Tracking Prehistoric Cascadia Tsunami Deposits at Nestucca Bay, Oregon, USA

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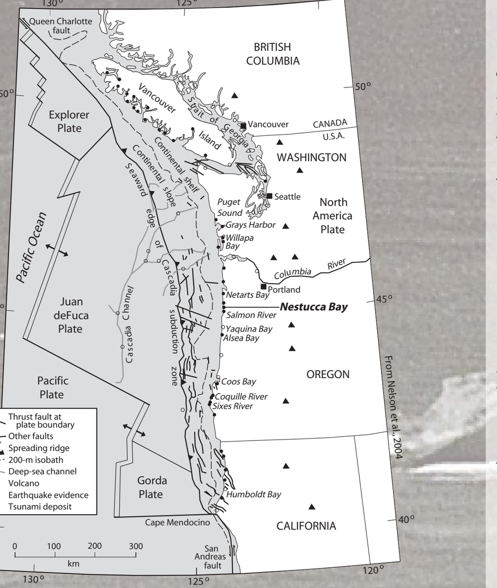
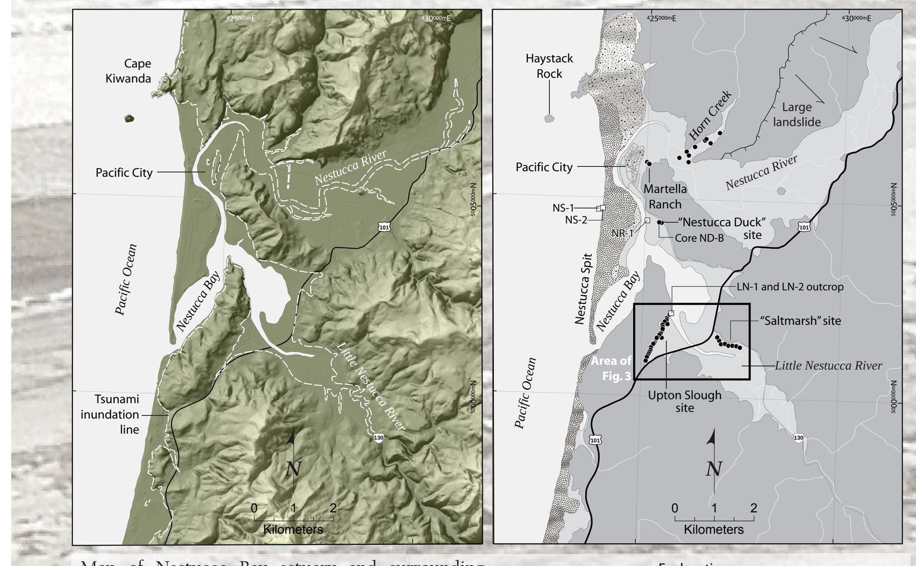


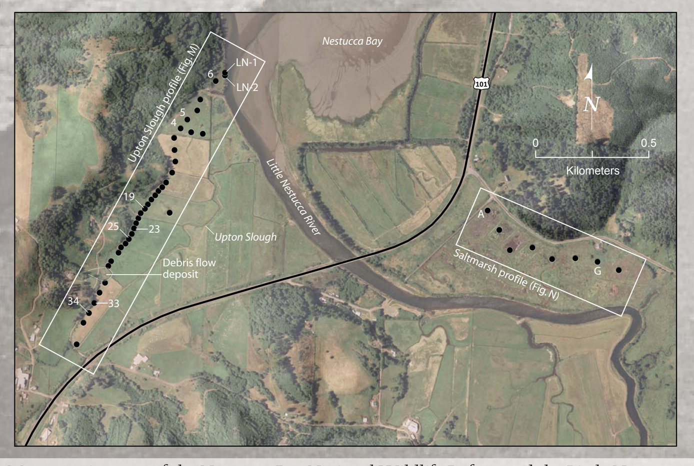
Tectonic setting of the Pacific northwestern U.S. showing the Cascadia subduction zone and other plate boundaries, Quaternary faults in the North American plate, and the location of the study site at Nestucca Bay in northwestern Oregon. The deformation front (barbed line) is defined by bathymetry where the abyssal plain meets the continental slope and is inferred to represent the surface projection of the Cascadia thrust fault. Open and closed circles represent sites with evidence for prehistoric Cascadia earthquakes and tsunamis. Closed circles also mark sites with deposits interpreted to record tsunami inundation caused by a M9 Cascadia earthquake on January 26, 1700 (Satake et al., 1996).

INTRODUCTION. Three tsunamis triggered by great earthquakes on the Cascadia subduction zone have inundated Nestucca Bay, Oregon over the past 2000 years. The primary evidence includes layers of sandy sediment that bury tidal marshes submerged by earthquake-related subsidence. Additional tsunami evidence includes: the spatial extent of sandy deposits, clear trends in deposit thickness and mean particle size that decrease with increasing distance inland, the presence of brackish-marine diatoms within the deposit and normally graded layers within each deposit. ^{14}C age ranges for the youngest tsunami sand span the date of the most recent Cascadia earthquake and tsunami in 1700. Sediment cores and a single tidal outcrop define the spatial limit of the 1700 tsunami deposit, which extended at least 4.4 km inland. The widespread extent of the 1700 deposits makes storm surges, and waves superimposed on them, an unlikely explanation. Physical attributes similar to beach and dune sand indicate an ocean-ward source and preclude river flooding.

STUDY AREA



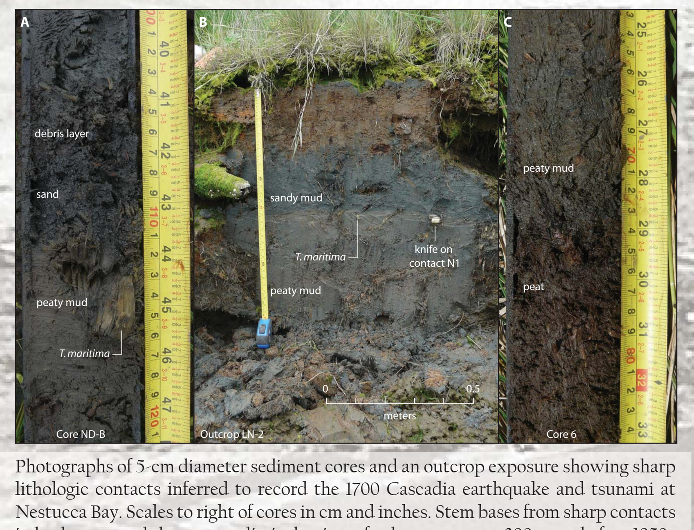
Map of Nestucca Bay estuary and surrounding uplands showing the locations of 37 sediment cores examined for evidence of sand layers deposited by tsunamis or river floods. (Left) Topographic hillshade (USGS 10 m DEM) of the Nestucca Bay area showing the Oregon tsunami inundation line used to restrict new development along the coast (Olmstead, 2003; Priest, 1995). (Right) Simplified geologic map of the Nestucca Bay area showing core sites (black dots) and sites sampled for sandy surface sediment (white squares).



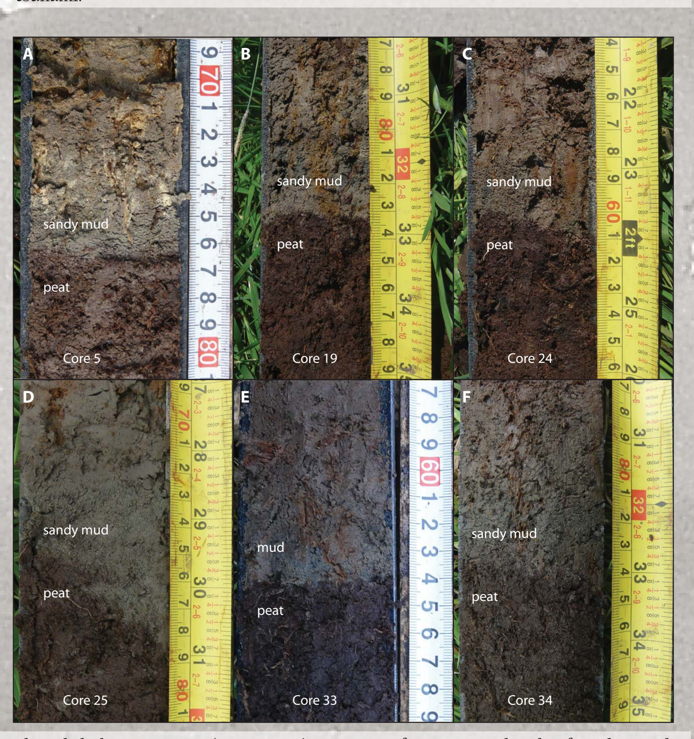
Map covering part of the Nestucca Bay National Wildlife Refuge and the Little Nestucca River showing core locations along two transects: one along Upton Slough and another within a saltmarsh east of Highway 101 restored by the U.S. Fish & Wildlife Service.

OLDER SANDY DEPOSITS. Two older sandy deposits record tsunamis that inundated the bay about 1.2 ka and 1.6 ka – times that correspond to widespread evidence for great Cascadia earthquakes and tsunamis at adjacent estuaries and in offshore turbidite records. Both deposits meet multiple criteria used to infer a tsunami origin, although the physical properties of the sand resembled sediment from the sandy flats of the Little Nestucca River rather than beach or dune sand over 5.5 km away. The physical characteristics of older sandy layers reflect sediment sources along the tsunami flow path.

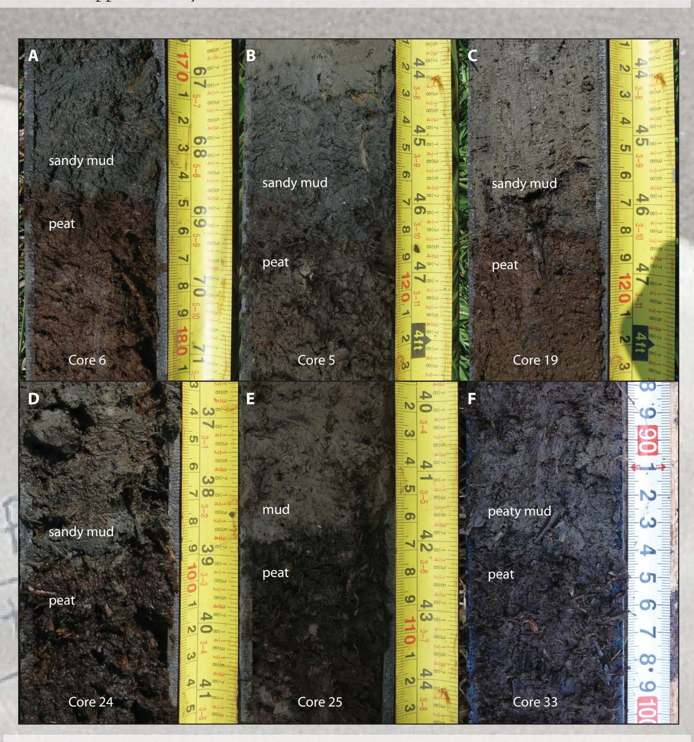
TSUNAMI DEPOSITS



Photographs of 5-cm diameter sediment cores and an outcrop exposure showing sharp lithologic contacts inferred to record the 1700 Cascadia earthquake and tsunami at Nestucca Bay. Scales to right of cores in cm and inches. Stem bases from sharp contacts in both cores and the outcrop limit the time of submergence to <300 years before 1950, which is consistent with regional evidence for the 1700 Cascadia earthquake and tsunami.

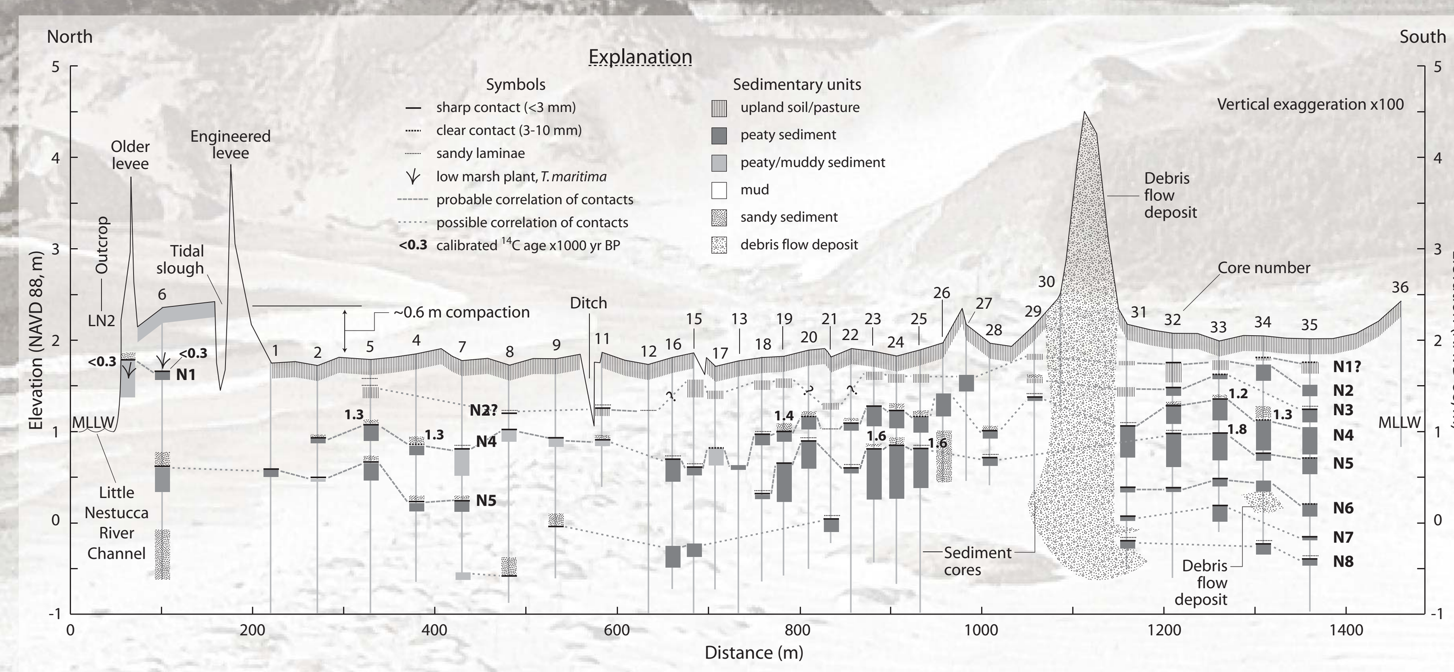


Sharp lithologic contacts (contact N4) in six cores from Upton Slough inferred to mark coseismic subsidence and tsunami deposition caused by a Cascadia earthquake that occurred approximately 1.2 ka.

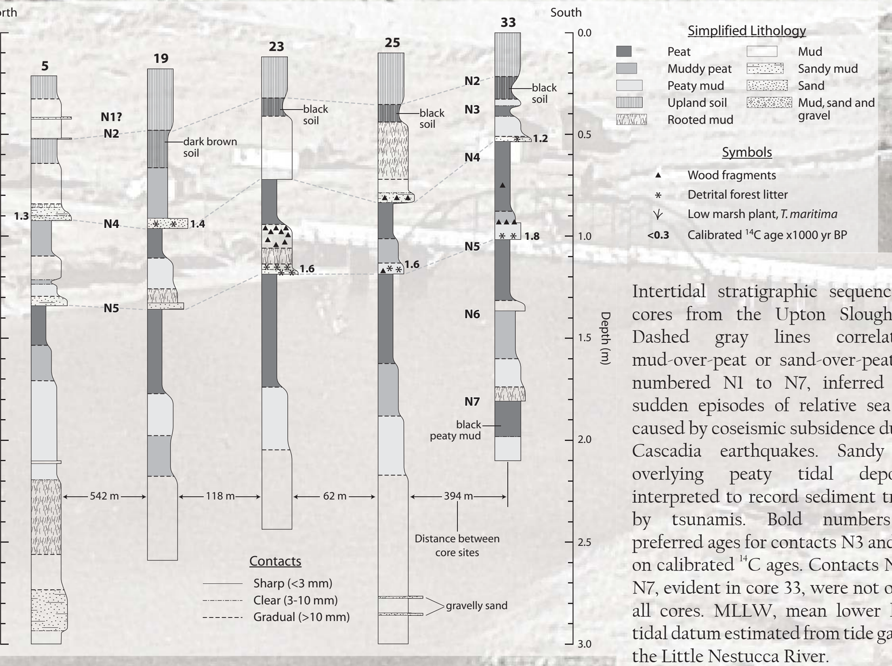


Sharp lithologic contacts (contact N5) in six cores from Upton Slough inferred to mark coseismic subsidence and tsunami deposition caused by a Cascadia earthquake that occurred approximately 1.6 ka.

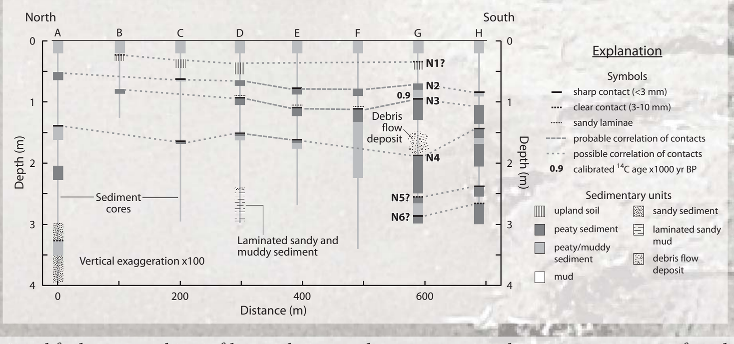
STRATIGRAPHIC PROFILES



Simplified stratigraphic profile correlating mud-over-peat or sand-over-peat contacts inferred to reflect sudden rises in relative sea level in cores along Upton Slough. Solid and dashed black lines mark sharp (<3 mm) and clear (3-10 mm) lithologic contacts, respectively. Gradual lithologic contacts lack either line symbol. Gray dashed lines labeled N1 through N8 correlate contacts inferred to record sudden episodes of relative-sea level rise. Bold numbers indicate preferred ages for contacts N1, N3 and N4, rounded to the nearest hundred years, based on calibrated ^{14}C ages. Core elevations determined by RTK GPS survey have <2 cm vertical error. We infer compaction of ~0.6 m lowered the north pasture, located behind large engineered levees that bar tidal flooding. MLLW, mean lower low water tidal datum estimated from tide gage data for the Little Nestucca River.

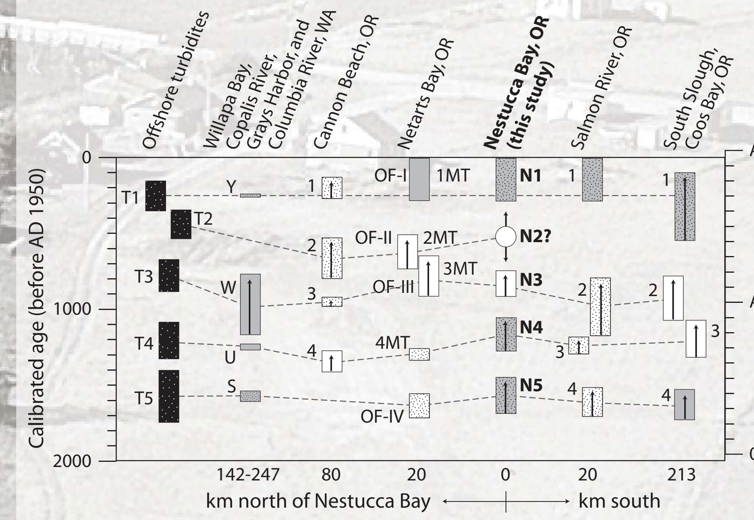


Intertidal stratigraphic sequences in five cores from the Upton Slough transect. Dashed gray lines correlate sharp mud-over-peat or sand-over-peat contacts, numbered N1 to N7, inferred to reflect sudden episodes of relative sea level rise caused by coseismic subsidence during great Cascadia earthquakes. Sandy sediment overlying peaty tidal deposits are interpreted to record sediment transported by tsunamis. Bold numbers indicate preferred ages for contacts N3 and N4 based on calibrated ^{14}C ages. Contacts N3, N6 and N7, evident in core 33, were not observed in all cores. MLLW, mean lower low water tidal datum estimated from tide gage data for the Little Nestucca River.



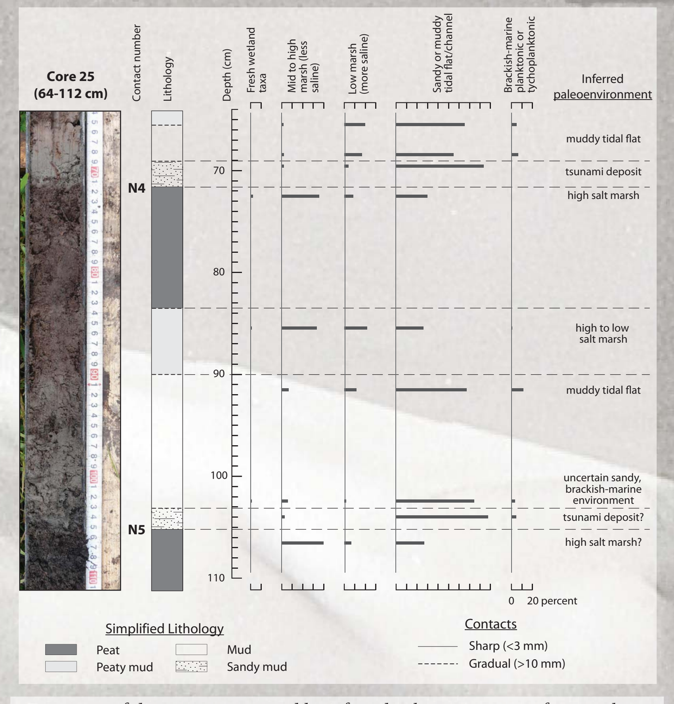
Simplified stratigraphic profile correlating mud-over-peat or sand-over-peat contacts inferred to reflect sudden or gradual rises in relative sea level in cores along the "Saltmarsh transect" in the Nestucca Bay Refuge. Vertical axis depicts depth, in meters, from the surface.

CHRONOLOGY OF TSUNAMIS

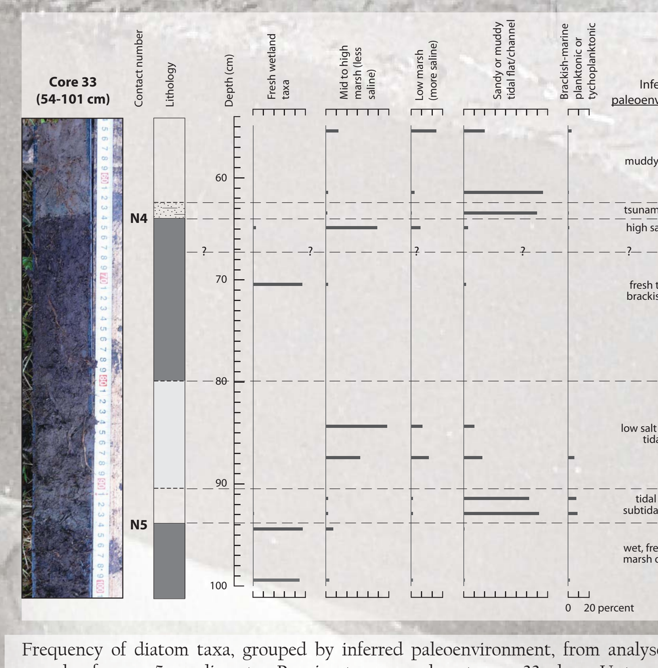


Comparison of calibrated ^{14}C ages and coastal evidence for great Cascadia earthquakes and tsunamis over the last two millennia at seven sites in southwestern Washington and northwestern Oregon (modified from Nelson et al., 2004). Black rectangles represent ages for offshore turbidite deposits inferred to record strong shaking during prehistoric Cascadia earthquakes (Goldfinger et al., 2009). Arrows indicate maximum limiting ^{14}C ages based on dates of detrital plant fossils and herbaceous stems rooted in marsh sediment. Ages for evidence at sites in southwestern Washington are from Atwater et al. (Atwater et al., 2003). Ages from coastal sites in Oregon come from Cannon Beach (Witter, 2008), Netarts Bay (Darienzo et al., 1994; Nelson et al., 1995; Shennan et al., 1998), Salmon River (Nelson et al., 2004; Nelson et al., 1995), and South Slough near Coos Bay (Nelson et al., 1998; Nelson et al., 1996). Local evidence for earthquake-related subsidence is lacking for one or more stratigraphic contacts at Cannon Beach, Netarts Bay and Coos Bay (e.g., Shennan et al., 1998).

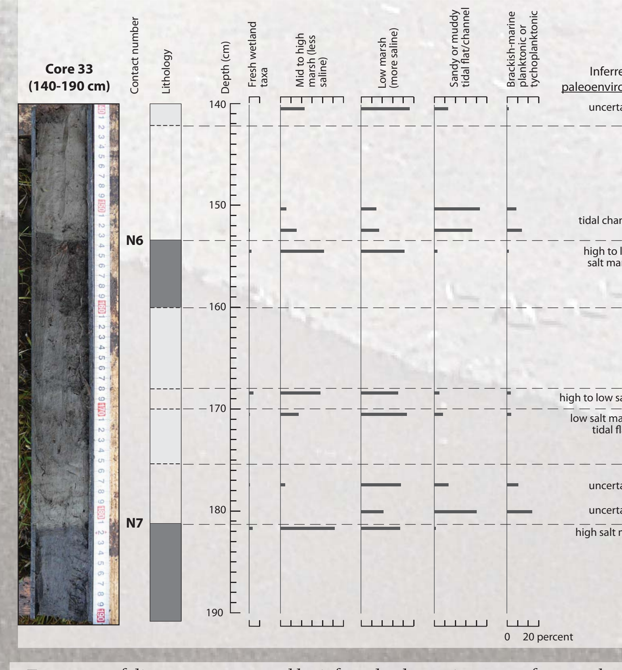
BIOSTRATIGRAPHY



Frequency of diatom taxa, grouped by inferred paleoenvironment, from analyses of 9 samples from a 5-cm-diameter Russian-type sampler at core 25 along Upton Slough. Diatom frequency is expressed as a percentage of total diatoms counted in each sample. The depths of contacts N4 and N5 in the Russian-type core were 10 to 20 mm deeper than contacts observed in gouge cores used to construct stratigraphic profiles. Photograph of Russian-type core at left.

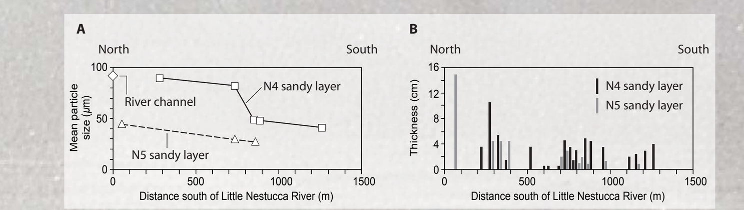


Frequency of diatom taxa, grouped by inferred paleoenvironment, from analyses of 11 samples from a 5-cm-diameter Russian-type sampler at core 33 along Upton Slough. Diatom frequency is expressed as a percentage of total diatoms counted in each sample. The depth of contacts N4 and N5 in the Russian-type core were approximately 10 mm deeper than the same contacts observed in gouge cores used to construct stratigraphic profiles. Photograph of Russian-type core at left; core lithology shown to the left.

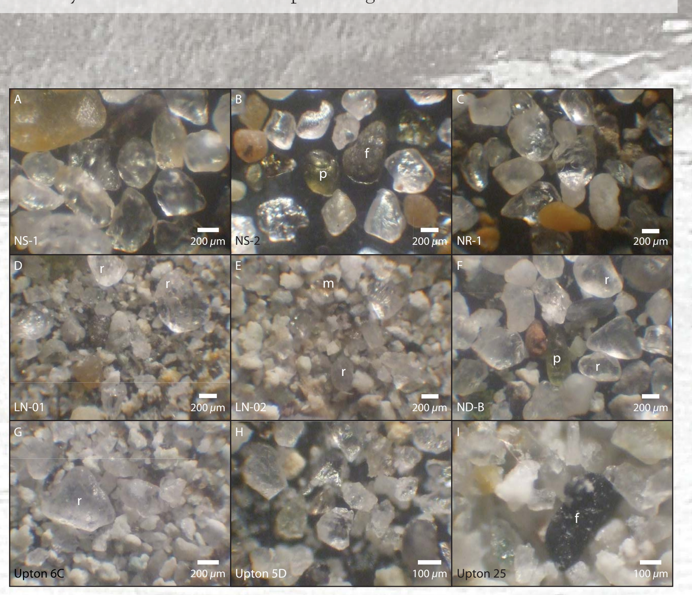


Frequency of diatom taxa, grouped by inferred paleoenvironment, from analyses of 9 samples from a 5-cm-diameter Russian-type sampler at core 33 along Upton Slough. Diatom frequency is expressed as a percentage of total diatoms counted in each sample. The depths of contacts N6 and N7 in the Russian type core differed by <20 mm compared to contacts observed in gouge cores used to construct stratigraphic profiles. Photograph of Russian-type core at left; core lithology shown to the left.

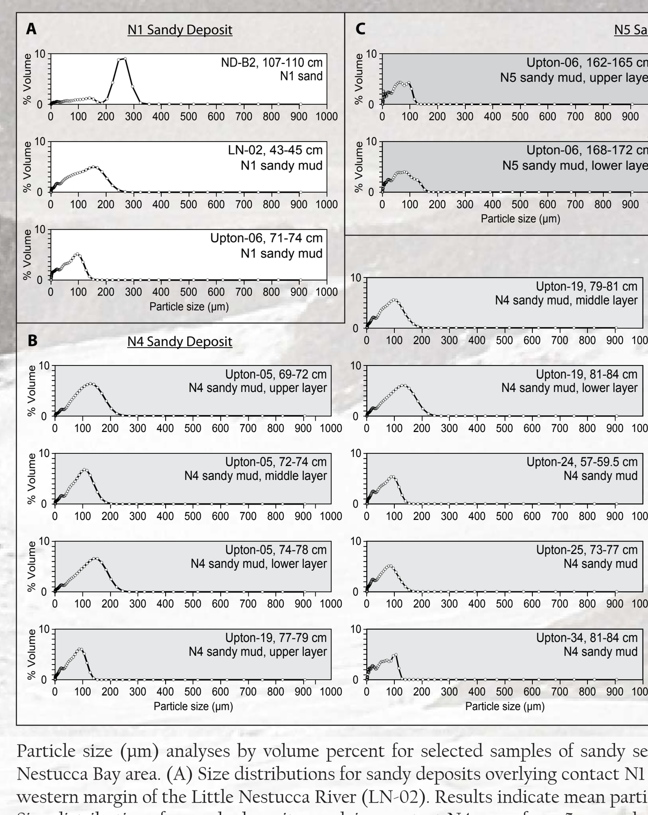
PHYSICAL PROPERTIES OF SAND



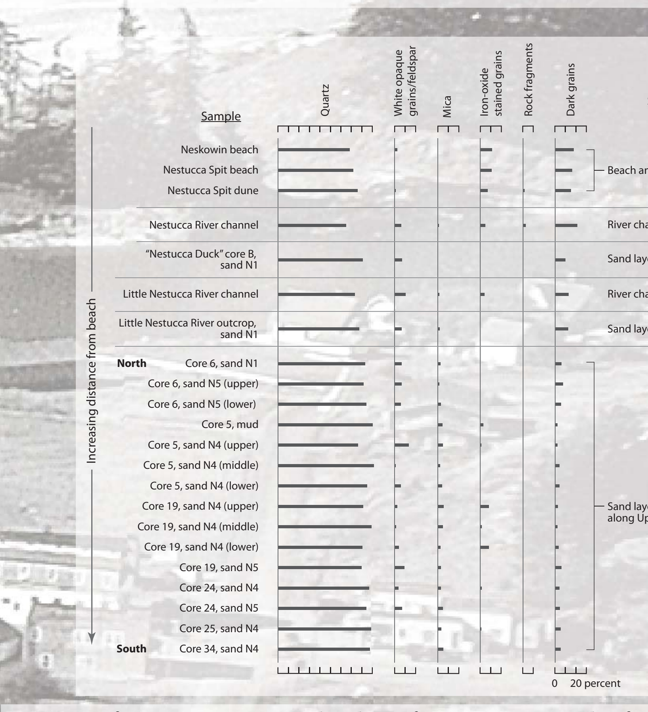
(A) Mean particle size versus distance from the Little Nestucca River channel for the N4 and N5 sandy layers. In both cases, sandy layers become finer grained with increasing distance from the river channel. Mean particle size of sandy sediment from the Little Nestucca River channel (open diamond) for comparison. (B) Sand layer thickness versus distance from the Little Nestucca River channel for the N4 and N5 sand layers as revealed in cores at Upton Slough.



Selected photographs of sand grains under 3.5x and 10x magnification using a petrographic microscope. (A and B) Examples of well-rounded beach (NS-1) and dune (NS-2) sand. Conspicuous pyroxene (p) and rock fragments (f) are visible in sample NS-2. (C) Sand sampled from the Nestucca River is subrounded. (D) Very fine, predominantly angular sand from the Little Nestucca River channel near Upton Slough contains rare larger (>300 µm) rounded quartz grains (r) probably redeposited by tidal currents. (E and F) Samples of sand above contact N1 from cores close to river channels contain rounded quartz grains (r), although they are more abundant in sample ND-B and rare in sample LN-02. A rounded pyroxene (p) occurs in sample ND-B and a mica (m) grain is visible in sample LN-02. (G) Rare, subrounded (r) quartz grains were identified in sand overlying contact N5 in core 6. (H and I) Sand overlying contact N4 lacks rounded grains and consists of abundant angular quartz grains and rare rock fragments (f). Note change in scale, lower right of photos.



Particle size (µm) analyses by volume percent for selected samples of sandy sediment from surface sites and cores in the Nestucca Bay area. (A) Size distributions for sandy deposits overlying contact N1 come from two cores and an outcrop on the western margin of the Little Nestucca River (LN-02). Results indicate mean particle size of the deposits decrease inland. (B) Size distributions for sandy deposits overlying contact N4 come from 5 cores along Upton Slough. (C) Size distributions for sandy deposits overlying contact N5 come from 3 cores along Upton Slough. (D) Particle size analyses of sandy sediment from the beach (NS-1, NESK-P1), dune (NS-2) and the western channel margin of the Little Nestucca River (LN-01) provide a basis for comparison with samples from outcrop and cores. Analyses of mud sampled from core 5 (Upton 05) provide particle size data for sediment deposited in a muddy tidal flat.



Frequency of constituent grains in sandy sediment from cores, outcrop and surficial deposits around Nestucca Bay. Samples are arranged vertically according to sample site proximity to the beach: samples at the top of the list are beach samples; samples at the bottom of the list are far from the beach. Analyses of sandy layers from cores are arranged vertically from north (top) to south (bottom). In general, quartz and mica sand components increased with increasing distance from the beach. We found no mica in samples of either beach or dune sand. Beach, dune and river channel sediment had higher components of dark sand grains relative to sandy layers in cores far from the beach.

CONCLUSIONS. Stratigraphic sequences of intertidal facies beneath the margins of Nestucca Bay archive a history of relative sea level change in response to the earthquake deformation cycle as well as the effects of tsunamis, but they may not capture the complete record of great Cascadia earthquakes and tsunamis at Nestucca Bay over the past 2000 years. This inference is supported by equivocal evidence for one or two peaty horizons buried between the times of the 1.2 ka and 1700 tsunamis. These buried marsh deposits,which largely lack distinctive, laterally continuous sandy deposits, probably reflect small changes in relative sea level that may have been caused by a number of processes, including earthquakes, climate variation and changes in the configuration of the estuary (Nelson et al., 1996). In addition, older sharp lithologic contacts recognized in stratigrphic sequences along Upton Slough lack the lateral continuity and biostratigraphic evidence necessary to confidently attribute them to Cascadia events. Therefore, the evidence we have uncovered at Nestucca Bay stresses the importance of understanding the variability of creation and preservation thresholds that control whether a particular site holds complete or incomplete geologic record of great Cascadia earthquakes and tsunamis.

(References available upon request)

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