															
Pinnularia	*viridis*		F/B																								1						1	
Pinnularia	*viridis*	*minor*	F/B																															
Rhoicosphenia	*curvata*		F/B			2	8	1													3			3	2	1					11	1	8	1
Rhopalodia	*gibba*		F/B				2	2																							1	1		
Rhopalodia	*gibberula*		F/B																	3		1	1	1			1							
Stauroneis	*anceps*		F/B						1							2																		
Stauroneis	*kriegerii*		F/B																													1		
Stauroneis	*phoenicenteron*		F/B													1			1		1													
Stephanodiscus	*astrea*		F/B																										1					
Surirella	*brebissonii*		F/B																											1	1			
Synedra	*ulna*		F/B		4	1	6	3	1		3								1		3	2	1	2	1						4			
Tabellaria	*fenestrata*		F/B													5	5						2	4	1									
Thalassiosira	*westflogii*		F/B																															
Total				0	7	9	41	38	5	0	6	0	1	0	0	63	79	14	77	49	84	121	160	76	96	89	83	12	62	19	88	52	53	10
% of Slide Total				0	70	53	85	90	63	0	67	0	100	0	0	76	87	54	59	29	69	66	78	72	63	73	47	7.5	43	13	60	44	45	71.4
Achnanthes	*brevipes*		B																												1		1	
Achnanthes	*brevipes*	*intermedia*	B																1		2						3	1	1					
Achnanthes	*exigua*		B													2																		
Achnanthes	*hauckina*		B																11			3	2		3		1	5		2	1			
Achnanthes	*hauckina*	*rostrata*	B																									73	2	34	2	7	7	
Amphora	*mexicana*		B																															
Amphora	*ovalis*	*pediculus*	B				3																					1			1	1	1	
Calonesis	*westii*		B																1	8	1	3			1		3	1	2		1		1	
Cocconeis	*disculus*		B																3		1	2	4		1		2		1	1	5	1	7	
Cyclotella	*striata*		B													1												1					2	
Denticula	*subtilis*		B																			1											10	
Diploneis	*didyma*		B																									1						
Diploneis	*interrupta*		B				1												1	1														
Diploneis	*ovalis*		B																						1									
Frustulia	*linkei*		B																															
Gomphonema	*pseudexigum*		B																											2				
Gyrosigma	*balticum*		B																	8		1								2	1			
Gyrosigma	*eximium*		B																	6	3		1		15	10	14	2						
Mastogloia	*exigua*		B																								1					1		
Melosira	*nummuloides*		B																														1	
Navicula	*cincta*		B			2													6	10	3	14	14	10	17	8	3	1	3	5	8	14	3	
Navicula	*cryptolyra*		B																															

				C17		Core 16					Core 15						C13	Core7		Core 8						Core 7								Core6
Genus	Species	Variety	**Salinity**	59	63	64	65	66	67	68	70	71	72	73	77	78	87	106	107	108	109	110	111	112	113	115	116	117	118	119	120	121	122	125
Navicula	*peregrina*		B														1			2	1	1		1				1					1	
Navicula	*pygmaea*		B																							5	1					1		
Navicula	*salinarum*		B																													2		
Nitzschia	*aerophila*		B																						2									
Nitzschia	*debilis*		B																			1					4		1				1	
Nitzschia	*fasciculata*		B																				1		1									
Nitzschia	*levidensis*		B																										1					
Nitzschia	*levidensis*	*victoriae*	B																								1							
Nitzschia	*littoralis*		B																			1										1		
Nitzschia	*longissima*		B																															
Nitzschia	*navicularis*		B																	1														
Nitzschia	*plana*		B																															
Nitzschia	*sigma*		B																	24	3	8	1	2	1	1	5		2					
Nitzschia	*vitrea*		B																														1	
Rhopalodia	*musculus*		B																	6	3													
Synedra	*fasciculata*		B													1			4	5	1	2	6	1	4	3		1	1				1	
Synedra	*gaillonii*		B																															
Total				0	0	2	4	0	0	0	0	0	0	0	0	4	1	0	27	71	18	37	29	14	46	27	38	88	14	46	20	28	37	0
% of Slide Total				0	0	12	8.3	0	0	0	0	0	0	0	0	4.8	1.1	0	21	42	15	20	14	13	30	22	22	55	9.7	31	14	24	31	0
Achnanthes	*delicatula*		M/B																1		2	1				1	2		1	42	2	13	7	
Actinocyclus	*spp.*		M/B																															
Actinoptychus	*senarius*		M/B																															
Amphora	*proteus*		M/B																			1								1	1			
Amphora	*ventricosa*		M/B																1											2	1		1	
Bacillaria	*paradoxa*		M/B																															
Camplyodiscus	*echineis*		M/B																	2														
Catentula	*adherens*		M/B																									5						
Cerataulus	*turgidus*		M/B																									1						
Cocconeis	*scutellum*		M/B						1								1			3					1	1		2						
Cocconeis	*scutellum*	*parva*	M/B						1	1	1								1		4	5	1					1	1		1			
Delphineis	*surirella*		M/B																	22	1	1					13	7	28	1	1		2	
Dimeregramma	*minor*		M/B																4				7		1		2	3	4					
Diploneis	*smithii*		M/B				2																											
Grammatophora	*oceanica*		M/B																										1					
Gyrosigma	*spencerii*		M/B																													1		
Hantzschia	*virgata*		M/B																															
Hyalodiscus	*scoticus*		M/B																															
Melosira	*moniliformis*		M/B																															
Navicula	*digitoradiata*		M/B																	2	1										1			
Navicula	*granulata*		M/B																															
Navicula	*lyra*		M/B																															
Navicula	*lyra*	*elliptica*	M/B																															
Navicula	*perminuta*		M/B																															
Navicula	*phyllepta*		M/B																					3				1		1	9	3	1	
Navicula	*rhyncocephala*		M/B					2												1		1		2		2	3			1	1	6		
Nitzschia	*acuminata*		M/B																		2													
Nitzschia	*bilobata*		M/B																			1												
Nitzschia	*compressa*		M/B																	2		1					2							
Nitzschia	*constricta*		M/B																	1	1		1			2	7	2		1	4	1		
Nitzschia	*granulata*		M/B																6	11	2	2	1		2		3	2	3	3				
Nitzschia	*lanceola*		M/B																															
Nitzschia	*obtusa*		M/B																															
Nitzschia	*punctata*		M/B																															
Opephora	*pacifica*		M/B																						1									
Opephora	*parva*		M/B													1	2		1	1	4	5	3	2	2			9	6	8	2	8	3	
Paralia	*sulcata*		M/B														1		11	1		3			1		4	8	15	1			1	2
Plagiogramma	*staurophorum*		M/B																															
Rhabdonema	*arcuatum*		M/B																															

				C17		Core 16					Core 15						C13	Core7		Core 8						Core 7								Core6
Genus	Species	Variety	**Salinity**	59	63	64	65	66	67	68	70	71	72	73	77	78	87	106	107	108	109	110	111	112	113	115	116	117	118	119	120	121	122	125
Rhaphoneis	*amphiceros*		M/B																															
Rhaphoneis	*psammicola*		M/B																									4	2					
Rhaphoneis	*surirella*		M/B																								1							
Scoliopleura	*tumida*		M/B																															
Surirella	*fastuosa*		M/B																															
Thalassiosira	*discepens*		M/B																			1												
Thalassiosira	*lacustris*		M/B																															
Total				0	0	0	2	2	2	1	1	0	0	0	0	1	4	0	25	46	17	22	13	7	8	6	37	45	61	61	23	32	15	2
% of Slide Total				0	0	0	4.2	4.8	25	50	11	0	0	0	0	1.2	4.4	0	19	27	14	12	6.4	6.6	5.3	4.9	21	28	42	41	16	27	13	14.3
Amphora	*angusta*		M																															
Amphora	*granulata*		M																															
Bidduluphia	*aurita*		M																															
Calonesis	*brevis*		M																															
Coscinodiscus	*radiatus*	*f. obscurus*	M																															
Cyclotella	*styrolum*		M																															
Diploneis	*smithii*	*rhombica*	M																															
Endictya	*sp.1*		M																								1							
Nitzschia	*compressa*	*vexans*	M																								4		1					
Odontella	*obtusa*		M																									1						
Opephora	*marina*		M																											13				
Rhaphoneis	*margaritalimbata*		M																								2							
Thalassionema	*nitzschioides*		M																	1								1	2	2				
Thalassiosira	*eccentrica*		M																									1			1	1	1	
Thalassiosira	*pacifica*		M																	3			1				8	9	4	4	3	3	2	
Trachyneis	*aspera*		M																															
Trachysphenia	*australis*		M																															0
Actinoptychus	*vulgaris*		M																															
Nitzschia	*coarctata*		M																															
Total				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	1	0	0	0	15	12	7	19	4	4	3	0
% of Slide Total				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2.4	0	0	0.5	0	0	0	8.6	7.5	4.8	13	2.7	3.4	2.5	0
Navicula	*capitata*		E													1									1		1							
Navicula	*capitata*	*hungarica*	E																			1	1	1										
Navicula	*cryptocephala*		E													1	2		1					1				2					4	
Tabellaria	*flocculosa*		E																															
Total				0	0	0	0	0	0	0	0	0	0	0	0	2	2	0	1	0	0	1	1	2	1	0	1	2	0	0	0	0	4	0
% of Slide Total				0	0	0	0	0	0	0	0	0	0	0	0	2.4	2.2	0	0.8	0	0	0.5	0.5	1.9	0.7	0	0.6	1.3	0	0	0	0	3.4	0
Achnanthes	*spp.*		Unknown																															
Amphora	*spp.*		Unknown																															
Calonesis	*spp.*		Unknown																															
Cocconeis	*klamathensis*		Unknown																													1		
Cocconeis	*spp.*		Unknown			3																												
Cyclotella	*caspia*		Unknown																															
Cyclotella	*spp.*		Unknown																											1			1	
Cymbella	*spp.*		Unknown																														1	
Diploneis	*spp.*		Unknown																															
Epithemia	*spp.*		Unknown		1						1	1		2				4																2
Fragilaria	*spp.*		Unknown														1																	
Gomphonema	*biunctum*		Unknown			1																		1										
Gomphonema	*spp.*		Unknown													1																		
Gyrosigma	*spp.*		Unknown																						1									
Hantzschia	*spp.*		Unknown																															
Mastogloia	*spp.*		Unknown																															
Melosira	*spp.*		Unknown																															
Navicula	*lapidosa*		Unknown																															
Navicula	*stroemii*		Unknown																															
Navicula	*sublucidula*		Unknown																											1				

				C17		Core 16					Core 15						C13	Core7		Core 8						Core 7								Core6
Genus	Species	Variety	**Salinity**	59	63	64	65	66	67	68	70	71	72	73	77	78	87	106	107	108	109	110	111	112	113	115	116	117	118	119	120	121	122	125
Navicula	*spp.*		Unknown																															
Nedium	*spp.*		Unknown																															
Nitzschia	*palustris*		Unknown																															
Nitzschia	*spp.*		Unknown																															
Pinnularia	*spp.*		Unknown													5		2																
Pleurosigma	*spp.*		Unknown																															
Rhopalodia	*spp.*		Unknown																															
Stauroneis	*spp.*		Unknown																															
Surirella	*spp.*		Unknown																															
Synedra	*spp.*		Unknown	1		2			1	1	1	1			4	1		5																
Tabellaria	*spp.*		Unknown													1																		
Thalassiosira	*spp.*		Unknown		1																									1				
Total				1	2	6	0	0	1	1	2	2	0	2	4	8	1	11	0	0	0	0	0	1	1	0	0	0	0	3	0	1	2	2
% of Slide Total				100	20	35	0	0	13	50	22	100	0	100	100	9.6	1.1	42	0	0	0	0	0	0.9	0.7	0	0	0	0	2	0	0.9	1.7	14.3
Total # of valves counted on slide				1	10	17	48	42	8	2	9	2	1	2	4	83	91	26	131	170	122	184	204	106	152	122	175	160	145	148	146	117	118	14

Appendix A: Diatom Counts																						
				Core 5			Core 4		Core 3			Core 2									C 1	
Genus	Species	Variety	**Salinity**	126	127	128	129	130	131	132	28	27	26	25	24	23	22	21	20	19	18	TOTAL
Achnanthes	*coarctata*		F																			1
Achnanthes	*suchlandtii*		F																			1
Cymbella	*similis*		F																			1
Cymbella	*tumidula*	*lancettula*	F															1				0
Diatoma	*anceps*		F																			3
Eunotia	*flexuosa*		F					2	1		1										1	5
Eunotia	*incisa*		F																			2
Eunotia	*maior*		F			1					13			3							5	4
Eunotia	*monodon*		F								1	2		1		1						4
Eunotia	*naegelii*		F												1							0
Eunotia	*parallela*		F								1										1	0
Eunotia	*pectinalis*		F					11	1		15		1	1	3	66	15	21	16	14	34	21
Eunotia	*praerupta*	*bidens*	F								2		1	1								6
Eunotia	*van heurckii*		F													2						0
Eunotia	*van heurckii*	*intermedia*	F													5						1
Eunotia	*valida*		F																			0
Eunotia	*spp.*		F			2		5							9	12	2		1	1	2	20
Fragilaria	*exigua*		F										1									0
Frustulia	*rhomboids*		F																			1
Gomphonema	*truncatum*		F								1											0
Navicula	*digitulus*		F			1																4
Navicula	*leptostriata*		F																			4
Navicula	*pupula*	*elliptica*	F																			0
Nedium	*hercynicum*		F																			1
Nedium	*iridis*	*iridis*	F					1									1			1		1
Nitzschia	*angustulata*		F																			2
Opephora	*martyii*		F																			1
Pinnularia	*acrosphaeria*		F					1			6			1			1		1		1	3
Pinnularia	*bogotensis*		F																			0
Pinnularia	*divergentissima*		F								1											0
Pinnularia	*gibba*	*linearis*	F					4			2								1			8
Pinnularia	*krockii*		F					1	1													4
Pinnularia	*maior*		F								3											0
Pinnularia	*microstauron*		F																			1
Pinnularia	*nodosa*		F					1			2		1				1			2	3	1
Pinnularia	*stomataphora*		F					1								2						2
Pinnularia	*subcapitata*	*paucistriata*	F							1			3									1
Pinnularia	*subgibba*		F																			3
Stauroneis	*phoenicenteron*	*brunii*	F								1											0
Stauroneis	*smithii*	*incisa*	F														1		1			1
Synedra	*rumpens*		F										1						1			2
Total				0	0	4	0	27	3	1	49	2	8	7	13	88	21	22	21	18	47	
% of Slide Total				0	0	7.5	0	20	2.3	5.6	37	67	6.3	30	12	73	15	18	19	17	43	
Achnanthes	*hustedtii*		F/B					4	4		1		1		1		8	2	5	2		11
Achnanthes	*lanceolata*	*dubia*	F/B												2	1		2	2			7
Achnanthes	*lanceolata*	*ssp.*	F/B																			1
Achnanthes	*lanceolata*	*lanceolata*	F/B					12	2		1				4		6	2	6	2		70
Achnanthes	*minutissima*		F/B																			22
Amphora	*coffeiformis*		F/B																			4
Amphora	*ovalis*		F/B								2											0
Amphora	*ovalis*	*affinis*	F/B														2					4
Amphora	*perpusilla*		F/B																			1
Aulacosira	*granulata*		F/B					5														26
Aulacosira	*islandica*		F/B					2			7											54

				Core 5			Core 4		Core 3			Core 2									C 1	
Genus	Species	Variety	**Salinity**	126	127	128	129	130	131	132	28	27	26	25	24	23	22	21	20	19	18	TOTAL
Aulacosira	*italica*		F/B																			7
Calonesis	*bacillum*		F/B		2		1	1	6	1												41
Cocconeis	*diminuta*		F/B						1													16
Cocconeis	*placentula*		F/B		1										1		2	6				29
Cocconeis	*placentula*	*euglypta*	F/B							1	1		1	1			2				1	76
Cyclotella	*meneghiniana*		F/B																			0
Cyclotella	*compta*		F/B																			1
Cyclotella	*ocellata*		F/B																			0
Cyclotella	*stelligera*		F/B																			3
Cymbella	*aspera*		F/B														2	1			1	0
Cymbella	*cistula*		F/B																		1	1
Cymbella	*minuta*		F/B		1			2				1	1		1	1					2	6
Cymbella	*sinuata*		F/B														1		1			22
Cymbella	*tumida*		F/B																			0
Diatoma	*mesodon*		F/B												1		2		1			9
Diploneis	*pseudovalis*		F/B						2				1									12
Epithemia	*sorex*		F/B	1														1				11
Epithemia	*turgida*		F/B							2				5								14
Epithemia	*turgida*	*westermannii*	F/B		1		4			2			1	3								41
Epithemia	*zebra*		F/B					1		1							1		1			6
Eunotia	*pectinalis*	*minor*	F/B													3						0
Fragilaria	*brevistriata*		F/B																			6
Fragilaria	*capucina*	*vaucheriae*	F/B																			1
Fragilaria	*construens*		F/B														1					3
Fragilaria	*construens*	*pumila*	F/B										1		1		1		1			7
Fragilaria	*construens*	*venter*	F/B						1				6		1	1	1		1	1		12
Fragilaria	*leptostauron*		F/B																			5
Fragilaria	*parasitica*		F/B										1							2		8
Fragilaria	*pinnata*		F/B																			9
Fragilaria	*virescens*		F/B																			2
Frustulia	*vulgaris*		F/B					1	1													13
Gomphoneis	*herculeana*		F/B			1																2
Gomphonema	*acutiusculum*		F/B													2		1				0
Gomphonema	*angustatum*		F/B					10		1	8				6	1	2	4	10	1	7	11
Gomphonema	*gracile*		F/B					4			2					1	3	2	1	2	3	7
Gomphonema	*parvulum*		F/B					28	4		19		2		18	13	36	35	22	35	7	59
Hantzschia	*amphioxys*		F/B											2								9
Melosira	*roeseana*		F/B																			8
Meridion	*circulare*	*constricta*	F/B																			3
Navicula	*accomoda*		F/B																			1
Navicula	*cari*		F/B																			2
Navicula	*contenta*		F/B														6	2	3	2	3	24
Navicula	*cryptotenella*		F/B	1																		7
Navicula	*elegans*		F/B		9		1		3					1								19
Navicula	*elginensis*		F/B																			1
Navicula	*elginensis*	*cuneata*	F/B								1				2	1				1		2
Navicula	*gallica*	*perpusilla*	F/B														1		2	1		6
Navicula	*lanceolata*		F/B																			3
Navicula	*minima*		F/B										4							1		3
Navicula	*mutica*		F/B		10	3	2	1	5				8				1	2				346
Navicula	*mutica*	*undulata*	F/B																			1
Navicula	*muticoides*		F/B				1															6
Navicula	*placentula*		F/B															1		2		0
Navicula	*pupula*		F/B					2							1			1	1	1		6
Navicula	*pusilla*		F/B		50	17	15	2	28	3			10		1							408
Navicula	*pusilla*	*1*	F/B						1													8
Navicula	*radiosa*		F/B																			3
Navicula	*stankovicii*		F/B																			4
Navicula	*tenelloides*		F/B																			3

				Core 5			Core 4		Core 3			Core 2									C 1	
Genus	Species	Variety	**Salinity**	126	127	128	129	130	131	132	28	27	26	25	24	23	22	21	20	19	18	TOTAL
Navicula	*tripuctata*		F/B																			3
Nitzschia	*brevissima*		F/B		4																	7
Nitzschia	*capitellata*		F/B										1		1							0
Nitzschia	*commutata*		F/B																			28
Nitzschia	*dissipata*		F/B																			4
Nitzschia	*inconspicua*		F/B																			10
Nitzschia	*nana*		F/B			1											1					46
Nitzschia	*palea*		F/B								1		3		1		1		1	3		27
Nitzschia	*parvula*		F/B																			1
Nitzschia	*pellucida*		F/B																			9
Nitzschia	*perminuta*		F/B																			3
Nitzschia	*pusilla*		F/B														1					17
Nitzschia	*scapelliformis*		F/B																			20
Nitzschia	*terrestris*		F/B					2									2				1	5
Nitzschia	*trybilonella*		F/B																			0
Pinnularia	*appendiculata*		F/B																			1
Pinnularia	*borealis*		F/B				1						1									22
Pinnularia	*intermedia*		F/B								1									1		14
Pinnularia	*lagerstedtii*		F/B		21	6	1	2	3	1			30		1							107
Pinnularia	*similiformis*		F/B		1			1			1					2	2		1	4	1	16
Pinnularia	*subcapitata*		F/B					1			8						7					9
Pinnularia	*viridis*		F/B		1			8			13			1	5	2	2					14
Pinnularia	*viridis*	*minor*	F/B		1			3			3					1		3			4	5
Rhoicosphenia	*curvata*		F/B		1	3				2					2		1		3	1		58
Rhopalodia	*gibba*		F/B														1					6
Rhopalodia	*gibberula*		F/B						1													8
Stauroneis	*anceps*		F/B																			7
Stauroneis	*kriegerii*		F/B					1			3		6		2	2	2			1		3
Stauroneis	*phoenicenteron*		F/B					1			2						2			1	1	5
Stephanodiscus	*astrea*		F/B																			1
Surirella	*brebissonii*		F/B																			2
Synedra	*ulna*		F/B										3									84
Tabellaria	*fenestrata*		F/B			1												1	1	1		18
Thalassiosira	*westflogii*		F/B																			1
Total				2	103	32	26	94	62	14	74	1	81	13	52	31	100	66	63	65	32	
% of Slide Total				50	82	60	81	70	47	78	56	33	64	57	50	26	70	54	57	60	29	
Achnanthes	*brevipes*		B																			2
Achnanthes	*brevipes*	*intermedia*	B					1														11
Achnanthes	*exigua*		B																			2
Achnanthes	*hauckina*		B					2	1				13		12		10	15	11	12	2	42
Achnanthes	*hauckina*	*rostrata*	B																			125
Amphora	*mexicana*		B																		1	0
Amphora	*ovalis*	*pediculus*	B																	1		7
Calonesis	*westii*		B					2	2		2											28
Cocconeis	*disculus*		B			1			1													32
Cyclotella	*striata*		B			1																5
Denticula	*subtilis*		B																			11
Diploneis	*didyma*		B																			1
Diploneis	*interrupta*		B						3													7
Diploneis	*ovalis*		B						8													9
Frustulia	*linkei*		B																			0
Gomphonema	*pseudexigum*		B																			2
Gyrosigma	*balticum*		B																			12
Gyrosigma	*eximium*		B																			52
Mastogloia	*exigua*		B																			2
Melosira	*nummuloides*		B																			1
Navicula	*cincta*		B		3				2		1										1	148
Navicula	*cryptolyra*		B																			0

				Core 5			Core 4		Core 3			Core 2									C 1	
Genus	Species	Variety	**Salinity**	126	127	128	129	130	131	132	28	27	26	25	24	23	22	21	20	19	18	TOTAL
Navicula	*peregrina*		B					1					5				1	4	3	5	1	12
Navicula	*pygmaea*		B																			8
Navicula	*salinarum*		B																			2
Nitzschia	*aerophila*		B																			2
Nitzschia	*debilis*		B																			7
Nitzschia	*fasciculata*		B																			2
Nitzschia	*levidensis*		B																			1
Nitzschia	*levidensis*	*victoriae*	B																			1
Nitzschia	*littoralis*		B																			2
Nitzschia	*longissima*		B																			0
Nitzschia	*navicularis*		B																			1
Nitzschia	*plana*		B																			0
Nitzschia	*sigma*		B						3													50
Nitzschia	*vitrea*		B																			1
Rhopalodia	*musculus*		B						1				2									12
Synedra	*fasciculata*		B				1		2				1									41
Synedra	*gaillonii*		B																			0
Total				0	3	2	1	6	23	0	3	0	21	0	12	0	11	19	14	18	5	
% of Slide Total				0	2.4	3.8	3.1	4.4	18	0	2.3	0	17	0	11	0	7.7	16	13	17	4.5	
Achnanthes	*delicatula*		M/B	1																		73
Actinocyclus	*spp.*		M/B																			1
Actinoptychus	*senarius*		M/B						3													3
Amphora	*proteus*		M/B																			4
Amphora	*ventricosa*		M/B						1													6
Bacillaria	*paradoxa*		M/B																			0
Camplyodiscus	*echineis*		M/B																			2
Catentula	*adherens*		M/B																			5
Cerataulus	*turgidus*		M/B																			1
Cocconeis	*scutellum*		M/B																			21
Cocconeis	*scutellum*	*parva*	M/B																			20
Delphineis	*surirella*		M/B		1				4													88
Dimeregramma	*minor*		M/B																			25
Diploneis	*smithii*		M/B																			2
Grammatophora	*oceanica*		M/B																			1
Gyrosigma	*spenceri*		M/B																			1
Hantzschia	*virgata*		M/B		1								1				1					1
Hyalodiscus	*scoticus*		M/B																			0
Melosira	*moniliformis*		M/B																			0
Navicula	*digitoradiata*		M/B										2		1							4
Navicula	*granulata*		M/B																			0
Navicula	*lyra*		M/B																			0
Navicula	*lyra*	*elliptica*	M/B																			1
Navicula	*perminuta*		M/B																			1
Navicula	*phyllepta*		M/B																			18
Navicula	*rhyncocephala*		M/B						3								4					22
Nitzschia	*acuminata*		M/B																			3
Nitzschia	*bilobata*		M/B																			1
Nitzschia	*compressa*		M/B																			6
Nitzschia	*constricta*		M/B																	1		22
Nitzschia	*granulata*		M/B		1	1	1	1	2													43
Nitzschia	*lanceola*		M/B																			0
Nitzschia	*obtusa*		M/B																			2
Nitzschia	*punctata*		M/B																			0
Opephora	*pacifica*		M/B																			1
Opephora	*parva*		M/B																			63
Paralia	*sulcata*		M/B		16	13	3	7	24	3	5											128
Plagiogramma	*staurophorum*		M/B																			0
Rhabdonema	*arcuatum*		M/B																			0

				Core 5			Core 4		Core 3			Core 2									C 1	
Genus	Species	Variety	**Salinity**	126	127	128	129	130	131	132	28	27	26	25	24	23	22	21	20	19	18	TOTAL
Rhaphoneis	*amphiceros*		M/B						1													1
Rhaphoneis	*psammicola*		M/B																			7
Rhaphoneis	*surirella*		M/B																			2
Scoliopleura	*tumida*		M/B																			0
Surirella	*fastuosa*		M/B																			0
Thalassiosira	*discepens*		M/B																			2
Thalassiosira	*lacustris*		M/B																			2
Total				1	19	14	4	8	38	3	5	0	3	0	1	0	5	0	0	1	0	
% of Slide Total				25	15	26	13	5.9	29	17	3.8	0	2.4	0	1	0	3.5	0	0	0.9	0	
Amphora	*angusta*		M																			0
Amphora	*granulata*		M																			1
Bidduluphia	*aurita*		M																			0
Calonesis	*brevis*		M																			0
Coscinodiscus	*radiatus*	*f. obscurus*	M																			0
Cyclotella	*styrolum*		M																			0
Diploneis	*smithii*	*rhombica*	M																			1
Endictya	*sp.1*		M																			1
Nitzschia	*compressa*	*vexans*	M						1													7
Odontella	*obtusa*		M																			1
Opephora	*marina*		M																			13
Rhaphoneis	*margaritalimbata*		M																			2
Thalassionema	*nitzschioides*		M																			6
Thalassiosira	*eccentrica*		M						3													7
Thalassiosira	*pacifica*		M				1		1													40
Trachyneis	*aspera*		M																			0
Trachysphenia	*australis*		M																			0
Actinoptychus	*vulgaris*		M																			1
Nitzschia	*coarctata*		M																			0
Total				0	0	0	1	0	5	0	0	0	0	0	0	0	0	0	0	0	0	
% of Slide Total				0	0.	0	3.1	0	3.8	0	0	0	0	0	0	0	0	0	0	0	0	
Navicula	*capitata*		E																			4
Navicula	*capitata*	*hungarica*	E																			3
Navicula	*cryptocephala*		E																			16
Tabellaria	*flocculosa*		E																1		1	0
Total				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	
% of Slide Total				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	0	0.9	
Achnanthes	*spp.*		Unknown												2				1			0
Amphora	*spp.*		Unknown																			2
Calonesis	*spp.*		Unknown																			1
Cocconeis	*klamathensis*		Unknown																			1
Cocconeis	*spp.*		Unknown																3			8
Cyclotella	*caspia*		Unknown																			0
Cyclotella	*spp.*		Unknown																			2
Cymbella	*spp.*		Unknown																		1	3
Diploneis	*spp.*		Unknown																		1	3
Epithemia	*spp.*		Unknown	1		1									1	1		1		1		37
Fragilaria	*spp.*		Unknown											1								1
Gomphonema	*bipunctum*		Unknown															1				2
Gomphonema	*spp.*		Unknown																1		4	2
Gyrosigma	*spp.*		Unknown																			1
Hantzschia	*spp.*		Unknown												1							0
Mastogloia	*spp.*		Unknown																			0
Melosira	*spp.*		Unknown																			0
Navicula	*lapidosa*		Unknown										1						1			0
Navicula	*stroemii*		Unknown																1			0
Navicula	*sublucidula*		Unknown																			1

				Core 5			Core 4		Core 3			Core 2									C 1	
Genus	Species	Variety	**Salinity**	126	127	128	129	130	131	132	28	27	26	25	24	23	22	21	20	19	18	TOTAL
Navicula	*spp.*		Unknown										1		2			2		1	2	3
Nedium	*spp.*		Unknown																		1	0
Nitzschia	*palustris*		Unknown										1									0
Nitzschia	*spp.*		Unknown										5	1	3	1		2	3	2	1	22
Pinnularia	*spp.*		Unknown										3	1	16		2	2	1	1	12	12
Pleurosigma	*spp.*		Unknown																			0
Rhopalodia	*spp.*		Unknown																			0
Stauroneis	*spp.*		Unknown														1		1			7
Surirella	*spp.*		Unknown												1		3	1		2	2	0
Synedra	*spp.*		Unknown										3		1			4				44
Tabellaria	*spp.*		Unknown															2			1	2
Thalassiosira	*spp.*		Unknown																			5
Total				1	0	1	0	0	0	0	0	0	14	3	27	2	6	15	12	7	25	
% of Slide Total				25	0	1.9	0	0	0	0	0	0	11	13	26	1.7	4.2	12	11	6.4	23	
Total # of valves counted on slide				4	125	53	32	135	131	18	131	3	127	23	105	121	143	122	111	109	110	

APPENDIX B: INTERTIDAL SETTING INTERPRETATIONS

Note: Species counts that do not add up to 100% are due to diatoms not identified to species level and/or lacking salinity preference data.

Core 4: Diatom Analysis

Sample: 18 Core section: 1
Depth below land surface: 0.6m (4.95 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Eunotia pectinalis, Eunotia maior, Gomphonema angustatum, Gomphonema parvulum, Pinnularia viridis* var. *minor, Achnanthes hauckina*
Environment: Probably freshwater wetland
Special notes: Preservation very good. Many intact diatoms present.
Species counts: Freshwater 43%; Fresh/Brackish 29%; Brackish 4.5%; Euryhaline 1%

Sample: 19 Core section: 2
Sediment description: silt/clay
Depth below land surface: 1.25m (4.30 m NGVD)
Pertinent diatom species: *Eunotia pectinalis, Achnanthes lanceolata, Gomphonema parvulum, Nitzschia palea, Pinnularia similiformis, Achnanthes hauckina* var. *rostrata, Navicula peregrina*
Environment: Probably freshwater wetland or brackish high marsh
Special notes: Preservation very good. Many intact diatoms present.
Species counts: Freshwater 16.5%; Fresh/Brackish 60%; Brackish 16.5%; Brackish/Marine 1%

Sample: 20 Core section: 2 (Just after submergence? Event A)
Depth below land surface: 1.29m (4.26 m NGVD)
Sediment description: clay/silt; sharp lower boundary (~3mm)
Pertinent diatom species: *Eunotia pectinalis, Achnanthes hustedtii, Achnanthes lanceolata, Gomphonema angustatum, Gomphonema parvulum, Rhoicosphenia curvata, Achnanthes hauckina* var. *rostrata, Navicula peregrina*
Environment: Probably brackish high marsh
Special notes: Preservation good. Many intact diatoms present. Assemblage similar to Sample 21, but more unidentified fresh/brackish to brackish *Nitzschia* spp. present.
Species counts: Freshwater 19%; Fresh/Brackish 57%; Brackish 13%; Euryhaline 1%

Sample: 21 Core section: 2 (Just before submergence? Event A)
Depth below land surface: 1.35m (4.20 m NGVD)
Sediment description: fine peaty mud; sharp lower boundary (~3mm)
Pertinent diatom species: *Eunotia pectinalis, Cocconeis placentula, Gomphonema angustatum, Gomphonema parvulum, Pinnularia viridis* var. *minor; Achnanthes hauckina; Navicula peregrina*; *Synedra spp.*
Environment: Probably brackish high marsh
Special notes: Preservation good. Many intact diatoms present. Similar to assemblage from Sample 20, but many of the unidentified valves are freshwater *Eunotia* and *Synedra* spp.

Species counts: Freshwater 18%; Fresh/Brackish 54%; Brackish 16%

Sample: 22 Core section: 2 (Just after submergence. Event B)
Depth below land surface: 1.365m (4.18 m NGVD)
Sediment description: silt/clay; sharp lower boundary (<2mm)
Pertinent diatom species: *Eunotia pectinalis, Eunotia spp., Achnanthes hustedtii, Achnanthes lanceolata, Cocconeis placentula, Gomphonema gracile, Gomphonema parvulum, Navicula contenta, Pinnularia subcapitata, Achnanthes hauckina, Hantzschia virgata, Navicula rhyncocephala*
Environment: Brackish high to low marsh
Special notes: Preservation moderate. A mixture of *in situ* freshwater and brackish diatoms. Many heavily and non-heavily silicified valves present, but most of both types are highly fragmented, perhaps indicating transport?
Species counts: Freshwater 15%; Fresh/Brackish 70%; Brackish 7.7%; Brackish/Marine 3.5%

Sample: 23 Core section: 2 (Just before submergence. Event B)
Depth below land surface: 1.39m (4.16 m NGVD)
Sediment description: silt/clay with detrital herbaceous organics (70%)
Pertinent diatom species: *Eunotia pectinalis, Eunotia* var. *heurkii, Eunotia spp., Gomphonema parvulum*
Environment: Freshwater wetland
Special notes: Preservation very good. Assemblage dominated by freshwater *Eunotia spp.*
Species counts: Freshwater 73%; Fresh/Brackish 26%

Sample: 24 Core section: 2 (Just after submergence. Event C)
Depth below land surface: 1.48m (4.07 m NGVD)
Sediment description: silt/clay; sharp lower boundary (~3mm)
Pertinent diatom species: *Eunotia pectinalis, Eunotia spp., Achnanthes lanceolata, Gomphonema angustatum, Gomphonema parvulum, Pinnularia viridis, Achnanthese hauckina, Navicula digitoradiata*
Environment: Brackish low marsh
Special notes: Preservation moderate. Many fragmented diatoms, perhaps indicative of allochthonous diatom transport and deposition. Mixture of freshwater species with brackish species indicates probable rapid inundation, perhaps associated with a submergence event.
Species counts: Freshwater 12%; Fresh/Brackish 50%; Brackish 11%; Brackish/Marine 1%

Sample: 154 Core section: 2 (Just before submergence. Event C)
Depth below land surface: 1.51m (4.03 m NGVD)
Sediment description: silt/clay; 20% fibrous organics
Pertinent diatom species: *Pinnularia gibba, Stauroneis smithii, Achnanthes hustedtii, Achnanthes lanceolata, Gomphonema angustatum, Gomphonema parvulum*
Environment: Freshwater wetland
Special notes: Preservation good.
Species counts: Freshwater 16%; Fresh/Brackish 81%; Brackish/Marine 2.5%

Sample: 25 Core section: 2
Depth below land surface: 1.56m (3.99 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Eunotia maior, other large Eunotia spp., Epithemia turgida, Epithemia turgida* var. *westermanii, Hantzschia amphioxys*
Environment: Freshwater wetland
Special notes: Preservation good. However, only a few large, heavily silicified species present in assemblage.
Species counts: Freshwater 30%; Fresh/Brackish 57%

Sample: 155 Core section: 2 (Just after submergence. Event D)
Depth below land surface: 1.58m (3.96 m NGVD)
Sediment description: silt/clay and very fine sand; sharp lower boundary (~3mm)
Pertinent diatom species: *Eunotia pectinalis, Fragilaria construens, Gomphonema parvulum, Nitzschia linearis, Nitzschia pellucida, Pinnularia obscura*
Environment: Brackish low marsh
Special notes: Preservation good. Many fragmented valves, especially the Brackish and F/B species. May indicate transport of more brackish-tolerant species. While many Fresh and F/B species are present, the most dominant species, *Fragilaria construens* and *Gomphonema parvulum,* are often associated with lower brackish marsh or channel bank localities (Hemphill-Haley 1993). This, and the marked difference in assemblage composition from the assemblage 1cm below, implies a distinct change in depositional setting.
Species counts: Freshwater 19%; Fresh/Brackish 74%; Brackish/Marine 6%

Sample: 26 Core section: 2 (Just before submergence. Event D)
Depth below land surface: 1.60m (3.95 m NGVD)
Sediment description: silt/clay; 20% organic fibers
Pertinent diatom species: *Pinnularia subcapita* var. *paucistriata, Fragilaria construens* var. *venter, Navicula minima, Navicula mutica, Navicula pusilla, Nitzschia palea, Pinnularia lagerstedtii, Stauroneis kriegerii, Synedra ulna, Achnanthes hauckina, Navicula peregrina, Navicula digitoradiata*
Environment: Brackish high marsh
Special notes: Preservation very good. According to Kelsey et al. 2002 (Appendix DR1), although the species *Navicula mutica, Navicula pusilla*, and *Pinnularia lagerstedtii* are individually found in freshwater wetlands, when found in assemblages together they are indicative of brackish high marshes (salt marshes above mean higher high water). Following this, all succeeding sample interpretations will take groupings of these species into account.
Species counts: Freshwater 6%; Fresh/Brackish 64%; Brackish 17%; Brackish/Marine 2%

Sample: 156 Core section: 2 (Just after submergence. Event E)
Depth below land surface: 1.63m (3.91 m NGVD)
Sediment description: silt/clay; sharp lower boundary (~2mm)
Pertinent diatom species: *Navicula mutica, Navicula pusilla, Nitzschia palea, Pinnularia lagerstedtii, Navicula peregrina, Nitzschia debelis, Nitzschia plana, Nitzschia sigma, Navicula digitoradiata*; *Synedra fasciculata, Thalassiosira* spp.

Environment: Brackish low marsh
Special notes: Preservation good. Many fragmented valves.
Species counts: Freshwater 1%; Fresh/Brackish 60%; Brackish 22%; Brackish/Marine 13%

Sample: 157 Core section: 2 (Just before submergence. Event E)
Depth below land surface: 1.64m (3.90 m NGVD)
Sediment description: silt/clay; 10% organic fibers
Pertinent diatom species: *Eunotia* spp., *Pinnularia acrosphaeria, Pinnularia nodosa, Gomphonema angustatum, Gomphonema parvulum, Pinnularia viridis, Pinnularia phoenicenteron, Navicula peregrina, Navicula rhyncocephala,*
Environment: Brackish high marsh
Special notes: Preservation good. Many robust forms present, with fewer fragile forms noted. Some dissolution of valves evident. Assemblage may be suspect. Smaller forms that are preserved are primarily freshwater (*Navicula contenta, Fragilaria* spp.), implying a freshwater skew to the original, unaltered assemblage.
Species counts: Freshwater 13%; Fresh/Brackish 62%; Brackish 16%; Brackish/Marine 9%

Sample: 27 Core section: 2
Depth below land surface: 1.83m (3.72 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Eunotia monodon, Cymbella minuta*
Environment: Freshwater wetland
Special notes: Preservation poor. Very few diatoms present.
Species counts: Freshwater 67%; Fresh/Brackish 33%

Sample: 158 Core section: 2 (Just after submergence. Event F)
Depth below land surface: 1.99m (3.55 m NGVD)
Sediment description: silt/clay and very fine sand
Pertinent diatom species: *Navicula cari, Achnanthes hauckina, Caloneis westii, Nitzschia constricta, Opephora parva, Paralia sulcata, Thalassiosira* spp.
Environment: Intertidal flat
Special notes: Preservation excellent. Many small and large forms present. Small brackish to marine epipsammic and planktonic species may indicate tsunami transport and deposition of valves.
Species counts: Freshwater 3%; Fresh/Brackish 6%; Brackish 17%; Brackish/Marine 71%; Marine 3%

Sample: 28 Core section: 2 (Just before submergence. Event F)
Depth below land surface: 2.01m (3.54 m NGVD)
Sediment description: organic silt/clay with some fine (1-5mm), sharply delineated laminae of silt to fine sand; sharp lower boundary (~3mm)
Pertinent diatom species: *Eunotia maior, Eunotia pectinalis, Pinnularia acrosphaeria, Aulacosira italica, Gomphonema angustatum, Gomphonema parvulum, Pinnularia subcapitata, Pinnularia viridis, Caloneis westii, Paralia sulcata*
Environment: Brackish high marsh

Special notes: Preservation good. Assemblage a mixture of *in situ* freshwater species and brackish tidal flat species, consistent with tsunami deposit. However, because no sample was analyzed from just below this sample the earthquake hypothesis is unsubstantiated.
Species counts: Freshwater 37%; Fresh/Brackish 57%; Brackish 2%; Brackish/Marine 4%

Sample: 132 Core section: 3
Depth below land surface: 2.64m (2.91 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Epithemia turgida, Epithemia turgida* var. *westermannii, Navicula pusilla, Rhoicosphenia curvata, Paralia sulcata*
Environment: Probably brackish high marsh
Special notes: Preservation moderately poor. Whole diatoms rare and when present are largely robust species.
Species counts: Freshwater 6%; Fresh/Brackish 78%; Brackish/Marine 16.7%

Sample: 131 Core section: 3
Depth below land surface: 2.84m (2.71 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Achnanthes hustedtii,, Caloneis bacillum, Gomphonema parvulum, Navicula elegans, Navicula mutica, Navicula pusilla, Pinnularia lagerstedtii, Diploneis interrupta, Diploneis ovalis, Nitzschia sigma*
Environment: Probably brackish low marsh, or transition from brackish low to high marsh
Special notes: Preservation very good. Many well-preserved diatoms present.
Species counts: Freshwater 2%; Fresh/Brackish 45%; Brackish 18%; Brackish/Marine 29%; Marine 4%; Euryhaline 3%

Sample: 130 Core section: 4
Depth below land surface: 3.7m (1.85 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Eunotia pectinalis, Eunotia spp., Pinnularia gibba* var. *linearis, Achnanthes hustedtii, Achnanthes lanceolata, Aulacosira granulata, Gomphonema angustatum, Gomphonema gracile, Gomphonema parvulum, Pinnularia viridis, Achnanthes hauckina, Caloneis westii, Paralia sulcata*
Environment: Brackish high marsh
Special notes: Preservation very good. Many well-preserved diatoms present.
Species counts: Freshwater 20%; Fresh/Brackish 70%; Brackish 4%; Brackish/Marine 6%

Sample: 129 Core section: 4
Depth below land surface: 3.96m (1.59 m NGVD)
Sediment description: silt/clay, some fine (<2mm) silt laminae
Pertinent diatom species: *Epithemia turgida* var. *westermanii, Navicula mutica, Navicula pusilla, Nitzschia granulata, Paralia sulcata, Thalassiosira pacifica,*
Environment: Brackish high marsh
Special notes: Preservation moderately poor. Some diatoms present, but primarily robust forms. Integrity of assemblage suspect.

Species counts: Fresh/Brackish 81%; Brackish 3%; Brackish/Marine 13%; Marine 3%

Sample: 128 Core section: 5
Depth below land surface: 5.13m (0.42 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Eunotia spp., Navicula mutica, Navicula pusilla, Pinnularia lagerstedtii, Rhoicosphenia curvata, Cocconeis disculus, Cyclotella striata, Paralia sulcata*
Environment: Brackish high marsh
Special notes: Preservation moderate. Many diatoms fragmented or dissolved. Assemblage dominated by brackish high-marsh species *Navicula mutica, Navicula pusilla,* and *Pinnularia lagerstedtii* and brackish-marine *Paralia sulcata.*
Species counts: Freshwater 8%; Fresh/Brackish 60%; Brackish 4%; Brackish/Marine 26%

Sample: 127 Core section: 5
Depth below land surface: 5.42m (0.13 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Navicula elegans, Navicula mutica, Navicula pusilla, Nitzschia brevissima, Pinnularia lagerstedtii, Navicula cincta, Paralia sulcata*
Environment: Brackish high marsh
Special notes: Preservation good. Assemblage dominated by brackish high-marsh species *Navicula mutica, Navicula pusilla,* and *Pinnularia lagerstedtii* and brackish-marine *Paralia sulcata*
Species counts: Fresh/Brackish 82%; Brackish 2%; Brackish/Marine 15%

Sample: 126 Core section: 5
Depth below land surface: 5.74 (-0.19 m NGVD)
Sediment description: silt/clay and very fine sand
Pertinent diatom species: *Epithemia sorex, Epithemia spp., Navicula cryptonella*
Environment: Brackish high marsh?
Special notes: Preservation very poor. Very few diatoms present, all highly fragmented.
Species counts: Fresh/Brackish 50%; Brackish/Marine 25%

Sample: 125 Core section: 6
Depth below land surface: 6.3m (-0.75 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Cocconeis placentula, Hantzschia amphioxys, Navicula pusilla, Nitzschia brevissima, Paralia sulcata*
Environment: Brackish high marsh
Special notes: Preservation poor. Few diatoms present, all highly fragmented.
Species counts: Fresh/Brackish 71%; Brackish/Marine 14.3%

Sample: 122 Core section: 7
Depth below land surface: 7.52m (-1.97 m NGVD)
Sediment description: clay/silt to very fine sand

Pertinent diatom species: *Achnanthes lanceolata, Achnanthes minutissima, Cocconeis placentula, Cocconeis placentula* var. *euglypta, Navicula mutica, Nitzschia pusilla, Rhoicosphenia curvata, Achnanthes hauckina* var. *rostrata, Cocconeis disculus, Denticula subtilis, Navicula cincta, Synedra fasciculata, Achnanthes delicatula, Opephora parva, Navicula cryptocephala*
Environment: Brackish low marsh or estuarine tidal flat
Special notes: Preservation moderately poor. Many diatoms present, but most are highly fragmented.
Species counts: Freshwater 3%; Fresh/Brackish 45%; Brackish 31%; Brackish/Marine 13%; Marine 3%; Euryhaline 3%

Sample: 121 Core section: 7 (just after submergence. Event G)
Depth below land surface: 7.65m (-2.10 m NGVD)
Sediment description: very fine sandy loam with some clay/silt masses (soft-sediment rip-up clasts?); sharp lower boundary (<2mm)
Pertinent diatom species: *Achnanthes lanceolata, Achnanthes minutissima, Pinnularia intermedia, Achnanthes hauckina* var. *rostrata, Navicula cincta, Achnanthes delicatula, Navicula phyllepta, Navicula rhyncocephala, Opephora parva, Thalassiosira pacifica*
Environment: Mixture of brackish low marsh species with some sandy brackish tidal-flat species. Tsunami deposit?
Special notes: Preservation moderately good. Diatoms fewer in number and more fragmented than in lower deposits. Assemblage dominated by small epispammic diatoms such as *Achnanthes hauckina* var. *rostrata,* and *Opephora parva.* Differences between sample assemblages 121 and 120 are minor, with greater percentages of epipsammic diatoms in the overlying deposit.
Species counts: Fresh/Brackish 44%; Brackish 24%; Brackish/Marine 27%; Marine 3%

Sample: 120 Core section: 7 (just before submergence. Event G)
Depth below land surface: 7.70m (-2.15 m NGVD)
Sediment description: silt/clay with fine (<2mm) organic-rich laminae
Pertinent diatom species: *Navicula leptostriata, Pinnularia krockii, Achnanthes lanceolata, Cocconeis placentula, Cocconeis placentula* var. *euglypta, Diatoma mesodon, Epithemia turgida, Gomphonema parvulum, Navicula cryptonella, Navicula tenelloides, Nitzschia inconspicua, Rhoicosphenia curvata, Synedra ulna, Cocconeis disculus, Navicula cincta, Navicula phyllepta, Nitzschia granulata, Thalassiosira pacifica*
Environment: Brackish low to high marsh?
Special notes: Preservation good. Diatom assemblage highly mixed, not indicative of any one specific environment
Species counts: Freshwater 7.5%; Fresh/Brackish 60%; Brackish 14%; Brackish/Marine 16%; Marine 3%

Sample: 119 Core section: 7
Depth below land surface: 7.77m (-2.22 m NGVD)
Sediment description: fine sand and silt

Pertinent diatom species: *Achnanthes lanceolata, Amphora coffeiformis, Cocconeis placentula* var. *euglypta, Nitzschia perminuta, Achnanthes hauckina* var. *rostrata, Navicula cincta, Achnanthes delicatula, Nitzschia granulata, Opephora parva, Opephora marina*
Environment: Sandy, estuarine tidal flat
Special notes: Preservation good. Assemblage dominated by small, epipsammic diatoms such as *Achnanthes hauckina* var. *rostrata, Achnanthes delicatula,* and *Opephora parva*
Species counts: Fresh/Brackish 13%; Brackish 31%; Brackish/Marine 41%; Marine 13%

Sample: 118 Core section: 7
Depth below land surface: 7.92m (-2.37 m NGVD)
Sediment description: silt/clay with organic inclusions (root casts?)
Pertinent diatom species: *Navicula mutica, Navicula pusilla, Nitzschia commutata, Navicula cincta, Delphineis surirella, Dimeregramma minor, Opephora parva, Paralia sulcata, Thalassiosira pacifica*
Environment: Probably low marsh or estuarine tidal flat
Special notes: Preservation moderately good. Many diatoms present, but some fragmentation of valves. Mixed assemblage of brackish high marsh species and brackish marine diatoms. Perhaps indicative of recent rapid rise in sea level
Species counts: Freshwater 1%; Fresh/Brackish 43%; Brackish 10%; Brackish/Marine 42%; Marine 5%

Sample: 117 Core section: 7 (just after submergence. Event H)
Depth below land surface: 8.04m (-2.49 m NGVD)
Sediment description: Normally graded fine sand to silt, abrupt lower boundary (~1mm)
Pertinent diatom species: *Achnanthes lanceolata, Achnanthes minutissima, Achnanthes hauckina, Achnanthes hauckina* var. *rostrata, Catentula adherens, Delphineis surirella, Dimeregramma minor, Opephora parva, Paralia sulcata, Rhaphoneis psammicola, Thalassiosira pacifica*
Environment: brackish-marine (tsunami deposit?)
Special notes: Preservation good. Assemblage dominated by *Achnanthes hauckina* var. *rostrata* and other brackish, epipsammic diatoms. Possible inundation of area by tidal flat deposits following sudden submergence.
Species counts: Freshwater 1%; Fresh/Brackish 7.5%; Brackish 55%; Brackish/Marine 28%; Marine 7.5%; Euryhaline 1%

Sample: 116 Core section: 7 (just before submergence. Event H)
Depth below land surface: 8.06m (-2.51 m NGVD)
Sediment description: silt/clay with many fine (<2mm) organic-rich laminae
Pertinent diatom species: *Achnanthes minutissima, Caloneis bacillum, Navicula mutica, Navicula muticoides, Navicula pusilla, Achnanthes brevipes* var. *intermedia, Caloneis westii, Gyrosigma eximium, Navicula cincta, Nitzschia debilis, Nitzschia sigma, Delphineis surirella, Nitzschia constricta, Nitzschia granulata, Paralia sulcata, Nitzscia compressa var. vexans, Thalassiosira pacifica*
Environment: Mixed fresh/brackish and brackish/marine deposits (low marsh?)
Special notes: Preservation good. Assemblage a mixture of *in situ* brackish to fresh-water diatoms and brackish water species.

Species counts: Freshwater 1%; Fresh/Brackish 47%; Brackish 22%; Brackish/Marine 21%; Marine 9%; Euryhaline 1%

Sample: 115 Core section: 7
Depth below land surface: 8.22m (-2.67 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Frustulia vulgaris; Navicula contenta; Navicula mutica, Navicula pusilla, Nitzschia nana, Pinnularia lagerstedtii, Gyrosigma eximium, Navicula cincta, Navicula pygmaea*
Environment: Brackish high marsh
Special notes: Preservation good. Assemblage dominated by *Navicula mutica, Navicula pusilla,* and *Pinnularia lagerstedtii* group
Species counts: Fresh/Brackish 73%; Brackish 22%; Brackish/Marine 5%

Sample: 113 Core section: 8
Depth below land surface: 8.90m (-3.35 m NGVD)
Sediment description: silt/clay to very fine sands with thick (~2cm) laminae of more highly organic silt to very fine sand
Pertinent diatom species: *Caloneis bacillum, Navicula mutica, Navicula pusilla, Nitzschia commutata, Nitzschia nana, Nitzschia palea, Pinnularia lagerstedtii, Gyrosigma eximium, Navicula cincta, Synedra fasciculata*
Environment: Brackish high marsh
Special notes: Preservation good. Assemblage dominated by *Navicula mutica, Navicula pusilla, Navicula cincta* and *Pinnularia lagerstedtii*
Species counts: Fresh/Brackish 62%; Brackish 30%; Brackish/Marine 5%; Euryhaline 2%

Sample: 112 Core section: 8
Depth below land surface: 9.13m (-3.58 m NGVD)
Sediment description: silt/clay with thick (~2cm) laminae of silt
Pertinent diatom species: *Epithemia turgida, Gomphonema parvulum, Navicula pusilla, Pinnularia lagerstedtii, Rhoicosphenia curvata, Navicula cincta, Navicula phyllepta*
Environment: Brackish high marsh
Special notes: Preservation good.
Species counts: Freshwater 6%; Fresh/Brackish 72%; Brackish 13%; Brackish/Marine 7%; Euryhaline 2%

Sample: 111 Core section: 8
Depth below land surface: 9.22m (-3.67 m NGVD)
Sediment description: silt/clay to very fine sand with thick (~2cm) laminae of more highly organic silt to very fine sand
Pertinent diatom species: *Diploneis pseudovalis, Navicula mutica, Navicula pusilla, Navicula pusilla* var.*1, Nitzschia nana, Pinnularia lagerstedtii, Cocconeis disculus, Navicula cincta, Synedra fasciculata, Dimeregramma minor*
Environment: Brackish high marsh

Special notes: Preservation good. Assemblage dominated by *Navicula mutica, Navicula pusilla, Navicula cincta* and *Pinnularia lagerstedtii.*
Species counts: Fresh/Brackish 78%; Brackish 14%; Brackish/Marine 6%

Sample: 110 Core section: 8
Depth below land surface: 9.34m (-3.79 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Caloneis bacillum, Navicula mutica, Navicula pusilla, Achnanthes hauckina, Caloneis westii, Nitzschia nana, Pinnularia lagerstedtii, Navicula cincta, Nitzschia sigma, Cocconies scutellum var. parva, Opephora parva*
Environment: Brackish low marsh?
Special notes: Preservation good. Mixture of brackish high marsh species with intertidal or tidal flat diatoms
Species counts: Freshwater 2%; Fresh/Brackish 66%; Brackish 20%; Brackish/Marine 12%;

Sample: 109 Core section: 8
Depth below land surface: 9.46m (-3.91 m NGVD)
Sediment description: silt to very fine sand
Pertinent diatom species: *Eunotia* spp., *Achnanthes lanceolata, Cocconeis placentula* var. *euglypta, Epithemia turgida* var. *westermanii, Navicula mutica, Navicula pusilla, Nitzschia nana, Pinnularia borealis, Pinnularia similiformis, Rhoicosphenia curvata, Synedra ulna, Gyrosigma eximium, Navicula cincta, Nitzschia sigma, Rhopalodia musculus, Cocconeis scutellum var. parva, Opephora parva*
Environment: Brackish high or low marsh?
Special notes: Preservation good. Mixture of fresh to brackish high marsh species with intertidal or tidal flat diatoms.
Species counts: Freshwater 2%; Fresh/Brackish 69%; Brackish 15%; Brackish/Marine 14%;

Sample: 108 Core section: 8
Depth below land surface: 9.48m (-3.93 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Navicula mutica, Navicula pusilla, Nitzschia commutata, Nitzschia palea, Nitzschia scapelliformis, Caloneis westii, Gyrosigma balticum, Gyrosigma eximium, Navicula cincta, Nitzschia sigma, Rhopalodia musculus, Synedra fasciculata, Delphineis surirella, Nitzschia granulata, Thalassiosira pacifica*
Environment: Brackish low marsh
Special notes: Preservation good. Assemblage dominated by low marsh species
Species counts: Fresh/Brackish 29%; Brackish 42%; Brackish/Marine 27%; Marine 2%

Sample: 107 Core section: 9 (just after submergence. Event I)
Depth below land surface: 9.88m (-4.33 m NGVD)
Sediment description: coarse to fine sand; sharp lower boundary (<3mm)
Pertinent diatom species: *Navicula mutica, Navicula pusilla, Nitzschia scapelliformis, Pinnularia lagerstedtii, Achnanthes hauckina, Cocconeis disculus, Navicula cincta, Synedra fasciculata, Nitzschia granulata, Paralia sulcata*

Environment: Intertidal flat or subtidal channel
Special notes: Preservation good. Mixture of *in situ* high marsh species with tidal flat species is consistent sudden subsidence
Species counts: Freshwater 1%; Fresh/Brackish 59%; Brackish 21%; Brackish/Marine 19%; Euryhaline 1%

Sample: 106 Core section: 9 (just before submergence. Event I)
Depth below land surface: 10.04m (-4.49 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Cocconeis placentula* var. *euglypta, Epithemia turgida, Hantzschia amphioxys, Pinnularia borealis*
Environment: Brackish high marsh
Special notes: Preservation poor. Diatoms highly fragmented. Much of the assemblage consists of unidentified *Synedra, Epithemia,* and *Pinnularia* spp., which are commonly associated with freshwater or fresh-brackish deposits.
Species counts: Freshwater 4%; Fresh/Brackish 54%

Sample: 87 Core section: 13
Depth below land surface: 15.16m (-9.61 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Aulocosira granulata, Aulocosira islandica, Fragilaria* spp., *Navicula mutica, Tabellaria fenestrata*
Environment: Brackish high marsh or freshwater wetland
Special notes: Preservation moderate. Many diatoms partially dissolved. Assemblage dominated by *Fragilaria* and the planktonic *Aulocosira* species, which may indicate freshwater ponding.
Species counts: Freshwater 4%; Fresh/Brackish 87%; Brackish 1%; Brackish/Marine 4%; Euryhaline 2%

Sample: 78 Core section: 15 (just after submergence. Event J)
Depth below land surface: 17.165m (-11.62 m NGVD)
Sediment description: fine sand; sharp lower boundary (<2mm)
Pertinent diatom species: *Aulocosira spp., Fragilaria* spp., *Melosira roeseana, Stauroneis anceps, Tabellaria fenestrata, Achnanthes exigua*
Environment: Brackish high marsh- ponding? Or transport from a lower, channel bank locality?
Special notes: Preservation moderate. Assemblage dominated by freshwater to fresh-brackish species often associated with standing water. May be indicative of a wetter, ponded brackish high marsh or the assemblage may indicate planktonic transport from a channel-fringing low marsh.
Species counts: Freshwater 7%; Fresh/Brackish 63%; Brackish 5%; Brackish/Marine 2%; Euryhaline 5%

Sample: 77 Core section: 15 (just before submergence. Event J)
Depth below land surface: 17.19m (-11.64 m NGVD)
Sediment description: silt/clay

Pertinent diatom species: *Synedra* spp.
Environment: Freshwater wetland?
Special notes: Highly fragmented, very few in number; 100% of diatoms are *Synedra* spp.
Species counts:

Sample: 73 Core section: 15
Depth below land surface: 17.70m (-12.15 m NGVD)
Sediment description: silt/clay
Pertinent diatom species:
Environment: Freshwater wetland?
Special notes: Preservation very poor. Only unidentified *Epithemia* spp. present.
Species counts:

Sample: 72 Core section: 15
Depth below land surface: 17.75m (-12.20 m NGVD)
Sediment description: medium to fine sand
Pertinent diatom species: Only species present is *Nitzschia brevissima*
Environment: Freshwater wetland? Brackish high marsh?
Special notes: Preservation very poor. Almost no diatoms present.
Species counts: Fresh/Brackish 100%

Sample: 71 Core section: 15
Depth below land surface: 17.80m (-12.25 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species:
Environment: Freshwater wetland? Brackish high marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented. Only unidentified *Epithemia* and *Synedra* spp. present
Species counts:

Sample: 70 Core section: 15
Depth below land surface: 18.00m (-12.45 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Cymbella sinuata, Navicula mutica, Pinnularia borealis, Synedra ulna, Cocconeis scutellum* var. *parva*
Environment: Brackish high marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented. Assemblage dominated by *Synedra* species.
Species counts: Fresh/Brackish 67%; Brackish/Marine 11%

Sample: 68 Core section: 16
Depth below land surface: 18.6m (-13.05 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Cocconeis scutellum* var. *parva*

Environment: Brackish low or high marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented and/or dissolved. Only *Cocconeis scutellum* var. *parva* identifiable.
Species counts: Brackish/Marine 50%

Sample: 67 Core section: 16
Depth below land surface: 18.95m (-13.40 m NGVD)
Sediment description: silt/clay and fine to medium sand
Pertinent diatom species: *Navicula mutica, Stauroneis anceps, Synedra ulna, Cocconeis scutellum, Cocconeis scutellum* var. *parva*
Environment: Brackish low marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented and/or dissolved.
Species counts: Fresh/Brackish 63%; Brackish/Marine 25%

Sample: 66 Core section: 16
Depth below land surface: 19.37m (-13.82 m NGVD)
Sediment description: medium to fine sand
Pertinent diatom species: *Achnanthes lanceolata, Cocconeis placentula, Cocconeis placentula* var. *euglypta, Cymbella sinuata, Navicula mutica, Rhopalodia gibba, Synedra ulna, Navicula rhyncocephala*
Environment: Brackish high marsh?
Special notes: Preservation moderately good, but few valves present.
Species counts: Freshwater 5%; Fresh/Brackish 90%; Brackish/Marine 5%

Sample: 65 Core section: 16
Depth below land surface: 19.39m (-13.84 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Achnanthes lanceolata, Cocconeis diminuta, Cocconeis placentula* var. *euglypta, Cymbella sinuata, Epithemia sorex, Epithemia turgida var. westermannii, Gomphonema parvulum, Rhoicosphenia curvata, Rhopalodia gibba, Synedra ulna, Amphora ovalis* var. *pediculus, Diploneis smithii*
Environment: Brackish high marsh?
Special notes: Preservation moderately poor. Few diatoms, many highly fragmented.
Species counts: Freshwater 2%; Fresh/Brackish 85%; Brackish 8%; Brackish/Marine 4%

Sample: 64 Core section: 16
Depth below land surface: 19.45m (-13.90 m NGVD)
Sediment description: fine sand to silt
Pertinent diatom species: *Cocconeis placentula* var. *euglypta, Rhoicosphenia curvata, Navicula cincta, Cocconeis spp.*
Environment: Brackish high marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Fresh/Brackish 53%; Brackish 12%

Sample: 63 Core section: 17
Depth below land surface: 19.77m (-14.22 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Eunotia monodon, Gomphonema parvulum, Navicula contenta, Navicula mutica, Synedra ulna*
Environment: Brackish high marsh? Freshwater wetland?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Freshwater 10%; Fresh/Brackish 70%

Sample: 57 Core section: 18
Depth below land surface: 20.86m (-15.31 m NGVD)
Sediment description: silt/clay to medium sand
Pertinent diatom species: *Gomphonema parvulum, Synedra ulna, Synedra* spp.
Environment: Brackish high marsh? Freshwater wetland?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Fresh/Brackish 50%

Sample: 56 Core section: 18
Depth below land surface: 21.02m (-15.47 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Cocconeis placentula* var. *euglypta, Epithemia turgida* var. *westermannii, Epithemia zebra, Fragilaria capuchina var. vaucherie, Gomphonema parvulum, Navicula mutica,Cocconeis disculus, Navicula cincta*
Environment: Brackish high marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Fresh/Brackish 67%; Brackish 22%

Sample: 55 Core section: 18
Depth below land surface: 21.10m (-15.55 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Cocconeis diminuta, Cocconeis placentula* var. *euglypta, Navicula gallica var. perpusilla, Stauroneis anceps, Epithemia* spp.
Environment: Brackish high marsh? Freshwater wetland?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Fresh/Brackish 46%

Sample: 54 Core section: 18
Depth below land surface: 21.21m (-15.66 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Achnanthes lanceolata, Cocconeis placentula, Cocconeis placentula* var. *euglypta, Epithemia turgida* var. *westermannii, Nitzschia palea, Stauroneis phoenicenteron, Epithemia* spp., *Nitzschia* spp.
Environment: Brackish high marsh? Freshwater wetland?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.

Species counts: Fresh/Brackish 58%

Sample: 53 Core section: 18
Depth below land surface: 21.59m (-16.04 m NGVD)
Sediment description: silt/clay to medium sand
Pertinent diatom species: *Eunotia pectinalis, Nedium hercynicum, Cocconeis placentula, Cocconeis placentula* var. *euglypta, Epithemia turgida* var. *westermannii, Meridion circulare* var. *constricta, Navicula mutica, Synedra ulna, Navicula cincta*
Environment: Brackish high or low marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented and dissolved.
Species counts: Freshwater 10%; Fresh/Brackish 45%; Brackish 15%

Sample: 52 Core section: 18 (Just after submergence. Event K)
Depth below land surface: 21.77m (-16.22 m NGVD)
Sediment description: silt/clay to medium sand
Pertinent diatom species: *Achnanthes lanceolata, Cocconeis placentula, Cocconeis placentula* var. *euglypta, Epithemia turgida* var. *westermanii, Hantzschia amphioxys, Navicula mutica, Pinnularia borealis, Synedra ulna, Amphora proteus, Navicula perminuta*
Environment: Brackish high to low marsh?
Special notes: Preservation moderately poor. Few diatoms, most highly fragmented. Mixture of fresh and brackish diatoms may indicate sudden salinity change.
Species counts: Freshwater 3.6%; Fresh/Brackish 89%; Brackish 1.8%; Marine/Brackish 3.6%

Sample: 51 Core section: 18 (Just before submergence. Event K)
Depth below land surface: 21.83m (-16.28 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Diatoma anceps, Eunotia pectinalis, Epithemia sorex, Navicula mutica, Rhoicosphenia curvata, Synedra* spp.
Environment: Brackish high marsh? Freshwater wetland?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Freshwater 14%; Fresh/Brackish 50%

Sample: 50 Core section: 19
Depth below land surface: 22.03m (-16.48 m NGVD)
Sediment description: silt/clay to coarse sand, some pebbles
Pertinent diatom species: *Aulacosira islandica, Cocconeis placentula* var. *euglypta*
Environment: Freshwater wetland?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Fresh/Brackish 75%

Sample: 49 Core section: 19
Depth below land surface: 22.24m (-16.69 m NGVD)
Sediment description: silt/clay to medium sand

Pertinent diatom species: *Cocconeis placentula* var. *euglypta, Navicula pusilla, Diploneis interrpta, Navicula cincta, Nitzschiza constricta, Navicula granulata, Paralia sulcata*
Environment: Brackish high marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Fresh/Brackish 20%; Brackish 20%; Brackish/Marine 30%

Sample: 48 Core section: 19
Depth below land surface: 22.35m (-16.80 m NGVD)
Sediment description: silt/clay to medium sand
Pertinent diatom species: *Navicula mutica, Diploneis* spp., *Nitzschia* spp.
Environment: Brackish high marsh?
Special notes: Preservation very poor. Few diatoms, most highly fragmented.
Species counts: Fresh/Brackish 33%

Sample: 47 Core section: 19
Depth below land surface: 22.43m (-16.88 m NGVD)
Sediment description: medium to fine sand
Pertinent diatom species: *Cocconeis diminuta, Pinnularia similiformis, Diploneis* spp., *Nitzschia* spp., *Synedra* spp.
Environment: Brackish high marsh?
Special notes: Preservation very poor. Few diatoms, mostly fragmented
Species counts: Fresh/Brackish 40%

Sample: 46 Core section: 19
Depth below land surface: 22.56m (-17.01 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Amphora ovalis* var. *affinis*, *Cocconeis placentula* var. *euglypta, Navicula mutica, Rhoicosphenia curvata, Synedra ulna, Epithemia* spp.
Environment: Brackish high marsh? Freshwater wetland?
Special notes: Preservation moderately poor. Very few diatoms present.
Species counts: Fresh/Brackish 63%

Sample: 45 Core section: 19
Depth below land surface: 22.73m (-17.18 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Eunotia spp., Pinnularia gibba* var. *linearis, Cocconeis placentula* var. *euglypta, Cymbella sinuata, Epithemia sorex, Epithemia zebra, Fragilaria brevistriata, Navicula mutica, Pinnularia borealis, Rhoicosphenia curvata, Synedra ulna, Nitzschia* spp., *Synedra* spp.
Environment: Brackish high marsh
Special notes: Preservation moderate.
Species counts: Freshwater 6%; Fresh/Brackish 67%

Sample: 44 Core section: 19

Depth below land surface: 23.05m (-17.50 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Cocconeis placentula* var. *euglypta, Navicula lanceolata, Navicula mutica, Nitzschia terrestris, Pinnularia borealis, Synedra ulna, Fragilaria* spp.
Environment: Brackish high marsh? Freshwater area?
Special notes: Preservation poor.
Species counts: Fresh/Brackish 50%

Sample: 43 Core section: 20
Depth below land surface: 23.24m (-17.69 m NGVD)
Sediment description: silt/clay to very fine sand
Pertinent diatom species: *Cocconeis placentula* var. *euglypta, Navicula mutica, Pinnularia borealis, Cocconeis spp., Synedra* spp.
Environment: Brackish high marsh? Freshwater area?
Special notes: Preservation very poor.
Species counts: Fresh/Brackish 60%

Sample: 41 Core section: 20 (Just after submergence. Event L)
Depth below land surface: 23.48m (-17.93 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Eunotia* spp., *Cocconeis placentula* var. *euglypta, Nitzschia commutata, Pinnularia subcapitata, Pinnularia viridis, Rhoicosphenia curvata, Stauroneis anceps, Stauroneis spp., Synedra ulna, Achnanthes brevipes* var. *intermedia, Synedra fasciculata, Cocconeis scutellum*
Environment: Brackish low marsh or intertidal zone
Special notes: Preservation moderately poor. Many valves broken/dissolved. Assemblage a mix of *in situ* freshwater diatoms and intertidal species, possibly indicative of a rapid rise in relative sea level
Species counts: Freshwater 6%; Fresh/Brackish 58%; Brackish 8%; Brackish/Marine 19%

Sample: 40 Core section: 20 (Just before submergence. Event L)
Depth below land surface: 23.5m (-17.95 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Eunotia* spp., *Synedra rumpens, Cocconeis placentula* var. *euglypta, Cymbella sinuata, Diatoma mesodon, Navicula contenta, Navicula gallica* var. *perpusilla, Pinnularia subcapitata, Rhoicosphenia curvata, Synedra ulna*
Environment: Brackish high marsh
Special notes: Preservation moderately poor. Assemblage dominated by freshwater to fresh/brackish species.
Species counts: Freshwater 14%; Fresh/Brackish 76%; Brackish 3%; Marine 3%

Sample: 39 Core section: 20
Depth below land surface: 23.68m (-18.13 m NGVD)
Sediment description: fine sand
Pertinent diatom species: *Gomphonema parvulum, Cybella sinuata, Epithemia sorex, Navicula mutica, Synedra ulna, Stauroneis* spp., *Synedra* spp.

Environment: Brackish high marsh
Special notes: Preservation poor.
Species counts: Fresh/Brackish 75%

Sample: 38 Core section: 20
Depth below land surface: 23.83m (-18.28 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Eunotia* spp., *Cocconeis placentula* var. *euglypta, Epithemia turgida* var. *westermannii, Synedra ulna, Epithemia* spp., *Synedra* spp.
Environment: Freshwater wetland? Brackish high marsh?
Special notes: Preservation poor. Very few diatoms present, many valves partially dissolved. Assemblage dominated by *Eunotia, Epithemia*, and *Synedra* species
Species counts: Freshwater 29%; Fresh/Brackish 41%

Sample: 37 Core section: 20
Depth below land surface: 23.92m (-18.37 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Cocconeis placentula* var. *euglypta, Synedra* spp.
Environment: Freshwater wetland? Brackish high marsh?
Special notes: Preservation very poor. Very few diatoms present.
Species counts: Fresh/Brackish 25%

Sample: 35 Core section: 20
Depth below land surface: 23.98m (-18.43 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Pinnularia borealis, Stauroneis kriegerii, Synedra ulna*
Environment: Freshwater wetland? Brackish high marsh?
Special notes: Preservation very poor. Very few diatoms present.
Species counts: Fresh/Brackish 75%

Sample: 31-34 Core section: 20
Depth below land surface: 24.13 to 24.22m (-18.58 to –18.67 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Synedra spp.*
Environment: Freshwater wetland? Brackish high marsh?
Special notes: Preservation very poor. Only highly fragmented *Synedra* spp. present
Species counts: Fresh/Brackish 100%

Sample: 17 Core section: 21
Depth below land surface: 24.46m (-18.91 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Achnanthes lanceolata, Aulacosira islandica, Cocconeis placentula* var. *euglypta, Navicula contenta, Navicula gallica* var. *perpusilla, Pinnularia borealis, Synedra ulna*

Environment: Freshwater wetland? Brackish high marsh?
Special notes: Preservation poor. Very few diatoms present, predominantly fragmented.
Species counts: Fresh/Brackish 91%

Sample: 16 Core section: 21
Depth below land surface: 24.56m (-19.01 m NGVD)
Sediment description: silt/clay to fine sand
Pertinent diatom species: *Epithemia turgida, Synedra ulna, Cocconeis scutellum, Thalassiosira discepens*
Environment: Brackish high marsh? Brackish low marsh?
Special notes: Preservation very poor. Very few diatoms present, mostly fragmented.
Species counts: Fresh/Brackish 62.5%; Brackish/Marine 25%

Sample: 15 Core section: 21
Depth below land surface: 24.79m (-19.24 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Eunotia maior, Aulacosira granulata, Cocconeis diminuta, Cymbella cistula, Synedra ulna, Cocconeis scutellum var. parva, Gyrosigma eximium, Epithemia* spp.
Environment: Brackish high marsh? Brackish low marsh?
Special notes: Preservation poor. Very few diatoms present, but fragile forms (ex. *Gyrosigma eximium)* found relatively whole.
Species counts: Freshwater 10%; Fresh/Brackish 50%; Brackish 10%; Brackish/Marine 10%

Sample: 14 Core section: 21
Depth below land surface: 25.00m (-19.45 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Achnanthes coarctata, Diatoma anceps, Aulacosira granulata, Pinnularia similiformis, Synedra ulna, Achnanthes brevipes* var. *intermedia, Nitzschia compressa, Thalassiosira lacustris*
Environment: Brackish high marsh? Brackish low marsh?
Special notes: Preservation very poor. Very few diatoms present, all fragmented.
Species counts: Freshwater 14%; Fresh/Brackish 43%; Brackish 7%; Brackish/Marine 21%

Sample: 13 Core section: 21
Depth below land surface: 25.18m (-19.63 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Cocconeis placentula* var. *euglypta, Synedra ulna*
Environment: Brackish high marsh? Freshwater wetland?
Special notes: Preservation very poor. Very few diatoms present, all fragmented.
Species counts: Fresh/Brackish 100%

Sample: 12 Core section: 21
Depth below land surface: 25.28m (-19.73 m NGVD)

Sediment description: silt/clay to very fine sand
Pertinent diatom species: *Synedra ulna, Tabellaria* spp.
Environment: Brackish high marsh? Freshwater wetland?
Special notes: Preservation very poor. Very few diatoms present.
Species counts: Fresh/Brackish 50%

Sample: 11 Core section: 21
Depth below land surface: 25.39m (-19.84 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Aulacosira granulata, Cocconeis disculus*
Environment: Brackish high marsh?
Special notes: Preservation very poor. Very few diatoms present.
Species counts: Fresh/Brackish 50%; Brackish 50%

Sample: 10 Core section: 21
Depth below land surface: 25.46m (-19.91 m NGVD)
Sediment description: silt/clay to very fine sand
Pertinent diatom species: *Aulacosira granulata, Nitzschia nana, Synedra ulna, Paralia sucata*
Environment: Brackish high marsh?
Special notes: Preservation very poor. Very few diatoms present.
Species counts: Fresh/Brackish 80%; Brackish/Marine 20%

Sample: 8 Core section: 22
Depth below land surface: 25.68m (-20.13 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Pinnularia subgibba, Caloneis bacillum, Navicula mutica, Navicula pusilla, Nitzschia scapelliformis, Pinnularia lagerstedtii, Achnanthes hauckina, Navicula cincta, Navicula peregrina, Synedra fasciculata, Delphineis surirella, Paralia sulcata, Actinoptychus vulgaris, Navicula cryptocephala*
Environment: Brackish low marsh
Special notes: Preservation moderately good. Assemblage dominated by the *Navicula mutica, Navicula pusilla, Pinnularia lagerstedtii* group and *Delphineis surirella,* a marine tychoplankton.
Species counts: Freshwater 3%; Fresh/Brackish 51%; Brackish 15%; Brackish/Marine 17%; Marine 2%; Euryhaline 2%

Sample: 7 Core section: 22
Depth below land surface: 25.47m (-20.19 m NGVD)
Sediment description: silt/clay
Pertinent diatom species: *Dimeregramma minor, Paralia sulcata*
Environment: Brackish low marsh? Estuarine tidal flat or channel?
Special notes: Preservation very poor. Very few diatoms present.
Species counts: Brackish/Marine 100%

Sample: 4 Core section: 22

Depth below land surface: 26.168m (-20.62 m NGVD)
Sediment description: silt/clay to very fine sand
Pertinent diatom species: *Achnanthes hustedtii, Achnanthes lanceolata, Navicula contenta, Navicula mutica, Navicula pusilla, Nitzschia palea, Achnanthes hauckina, Navicula cincta, Synedra fasciculata, Cocconeis scutellum, Dimeregramma minor, Nitzschia obtusa, Opephora parva, Paralia sulcata, Navicula cryptocephala, Nitzschia* spp.
Environment: Estuarine tidal flat or channel
Special notes: Preservation moderately poor. Many diatoms present, but very fragmented. Fresh/brackish portion of assemblage dominated by *Navicula mutica*. Small, brackish epipsammic diatoms common.
Species counts: Freshwater 3%; Fresh/Brackish 47%; Brackish 19%; Brackish/Marine 18%; Marine 2%; Euryhaline 3%

Core 6: Diatom Analysis

Sample: 6-21 Core section: 9 (Just after submergence. Event G)
Depth below land surface: 9.82m (-4.36 m NGVD)
Sediment description: silt to coarse sand and pebbles
Pertinent diatom species: *Cocconeis delicatula, Navicula mutica, Nitzschia nana, Achnanthes haukina, Rhopalodia muscalus, Achnanthes delicatula, Cocconeis scutellum* var. *parva, Delphineis surirella, Opephora parva, Paralia sulcata, Thalassiosira*
Environment: Estuarine tidal flat or channel
Special notes: Preservation good. Many diatoms present, some fragmentation. Fresh/brackish portion of assemblage dominated by *Navicula mutica*. Small, brackish epipsammic diatoms common.
Species counts: Freshwater 1%; Fresh/Brackish 33%; Brackish 29%; Brackish/Marine 28%; Marine 5%; Euryhaline 2%

Sample: 6-20 Core section: 9 (Just before submergence. Event G)
Depth below land surface: 9.86m (-4.40 m NGVD)
Sediment description: silt/clay to very fine sand
Pertinent diatom species: *Caloneis bacillum, Diploneis pseudovalis, Navicula mutica, Navicula pusilla, Pinnularia lagerstedtii, Navicula tenelloides, Nitzschia nana, Gyrosigma eximium, Navicula cincta, Nitzschia debilis, Navicula phyllepta, Nitzschia constricta*
Environment: High to low brackish marsh
Special notes: Preservation good. Dominant species *Navicula mutica, Navicula pusilla,* and *Pinnularia lagerstedtii* imply brackish high marsh, but many low marsh species imply more of a transitional zone between high and low region.
Species counts: Freshwater 1%; Fresh/Brackish 66%; Brackish 23%; Brackish/Marine 11%

Sample: 6-18 Core section: 9
Depth below land surface: 10.24m (-4.78 m NGVD)
Sediment description: upward fining fine sand to silt
Pertinent diatom species: *Navicula mutica, Nitzschia nana, Nitzschia palea, Cocconeis disculus, Navicula gregaria,* numerous marine/brackish, epipelic *Nitzschia* spp.

Environment: Intertidal mud flat, channel bank, or low brackish marsh
Special notes: Preservation excellent. Many fragile epipelic species occur as whole valves. Dominant fresh/brackish species is *Navicula mutica*, a species commonly found in low marshes. Other dominant group includes intertidal mud flat *Nitzschia* spp.
Species counts: Freshwater 3%; Fresh/Brackish 58%; Brackish 26%; Brackish/Marine 11%; Maine 1%; Euryhaline 1%

Sample: 6-17 Core section: 9
Depth below land surface: 10.26m (-4.80 m NGVD)
Sediment description: silt/clay to very fine sand
Pertinent diatom species: *Nitzschia angustulata, Navicula mutica,* numerous fresh/brackish, brackish, and marine/brackish epipelic *Nitzschia* spp., *Cocconeis disculus, Opephora parva*
Environment: Intertidal mud/sand flat
Special notes: Preservation good, many fragile valves present and intact. Many epipsammic or epipelic brackish species indicates intertidal flat.
Species counts: Freshwater 3%; Fresh/Brackish 54%; Brackish 21%; Brackish/Marine 20%; Marine 1%

Sample: 6-16 Core section: 9 (Just after submergence. Event H)
Depth below land surface: 10.36m (-4.90 m NGVD)
Sediment description: silt/clay with very fine laminae of silt to fine sand
Pertinent diatom species: *Nitzschia angustulata,* numerous fresh/brackish, brackish, and marine/brackish epipelic *Nitzschia* spp,,*Denticula subtilis, Gyrosigma eximium, Navicula cincta, Navicula pygmaea*
Environment: Intertidal mud flat
Special notes: Preservation good. Intertidal epipelic species most common
Species counts: Freshwater 3%; Fresh/Brackish 33%; Brackish 38%; Brackish/Marine 23%; Marine 3%; Euryhaline 1%

Sample: 6-15 Core section: 9 (Just before submergence. Event H)
Depth below land surface: 10.42m (-4.96 m NGVD)
Sediment description: silt/clay; highly organic
Pertinent diatom species: *Eunotia* spp., *Aulocosira* spp., *Tabellaria* spp., *Cymbella minuta, Cymbella pusilla, Fragilaria* spp., *Nitzschia compressa, Nitzschia constricta*
Environment: Freshwater wetland to high brackish marsh
Special notes: Preservation excellent. Most common forms are *Aulocosira* and *Tabellaria* spp., which imply standing freshwater
Species counts: Freshwater 4%; Fresh/Brackish 67%; Brackish 4%; Brackish/Marine 7%; Euryhaline 17%

Sample: 6-14 Core section: 9
Depth below land surface: 10.70m (-5.74 m NGVD)
Sediment description: silt/clay, organic laminae
Pertinent diatom species: *Eunotia* spp., *Stauroneis smithii, Achnanthes lanceolata, Cyclotella meneghiniana, Gomphonema parvulum, Tabellaria fenestrata*

Environment: Frashwater wetland
Special notes: Preservation excellent. Most common species is *Tabellaria fenestrata,* often indicate standing freshwater
Species counts: Freshwater 18%; Fresh/Brackish 80%; Brackish/Marine 2%

Sample: 6-13 Core section: 9
Depth below land surface: 10.80m (-5.34 m NGVD)
Sediment description: silt/clay to very fine sand
Pertinent diatom species: *Eunotia* spp., *Cyclotella meneghiniana, Diatoma tenue, Rhopalodia gibba, Tabellaria fenestrata*
Environment: Freshwater wetland to high brackish marsh
Special notes: Preservation good. Fresh to fresh/brackish forms most common.
Species counts: Freshwater 10%; Fresh/Brackish 82%; Brackish 2%; Brackish/Marine 6%

Sample: 6-12 Core section: 9
Depth below land surface: 10.82m (-5.36 m NGVD)
Sediment description: silt/clay to very fine sand
Pertinent diatom species: *Eunotia* spp., *Cyclotella meneghiniana, Diatoma mesodon, Diatoma tenue, Gomphonema angustulum, Gomphonema parvulum, Navicula mutica*
Environment: Freshwater wetland to high brackish marsh
Special notes: Preservation good. Fresh to fresh/brackish forms most common.
Species counts: Freshwater 30%; Fresh/Brackish 59%; Brackish 1%; Marine 3%; Euryhaline 7%

APPENDIX C: GENERAL PALEOENVIRONMENTAL SETTING EVOLUTION AND RELATIVE SEA LEVEL (RSL) CHANGES

Using information from the diatom assemblage analysis and the radiocarbon dates returned on organic materials from buried soils, we reconstruct dominant depositional setting trends and relative sea level history within the meander study site beginning with the lowest section of the core, Section 22, which reaches a depth of nearly 27 meters below the ground surface. The earliest radiocarbon age returned on organic material from Core 4 is from this lowest section, at -20.63m NGVD, and dates to Cal BP 10220 or 10140 or Cal BP 10000 to 9960 (Radiocarbon dates returned on all organic samples are listed in Table 1).

Diatom counts for each sample extracted from all of the core sections are organized based on salinity preference. Salinity organizational groups include freshwater species (does not tolerate any amount of salt), freshwater-brackish species (salinity tolerance range from 0 to <0.2 $^{o}/_{oo}$), brackish (0.2-10 $^{o}/_{oo}$), brackish-marine (10-30 $^{o}/_{oo}$), marine (>30 $^{o}/_{oo}$), and euryhaline (tolerate a range of salinity). Those diatom valves which could not be identified to species level or for which no salinity preference information was available are classified as "unknown". For each sediment sample, we compute what percentage of the total diatoms counted per slide each salinity group represents. From this salinity data and based on the dominant species present at each sediment interval, we make inferences about the paleo-environmental setting at the coring site through time. A discussion of diatom salinities and inferred depositional setting is presented in Appendix 1 and summarized in Figure 4.

Freshwater and fresh-brackish diatoms are most dominant in the upper two meters of the core, with assemblages indicating a predominantly freshwater marsh or upland environment. While our chronostratigraphic data does not directly indicate when the change from predominantly freshwater deposition at the site to brackish high and low marsh deposition occurred, accretion of the marsh surface in nearby areas reached elevations above brackish high marsh elevation (assuming a maximum elevation of 1.6m above MTL for a brackish high marsh (Nelson and Kashima 1993)) around 3,000 cal yr BP (Kelsey et al. 2002:Fig. 7).

From around -2 to -10m depth below the ground surface (~ 3.5 to -4.75m NGVD), diatom assemblages are mixed, with spikes in low salinity tolerant species interspersed with more saline-tolerant species assemblages. Dominant diatoms include high and low brackish marsh species, with occasional build up of a more freshwater assemblage or sudden influxes of predominantly brackish to marine valves. A heavier conglomeration of brackish to brackish-marine species occurs at a depth of -6.5 to -8m (~ -1.0 to -2.5m NGVD). Species associated with intertidal mud or sand flats, *Zostera* beds, and subtidal channels are common in this interval, indicating a brackish low marsh or estuarine tidal flat environment. Using age data from seeds extracted from -9.97m depth (-4.42m NGVD) this area remained an intertidal wetland depositional setting until ca. 6690 to 6890 cal yr BP (Table 1).

At approximately 10m below the coring surface (-4.75m NGVD) to nearly -17m depth, the diatom assemblage data becomes sparse, with only a few valves and valve fragments preserved for analysis. The identifiable whole and fragmented valves indicate a dominantly freshwater depositional environment at this time, from nearly 7,000 cal yr BP lasting until around 9,000 years ago. By 9120 to 9440 (Table 1) diatom salinity preferences again become predominantly fresh-brackish, with punctuated episodes of more saline-tolerant assemblages, especially in the lowest 2.5 meters of the core. Brackish high or low marshes are indicated by samples extracted from a depth of approximately -17m (-11.5m NGVD) to -25.5m depth (-18.5m NGVD). The lowest 1.5 meters of core sediments are characterized by brackish assemblages, with numerous tidal flat and low to high brackish marsh species identified.

We construct a general history of relative sea level (RSL) at the site using radiocarbon age assignments for buried soils (Table 1) in association with diatom-derived estimates of paleo-mean tide levels (MTL) (Table 2). No attempt to estimate downcore compaction amounts was attempted. In general, the slope of the sea level curve is steepest from around 10,000 to 6,500 cal yr BP, whereupon the curve begins to level out (Figure 5). This implies that the highest rate of RSL rise is during the late Pleistocene to the mid Holocene, a contention that agrees well with global estimates of eustatic sea level rise (Bloom 1980; Fairbanks 1989). After 6,500 cal yr BP, RSL rise slows until ca. 2500 years ago, when it levels to near its present elevation. Sediment accretion at the site kept pace with sea level rise until ca. 2500 years ago (Dashed line, Figure 5). At that time, the site became emergent as the marsh surface continued to accrete sediment while eustatic sea level maintained a near steady state. This is recorded in Figure 5 as RSL fall.

Superimposed upon the general sea level curve constructed for the area are six instances of sudden relative sea level change (Figure 5). As with the paleo-environmental setting reconstruction, diatom assemblage data compiled in Appendix 1 are used to infer intertidal zonation of diatom samples extracted from above and below buried soil horizons. Based on elevation ranges relative to NGVD of intertidal zones derived from Nelson and

Kashima (1993), we estimate the magnitude of vertical change across each of the six radiocarbon dated buried soils (Events A, G, I, J, K, and L). The constructed relative sea level curve (Figure 5) incorporates error margins related to these ranges in elevation for each diatom assemblage as rectangle height. Additionally, errors in age estimates for each sample are listed in Table 2 and are portrayed in Figure 5 as rectangle width. The amount of subsidence incurred by the site during each event ranged from 0 to 3.2m (Table 2). We infer that submergence for each event exceeded the estimated minimum because in each case the diatom assemblage data indicate a change from a higher to a lower intertidal zone across the buried soil horizon.

The paleoenvironmental reconstruction of the environment is important for determining what sediments have a higher likelihood of preserving a record of marsh surface burial by sudden inundation and a lasting change to a lower intertidal environment. If intertidal marsh sediments are preserved throughout the length of the core, then preservation of stratigraphic data that meets the criteria in support of a coseismic origin for soil burial is possible. Our Core 4 contains intertidal sediments as deep as the lowest section of the core, which dates to the late Pleistocene/early Holocene transition. Although this record is not continuous, as fluvial deposition of larger grained sediments dominates the middle portion of the core, the record does provide excellent preservation of intertidal sediments dating to the late to middle Holocene, a time period sorely underrepresented in the current database of CSZ tectonic study.

APPENDIX D: LITHO-,BIO-, AND CHRONOSTRATIGRAPHIC METHODS FOR CHAPTER 4

Core 4 was extracted in 22 sections, measuring 1.22m each, to a depth of -21.2 m NGVD. In order to minimize mixing of sediments between sections, the Geoprobe corer was lowered to the appropriate depth within the core hole before the probe barrel was opened for sediment retrieval. In this way, only those sediments encountered between a known range of depths spanning 1.22 m were recovered and compaction amounts due to coring activities could be determined on a section-by-section basis. Unfortunately, due to the nature of the coring device, some of the wetter sediments from core Sections 1, 3, and 4 were lost during the coring process. All sections below Section 4 (below 0.67 m) were recovered intact with minimal amounts of compaction or sediment loss.

Following recovery of sediment cores, we employed a number of litho-, bio- and chronostratigraphic analyses to reconstruct the evolution of depositional environments at the site. Our objective was to determine general trends in relative sea level (RSL) rise and fall at the site, as well as to differentiate between dominant depositional forces operating through time. We aimed to identify instances of rapid RSL rise that left a stratigraphic signal consistent with those identified in other studies of great CSZ earthquakes, and to gather evidence to assess the plausibility of a coseismic origin for the subsidence following the criteria outlined by Nelson et al. (1996b) and Hemphill-Haley (1995b). We concentrated our efforts on the longest of the cores, Core 4, in order to determine the site's potential as an on-shore recorder of coseismic subsidence dating back to the late Pleistocene/early Holocene time period. We also performed some limited litho- and biostratigraphic analyses of Core 6 in order to assess the lateral extent of buried soil horizons older than the oldest event reported by Kelsey et al. (2002).

Lithostratigraphic Investigations

Laterally extensive, sudden submergence of tidal wetlands and tsunami deposits overlying buried wetland soils are two forms of lithostratigraphic evidence for plate boundary earthquakes (Nelson et al. 1996b). Research in coastal settings along the CSZ indicates that a coseismic vertical drop in land level of over 0.5m will result in widespread stratigraphic and ecological changes in coastal wetlands that lie within the range of mean tide to mean higher high water. These changes indicate sudden rises in relative sea level as the land drops in relation to tidal levels and are recorded in the stratigraphy of the wetland sediments (Atwater 1987; Darienzo and Peterson 1990; Nelson and Kashima 1993; Darienzo et al. 1994; Guilbault et al. 1995; Hemphill-Haley 1995; Nelson et al. 1996a; Shennan et al. 1996; Atwater and Hemphill-Haley 1997; Nelson et al. 1998; Shennan et al. 1998; Kelsey et al. 2002; Witter et al. 2003). Tsunamis accompanying regional slip along the CSZ will result the landward transport and deposition of continuous or discontinuous sheets of sandy sediment onto coastal areas within 3-10m above sea level. A sharp (<3mm) boundary will separate underlying, buried wetland sediments and these rapidly deposited tsunami deposits (Bourgeois and Reinhart 1989; Minoura and Nakaya 1991; Clague and Bobrowsky 1994; Dawson 1994; Hemphill-Haley 1995; Atwater and Hemphill-Haley 1997).

Prior to splitting, we analyzed each core section for magnetic susceptibility and gamma density. Each section was passed through the Geotek multi-sensor core logger at Oregon State University's Department of Oceanography and Atmospheric Sciences core analysis and storage facility to determine downcore magnetic susceptibility of sediments. Sediments with higher proportions of magnetic minerals give higher susceptibility readings. A study conducted by Boggs (1969) of heavy minerals from within the Sixes River basin shows that greater relative amounts of the highly susceptible mineral magnetite are found within river sediments versus beach or estuary sediments. General trends in the relative influence of river deposition versus deposition from an estuary or beach source appear as relatively higher or lower magnetic susceptibility readings through the stratigraphic record in the extracted cores. Gamma density is a remotely sensed measure of bulk density, which can be considered a proxy for grain size in that smaller grains will be consolidated more tightly and with less porosity than larger grains for a given volume of sediment under conditions of high compaction (Brady 1990).

Cores were split into halves, digitally and x-ray photographed, and described with special attention to color, grain size, sorting, bedding, inclusions, and boundaries (Figure 3). Physical grain size was determined by visual inspection and manual measurement of the sediments using sieves to separate clays/silts from sand sizes. We also conducted loss on ignition (LOI) tests on core sediments to determine relative amounts of organic carbon content.

Biostratigraphic Investigations

Environments of deposition can be inferred through the identification of litho-stratigraphic boundaries and analysis of fossil diatom assemblages within sediments on each side of these boundaries (Nelson and Kashima 1993; Hemphill-Haley 1995; Nelson et al. 1996b). Because specific diatom assemblages are associated with distinct freshwater, brackish, and marine settings, identification of changes in assemblage composition over lithologic boundaries can inform about shifts in depositional environments. Studies of extant diatom species extracted from defined elevation ranges in tidal marsh settings reveals patterns in assemblage composition based on intertidal zone (Nelson and Kashima 1993; Hemphill-Haley 1995). Based on these observations, sudden relative sea level fluctuations can be identified and magnitudes of local elevation shifts during burial events estimated.

Samples from Core 4 were chosen for extraction based on three primary factors: lithology and/or soil characteristics, magnetic susceptibility readings, and gamma density. Apparent changes in any of these factors within a core section may imply a change in depositional state. Sediments on each side of these changes were sampled for quantitative biostratigraphic examination. About 1-2cc of sediment was extracted for each sample. Sediment samples were cleaned by oxidizing in 30% H_2O_2 and rinsing with distilled water. Silica was separated from heavy mineral sediments by flotation in a sodium polytungstate solution with a specific gravity of 2.56, transferred to a separate centrifuge tube, and repeatedly rinsed using distilled water. An aliquot of approximately 0.05 to 0.10 ml of the cleaned water-silica solution was then transferred to a cover slip, allowed to dry, and permanently mounted on a glass slide using Hyrax.

Diatom preservation throughout the core was variable, with the best preservation occurring in the upper eight core sections (to approximately -4.00 m NGVD). Where possible, 100+ diatoms were identified to the species level and counted per slide at a magnification of 1000x. In cases where <100 diatoms were counted, paleosalinity and paleoenvironmental inferences were based on those diatoms valves that could be identified. Salinity tolerances for each species and variety were compiled from a number of sources, including Patrick and Reimer (1966; 1975); Nelson and Kashima (1993); Hemphill-Haley (1993); Hemphill-Haley and Lewis (1995); Laws (1988); John (1983); Foged (1981); Pankow (1990); and Krammer and Lange-Bertalot (1986-1991). We gave special attention to studies from the Pacific Northwest region that compare modern assemblage data to intertidal depositional environment, including Laws (1988); Nelson and Kashima (1993); Hemphill-Haley (1993); Hemphill-Haley and Lewis (1995); and Hemphill-Haley (1995a,b).

Chronostratigraphic Investigations

Samples for radiocarbon dating were chosen based on their association with buried wetland soils. Materials were extracted for dating from within 1 cm of the boundary between the buried wetland soil and the overlying tsunami deposit or intertidal mud in order to best estimate the time of land subsidence and burial. Each sample was mixed with 30 ml of distilled water and sodium metahexaphoshate to allow botanical and charcoal remains to deflocculate from clays and float to the surface. These samples were then filtered through a fine mesh and allowed to dry. When present, specimens of identifiable seeds or woody detritus, botanical fossils considered most reliable for dating (Nelson 1992; Kelsey et al. 2002), were picked using a dissecting microscope and submitted for accelerator mass spectrometry (AMS) radiocarbon dating. Charcoal fragments were selected for dating when other biological remains were absent. In these cases, care was taken to choose angular rather than rounded specimens to avoid redeposited samples.