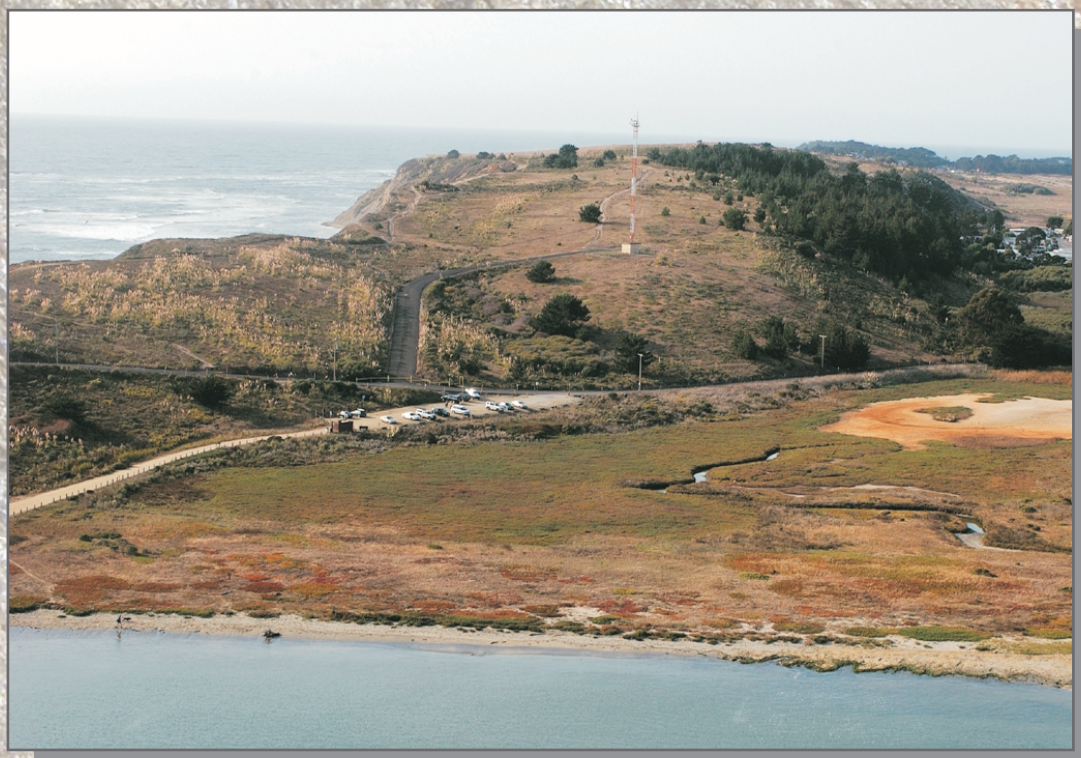
WILLIAM LETTIS & ASSOCIATES, INC.

FINAL TECHNICAL REPORT

Paleoseismic Investigation of the Northern San Gregorio Fault at Pillar Point Marsh near Half Moon Bay, California



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U.S. Geological Survey
National Earthquake Hazards
Reduction Program
Award Number 02HQGR0071

Submitted by:
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March 2004

WLA

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March 1, 2004

Dr. John Unger
U.S. Geological Survey
905 A National Center
12201 Sunrise Valley
Reston, Virginia 20192

Dear Dr. Unger:

We are pleased to submit the final technical report for our study conducted for the National Earthquake Hazards Reduction Program. Please find the unbound original, five bound copies, and a PDF copy of the report entitled "Paleoseismic Investigation of the Northern San Gregorio Fault at Pillar Point Marsh near Half Moon Bay, California". We have submitted the financial status report, SF 269, directly to the Contracting Officer. The preliminary findings of this investigation were presented at the First Annual Northern California Earthquake Hazards Workshop in Menlo Park, January 13-14, 2004.

Title of Grant:	Paleoseismic Investigation of the Northern San Gregorio Fault at Pillar Point Marsh near Half Moon Bay, California.
Award #:	02HQGR0071
Principal Investigators:	Rich D. Koehler and William R. Lettis; William Lettis & Associates, Inc., 1777 Botelho Drive, Suite 262, Walnut Creek, CA 94596

We have appreciated the opportunity to conduct this research. Please do not hesitate to contact me if you have any questions or if we can be of further assistance.

Sincerely,
William Lettis & Associates, Inc.

Rich D. Koehler
Project Geologist

cc: Sherri Ly Newman

FINAL TECHNICAL REPORT

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ABSTRACT

The 110-km-long northern San Gregorio fault system (SGF) is an active, northwest trending right-lateral strike-slip fault zone that extends from Monterey Bay to Bolinas Lagoon, California. Despite its significance, the SGF has received relatively little attention regarding its late Holocene paleoseismic behavior because much of the fault lies offshore. Data on the amount and timing of prehistoric earthquakes on the northern SGF are essential to evaluating probabilistic seismic hazard assessments for the San Francisco Bay Area.

Abrupt stratigraphic succession of fresh-brackish marsh soils and intertidal mud within Pillar Point marsh record evidence for sudden changes in relative sea level. The marsh lies within an inferred pull-apart structure between two right-stepping strands of the SGF along the northern margin of Half Moon Bay. Changes in the depositional environment are a function of sudden tectonic subsidence and gradual eustatic sea level rise. Diatom paleoecology and stratigraphic relations are used to evaluate the origin and timing of abrupt changes in the depositional record. Rapid submergence is indicated for two buried marsh surfaces by an abrupt change in diatom assemblage from fresh-brackish species below the contact to brackish marsh/tideflat species above the contact. The abrupt transition from a grassy meadow or dune field to a brackish marsh provides possible evidence for a third subsidence event. A sustained period of aggradation, abrupt upper contact, and a change in diatom assemblage from fresh brackish soil below the contact to a fresh-brackish pond above the contact indicates the possibility of a fourth subsidence event. We can not rule out, however, that erosion and alluvial deposition involved a shift to a wetter climatic period that formed a fresh-brackish pond unrelated to coseismic deformation. These data support the occurrence of at least two and possibly four Holocene earthquakes on the northern SGF. Radiocarbon analyses for deposits associated with the older subsidence events are necessary to provide a preliminary earthquake chronology for the fault.

Existing paleoseismic data on the northern SGF is compared with results of this study in order to evaluate the dates of prehistoric earthquakes. These data indicate that the most recent earthquake occurred between AD 1667 and 1802, synchronous with the date of the MRE determined at the nearby Seal Cove trench site. Therefore, the results obtained in this study demonstrate the utility of using marsh stratigraphic techniques to evaluate paleoearthquakes along strike-slip faults.

1.0 INTRODUCTION

The San Gregorio fault system is an active, northwest-trending right-lateral strike slip fault zone that extends from Monterey Bay to Bolinas Lagoon (Figure 1). In coastal San Mateo County, the northern San Gregorio fault lies approximately 14 km west of the San Andreas fault and is exposed on land in only two places: between Point Ano Nuevo and San Gregorio, and between Pillar Point and Moss Beach (Figures 1 and 2). Despite geomorphic and paleoseismic evidence of Holocene activity (Simpson et al., 1997; 1998 Simpson and Knudsen, 2000), data on the timing and recurrence of past earthquakes along the northern San Gregorio fault (SGF) are sparse.

The Pillar Point marsh study site is located adjacent to the SGF along the northern margin of Half Moon Bay, directly east of the Pillar Point headland (Figure 2). In this area, the SGF appears to form a 4- to 5-km-wide right-releasing stepover across Half Moon Bay (Figure 1). This interpretation of the tectonic geomorphology of the SGF is consistent with offshore marine geophysical surveys across Half Moon Bay that image at least one, prominent fault strand outside (i.e., west) of the Bay. The Pillar Point Marsh lies within an inferred pull-apart structure between two fault strands within this right-stepover region (Figures 1 and 2). This right-releasing geometry produces subsidence within Half Moon Bay and Pillar Point marsh. Changes in the depositional environment of Pillar Point marsh are a function of tectonic subsidence and gradual eustatic sea level rise.

Coseismic subsidence of coastal marshes can cause environmental changes that may be recorded in the sedimentary stratigraphy and fossil floral and faunal assemblages of a marsh system. Rapid environmental changes within marsh deposits have been attributed to coseismic land-level changes along the Cascadia Subduction Zone (Witter et al., 2003; Atwater and Hemphill-Haley, 1997; Carver et al., 1996; 1995; Abrahamson, 1998; Nelson et al., 1996b; Atwater, 1992; Darienzo and Peterson, 1990) and in localized pull-apart basins along the San Andreas fault at Bolinas Lagoon and Bodega Bay (Knudsen et al., 2002). Therefore, the intent of this study is to address the possibility that surface-faulting earthquakes on the SGF may cause coastal subsidence and environmental changes in the sedimentary stratigraphy and floral and faunal assemblages of the Pillar Point marsh sediments. The geographic position of Pillar Point marsh between two active strands of the SGF and the presence of stratigraphy indicative of different tidal levels, makes Pillar Point marsh a unique location to study evidence for sudden changes in land level induced by coseismic subsidence, similar to stratigraphic changes documented in pull-apart basins along the San Andreas fault at Bolinas Lagoon and Bodega Bay (Knudsen et al., 2002).

This report presents new paleoseismic information for the northern SGF from a shallow stratigraphic investigation of the Pillar Point marsh site. This research was conducted to develop evidence for paleo-earthquakes by evaluating the stratigraphic position, sedimentology, and microfaunal assemblages associated with abrupt changes in fresh-brackish marsh soils. Stratigraphic relations are evaluated with respect to the criteria outlined by Knudsen et al. (2002) and provide evidence of at least two, and up to four rapid relative sea level changes in the marsh that may be associated with large earthquakes along the SGF. The results of this study also demonstrate the utility and limitations of the marsh stratigraphic approach to paleoseismic studies on strike-slip faults.

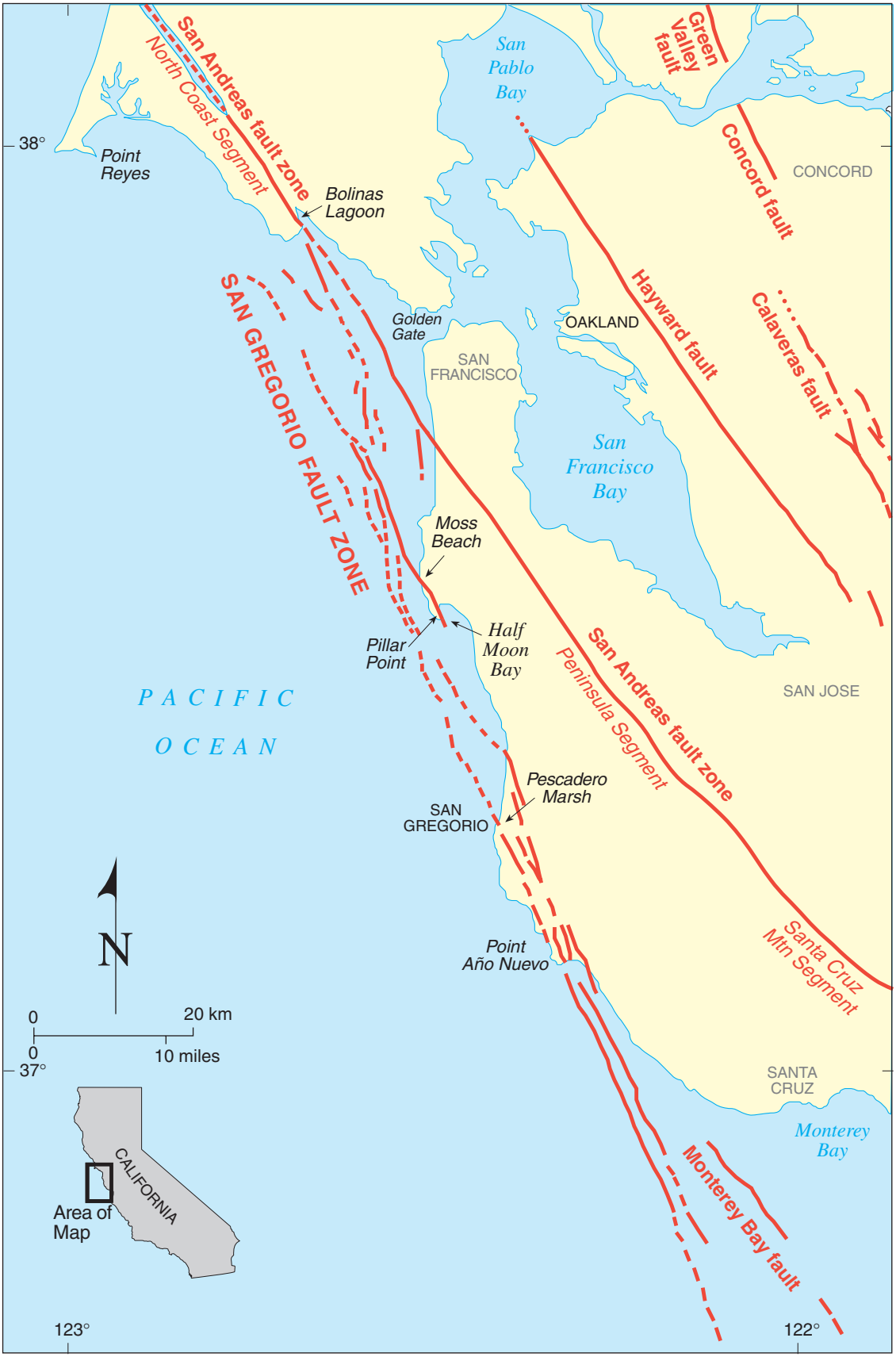
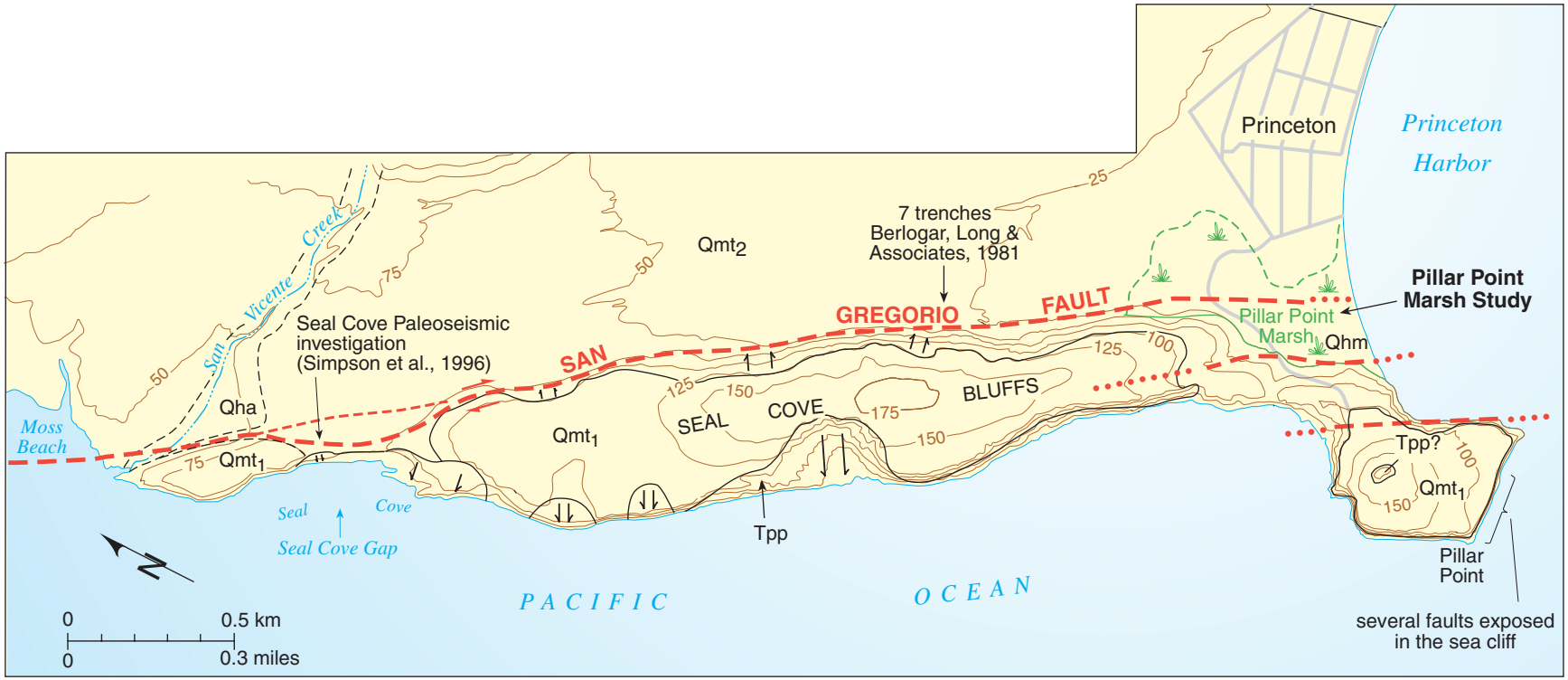


Figure 1. Map showing the San Gregorio fault zone and other principal Holocene faults in the San Francisco Bay area. Modified from Jennings (1994).



Explanation

Symbols

Northern San Gregorio Fault

Previously mapped trace of San Gregorio fault

Geologic contact; dashed where approximate

Landslide

Geologic Units

Qha	Holocene Alluvium
Qmt_2	Marine terrace, 83,000 yrs. old
Qmt_1	Marine terrace, 100,000 to 125,000 years old
Tpp	Purisima formation

Figure 2. Site location map showing Pillar Point marsh, Seal Cove Bluffs, and the Seal Cove reach of the northern San Gregorio fault.

2.0 GEOLOGIC, GEOMORPHIC AND TECTONIC SETTING OF THE PILLAR POINT AREA

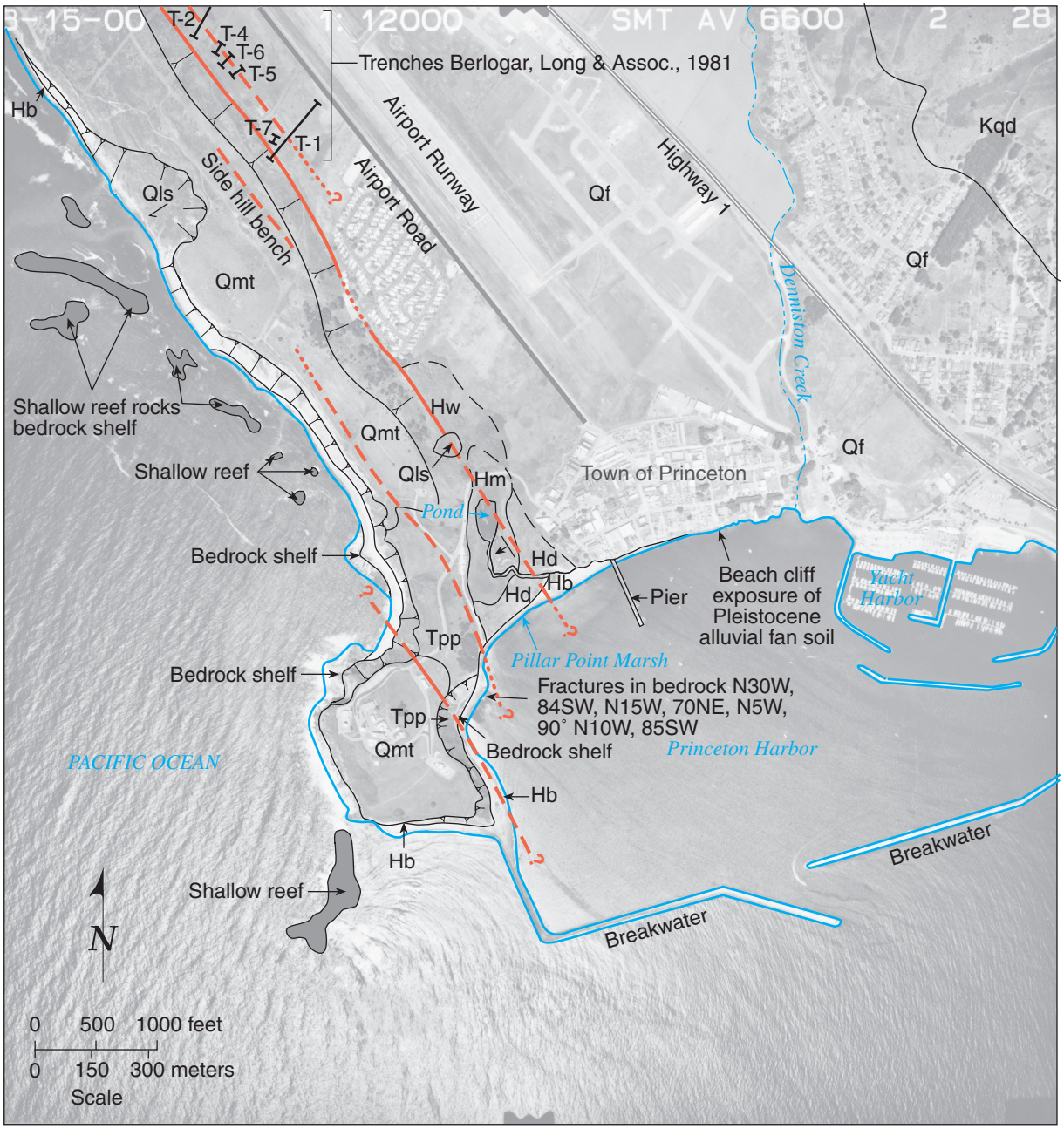
The San Gregorio fault is a complex fault zone extending approximately 110 km from the northern limit of the San Simeon fault near Monterey Bay to Bolinas Lagoon (Figure 1). Jachens and Zoback (1999) interpret high-resolution aeromagnetic data and seismicity data to indicate a 4-km-wide right-stepping extensional stepover between the San Gregorio fault and the San Andreas fault south of Bolinas Lagoon. The regional geology and tectonic history along the fault has been documented by many researchers including studies on bedrock lithologies juxtaposed by the fault (Touring, 1959; Hall, 1975; Graham and Dickinson, 1978; Clark et al., 1984), offset marine terraces (Weber, 1995; 1994; 1980), and offshore seismic reflection across the fault (Brocher, 1993; Lewis, 1993; 1994). These studies are summarized in Simpson et al. (1997), providing a comprehensive summary of the current state of knowledge on the San Gregorio fault.

The Working Group on California Earthquake Probabilities (WGCEP, 2003) divides the San Gregorio fault into two main segments. The San Gregorio South segment extends 66 km from Point Sur to the northern margin of Monterey Bay and the San Gregorio North segment extends 110 km from northern Monterey Bay to Bolinas Lagoon. Although both segments are located primarily offshore, the San Gregorio North segment is exposed on land in two locations in San Mateo County (Figure 1). These locations are informally named the Ano Nuevo and Seal Cove on-land traces of the SGF, the latter of which is the focus of this report (Figure 2).

The Ano Nuevo on-land trace of the SGF (Figure 1) extends from Point Ano Nuevo to San Gregorio and is characterized by multiple fault strands in an approximately 3-km wide zone, including from west to east, the Point Ano Nuevo fault, the Green Oaks fault, the Frijoles fault, and the Coastways fault. Based on cumulative right-lateral offset of marine shoreline angles across the Coastways, Frijoles and related faults and also on right-lateral offsets of Ano Nuevo Creek and Cascade Creek, as averaged over the past ~100,000 years, Weber and Cotton (1981), Weber (1994), and Weber et al. (1997) estimate a slip rate of 4-11 mm/yr (As cited in WGCEP, 2003). A recent paleoseismic study at Cascade Ranch near Point Ano Nuevo found evidence for three or four events in deposits interpreted to be as old as 6000-8,000 years, suggesting a minimum recurrence interval of 1500-2000 years (Thornburg and Weber, 1998).

The Seal Cove on-land trace of the SGF extends from Pillar Point to Moss Beach and appears to consist of three en echelon, right-stepping fault traces (Figures 2 and 3). Based on geomorphic expression and sea cliff exposures, the western-most on-land fault trace extends across the headland of Pillar Point. The middle fault trace extends along the western edge of Pillar Point marsh and through the middle of Seal Cove Bluffs. The location of this trace is inferred from small faults in the seacliff and a linear swale and saddle on the Pillar Point headland. The eastern fault trace extends from the eastern edge of Pillar Point marsh to Moss Beach, and is geomorphically well-expressed as a northeast-facing escarpment over 30-meters high along the east side of Seal Cove Bluffs (Figure 4). A topographic scarp across the Denniston Creek fan, north of Princeton may represent a fourth on-land trace of the fault, however, the existence of this strand is uncertain (CDMG, 1974; Weber and Lajoie, 1980).

Topographic expression of these fault strands suggests localized uplift and subsidence along the northern San Gregorio fault. Seal Cove Bluff has been deformed by the interaction of multiple



Explanation

Hb	Holocene beach	Kqd	Cretaceous Quartz Diorite of Montara Mountain
Hd	Holocene dune		San Gregorio fault
Hm	Holocene marsh		Geologic contact
Hw	Holocene wetland		Monoclinal fold
Qf	Quaternary alluvial fan (deposited on 83,000 year old marine terrace)		Slope
Qls	Quaternary landslide		
Qmt	Marine terrace (100,000 to 125,000 years old		
Tpp	Purisima formation		

Figure 3. Aerial photograph interpretation of the Pillar Point vicinity, showing beach, dune, marsh, and wetland deposits associated with Pillar Point marsh.

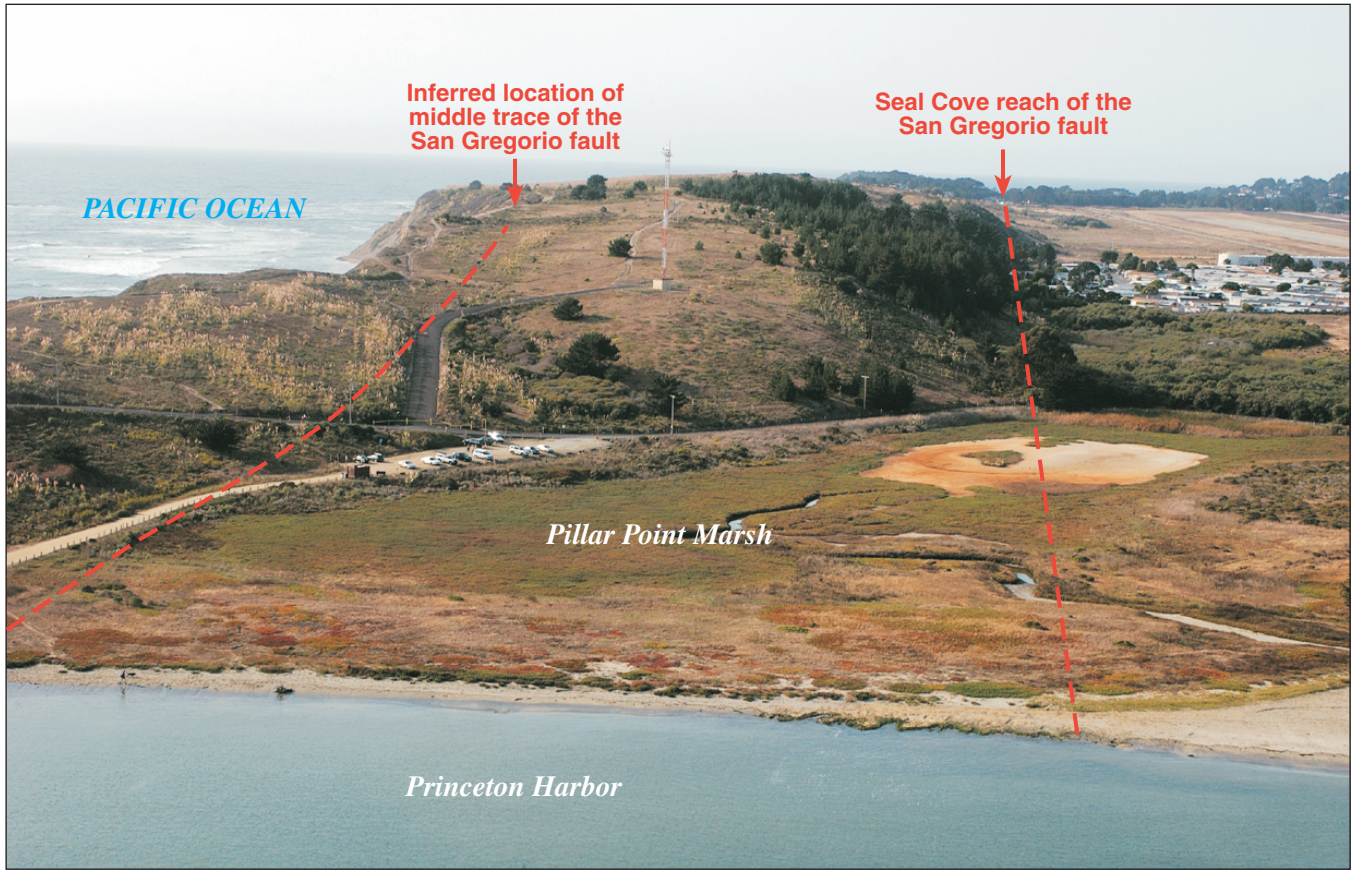


Figure 4. Fault locations superimposed on photo showing Pillar Point marsh. Strands of the northern San Gregorio fault appear to border both sides of the marsh. The main eastern trace extends along the base of Seal Cove Bluffs towards Moss Beach. View to the northwest. Photo copyright (c) 2002-2003 Kenneth Adelman, California Coastal Record project, www.californiacoastline.com <http://www.californiacoastline.com> .

fault strands in a right lateral transpressional system. The surface morphology of the crest of the Bluffs is characterized by a series of right-stepping, rhomb-shaped ridges and swales, consistent with localized uplift. Pillar Point marsh is consistent with localized subsidence, as described below.

Southeast of the Seal Cove Bluff, Pillar Point marsh lies within an inferred pull-apart structure between the middle and eastern fault strands (Figures 2 and 3). The marsh basin suggests that the extensional fault geometry has caused long term structural down-warping of the Stage 5a marine terrace. Abrupt stratigraphic succession of fresh-brackish marsh soils and intertidal mud record evidence for sudden changes in relative sea level that control the depositional environment of the marsh.

The Half Moon Bay marine terrace (Lajoie et al., 1979; Lajoie, 1986) comprises the coastal plain between the SGF and Pillar Point marsh on the west, and the coastal foothills to the east, and extends several kilometers north to the town of Montara. This marine terrace is correlated to the Stage 5a (83 ka) sea-level high stand based on a correlation of molluscan zoogeography and paleoclimatic events, as well as amino acid racemization analyses of bivalve shells (Kennedy et al., 1982a; 1982b). Another marine terrace, the Seal Cove Bluffs terrace, occurs between the fault and the Pacific Ocean. The age of this terrace is not well constrained, and subject to differing interpretations. For example, Lajoie et al. (1979) correlate the Seal Cove Bluffs terrace with the Half Moon Bay terrace. However, Jack (1969) and Simpson et al. (1998) inferred an older age for the terrace. If the Seal Cove Bluffs terrace is older than the Half Moon Bay terrace, it may correlate to the Stage 5c (100,000 ka) or the Stage 5e (125,000 ka) sea-level high stand. Alternatively, if the Seal Cove Bluffs terrace correlates to the Half Moon Bay terrace, approximately 50 m of vertical separation of the abrasion platform has occurred in the last 83,000 years suggesting a vertical separation rate of up to 0.6 mm/yr along the San Gregorio fault (Weber and Lajoie, 1980; Lajoie et al., 1979). Both the Half Moon Bay and Seal Cove Bluffs terraces overlie nearshore marine sandstone and siltstone of the Pliocene Purisima Formation.

Pillar Point marsh is connected to Half Moon Bay by a small flood channel and is geomorphically isolated from the bay by a narrow beach and a low dune field (Figure 4). North of the dune field, fresh-brackish marsh environments flank the eastern and western margins of the marsh. The center of the marsh consists of a small freshwater pond or bog (Figure 4) that has standing water in the winter and an alluvial channel. At the northern end of the marsh, the environment transitions to a forested wetland/upland setting that is drained by a small intermittent creek. This creek supplies fine-grained alluvial sediment derived from the Half Moon Bay terrace and Seal Cove Bluffs to the marsh. Because the marsh collects both intertidal and alluvial sediments, it is ideally suited for preserving a stratigraphic record of sea level change.

2.1 Previous Investigations along the Seal Cove reach of the northern San Gregorio fault

Data on the timing of past earthquakes are essential for evaluating the seismic potential of the SGF and assessing its contribution to seismic hazards in the San Francisco Bay area. Due to the faults' limited exposure on-land, few paleoseismic studies of the fault have been performed. However, three recent studies along the northern on-land reach of the SGF have contributed

valuable data on the late Holocene behavior of the fault including estimates of slip rate and earthquake timing (Simpson et al., 1997; 1998; Simpson and Knudsen, 2000). Additionally, an Alquist-Priolo fault study conducted by Berlogar, Long & Associates (1981) confirmed the existence of the eastern on-land strand of the fault north of Pillar Point marsh (Figure 3).

Simpson et al. (1997; 1998) performed a detailed paleoseismic and geoarchaeological studies at Seal Cove that produced broad constraints on the timing of the two most recent earthquakes, an estimate of the amount of slip associated with the penultimate event, and a Holocene slip rate estimate for the fault. Trench exposures showed that the most recent event (MRE) occurred between A.D. 1270 and 1775 (Simpson et al., 1997). This age range estimate is constrained by the lack of seismicity on the SGF in historic time and radiocarbon analyses on material from a faulted native Californian cooking hearth. Stratigraphic relations in the trench suggested that about 3 meters of dextral displacement occurred during the penultimate event. This event was identified by upward fault terminations and occurred between A.D. 670 and 1400. Simpson et al. (1998) determined a minimum Late Pleistocene slip rate of 3.5-4.5 mm/yr based on offset of the San Vicente Creek paleochannel from a prominent wind-gap, Seal Cove Gap. Because the trench did not cross all of the on-land traces and additional active traces lie directly offshore, the cumulative slip rate across the entire fault zone likely is greater than 4.5 mm/yr, and may be as much as 7 to 10 mm/yr (Weber, 1994).

Preliminary stratigraphic investigations at Pillar Point marsh (Simpson and Knudsen, 2000) identified a sharp contact between peat and overlying mud at depths of between 1 and 2 meters below the surface in four manually advanced drive cores. Fossil diatoms characteristic of tidal flats preserved in inorganic mud that abruptly overlies the peat, which contains fresh water diatom species, was interpreted as evidence of sudden submergence of a coastal wetland marsh and rapid burial by intertidal deposits. The presence of a tidal flat diatom assemblage in a mud overlying a freshwater diatom assemblage in a peat was used to infer a tectonic subsidence mechanism accompanied by rapid relative sea-level rise (Simpson and Knudsen, 2000). Combined calibrated radiocarbon ages on materials directly above and below the inferred event horizon indicate soil burial between A.D. 1667 and A.D. 1802. This age is consistent with the timing of the MRE from the Seal Cove study (Simpson et al., 1997), and provides a refinement of the maximum age constraints of the MRE for the northern San Gregorio fault. Although the Simpson and Knudsen (2000) study demonstrated the potential of using marsh stratigraphic techniques to evaluate paleoearthquakes on the SGF, they could not drive the cores deep enough using manual methods to encounter potential event horizons associated with older paleo-earthquakes.

3.0 APPROACH AND METHODS

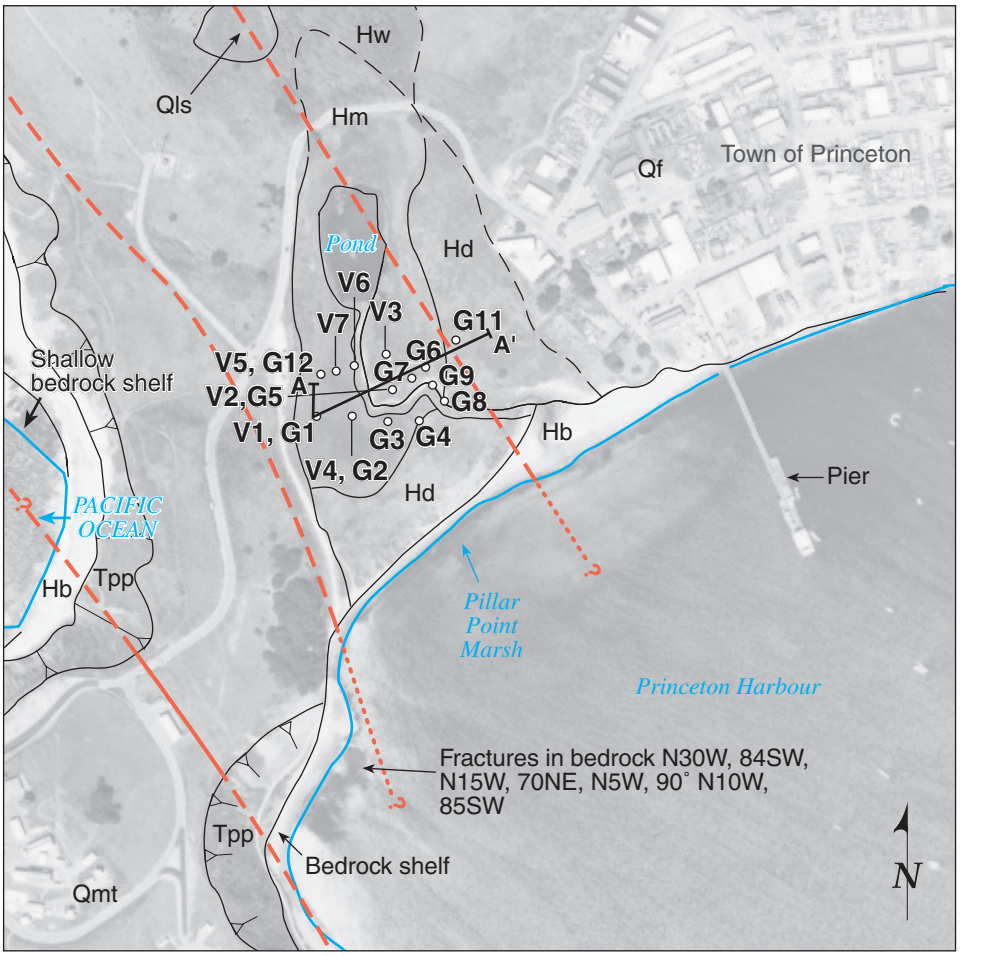
The subsurface stratigraphy and environments of deposition of sediment within Pillar Point marsh were investigated to identify rapid environmental changes that may be indicators of coseismic subsidence related to large magnitude earthquakes on the SGF. Because the marsh occupies an inferred pull-apart basin between two strands of the SGF, this study evaluated whether late Holocene stratigraphic relations record tectonic subsidence during paleo-earthquakes or whether they record sedimentation in response to some other fluvial or climatic process. We used diatom paleoecology and stratigraphic relations to evaluate the origin and timing of abrupt changes in the late Holocene depositional record of the marsh.

An initial survey was conducted to evaluate the geomorphic setting of the marsh and to characterize the marsh subsurface stratigraphy and geometry by collecting detailed lithologic data on late Holocene wetland deposits in the marsh. We conducted a reconnaissance stratigraphic survey consisting of twelve 2.5-cm-diameter gouge cores along two transects oriented roughly east-west across Pillar Point marsh (Figure 5). We mapped surficial deposits and geomorphology on aerial photos and in the field. Additionally, we observed and described two fluvial channel outcrop exposures and a beach cliff exposure east of the marsh. Detailed descriptions of the gouge cores are presented in Appendix A. Data collected during the initial field survey was used to guide the vibra-coring effort.

Based on the results of the initial investigation, we extracted seven 7.6-cm diameter cores using a vibra-core apparatus at locations determined to have the greatest potential to record a sequence of buried marsh soils (Figure 5). We advanced thin-walled aluminum irrigation pipe into the marsh sediment to depths of 3 to 5 meters using high frequency, low amplitude vibrations generated by a 5-hp motor and steady downward pressure applied manually (Figure 6). The cores were advanced to the base of the Holocene marsh, or to refusal, and then extracted using a "come-along" winch attached to a step ladder. The cores were described and logged in detail (Figures 7 to 10), and sampled for diatom, radiocarbon, and sedimentological analyses. Contact elevations were restored to account for compaction of core sediments by comparing the gouge core data (negligible compaction) to the vibra core data (compaction ranging from 3.3% to 20%). Based on these corrected elevations, we constructed a schematic fence diagram across the marsh in order to correlate buried marsh soils and determine the extent of relative sea level changes (Figure 11). Interpretation of the fence diagram was then combined with lithologic and paleontologic analyses to determine the origin of the sea level changes.

The characteristics of sediment texture, and occurrence of macrofossils and microfossils are used to evaluate paleo-depositional environments and to infer relative sea level changes. In most salt marshes and coastal wetlands, bands of vegetation lie roughly parallel to the shoreline, with individual species occupying characteristic vertical ranges in relation to sea level (Carver and McCalpin, 1996). Such zonation occurs at both the macrofossil and microfossil scale. Diatoms are microscopic, unicellular plants (algae) that proliferate in marine, estuarine, and freshwater aquatic environments. Because of distinct salinity tolerances for different species, groups of diatoms occupy distinct vertical elevation zones, and thus define unique depositional environments (Nelson and Kashima, 1993; Hemphill-Haley, 1995a). Diatoms also have been used to examine marine inundations into freshwater lakes or ponds by identifying marine or brackish diatom species in an otherwise freshwater environment (Witter, 1999; Garrison-Laney, 1998).

Fifteen samples were submitted for diatom analysis at the sedimentology lab at Humboldt State University. The analysis was completed using the following technique: Approximately 1-2 cc of sediment was placed in a 50 ml beaker, and 10-20 ml 30% H_2O_2 added to remove organic material. When the chemical reaction was complete, the sample was then transferred to a centrifuge tube and put through a series of rinses by adding distilled water and centrifuging at 1500 rpm. After the final rinse, the supernatant was decanted and the volume of the cleaned sample was recorded. The sample was next diluted 10x with distilled water, and a 40 µl aliquot was removed with a mechanical pipette. The aliquot was then transferred to a 22 mm x 30 mm



0 500 1000 feet

0 150 300 meters

Scale

Explanation

Hb	Holocene beach
Hd	Holocene dune
Hm	Holoccene marsh
Hw	Holocene wetland
Qf	Quaternary alluvial fan deposited on 83,000 year old marine terrace
Qls	Quaternary landslide
Qmt	Marine terrace 100,000-125,000 years old
Tpp	Purisima formation
	San Gregorio fault
	Geologic contact
	Monoclinal fold
	Slope
A A'	Cross section location

Figure 5. Aerial photograph enlargement showing locations of gouge cores and vibra-cores from Pillar Point marsh.

A) B) C)

Figure 6. a) Vibra-core apparatus showing power generator, aluminum core barrel, and vibrating head; b) geologists hoist core barrel into position to drive a 4-meter long sample; and c) geologists manually push vibrating core barrel into the marsh.

Core 02-V1 (3.3% compaction)

Depth Interval Descriptions

0-20
Modern marsh peat

20-38.5
Peaty mud, clayey silt, black, many f. to med. roots, few coarse roots, undecomposed, ~20% clay, lower contact over 20 mm.

38.5-52
Peaty mud, clayey silt, very dark brown, few f. and med. roots, trace coarse roots, very few v.f. roots, massive, ~15% clay, ~10% peat, lower contact over 4 mm.

52-56
Peaty mud, clayey silt, dark grey brown, common f. roots, more roots than above, massive, lower contact over 1 mm.

56-82
Peat, dark reddish brown, well decomposed, common f. and v.f. roots, mineral component silt, no significant odor, lower contact over 2-3 mm.

82-92.5
Mud, Silt loam to silty clay loam, dark gray, trace v.f. sand, massive, very few v.f. roots, very few med. peat fragments, pocket of coarse plant fragments between 82 and 84 cm, lower contact over 1 mm.

92.5-125
Peat, dark reddish brown, contains seeds at 94 cm., very well decomposed, ~70-80% organics, few f. roots, very few v.f. roots, common coarse plant fragments, massive, mineral component silt, lower contact over 10 mm.

125-130
Mud, silt loam, dark olive brown, micaceous, very few v.f. roots, trace v.f. sand, <10% clay, lower contact over 2 mm.

130-135
Very fine sand, gray, clean, single grain supported, micaceous, well sorted, similar to beach sand, lower contact over 2 mm.

135-139.5
Sandy mud, sandy silt loam, dark brown, massive, very few v.f. and f. roots, lower contact over 10 mm.

139.5-181
Loamy sand, dark gray, sand is very fine grained, clean, micaceous, massive, faint color mottles, no roots, contains 1-2 cm thick dark brown mud laminae at 169, 172.5, and 178.5 cm, lower contact over 5 mm.

181-204
Mud, clayey silt, dark olive brown, massive, trace coarse peat fragments, trace v.f. random roots, micaceous, ~30% organics, ~15% clay, 5 mm thick v.f. grained, clean, gray sand layer at base, lower contact over 2 mm.

204-246
Mud, silty clay loam, dark olive brown, massive, trace v.f. random roots, trace pebbles up to 1 mm, strong odor, more organics than above, ~50% organics, ~25% clay, pebbly stringer of sand at 229, less mica than above, lower contact over 5 mm.

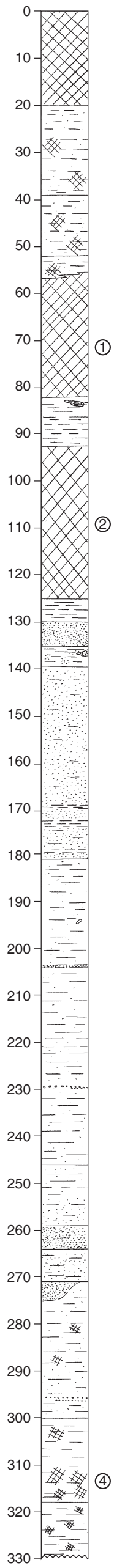
246-259
Mud, Silty clay loam w/ sand, dark olive brown, slight odor, massive, ~20 % organics, ~25% clay, ~5% sand grading downward to ~20% sand at base of unit, trace v.f. roots, lower contact over 5 mm.

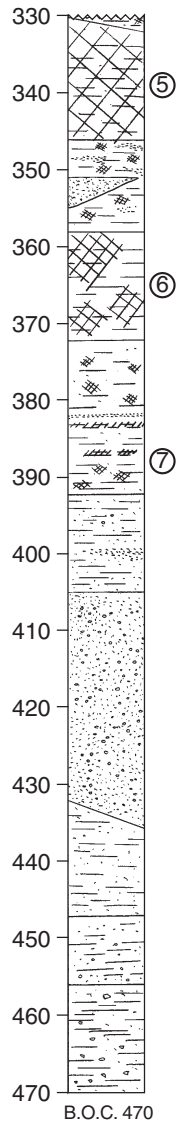
259-264
Sand, gray, massive, above 261.5 cm sand is coarse w/ pebbles up to 3 mm, below 261.5 cm, sand is fine grained w/ trace coarse clasts, no roots, lower contact over 5 mm.

264-271
Loamy sand, dark gray to dark olive gray brown, faint organic odor, v.f. grained sand, common v.f. roots, massive, lower contact over 2 mm.

271-300
Silt loam to silt clay loam, micaceous, common v.f. roots, massive, no odor, ~10% decomposed organics, trace v.f. sand, pocket of gray clean v.f. to f. sand at top of unit, lower contact over 5-10 mm.

300-318
Peaty mud to muddy peat, silty clay loam, massive, dark olive brown, more organics than above, ~40% organics, common v.f. to f. roots, lower 10 cm more peat than above (muddy peat), strong odor, ~50% organics, lower contact over 5 mm.





318-332
Organic peaty mud, clay loam, less peat than above patchy pockets of gray mud, black mud and brown mud, ~25% clay, common v.f. roots, common coarse plant fragments, ~ 30% organics, lower contact over 1 mm.

332-346
Peat, slightly muddy, dark brown, highly compressed, many v.f. roots, fibrous, moderately decomposed, moderate odor, ~60% organics, ~20% clay, mineral component silt clay loam, lower contact over 5 mm.

346-358
Peaty mud, clay loam, black, patchy f. to v.f. sand, massive, pocket of clean micaceous sand between 351 and 356 cm, lower contact over 2 mm.

358-372
Muddy peat, slity clay loam, dark brown, common med. plant fragments, appears matted, fibrous, compressed, no mica, ~50-60% organics, ~20% clay, lower contact over 2 mm.

372-392
Peaty mud, silty clay loam, olive gray brown, massive to weakly laminated, ~30-40% organics, few f. roots, many v.f. roots, common med. plant fragments, ~20% clay, trace mica, plant fragments concentrated in <5mm thick mats, 2 mm thick v.f. sand laminae at 382 cm, lower contact over 5 mm.

392-405
Mud, clay loam w/ sand and trace gravel, gray to olive gray, micaceous, ~30% clay, contains ~10% med. sand, concentration of med. sand between 399 and 401 cm, lower contact over 3-4 mm.

405-436
Loamy sand and gravel, gray, sub-angular to sub-rounded granitic gravels up to 3 mm, trace plant fragments, few v.f. roots, single grain supported in places, interpreted as an alluvial channel deposit, lower contact over 2 mm.

436-447
Silty clay loam w/ sand, dark gray brown, massive, sand is f. grained sub-angular quartz, ~25% clay, trace v.f. roots, trace med. plant fragments, no odor, lower contact over 5 mm.

447-456
Sandy clay loam, dark gray brown, massive, similar gravels as above but more abundant, ~15-20% clay, gravels make up ~5% of unit, lower contact over 2-3 mm.

456-470
Clay, black, reduced bluish gray patches, ~35-40% clay, few med. to coarse plant fragments, ~10-15% sub-angular gravels up to 4 mm, occasional gravels up to 1 cm, interpreted as Pleistocene alluvial fan soil, bottom of core at 470 cm,

Figure 7. Detailed stratigraphic descriptions for vibra-cores 02-V1 and 02-V2. The location of buried marsh soils as described in text are numbered and shown on the right side of core.

Core 02-V2 (3.8% compaction)

Depth Interval Description

0-15
Modern marsh peat

15-31.5
Loamy sand, tanish gray, v.f. to f. sand, micaceous, faint orange mottling, common f. to med. roots, < 1 cm thick brown peat laminae at 18, 20, and 27 cm, color becomes more gray below 27 cm, lower contact over 1 mm.

31.5-44
Peaty mud, Silt loam, black, massive, contains coarse decayed, humified peat fragments, strong odor, ~ 25% organics, ~ 10-15% clay, trace to few f. roots, common f. to med. horizontal rhizomes, no mica, lower contact over 3 mm.

44-72.5
Peaty mud, silty clay loam to silt loam, interbedded layers of black and dark brownish gray, black layers have larger mineral component, abundant v.f. horizontal roots, common f. vertical roots and horizontal rhizomes, massive to weakly bedded, no mica, 1 cm thick peat beds at 51, 63, and 69 cm, similar to unit above, lower contact over 4 mm.

72.5-135.5
Peat, dark reddish brown, horizontally matted, ~70% organics, moderately decomposed, abundant v.f. random roots, few to common med. rhizomes, trace sand, trace coarse rhizomes, strong odor, mineral component is silt, 1 cm thick v.f. grained gray sand laminae at 75.5 cm, below 92 cm peat is well decomposed w/ velvety structure, and trace sand grains, lower contact over 1 mm.

135.5-149
Mud, silt loam, dark olive brown, trace v.f. random roots, massive, no mica, organic odor, trace f. vertical rhizomes, trace v.f. sand, lower contact over 1 mm.

149-179
Peat, dark reddish brown, well decomposed, velvety structure, common v.f. random roots, common f. rhizomes, organic odor, mineral component is silt, lower contact over 1 mm.

179-198
Mud, silt loam, dark olive brown, organic odor, ~5% mica grains, massive, trace v.f. sand, ~ 10% organics, ~10-15% clay, lower contact over 2 mm.

198-216
Sand to Sandy silt loam, dark gray, massive to weakly laminated, single grain supported, micaceous, ~ 10% silt, ~10% coarse to med. sand, dominantly fine sand, trace v.f. random roots, few coarse horizontal rhizomes, upper 4 cm has more silt, lower 6 cm is interbedded w/ 2-3 mm thick dark brown mud laminae, lower contact over 1-2 mm.

216-246
Mud, silt loam, dark olive brown, organic odor, massive, trace mica, ~ 15% clay, trace f. sand, common f. random roots, upper 4 cm slightly more organic, lower contact over 3 mm.

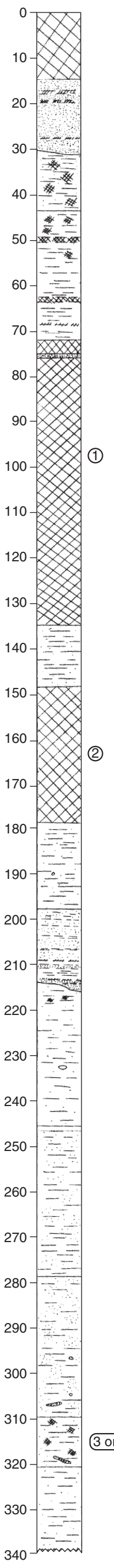
246-279
Sandy silt loam, dark olive brown, similar to above but slightly grayer and more sand, <10% sand, micaceous (<5%), massive, few v.f. random roots, trace coarse granitic clasts up to 2 mm, slight increase in sand content towards base, lower contact over 3 mm.

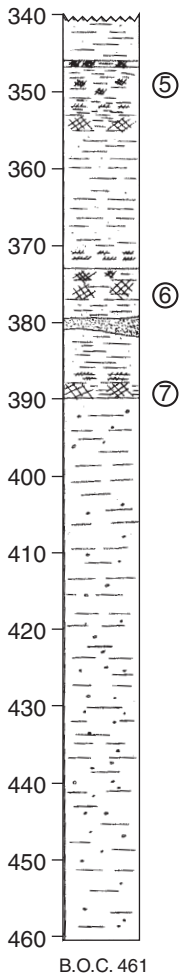
279-310
Sandy silt loam, dark olive brown, slightly darker than above, organic smell, massive, similar to above but more sand, ~10% v.f. sand, trace coarse sand, trace mica, ~15% clay, common v.f. random roots, few f. roots, contains coarse wood up to 2 cm long, contains rare seeds, lower contact over 2 mm.

310-321
Mud, silt loam, dark brown, slight organic odor, ~15% clay, more organics than above (~15%), massive, micaceous, trace v.f. roots, contains a pocket of clean v.f. sand at 320 cm, lower contact over 10 mm.

321-390
Mud, silt loam to silty clay loam, interbedded dark gray and dark brown mud, less organics than above, micaceous, trace v.f. and f. roots, Dark gray layers are silty clay loam w/ ~25% clay, concentration of 3 mm to 3 cm thick brown peaty mud laminae between 346 and 355 cm, an olive brown muddy peat lies between 373 and 377 cm (well decomposed w/ ~50-60% organics), 3 cm thick brownish gray sand at 379.5 cm, 2 cm thick dark brown muddy peat at base of unit, possible relative sea level rise indicated by contacts at 346, 373, and 388 cm, lower contact over 2 mm.

390-461
Gravelly clay loam to gravelly silty clay loam, dark bluish gray, massive, granitic clasts up to 5 mm, very few f. roots, interpreted as Pleistocene alluvial fan soil, bottom of core at 461 cm.





1506 Pillar Point

Core 02-V3 (10% compaction)

Depth Interval Description

0-18
Modern marsh peat

18-31
Sand, tan to brown, clean, v.f. grained, trace mica, few v.f. roots, below 25 cm sand is darker brown w/ sandy mud laminae, contains coarse woody debris between 28 and 30 cm, lower contact over 1 mm.

31-50
Interbedded black mud (silty clay loam) and dark gray v.f. sand, sands have 1-2 mm thick organic sandy laminae, common roots in mud are horizontally matted, individual beds are massive w/ weak laminae, non-organic sands are very clean and similar to beach sand, lower contact over 1 mm.

50-62
Mud, silt loam, black, organic odor, ~20% organics, massive, few v.f. roots, no mica, lower contact over 1 mm.

62-96
Peat, dark reddish brown, ~80% organics, mineral component silt, common f. and v.f. roots, common to many macro peat fragments, becomes more decomposed w/depth, moderately fibrous at top grading to velvety structure near base, trace seeds, trace v.f. to f. grained sand, 2 cm long stick at 80 cm, lower contact over 2 mm.

96-104
Mud, silt loam, dark gray, ~20% organics, massive, few to common coarse peat fragments, no mica, few v.f. random roots, humified, lower contact over 2 mm.

104-134
Peat, dark reddish brown, well decomposed, ~70-80% organics, trace coarse sand, common v.f. random roots, common coarse peat fragments concentrated in upper 1 cm of unit, 3 mm thick mud laminae at 105, 114, and 116 cm, below 129 cm organic content decreases to <10% and is dark olive gray silt loam w/ coarse peat fragments and very few roots and rhizomes, lower contact over 10 mm.

134-137.5
Mud, silt loam, dark olive gray, massive, very few v.f. vertical roots, similar to lower part of unit above but less organic, lower contact over 1 mm.

137.5-198
Mud, silt loam, dark olive brown, micaceous, ~20% organics, ~70% silt, ~10% clay, massive, very few v.f. roots, ~5% mica, detriatal wood fragments 0.5 cm long at 152 and 169 cm, lower contact over 3 mm.

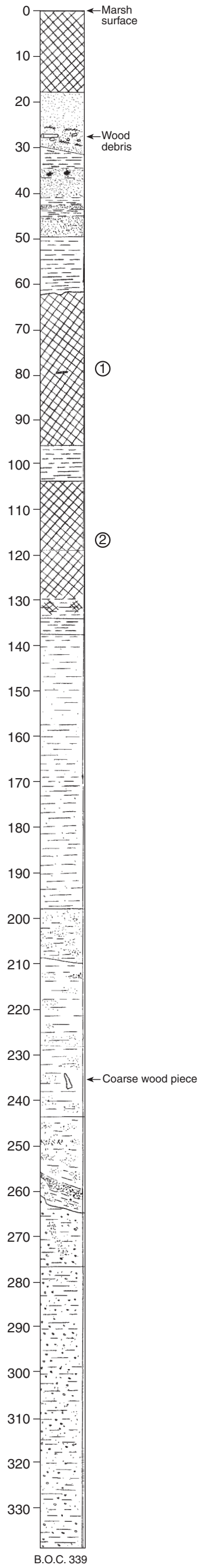
198-210
Sandy loam, dark olive brown, ~30-40% f. to v.f. sand w/ trace gravels up to 5 mm, massive, sand is distributed in patchy zones, quartz clast lithology, no roots, lower contact over 2 mm.

210-244
Sandy silt loam, dark olive brown, ~10% v.f. sand, ~10% clay, <5% mica, trace coarse sand, few v.f. random roots, sand distribution in patchy zones (possibly related to bioturbation), pocket of clean sand (1.5 cm diameter) at 213 cm, 7 cm long wood piece in sub-vertical/diagonal position between 234 and 238 cm, lower contact over 2 mm.

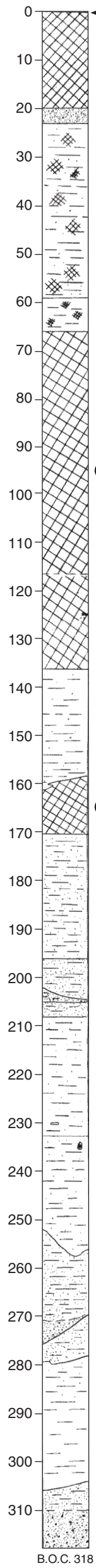
244-265
Sandy silt loam, dark olive brown, similar to above but more sand, ~15% clay, ~30% sand concentrated in patchy zones, sand is poorly sorted and ranges between v.f. and coarse grained, trace gravels up to 5 mm, <10% organics, lower contact over 2 mm.

265-277
Mud, silty clay loam, dark gray to black, contains weathered rock clasts (up to 1 cm) derived from the soil below and sub-vertical cracks filled with clean v.f. sand derived from above, interpreted as a transitional unit between Pleistocene soil below and Holocene marsh deposits above, lower contact over 5-10 mm.

277-339
Silty clay loam to gravelly clay loam, dark bluish grey to dark greenish gray, gleyed or reduced in places, contains weathered angular granitic and Franciscan rock clasts up to 1.5 cm diameter, few to common coarse roots, color turns lighter green in lower 13 cm, interpreted as Pleistocene alluvial fan soil, bottom of core at 339 cm.



Core 02-V4 (8.4% compaction)



Depth Interval Description

0-20
Modern marsh peat

20-23
Sand, gray brown, v.f. grained, micaceous, clean, single grain supported, f. roots growing through unit from modern marsh peat, lower contact over 1 mm.

23-59
Peaty mud, clayey silt to silt loam, black, massive, weak odor, many v.f. to f. horizontal and vertical roots, ~50-60% organics, ~20% clay, contains common coarse peat fragments that are horizontally matted, below 45 cm organic content decreases to ~30%, lower contact over 5 mm.

59-66
Mud, slightly peaty, silt loam, dark brown, massive, micaceous, many f. to v.f. vertical roots, ~20% organics, ~5-10% clay, lower contact over 5 mm.

66-136
Peat, dark reddish brown, mild odor, well decomposed, ~70% organics, more compressed with depth, common v.f. roots, few f. roots, common med. plant fragments, mineral component is silt, below 116 unit is more compressed than above and has slightly less organics (~50%), lower contact over 2mm.

136-158
Mud, silt loam, dark gray to dark olive brown, trace v.f. roots, massive, trace mica, ~20% clay, lower contact over 2 mm.

158-170
Peat, dark reddish brown to black, very decomposed, ~60% organics, velvety, mineral component is silt, organic content decreases with depth, lower contact over 20 mm. (very gradual contact, possibly indicating slow growth of the marsh).

170-196
Sandy mud, sandy silt loam, olive brown, ~5-10% v.f. grained sand, micaceous (<5%), massive, trace f. plant fragments, trace coarse sand, trace v.f. random roots, contains 1 cm long, 4 mm diameter stick at 193.5 cm, lower contact over 4 mm.

196-208
Sandy silt loam, olive brown, massive, slightly more sand than above (~15% v.f. grained sand), no roots, contains an interbed of sandy loam to loamy sand between 202 and 205 cm, lower contact over 2 mm.

208-232
Mud, silt loam, dark olive brown, few v.f. roots, trace coarse plant fragments, minor odor, ~10% clay, <10% fine decomposed peat fragments, less mica than above, weathered granitic rock clast (1 cm long) at 230 cm, lower contact over 40 mm. (very gradual contact, possibly indicating slow sedimentation rate in the marsh).

232-256
Organic mud, Silt loam, dark olive brown, similar to above but slightly darker, massive, ~15% clay, ~15-20% organics, organic smell, few v.f. random roots, trace mica, wood chunk 2 cm diameter between 233 and 235 cm, trace coarse plant fragments and detrital peat, lower contact over 2-3 mm.

256-269
Sandy mud, sandy silt loam, olive brown, massive, ~15% clay, ~10-15% coarse granitic sand, organic odor, trace v.f. roots, sandier than above, lower 5 cm of unit is clean med. to coarse sub-angular sand, 1 cm long mudstone clast at contact, lower contact over 1 mm.

269-278
Sandy loam, dark gray brown, massive, no roots, micaceous, ~5% clay, lower contact over 2 mm.

278-304
Organic mud, Silt loam, dark olive brown, organic odor, ~12% clay, trace mica, massive, trace f. to v.f. roots, trace coarse plant fragments, contains shells in lower 9 cm, lower contact over 5 mm.

304-318
Loamy sand to sand with gravel, upper 6 cm is dark brown gray loamy sand, poorly sorted, clasts up to 7 mm, lower 8 cm is clean coarse sand and gravel, poorly sorted, no roots, interpreted as an alluvial deposit, core refusal at 318 cm.

Figure 8. Detailed stratigraphic descriptions for vibra-cores 02-V3 and 02-V4. The location of buried marsh soils as described in text are numbered and shown on the right side of core.

Core 02-V5
(9.8% compaction)

Depth Interval

0-19
Modern marsh peat

19-22
Peaty mud, silty clay loam, tan to brown w/orange oxidation nodules, many v.f. to f. random roots, massive, ~25-30% clay, ~20% organics (peat), lower contact over 3 mm.

22-60.5
Peaty mud, silt loam, dark brown to black, ~15-20% clay, common f. vertical roots, many v.f. random roots, trace coarse peat fragments, weak horizontal matting, ~20% organics (peat), less clay than above, no mica, contains 0.5 cm thick clean v.f. gray sand (similar to beach sand) between 23.5 and 24 cm, lower contact over 2 mm.

60.5-96.5
Peat, dark reddish brown w/ dark brown to black mottles over 30-40% of unit, well decomposed, velvety structure, mineral component silt (<10%), organic odor, 5 cm long wood chunk in horizontal position between 63 and 64 cm, herbaceous seeds present near top of unit, no mica, lower contact over 1 mm.

96.5-103.5
Mud, silt loam, dark gray, organic, slight odor, common v.f. random roots, <10% clay, massive, trace peat chunks, much less organics (<10%) than black mud above, no mica, lower contact over 1 mm.

103.5-127
Peat, dark reddish brown, slight odor, ~80% organics, mineral component silt (~10-15%), slightly more mineral component than peat above, many v.f. random roots, trace coarse peat fragments, very well decomposed, velvety structure, no mica, lower contact over 30 mm.

127-139
Mud, silt loam, dark olive brown, very few f. random roots, no odor, massive, <10% clay, ~5% mica, trace humified organics, contains irregular 5 mm thick v.f. grained gray sand pocket at 134 cm, lower contact over 3 mm.

139-162
Divided into 3 subunits; upper unit (139-150 cm): sandy loam, dark olive brown, ~50% v.f. sand, 10% mica, massive, very few med. vertical roots, trace v.f. roots; middle unit (150-157 cm): Sandy silt loam, dark olive brown, <5% clay, ~5% mica, ~20% v.f. sand, massive to weakly laminated w/ v.f. sand laminae 1-2 mm thick, trace f. and v.f. random roots; lower unit (157-162): sandy loam, dark olive brown, weakly laminated, ~30% v.f. sand, ~5% mica, common v.f. random roots, lower contact over 2 mm.

162-193
Mud, silt loam, dark olive brown, slight odor, massive, ~10% clay, trace peat fragments, few v.f. random and trace f. vertical roots, inorganic relative to unit below, contains flat lying wood chunk (3 X 2.5 cm) between 164 and 165 cm, lower contact over 2 mm.

193-209
Mud, silt loam, dark olive brown, micaceous, massive, slightly more organics than above, slight odor, few v.f. random roots, ~15% clay, ~15% organics, lower half of unit contains irregular zones of sand (v.f. to f., w/ trace coarse grains), sand may be result of mixing of unit below by tidal processes, lower contact over 3 mm.

209-223.5
Sandy loam to loamy sand w/ gravel, dark brown gray, weakly bedded, trace mica, sand is coarse grained w/ granite clasts up to 1 cm, interpreted as alluvial deposit, lower contact over 1 mm.

223.5-244
Sandy silt loam, dark gray brown, ~30% v.f. sand and trace coarse sand, trace mica, trace woody debris, no odor, massive, rare large 5 mm diameter feldspar clasts (angular), lower contact over 4 mm.

244-248
Mud, silt loam, dark olive gray brown, lower contact has relief over 2 cm, trace woody debris.

248-259
Peat, dark brown, well decomposed, ~70% organics, velvety, trace coarse peat fragments, trace v.f. random roots, moderate smell, mineral component silt (~30%), lower contact over 1 mm.

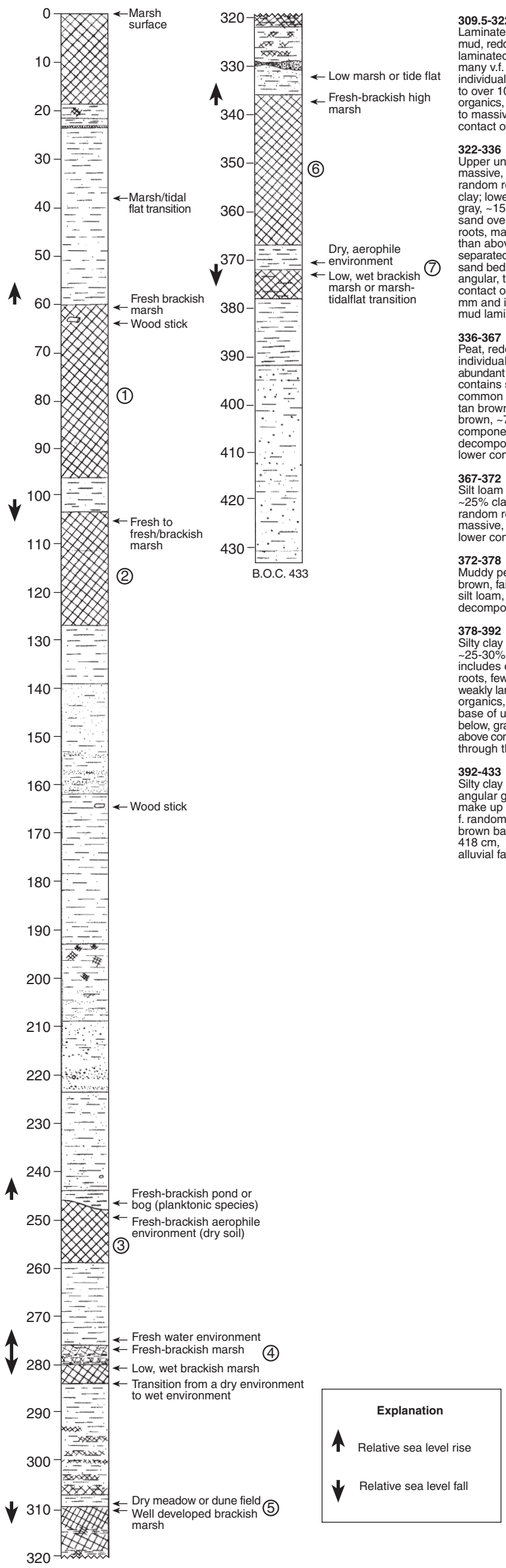
259-276
Mud, silt loam, dark olive gray grading downward to dark gray, massive weakly laminated (2 mm scale laminae), slight odor, ~15% organics above 269 cm, <10% organics below 269 cm, trace v.f. random roots, trace coarse plant fragments, trace to no mica, lower contact over 2-3 mm.

276-280
Interbedded muddy peat and mud, muddy peats; dark brown to light olive brown, common v.f. roots, trace coarse peat fragments, ~50% organics, mud beds; silt loam, gray, massive w/ no roots, lower contact over 1 mm.

280-284
Peat, brown to dark brown, >60-70% organics, trace coarse peat fragments, velvety, mineral component silt (~20%) and clay (<10%), strong organic odor, upper 1 cm is less decomposed and darker color, lower contact over 1-2 mm.

284-307
Peaty mud, silt loam, dark olive gray w/ brown peat zones, ~20-25% clay, >10% mica, <20% peat concentrated below 293 cm, occurs in beds and pockets, few v.f. random roots, trace f. sub-vertical roots, massive w/ weakly laminated peaty layers, lower contact over 3 mm.

307-309.5
Organic mud, silt loam, dark gray, strong odor, ~10% mica, massive, trace coarse peat fragments, common v.f. random roots, lower contact over 1 mm, interpreted as a possible storm deposit based on a rapid return to organic deposition in unit above.



309.5-322
Laminated peat, muddy peat, and peaty mud, reddish brown to black, moderately laminated, trace coarse peat fragments, many v.f. roots, trace f. vertical roots, individual gray mud laminae are 3-4 mm to over 10 mm thick, strong odor, ~60% organics, mineral component silt, velvety to massive, ~15-20% organics, lower contact over 20 mm.

322-336
Upper unit: silt loam, dark olive brown, massive, trace mica (<5%), common v.f. random roots, ~20% organics, ~15% clay; lower unit: sandy silt loam, dark gray, ~15% clay, ~5% mica, v.f. grained sand over 20% of unit, trace f. vertical roots, massive, no odor, less organic than above; upper and lower unit separated by a 2 cm thick med. to coarse sand bed, clean, single grain supported, angular, trace gravels up to 4 mm, lower contact of entire unit is gradual over 20 mm and is characterized by peat and mud laminae.

336-367
Peat, reddish brown, fibrous, laminated, individual lams from 1-2 cm. thick, abundant to many coarse peat fragments, contains seeds, many v.f. random roots, common f. random roots, laminae are tan brown, dark brown, and reddish brown, ~70% organics, mineral component is silt, notably less decomposed than other peats in core, lower contact over 20 mm.

367-372
Silt loam to silty clay loam, dark gray, ~25% clay, ~10% mica, common v.f. random roots, trace f. random roots, massive, trace coarse peat fragments, lower contact over 10 mm.

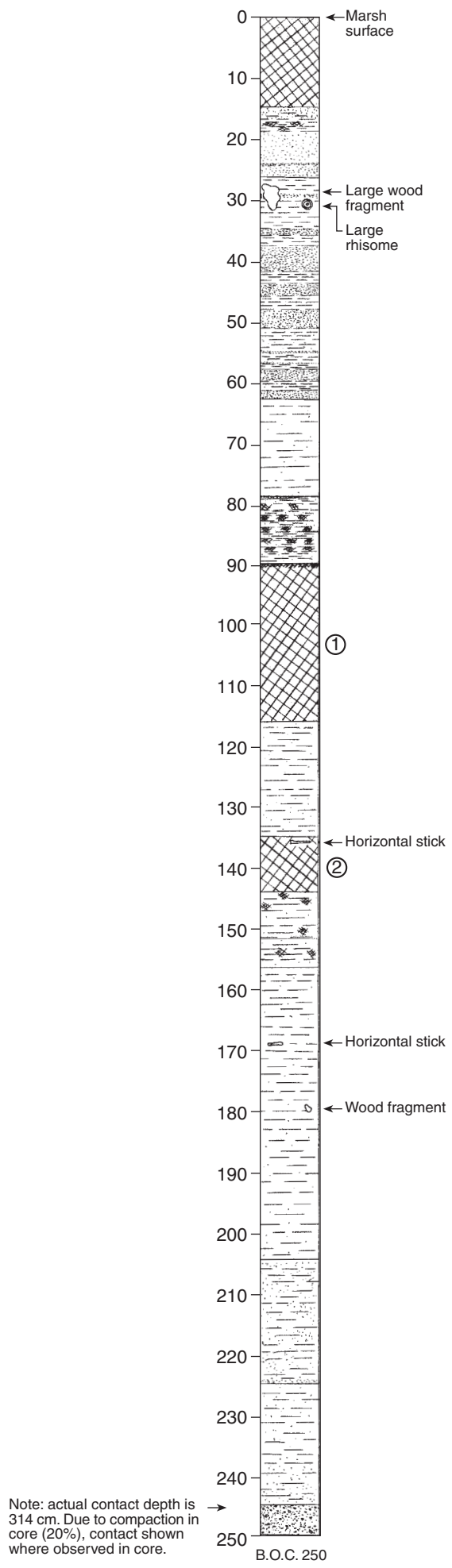
372-378
Muddy peat, dark brown to reddish brown, faint odor, ~60% organics, ~40% silt loam, massive to velvety, well decomposed, lower contact over 2 mm.

378-392
Silty clay loam, olive gray to olive brown, ~25-30% clay, mottled black in places, includes coarse peat fragments, few v.f. roots, few f. random roots, massive to weakly laminated, strong odor, up to 30% organics, lower contact over 20 mm, at base of unit mixing occurs with the soil below, gravels from soil occur up to 2 cm above contact and vertical roots penetrate through the contact.

392-433
Silty clay loam, dark bluish gray to black, angular gravels up to 1 cm diameter make up ~10% of unit, few to common f. random and trace med. roots, olive brown band occurs between 416 and 418 cm, interpreted as Pleistocene alluvial fan soil, base of core at 433 cm.

Figure 9. Detailed stratigraphic descriptions for vibra-core 02-V5. The location of buried marsh soils as described in text are numbered and shown on the right side of core.

Core 02-V6
(20% compaction)



Depth Interval

0-15
Modern peat marsh

15-26.5
Sand, olive gray, f. to v.f. grained, trace mica (~5%), single grain supported, weakly laminated, common v.f. horizontal roots, trace macro plant fragments, contains 2 cm thick sandy mud layer at 15 cm. w/ ~30% fine sand, woody debris, and common fine roots, contains 2 cm thick olive brown mud layer at 17 cm w/ less sand than above and concentrated horizontal peat, contains a rusty 5 mm thick oxidized sand layer at 24.5 cm, lower contact over 1 mm.

26.5-63
Interbedded fine sand with silty organic mud, dark gray and black respectively, sand texture is loamy w/~10-20% silt, trace mica (<5%), and trace organic detritus, mud laminae are predominantly silt w/ trace fine sand, very few v.f. roots, and discontinuous horizontal peat mats, contains a 5 cm long redwood stick between 28 and 32 cm, lower contact over 1 mm.

63-79
Silty mud, black, ~5-8% clay, very few v.f. horizontal roots, trace f. sand, few v.f. pores, weak horizontal partings, massive, slight odor, ~20% organics, lower contact over 1 mm, base of contact has a 2 mm thick discontinuous f. to v.f. sand laminae.

79-90
Peaty mud interbedded w/ dark gray to brown silt w/ up to 40% organics, weakly laminated, trace sand and mica grains, few coarse peat fragments, very few v.f. random roots, velvety texture, laminae are predominantly 5 mm thick, lower contact over 1 mm.

90-116
Peat, dark reddish brown, well decomposed, strong odor, ~80% organics, contains seeds (<1 mm diameter), few v.f. random roots, few coarse peat fragments, mineral component silt, no mica, uppermost 0.5 cm of unit has dark coarse peat fragments that may have been rooted in the unit.

116-135
Mud, silt loam, dark gray, massive, trace mica (~5%), mica increases towards base of unit, <20% clay, ~80% silt, trace v.f. random roots, weak sub-horizontal partings, lower contact over 1 mm.

135-144
Peat, dark grayish brown, well decomposed, ~80% organic peat, mineral component silt, trace mica, very few random roots, few coarse peat fragments near base, 2 cm long horizontal stick at 136 cm, lower contact over 3-5 mm.

144-156.5
Mud, silt loam to silt, dark olive brown, micaceous, very few v.f. and f. roots, very few v.f. pores, massive, ~20% organics, ~10-15% clay, ~70% silt, lower contact over 5 mm.

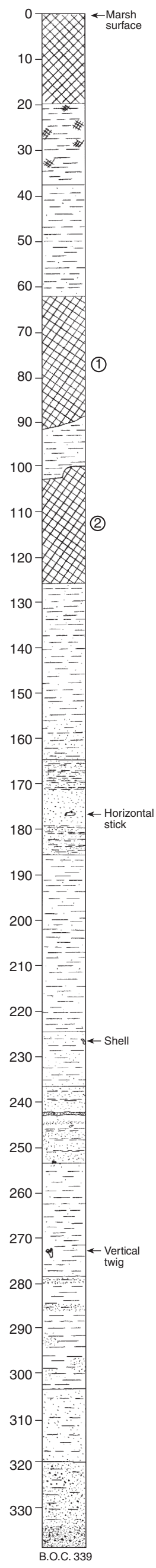
156.5-204.5
Mud, silt loam, dark olive brown, micaceous, ~7-12% clay, ~60% silt, ~30% organics, similar to unit above but more organics, contains horizontal stick 2.5 cm long at 169 cm, lower contact over 3-5 mm.

204.5-225
Sandy silt loam, dark olive brown, ~10% v.f. sand w/ trace coarse sand and granules, micaceous (<5%), ~10-20% organics, slight odor, massive, weakly laminated in lower 4 cm of unit, trace coarse plant fragments, very few v.f. random roots, contains a 3 cm thick silt loam without sand directly above 5 mm thick v.f. grained sand laminae at base, lower contact over 1 mm.

225-245
Mud, silt loam w/ sand, dark brown, micaceous, ~10% organics, very few v.f. random roots, trace coarse sand near top of unit increasing downward to ~15% coarse sand at base, granules up to 3 mm long, common v.f. random roots near base, few coarse peat fragments, lower contact gradual over 10 mm.

245-250
Gravel w/ coarse sand, clean, angular clasts up to 5 mm include quartz and feldspar, interpreted as an alluvial channel deposit, contact between overlying unit and gravel unit was observed in the core catcher, core refusal at 250 cm.

Core 02-V7
(14.4% compaction)



Depth Interval

0-20
Modern marsh peat

20-38
Peaty mud, silt loam, black, ~20% clay, massive, common v.f. roots, few f. vertical roots, no mica, lower contact over 3 mm.

38-62.5
Mud, Silt loam, dark brown to black, massive, few f. vertical, common v.f. random roots, ~10% clay, no mica, unit is similar to unit above but less clay and lighter color, lower contact over 1-2 mm.

62.5-92
Peat, dark reddish brown, fibrous, common coarse peat fragments, many v.f. random roots, ~80% organics, ~20% mineral component (silt), contains seeds, below 76 cm peat is more decomposed w/ fibrous to velvety texture.

92-103
Mud, silt loam, dark gray, few to common f. pores, trace med. random roots, no mica, few v.f. random roots, massive, slight odor, <10% clay, lower contact over 2 mm.

103-126
Peat, dark reddish brown, ~80-90% organics, well decomposed, common v.f. random roots, common coarse peat fragments, velvety structure, lower contact over 5 mm.

126-165
Mud, silt loam, dark olive brown, micaceous, (~5%), massive, common v.f. random and trace f. random roots, contains <5% woody debris, ~10-15% clay, ~75-80% silt, no odor, ~25-30% v.f. sand throughout unit, sand concentration increases near base, lower contact over 3 mm.

165-186
Interlaminated sand and loamy sand, dark gray, some laminae are dark brown color indicating reworked organic mud from below, ~10% mica, >80% sand, <10-20% silt, trace wood and twigs, trace v.f. and f. roots, contains a horizontal stick (2 cm long and 0.5 cm in diameter) at 377 cm, mud laminae are concentrated in upper 7 cm and lower 7 cm of unit, lower contact over 2 mm.

186-225
Mud, silt loam, dark olive brown, organic odor, micaceous (<5%), few f. and v.f. random roots, trace woody debris, massive, <10% clay, ~10% organics, contains small twigs w/bark at 209 cm, lower contact over 10 mm.

225-237
Sandy silt loam, dark olive brown, ~20% v.f. sand, trace coarse sand, massive, organic odor, ~10% organics, trace v.f. random roots, lower contact over 5 mm.

237-254
Loamy sand with gravel, dark gray to brown, >70% sand, trace woody debris, trace v.f. random roots, weakly laminated, individual laminae range from 0.5-1 cm thick, contains a 1 cm thick coarse sand layer, some pockets of silt near base suggest bioturbation, lower contact over 3 mm

254-279
Silt loam, dark olive brown, massive ~15-20% clay, few v.f. random roots, trace gravel, trace mica, contains a woody twig from 273-275 cm, organic odor, ~10% organics, lower contact over 2 mm

279-304
Silt loam, dark olive brown, massive, ~10% clay, very few v.f. roots, trace woody debris, no odor, trace mica, similar to unit above but more sand, sand occurs in patches and in layers between 280-282 cm and 285-287 cm, lower contact over 10 mm.

304-320
Loamy sand, dark olive brown, trace mica, ~80-90% v.f. grained sand, trace med. to coarse sand, trace angular gravel up to 4 mm, lower contact over 10 mm.

320-339
Loamy sandy gravel, dark olive brown, massive to single grained structure, feldspar and granitic clasts are angular and up to 1 cm diameter, below 334 cm material is a pure sandy gravel, interpreted as an alluvial channel, core refusal at 339 cm.

Figure 10. Detailed stratigraphic descriptions for vibra-cores 02-V6 and 02-V7. The location of buried marsh soils as described in text are numbered and shown on the right side of core.

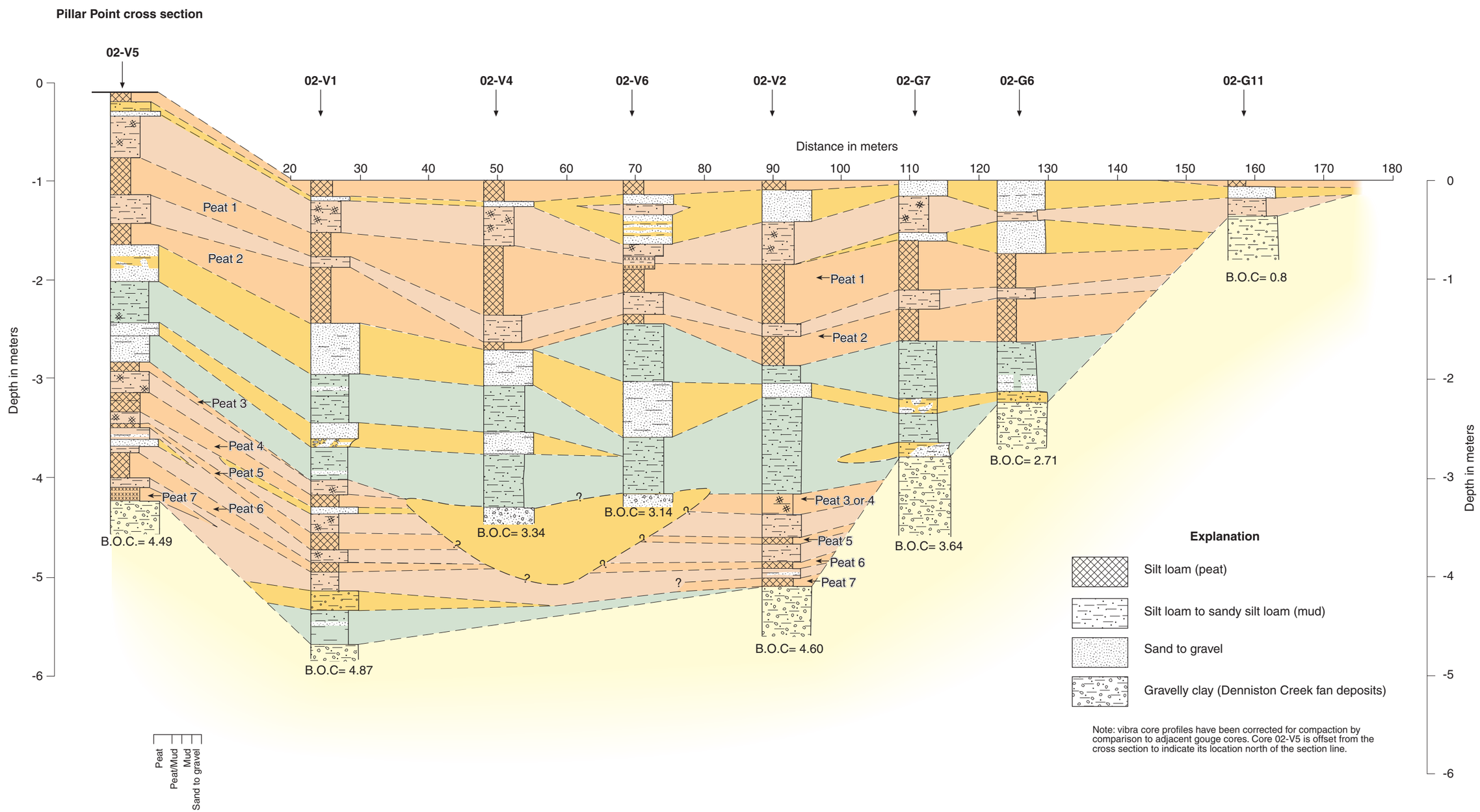


Figure 11. Cross section A-A' of Pillar Point marsh showing stratigraphic unit correlations. Cross section location shown on Figure 5.

glass cover slip and allowed to dry slowly under a heat lamp. The cover slip was then permanently attached to a glass slide with Hyrax mounting medium. Where possible, at least 100 diatoms were identified and enumerated for each sample at 1250x magnification using an Olympus BH2 microscope. Results of the diatom analyses are listed in Table 1 and Appendix B.

Radiocarbon dating is the principle means of constraining the timing of past earthquakes recorded in coastal marsh stratigraphy. Because bulk peat samples commonly contain roots and recycled organic material, the most reliable age estimates are derived by AMS dating of delicate detrital seeds, sticks, leaves, or bark from trees that perished within decades prior to the time of the event (Kelsey et al., 2002, Witter et al., 2003). We currently are awaiting results of samples collected during this study. We collected plant macrofossils preserved near the upper abrupt contact of each mud over peat couplet for AMS radiocarbon analyses to constrain the timing of marsh soil submergence. To avoid sampling organic material that does not closely limit the time of soil burial, we selected macrofossils sieved from peat and mud near the upper soil contact. These samples will be submitted to Arizona State University, through a cooperative agreement with the U.S. Geological Survey.

Nelson et al. (1996b) proposed five criteria to assess the likelihood that marsh stratigraphic sequences were formed by coseismic subsidence during earthquakes on the Cascadia subduction zone. These stratigraphic criteria were modified by Knudsen et al. (2002) in an attempt to define criteria to identify earthquakes in small basins along strike-slip faults. Based on the results from the stratigraphic and micropaleontological analyses, we evaluate the marsh stratigraphy with respect to the Nelson et al. (1996b) and Knudsen et al. (2002) criteria to determine whether environmental changes within the marsh occurred due to tectonic subsidence or other non-tectonic processes.

4.0 RESULTS

The results of this investigation include: (1) observations of the geological and geomorphic setting of the area around Pillar Point marsh that provide information on the long-term style of deformation and surficial processes occurring in the marsh; and (2) detailed data on the marsh stratigraphy and ecology that provide information regarding potential coseismic subsidence events. These data are used to evaluate the origin of Pillar Point marsh, and to deduce an earthquake chronology for the northern SGF.

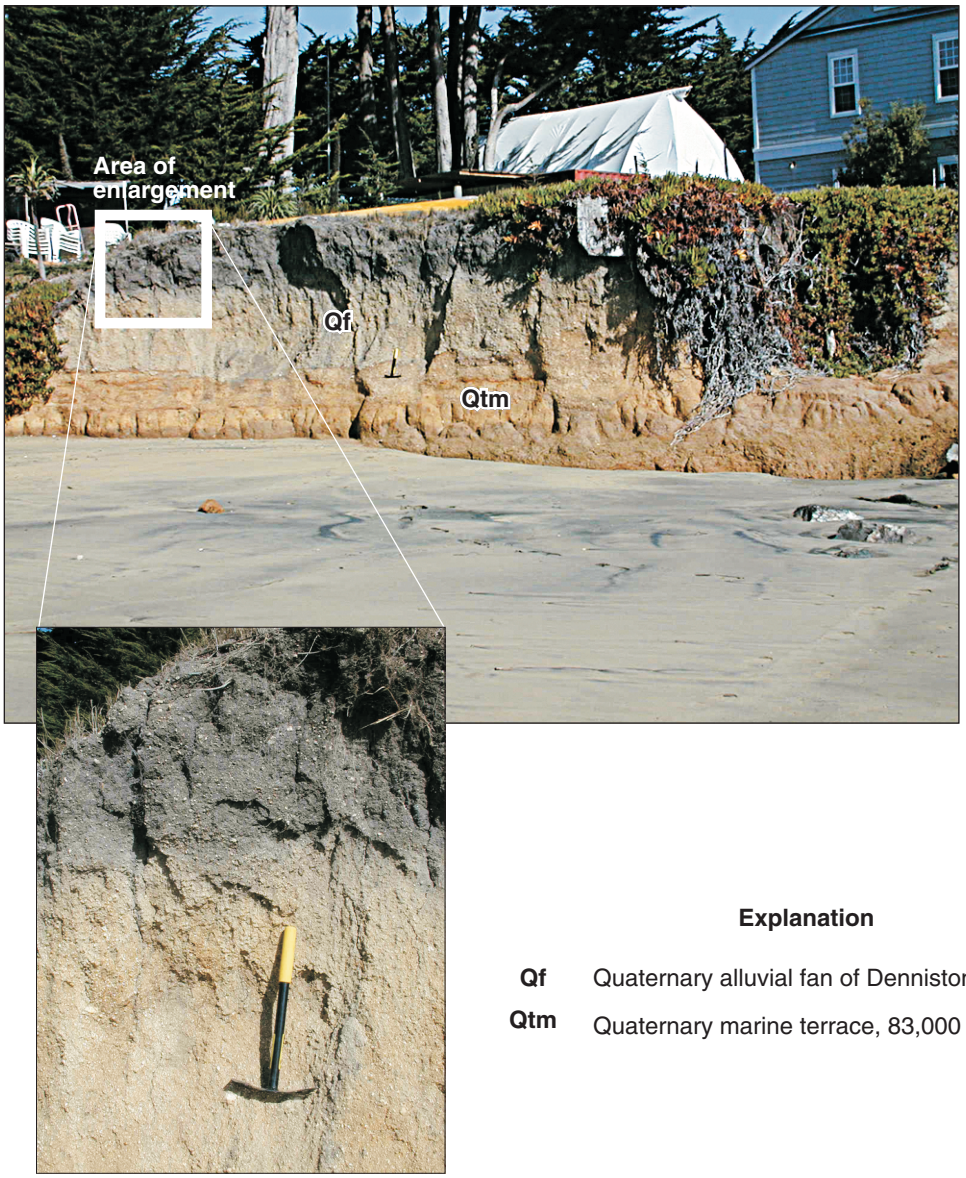
4.1 Reconnaissance Mapping

Sediments in a beach cliff exposure approximately 300-meters east of the marsh consist of a basal sandy clay unit overlain by 2 meters of clayey sand with gravel (Figure 12). The gravel consists of dominantly angular feldspar clasts derived from the granodioritic basement rock that forms the core of the Coast Range and Montara Mountain directly east of the site. We interpret the deposits to be an alluvial fan from the mouth of Denniston Creek that prograded over the 83 ka Stage 5a marine terrace. A well-developed dark-gray brown, gravelly silty clay loam soil is developed in the deposits of the alluvial fan (Figure 12). This soil is exposed along the sea cliff continuously from Princeton to Pillar Point marsh.

Table 1. Fossil Diatom Data from the Pillar Point marsh site, Core 02-V5.

Depth Interval (cm)[a]	Stratum/ Lithology	Paleo-environment	Comments
59.5-60.5	Mud above Peat 1	Brackish low marsh or marsh/tideflat transition	Higher relative percentage of brackish species than underlying sample, including Gyrosigma spenceri, Achnanthes spp., Surirella gastuosa, Melosira moniliformis, and Amphora coffaeaformis.
60.5-61.5	Peat 1	Fresh-brackish marsh	Dominant species are fresh-brackish.
102.5-103.5	Mud above Peat 2	Meadow or dune field	Coarse, dry environment, contains only reworked valves.
103.5-104.5	Peat 2	Fresh to fresh-brackish marsh	Frequent periods of standing water at the surface, but very low salinities.
247-248	Mud above Peat 3	Fresh-brackish pond or bog	Contains abundant diatoms including a large percentage of planktonic species.
248-249	Peat 3	Fresh-brackish aerophile	High, dry soil. Diatoms not abundant, but they are diverse and moderately well-preserved, and include fresh-brackish aerophile species.
275-276	Mud above Peat 4	Fresh marsh	Transition to even fresher conditions than the underlying sample.
276-277	Peat 4	Fresh-brackish marsh	Slight increase in numbers of fresh-brackish species compared to the underlying sample; probably formed higher in the intertidal zone.
280-281	Peat 4 below mud laminae	Low, brackish marsh	Diatoms consistent with a wet, saline environment.
308.5-309.5	Mud above Peat 5	Grassy meadow or dune field?	Environment not conducive to diatom productivity. Environment was probably coarse grained and fairly dry.
309.5-310.5	Peat 5	Well-developed brackish marsh	Probably middle to high marsh, not too low or too wet.
334-335	Mud above Peat 6	Low marsh or tide flat	Represents a wetter, more saline environment than the underlying sample.
336-337	Peat 6	Fresh-brackish high marsh	Marsh was probably inundated frequently.
371-372	Mud above Peat 7	High, dry aerophile setting	Not conducive to diatom productivity.
372-373	Peat 7	Low brackish marsh or marsh-tideflat transition	Diatoms consistent with a wet, saline environment.

[a] Depth interval below ground surface.
See Figure 9 for core log.
Diatom analyses conducted by EHH Consulting Micropaleontology at the sedimentology lab at Humboldt State University.



Explanation

Qf	Quaternary alluvial fan of Denniston Creek.
Qtm	Quaternary marine terrace, 83,000 years old.

Figure 12. Sea cliff exposure of the alluvial fan deposits overlying the Stage 5a 83 ka maring terrace, Princeton, California. Enlargement is a close up view of the soil developed in the alluvial fan. Angular granitic clasts within the soil are used to correlate the soil across the base of Pillar Point marsh.

We correlate the alluvial fan soil with an identical dark gray gravelly clay loam that forms the base of Pillar Point marsh. The correlation is based on similarities in the texture, color, and distribution of feldspar and granitic clasts. On the northern and eastern margins of the marsh, the alluvial fan soil crops out in tidal channel exposures (Figure 13). Gouge core and vibra-core data indicate that the soil dips steeply to the west from the eastern margin of the marsh to the location of Core 02-V2 and then flattens out toward the western margin of the marsh where it is buried (Figure 11). The steep west-facing subsurface slope bounding the eastern margin of the marsh is continuous and projects to the eastern on-land strand of the fault, adjacent to Seal Cove Bluffs. In the center of the marsh, the soil dips gradually to the south. At the western margin of the marsh, the alluvial fan soil lies approximately 4.5-meters below the marsh surface. Therefore, the alluvial fan surface defines a roughly triangular-shaped south-dipping basin approximately 245-meters-long by 150-meters-wide.

Beneath Pillar Point marsh, the alluvial fan soil is buried by interbedded fresh-brackish marsh, alluvial channel, dune, and intertidal mud deposits, and represents the former gently sloping landscape surface prior to formation of the marsh. The basin that presently characterizes the former landscape surface presumably began to fill with sediment around the time that sea level reached the vicinity of the marsh in the middle Holocene. Since that time, depositional processes within the marsh have been dominated by fresh-brackish marsh aggradation interrupted by periods where tidal flat and brackish marsh sediments inundated and buried the fresh-brackish marsh.

4.2 Marsh Stratigraphy

In describing the buried marsh stratigraphy, we present lithologic and paleontologic data and use these data to determine the environment of deposition. We then use the inferred depositional environment for the marsh soils to interpret the history of sediment accumulation and relative sea level changes that affected Pillar Point marsh. The implications of the stratigraphic record to a potential earthquake chronology are discussed in the Discussion section below.

Subsurface materials identified in the Pillar Point marsh cores consist of buried peaty soils, alluvial channel deposits, intertidal mud, storm or flood, and dune deposits (Figures 7 to 10). The buried peat soils are separated by sequences of fining upward intertidal mud deposits with gradual upper contacts. This relationship is interpreted as representing periods of relative landscape stability followed by periods of relative sea level rise and sediment deposition. Only the age of the uppermost sediments is currently known. However, based on the slowing of sea level rise in the middle Holocene (Atwater, 1977), we infer that the deepest sediments in the marsh are no older than middle Holocene in age. The stratigraphic, lithologic and biostratigraphic characteristics of these deposits are described below and summarized in Table 1, and Figures 7 to 10. Peat soils are labeled sequentially from oldest (Peat 7) to youngest (Peat 1).

Seven peat soils are preserved in the marsh and are interpreted to represent former marsh surfaces. All of the buried peat soils have abrupt to clear upper soil contacts and are overlain by inorganic mud to peaty mud. Two well-developed peat soils (Peat 1 and 2) occur within 2 meters of the marsh surface and are laterally continuous for at least 130 meters. Five less-developed peat soils (Peats 3 to 7) occur between 3.2 to 4.1 meters depth. Three of these deeper peat soils (Peats 4, 5, and 6) extend laterally at least 70 meters. Peats 3 and 7 are not continuous

Figure 13. Alluvial fan soil exposed in a tidal channel outcrop overlain by dune sand. Note angular granitic clasts similar to clasts in sea cliff exposure of the soil (Figure 12).

and may have been deposited in a narrow band along the marsh margin or were eroded in the center of the marsh.

Peat 7 is a massive, well-decomposed dark brown to reddish brown muddy peat. Diatom assemblages within Peat 7 indicate formation in a wet brackish marsh or marsh-tideflat transitional environment. This peat occurs in cores 02-V5 and 02-V2, extends over 70 m across the deepest part of the basin, and represents the first deposition of marsh sediments on the alluvial fan soil. These first sediments probably accumulated around marsh plants colonizing the margin of the basin. A dark gray, massive, silt loam to silty clay loam (mud) overlies Peat 7 and has a diatom assemblage indicative of a dry, aerophile environment. The gradual (10 mm) upper contact of Peat 7 indicates that the environmental change occurred gradually. Peat fragments within the mud over Peat 7 suggest that marsh development was interrupted by periods of drying possibly related to sediment aggradation and emergence of the marsh surface.

Peat 6 is a well developed, fibrous, laminated, dark reddish brown peat. Diatom assemblages within Peat 6 indicate development in a fresh-brackish high marsh environment. This peat is observed in cores 02-V5, 02-V1, and 02-V2, and extends over 70 m from the marsh's western margin to the buried west-facing slope of the alluvial fan soil along the eastern margin. Peat 6 is overlain by dark gray to dark olive brown silt loam to sandy silt loam (mud) that contains tidal flat or low marsh diatom species. The gradual lower contact of Peat 6 indicates that the peat slowly aggraded to a higher intertidal level in response to sediment accumulation in the marsh. The abrupt transition (2 mm) from a fresh-brackish high marsh to an interbedded tidal flat or low marsh environment indicates rapid relative sea level rise associated with subsidence of Peat 6 to a lower, more saline intertidal level.

Peat 5 is an interbedded peat, muddy peat and peaty mud deposit. Individual peat layers range in color from reddish brown to black and peaty mud layers contain 3-4 mm thick gray mud laminae. Diatom assemblages within Peat 5 indicate growth in a well-developed brackish marsh. Peat 5 is observed in cores 02-V5, 02-V1, and 02-V2, and extends over 70 m from the marsh's western margin to the buried west-facing slope of the alluvial fan soil. Peat 5 is overlain by a massive to weakly laminated, dark gray to dark olive gray silt loam (mud) that contains peat laminae. The assemblage of diatoms at the base of the mud over Peat 5 suggest it was a dry environment such as a grassy meadow or dune field, however, peat laminae suggest that the marsh occasionally dried but was flooded frequently enough to support marsh growth. The gradual lower contact of Peat 5 indicates that the soil gradually developed over the underlying tideflat/low marsh environment in response to aggradation in the marsh. The clear upper contact of Peat 5 indicates that the marsh dried up quickly, possibly due to climatic variables such as a decrease in rainfall during a drought.

Peat 4 is a massive, well-decomposed, dark brown peat deposit. Diatom assemblages within Peat 4 indicate development in a low, wet brackish marsh to fresh-brackish marsh. The peat occurs in cores 02-V5, 02-V1, and 02-V2 and transitions over a distance of 70 m from a peat, to muddy peat, to organic mud in an eastward direction across the marsh. The sharp lower contact of Peat 4 indicates that the brackish marsh began to form quickly possibly related to increased flooding of the marsh. Alternatively, the sharp lower contact may indicate that the dry environment below Peat 4 was subsided allowing the wet, brackish marsh to develop. Peat 4 is

overlain by a 4 cm thick thinly laminated deposit that consists of muddy peat and mud (silt loam) deposits. A dark gray massive silt loam (mud) deposit abruptly overlies the laminated beds. Although individual upper contacts for Peat 4 and the overlying muddy peat laminae are abrupt, fossil diatom data indicate that the environment of deposition gradually changed from a low, brackish marsh to a fresh-brackish marsh to a fresh water marsh. This gradual environmental change indicates a gradual emergence of the marsh surface due to accumulation of interfingering peat and mud laminae close to the limit of tidal influence.

Peat 3 is a dark brown well-decomposed peat deposit. Fossil diatom data indicate that Peat 3 formed in a fresh-brackish aerophile environment diagnostic of a dry marsh soil. This peat is observed in core 02-V5 along the western marsh margin and may have been eroded by alluvial channels in the middle of the marsh. Abrupt upper and lower contacts of Peat 3 indicate that environmental changes within the marsh were rapid. Because Peat 3 overlies an apparent fresh water environment, the brackish component of the Peat 3 soil may be related to storm wash-over deposits interfingering with dominantly fresh water marsh deposits. A dark olive gray silt loam (mud) overlies Peat 3 and has a diatom assemblage indicative of a fresh-brackish pond or bog that supported planktonic diatoms. The pond or bog deposit is overlain by approximately 2 meters of interbedded dark olive brown micaceous silt loam and sandy loam deposits. These estuarine and alluvial sediments provide evidence for a sustained period of marsh aggradation due to gradual sea level rise. Alternatively, subsidence of Peat 3 could have caused erosion in the middle of the marsh and a sustained period of aggradation as the marsh adjusted to a new tidal datum.

Peat 2 is a very well-decomposed dark reddish brown peat deposit that contains diatoms diagnostic of a fresh to fresh-brackish marsh. This deposit was observed in all cores and extends for over 130 m across the entire marsh. The base of Peat 2 is characterized by a gradual contact (30 mm) suggesting that the peat developed in response to aggradation of estuarine and alluvial sediment. A thin dark gray silt loam (mud) overlies Peat 2 and has a diatom assemblage indicative of a dry environment such as a high meadow or dune field. The sharp upper contact of Peat 2 indicates that the marsh rapidly dried up, however this environmental change was short lived and did not significantly alter the depositional environment in the marsh.

Peat 1 is a well-decomposed dark reddish brown peat deposit. Fossil diatoms indicate that Peat 1 developed in a fresh-brackish environment similar to Peat 2. This peat was observed in all cores and has a similar lateral extent as Peat 2 (>130 m). The sharp contact at the base of Peat 1 indicates that the environmental change was rapid possibly related to increased rainfall or sand bar breaching. Peat 1 is overlain by a dark brown to black silt loam (peaty mud) deposit that contains a brackish low marsh to marsh/tideflat transition diatom assemblage. The abrupt transition (~1 mm) from a fresh-brackish environment to a low marsh/tideflat environment indicates rapid sea level rise associated with submergence of Peat 1 to a lower intertidal level.

4.3 Radiocarbon Data

Samples have been collected for radiocarbon analysis, but are pending processing by the U.S. Geological Survey and Arizona State University.

4.4 Evolution of Pillar Point Marsh

Based on diatom assemblages and sedimentologic characteristics of the buried peat soils described above, we infer the following history of sediment accumulation and environmental change within Pillar Point marsh. In forming this interpretation we make the following assumptions: (1) abrupt mud over peat contacts associated with a change in diatom assemblage from high intertidal species below the contact to lower intertidal species above the contact indicate sudden relative sea level rise; (2) in the opposite scenario, peat over mud contacts associated with a change in diatom assemblage from lower intertidal levels below the contact to higher intertidal levels above the contact indicate marsh aggradation; and (3) gradual mud over peat contacts with diatom assemblages that indicate a change from brackish conditions to fresh water environment indicate gradual aggradation and ponding.

Pillar Point marsh coincides with an apparent sag pond between two strands of the SGF (Figure 2). Right lateral transtentional deformation on these fault strands created a depression in the marine terrace and alluvial fan. Sedimentation in the marsh began when sea level rose high enough to enter the depression and allow intertidal processes to influence deposition in the marsh. A fresh-brackish marsh environment dominated the depositional setting in Pillar Point marsh through most of its history. However, fresh-brackish marsh development was interrupted 2 - 4 times by rapid relative sea level rise and associated tide flat sedimentation causing submergence of the fresh-brackish marsh environment.

Transition from the alluvial fan environment to the intertidal marsh environment began with a tidal flat that progressively aggraded from a brackish marsh (Peat 7) to a fresh-brackish high marsh (Peat 6) that was suddenly buried. Tidal flat sediments are intermixed with rip-up clasts of the alluvial fan soil at the base of the marsh, indicating active erosion by tidal processes. As a result of this incursion, a low, wet brackish marsh (Peat 7) developed on the tidal flat sediments. Based on diatom ecology, this marsh dried up for a short period of time and then gradually aggraded to a fresh brackish high marsh (Peat 6). During this time, marsh aggradation is inferred to have kept pace with gradual sea level rise. The lateral continuity and sharp upper contact of Peat 6 indicate that sea level rose rapidly and caused an abrupt transition from a fresh-brackish high marsh (Peat 6) to an interbedded tidal flat and low marsh environment. The stratigraphic and paleontologic evidence for rapid submergence of the fresh-brackish marsh soil (Peat 6) may represent a coseismic land-level change within Pillar Point marsh due to an earthquake on the SGF.

After the possible submergence of Peat 6, interbedded sand, muddy peat, and tidal mud deposits accumulated in the low marsh environment and a brackish marsh soil (Peat 5) developed. This soil intermittently dried up and eventually was submerged allowing the formation of Peat 4. Peat 4, characterized by a return to a low, wet brackish environment, formed on the intermittently dry brackish marsh. The laterally continuous transition from a high, dry brackish marsh environment to a wet brackish marsh and the sharp contact at the base of Peat 4 indicates that relative sea level may have rapidly rose across the entire marsh just prior to the formation of the brackish peat deposit (Peat 4). The stratigraphic and paleontologic evidence for rapid submergence of the dry brackish marsh (below Peat 4) may represent another coseismic land-level change associated with an earthquake on the SGF.

After deposition of Peat 4, the marsh progressively evolved to a fresh brackish environment and then a fresh water environment. Sediment aggraded in the marsh until it eventually dried up supporting a fresh-brackish aerophile soil (Peat 3). A fresh-brackish pond or bog deposit was deposited on Peat 3. After this abrupt transition, two meters of interbedded estuarine and alluvial sediments gradually accumulated in the marsh. This sustained period of marsh aggradation provides evidence for either sedimentation keeping pace with gradual sea level rise or rapid sea level rise associated with submergence of the marsh surface (Peat 3) during an earthquake on the SGF.

The sharp upper contact of Peat 1 and the lateral continuity of the associated mud over peat contact across the marsh provides possible evidence for another rapid relative sea level rise. After the deposition of Peat 3 the marsh eventually aggraded into a fresh to fresh-brackish marsh environment (Peat 2 and Peat 1) that was interrupted by deposition of a dark gray silt loam (mud) during a brief period of marsh drying. This was a short lived change and did not significantly alter the depositional environment, allowing the fresh-brackish marsh to continue to develop (Peat 1). The rapid transition to a marsh tide flat environment that buried the fresh-brackish marsh soil (Peat 1) may record coseismic land-level change associated with an earthquake on the SGF. This contact was inferred by Simpson and Knudsen (2000) to represent an earthquake event horizon that occurred between A.D. 1667 and A.D. 1802. Tide flat mud with interbedded sand and peaty mud deposits accumulated in the marsh tideflat until formation of a modern fresh-brackish marsh.

In summary, abrupt upper contacts and diatom data support the interpretation of rapid relative sea level rise for Peats 1, 4, and 6. The stratigraphic relationships also support rapid relative sea level rise for Peat 3, however diatom data indicate that the magnitude of relative sea level rise that affected Peat 3 was not as large as indicated by Peats 1, 4, and 6. Therefore, the sequence of marsh deposits overlying the alluvial fan soil and changes in the environment of these deposits record evidence of at least two and possibly as many as four rapid relative sea level rise events. These events may be related to coseismic land level changes associated with earthquakes on the northern SGF. Additional radiocarbon and diatom analyses are necessary to characterize sediment age and substantiate the observed environmental changes.

5.0 DISCUSSION

5.1 Marsh Development along the California Coast

Early to mid-Wisconsin sea level was at a minimum about 15,000 years ago and rose rapidly thereafter until about 7000 BP in response to large scale glacial melting (Bloom 1971; Flint, 1971; Fairbridge, 1976). Since that time, sea level has risen at a much slower rate, approximately 1-2 mm/yr, to the present (Bloom, 1971; Emery, 1969; Atwater, 1977). Estuaries, tide flats, salt marshes, and wetlands formed along the California coastline as sea level rise diminished and allowed coastal marshes to aggrade at the same rate as sea level rise (Atwater, 1976; 1979).

In areas where the tectonic uplift rate is not high enough to out-pace sea level rise, marine terrace platforms are submerged below sea level. Sea level rise floods coastal embayments and topographic lows and allows marsh sediments to accumulate. Local tectonic subsidence can

increase the magnitude of relative sea level rise and contribute to marsh genesis. In southern San Francisco Bay, Atwater (1977) attributed 0.1 to 1.5 mm/yr of relative sea level rise to tectonic subsidence possibly augmented by isostatic adjustment based on comparison to global eustatic sea level curves. This interaction of rising sea level and tectonically subsiding landscape allowed large volumes of Holocene estuarine sediment to accumulate in southern San Francisco Bay. Alternatively, in coastal northern California where tectonic uplift rates are high, the coastal morphology is characterized by offshore reefs and emergent terraces (Merritts and Bull, 1989; Merritts et al., 1994), and generally lacks coastal marshes.

The development of marshes along the California coast, therefore, is largely the result of sea level that is slowly rising and keeping pace or exceeding coastal uplift or subsidence.
The modern sea cliff morphology along the northern margin of Half Moon Bay is the result of tectonic uplift rates exceeding late Quaternary sea level rise. Local downwarping of the Half Moon Bay terrace along the SGF has caused net subsidence of Pillar Point marsh, allowing marsh sediments to accumulate.

5.2 Origin of the Pillar Point Marsh Basin

The Pillar Point marsh basin is contained between the Seal Cove Bluff on the west and the Denniston Creek alluvial fan on the east. The origin of this basin, and in particular, the process that created the subsurface slope of the alluvial fan soil along the eastern side of the marsh can be explained by several mechanisms. These mechanisms include: (1) channel downcutting and alluvial fan processes associated with Denniston Creek; (2) wave erosion associated with winter storms and/or tsunamis; and (3) tectonic subsidence or folding associated with right-stepping strands of the SGF.

A channel downcutting scenario would require stream erosion into the alluvial fan sediments followed by channel abandonment. The abandoned channel would then be filled by estuarine sediment during Holocene sea level rise. Based on alluvial channel deposits within the marsh, a present day ephemeral creek, and the subsurface topographic slope on the eastern side of the marsh, it is possible that Denniston Creek drained across the Denniston Creek fan towards the Seal Cove Bluff. The Seal Cove Bluff would have prevented the creek from draining west to the Pacific Ocean and diverted the stream to the south through the present location of Pillar Point marsh. Downcutting of the stream during sea level lowstands may have created a channel that was subsequently abandoned. If downcutting occurred, it happened prior to soil formation on the alluvial fan because the soil is preserved beneath the marsh. A landslide or debris flow from Denniston canyon may have caused channel abandonment and diversion of the creek to its present location on the eastern side of the town of Princeton.

Although the scenario described above is possible, several lines of evidence do not support downcutting as the primary mechanism for basin formation. First, topographic data from the alluvial fan surface northeast of the marsh indicate that a channel topographic form or feeder channel of similar size and depth to the Pillar Point marsh basin does not exist. Secondly, the lack of alluvial channel deposits on the alluvial fan soil does not support basin formation by channel downcutting. Lastly, the presence of the alluvial fan soil across the marsh indicates that the soil was not eroded by a channel.

Wave erosion is another possible mechanism for formation of the Pillar Point marsh basin. This mechanism would require strong winter waves to erode a small embayment in the vicinity of the marsh. Erosion of the embayment could have occurred during the Stage 5a sea level high stand. Based on the presence of the alluvial fan soil at the base of the marsh, the eroded embayment would have been abandoned during the subsequent sea level lowstand allowing the alluvial fan soil to develop across a small depression. Because Pillar Point marsh is a localized feature within Half Moon Bay and is relatively protected from strong northwest swells by a large offshore rocky reef complex and the Pillar Point headland, we consider wave erosion to be an unlikely mechanism for basin formation.

Our preferred mechanism controlling formation of the basin is tectonic subsidence between the middle and eastern strands of the on-land SGF. The eastern on-land strand projects southeast from the Seal Cove Bluff into the marsh and coincides with the location of the apparent monocline along the eastern margin of the marsh (Figure 4). North-northwest trending bedrock fractures in the Pillar Point headland near the western margin of the marsh and a linear swale and saddle extending obliquely northwest across the headland, define the middle fault strand (Figures 2 and 3). Subsurface data indicate that the inferred pull apart basin dips to the south, consistent with the southerly divergent geometry of the eastern and middle fault strands.

5.3 Tectonic Model for Pillar Point Marsh Subsidence and Earthquakes on the SGF

We propose a model of tectonic deformation to create the observed marsh stratigraphy as a result of coseismic subsidence of Pillar Point marsh within a pull-apart basin. This model requires that gradually rising sea level causes long periods of sediment aggradation that is periodically interrupted by rapid relative sea level rise as a result of coseismic land level change. Because multiple earthquakes have affected the basin, stratigraphically lower peats are preserved in the deepest (western) part of the marsh and do not exist in the shallower (eastern) part of the marsh. As the marsh filled with sediment and the basin continued to subside, stratigraphically higher peats were deposited across the entire marsh.

Nelson et al. (1996) proposed five criteria to help distinguish changes in coastal stratigraphy produced by gradual relative sea level changes from those that may have been produced by local or regional coseismic subsidence events along the Cascadia subduction zone. These criteria include: (1) suddenness of submergence, (2) amount of submergence, (3) lateral extent of submerged tidal wetland soils, (4) coincidence of submergence with tsunami deposits or liquefaction, and (5) synchroneity of submergence events at multiple sites. Rigorous application of these criteria in detailed studies along the Cascadia margin (Atwater and Yamaguchi, 1991; Atwater et al., 1991; Atwater, 1992; Clague and Bobrowsky, 1994a) has allowed these researchers to discriminate the origin of multiple peat-mud contacts preserved in tidal wetlands. Because peat-mud contacts can be formed by the effects of many sedimentologic, hydrographic, and oceanographic processes, Nelson et al. (1996) recognized that the above criteria must be combined with paleoecologic studies in order to infer a coseismic origin for a particular stratigraphic sequence. The argument for a coseismic origin of a stratigraphic event becomes more robust when the majority of the criteria can be satisfied at multiple sites.

Differences in environment and style of deformation associated with earthquakes along the Cascadia margin and along strike slip faults led Knudsen et al. (2002) to modify the Nelson et al.

(1996) criteria in order to identify coseismic subsidence in small pull-apart basins along the San Andreas fault in northern California. Knudsen et al. (2002) recognized that the magnitude of deformation associated with coseismic subsidence along strike-slip faults is localized, related to grabens and releasing step-over geometries, and much less widespread than vertical deformation associated with subduction zone events. Knudsen et al. (2002) also recognized that tsunami deposits coincident with evidence of marsh submergence may not be a useful criteria for strike-slip faults. Additionally, Knudsen et al. (2002) proposed that rapid fluvial aggradation coincident with stratigraphic sequences indicating relative sea level rise may be a reasonable criteria for identifying coseismic subsidence along strike-slip fault systems. Based on paleoecology and contact abruptness, we propose herein that abrupt lower contacts with a change of depositional environment to a lower intertidal level may also be a reasonable criteria.

In the short term, non-tectonic processes can produce stratigraphic sequences in coastal marshes that closely resemble those produced by coseismic subsidence (Carver and McCalpin, 1996; Nelson et al., 1996b, Nelson, 1992a; Shennan, 1989). These non-tectonic processes include variations in local sea level due to ocean currents, sea surface temperatures and unusual tides, changes in coastal geomorphology due to growth or breaching of barrier spits and migration of tidal channels and deltas, and gradual local subsidence associated with sediment compaction. Increases in sediment supply due to landslides or debris flows in marsh tributary alluvial channels also may alter the depositional environment within the marsh and obscure the coseismic subsidence signal.

The above nontectonic processes may be responsible for particular stratigraphic sequences observed in Pillar Point marsh. However, it is unlikely that any buried soil evident in stratigraphic sequences formed by non-tectonic processes could satisfy more than two of the co-seismic criteria proposed by Nelson et al. (1996b) (Carver and McCalpin, 1996, as cited in Knudsen et al., 2002).

To determine whether Pillar Point marsh soils (i.e., peats) were buried by rapid sea level rise associated with tectonic subsidence or some other non-tectonic process, we evaluate criteria modified from Nelson et al. (1996b) and Knudsen et al. (2002). These criteria are shown in Table 2, and include: (1) abrupt upper lithologic contact; (2) diatom evidence for relative sea level rise; (3) evidence for sustained submergence and/or rapid aggradation; (4) wide lateral extent of submergence; and (5) synchroneity with other paleoseismic events. Buried peaty soils that satisfy more than three coseismic criteria, are considered more likely to have a coseismic subsidence origin than a non-tectonic origin. Therefore, we sum the number of criteria satisfied for each buried peat soil (Table 2), and present evidence supporting at least two (Peats 6 and 1) and possibly four (Peats 1, 3, 4, and 6) marsh burial events caused by rapid relative sea level rise. These events are consistent with the hypothesis that surface rupture on the SGF caused submergence and burial of marsh soils at Pillar Point marsh.

Peat 6 satisfies four of the criteria proposed to distinguish co-seismic from non-tectonic sea level change (Table 2). Diatom assemblages above and below the upper contact of Peat 6 indicate that the environment of deposition changed from a fresh-brackish high marsh to a tide flat or low marsh environment. Based on the abrupt upper contact that is overlain by greater than 20 cm of

Table 2. Criteria indicative of coseismic subsidence for peat soils (Peat 1 to 7), Core 02-V5, Pillar Point marsh.

Stratigraphic horizon	Abrupt upper lithologic contact	Diatom evid. for relative sea level rise	Evidence for sustained submergence and/or rapid aggradation[c]	Wide lateral extent of submergence (m)	Synchronous with other paleoseismic events	Number of criteria satisfied	Caused by co-seismic subsidence
Peat 1	Yes (2 mm)	Yes	Yes	Yes (130 m)	Yes	5	Yes
Peat 2	Yes (1 mm)	No	No	Yes (130 m)	?	2	No
Peat 3	Yes (3 mm)[a]	Yes ?	Yes	No	?	3	Possible
Peat 4	Yes (1 mm)	Yes ?	Yes	Yes (70 m)	?	3-4	Possible
Peat 5	Yes (1 mm)	No	No	Yes (70 m)	?	2	No
Peat 6	Yes (2 mm)[b]	Yes	Yes	Yes (70 m)	?	4	Yes
Peat 7	Yes (5 mm)	No	No	No	?	1	No

[a] Lower contact has relief of 2 cm across the core.
[b] Upper 20 mm of peat characterized by micro laminae (1 mm) of peat and mud possibly in a marsh tide flat transition environment.
[c] Sustained submergence is indicated by thick (>10-cm-thick) mud deposits that abruptly bury peaty soils, diatom assemblages that indicate a lasting change in environment and gradual stratigraphic succession from mud to overlying peat. Sustained submergence is not indicated for thin mud strata (<10-cm-thick) that separate two similar peat deposits.

mud, this change occurred rapidly and was sustained for a period long enough for sedimentary processes to adjust to a new base level by aggradation. Finally, Peat 6 is laterally continuous across the width of the paleo-marsh (70 m) indicating that subsidence occurred across the entire paleo-marsh surface.

The abrupt change from mud to the overlying soil developed in Peat 4 is consistent with a coseismic subsidence interpretation and presents an alternative peat over mud stratigraphic sequence. Mud overlying Peat 5 shows a notable absence of diatoms that indicates the marsh was dry and likely a grassy meadow or dune field. The sudden formation of a low brackish marsh (Peat 4) provides evidence for relative sea level rise. However, because diatoms analyzed were from intervals several centimeters from the abrupt peat over mud contact, we cannot preclude that the environmental change from upland meadow/dune to brackish low marsh occurred gradually. Other criteria that support a coseismic subsidence interpretation include lateral continuity and a sustained period of aggradation (20 cm) associated with a gradual transition to fresher conditions. Therefore, Peat 4 satisfies at least three stratigraphic criteria including lateral continuity, sustained aggradation, and abrupt contacts (upper and lower) and may contain diatom evidence for relative sea level rise (Table 2). We propose that abrupt lower lithologic contacts consistent with relative sea level rise may be an additional criteria to consider in stratigraphic evaluations of earthquake chronologies. Future paleoseismic studies should consider collecting diatom samples from the base of suspect peat deposits in addition to the traditional method of analyzing diatom assemblage above and below the upper contact.

Peat 3 satisfies three of the stratigraphic criteria (Table 2). The abrupt upper contact and change in diatom assemblage across the contact from a dry fresh-brackish soil to a fresh-brackish pond or bog indicates rapid subsidence associated with a relative sea level rise. Other criteria that satisfy a coseismic subsidence interpretation include a wide lateral extent and thick alluvial deposit that indicates a sustained period of aggradation following burial of Peat 3. However, we cannot rule out that erosion and alluvial deposition involved a shift to a wetter climatic period that formed a fresh-brackish pond unrelated to coseismic deformation. This rapid change was associated with erosion of Peat 3 by an alluvial channel followed by aggradation of a thick sequence of interbedded mud and sand across the entire marsh. The alluvial channel deposit at the base of cores 02-V4 and 02-V6 occurs at a similar stratigraphic level as Peat 3 (Figure 11) and may represent the base of the erosional contact that stripped Peat 3 from the center of the marsh. The evidence presented above supports the possibility that a large subsidence event may have caused significant land level change across the marsh. Land level change was large enough to cause first erosion and then aggradation across the entire marsh.

Peat 1 represents the stratigraphically highest buried peaty soil and satisfies all five of the stratigraphic criteria. Rapid submergence and relative sea level rise is indicated by the abrupt upper contact between Peat 1 and the overlying mud. The change in diatom assemblage from fresh-brackish species below the contact to brackish, low marsh/tideflat species above the contact is consistent with rapid relative sea level rise. Sustained submergence is indicated by tide flat mud aggradation of ~0.5 m above Peat 1. The deposit is laterally continuous for over 130 m indicating that submergence affected the entire marsh. Finally, radiocarbon analyses above and below the contact (Simpson and Knudsen, 2000) suggest the earthquake occurred

between A.D. 1667 and A.D. 1802 and support synchroneity with a paleoseismic event observed in nearby trenches at Moss Beach (Simpson et al., 1997).

The interpretation presented above provides an initial evaluation of potential earthquakes recorded in the Pillar Point stratigraphy. The stratigraphic and paleontologic data strongly supports the occurrence of at least two (Peats 1 and 6) and possibly four (Peats 1, 3, 4, and 6) Holocene earthquakes on the northern San Gregorio fault. Radiocarbon analyses are necessary to provide a preliminary earthquake chronology for the fault. A more detailed radiocarbon and diatom sampling program will provide more confidence in correlating stratigraphic units, will help refine estimates of the timing of these events, and may provide better constraints on the recurrence interval. If the subsidence events described above are caused by large magnitude earthquakes, a preliminary recurrence interval can be estimated. Assuming that marsh sediments began to accumulate at about the time that relative sea level rise slowed to 1-2 mm/yr in the mid Holocene, the marsh is no older than approximately 6,000 years. As described above, 2 to 4 earthquakes have subsided the marsh to a lower intertidal level. Therefore, we estimate a preliminary recurrence interval for large magnitude earthquakes on the northern San Gregorio fault of between 1500 and 3000 years.

The number of possible earthquakes recorded in Pillar Point marsh (4) is consistent with the number of earthquakes on the northern San Gregorio documented by Thornburg and Weber (1998) at the Cascade Ranch trench site approximately 42 km south of Pillar Point. Although the ages of these events are poorly constrained, potential synchroneity between the Pillar Point marsh site and the Cascade Ranch site may provide information on rupture length and magnitude estimates for earthquakes on the northern San Gregorio fault.

6.0 CONCLUSIONS

The Pillar Point marsh site lies between two strands of the northern San Gregorio fault on the north side of Half Moon Bay. The marsh is characterized by a small basin within which tidal and alluvial sediments have accumulated. We extracted 12 gouge cores and 7 vibra-cores oriented along a transect across the marsh orthogonal to the fault to evaluate the hypothesis that Pillar Point marsh subsides during earthquakes on the northern San Gregorio fault.

In general, the vibra-cores show a sequence of Holocene alluvial and marsh sediments including marsh soils (peat), quiet water deposits (mud), and sand that overlie a Pleistocene alluvial fan soil which marks the base of the marsh. On the eastern side of the marsh, this soil rises to the surface defining a west facing subsurface slope. Based on the location of this slope along the projection of the Seal Cove strand of the San Gregorio fault, we interpret this slope as a tectonically controlled monoclinal fold or warp.

Based on stratigraphic relations observed in the cores and stratigraphic correlations, the marsh sediments onlap the monoclinal warp such that successively higher buried marsh soils are more laterally extensive. A series of criteria modified from Knudsen et al (2002) and Nelson et al. (1996) were employed to evaluate whether abrupt changes in the late Holocene depositional record indicate tectonic subsidence during paleo-earthquakes. Seven buried peat soils were identified in the marsh and paleontologic analyses indicate that three to four of these soils contain diatom evidence that support a relative sea level rise. Based on the stratigraphic,

paleontologic, and criteria matrix, we infer that Peat 1 and Peat 6 were buried during a subsidence event. Peat 3 and Peat 4 may also have been buried during a subsidence event, however, a more extensive diatom sampling program is necessary to confirm the stratigraphic relations. Peat 7, Peat 5, and Peat 2 satisfy less than three criteria and likely record sedimentation in response to some other fluvial or climatic process (non-tectonic).

This field effort contributes new information on the number of late Holocene earthquakes that have occurred on the northern San Gregorio fault and thus provides an initial estimate of Holocene recurrence interval. The data developed in this study support the possibility that at least two and possibly four earthquakes are recorded in the marsh stratigraphy. Available radiometric data suggest that the most recent earthquake occurred between A.D. 1667 and A.D. 1802. This age is consistent with the age of the MRE determined at the nearby Seal Cove trench site at Moss Beach. The ages of the three older possible paleoearthquakes are pending radiometric analyses by the U.S. Geological Survey. Assuming the marsh began accumulating sediment in the middle Holocene and two to four earthquakes are recorded in the marsh, we estimate a preliminary Holocene recurrence interval of 1500 to 3000 years. We emphasize that more detailed paleontologic and radiometric analyses are necessary to more confidently assign a coseismic origin to the buried marsh soils and better constrain the ages of the inferred paleo earthquakes.

The results obtained in this study demonstrate the utility of using marsh stratigraphic techniques to evaluate paleoearthquakes along strike-slip faults. Closely spaced coring intervals and detailed cross sections can be used to correlate buried peaty soils across small marshes that contain a variety of interfingering depositional environments. Therefore, this technique has proven to be a viable approach to future paleoseismic marsh studies along strike-slip faults where conventional paleoseismic methods may not be possible.

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8.0 NON-TECHNICAL SUMMARY

Pillar Point marsh lies within a subsiding basin between two active traces of the on-land northern San Gregorio fault (SGF). Earthquakes on the SGF produce abrupt land-level change that leads to submergence and burial of Pillar Point marsh. This research was designed to evaluate the paleo-earthquake history of the northern SGF by investigating marsh stratigraphy sampled by vibra-coring. Analyses of the cores identified at least two and possibly up to four buried soils that may reflect marsh submergence due to earthquakes. The most recent earthquake occurred

between AD 1667 and AD 1802. Analyses of radiocarbon samples is in progress under second year funding from NEHRP and will be used to estimate the age of the penultimate earthquake and possible older paleo-earthquakes on the SGF.

9.0 REPORTS PUBLISHED

No reports have been published yet as a result of this study. However, pending radiocarbon results from our second year funding will be combined with the results of this study for publication.

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APPENDIX A

Gouge core field stratigraphic descriptions (cores 02-1 to 02-12).

Appendix A. Gouge Core field stratigraphic descriptions (cores 02-1 to 02-12, locations shown on Figure 5)

Core 02-1

Depth Interval	Description
0-12	Peat with black peaty mud, dark brown, fibrous (undecompossed), few coarse and many fine to v. fine roots, lower contact over 2 mm.
12-12.5	Sand, medium to fine grained, clean, single grained, roots penetrate from unit above, lower contact over 1 mm
12.5-52	Peaty mud, black to gray, 10% peat, 90% silty clay, 3 mm thick laminae at top, common fine random roots, lower contact over 10 mm.
52-79.5	Peat w/ silt, dark brown,70% organics, fine decomposed peat, silky feel, common v. fine random roots., lower contact over 10 mm
79.5-88	silty clay loam (mud) w/ trace fine sand and peat chunks, dark bluish gray, soft, not very stiff, massive, few v. fine roots
88-94	Poor recovery, obscures contact between unit above and unit below
94-99	Peat, very dark brown, fibrous, coarse rhizomes, many v. fine roots, lower contact over 10 mm.
99-104	Peaty mud w/ trace white sand grains, dark bluish gray, massive, few med roots, 2 mm plant fragment (husk), lower contact over 4-5 mm.
104-146	Peat w/trace sand, dark brown, no clay, approx. 30% silt, 70% organics, well decomposed, not fibrous, soft, few v. fine horizontal roots, contains seeds, lower contact over 2mm.
146-192	Sandy loam, dark bluish gray, approx. 70% fine sand, massive, no roots, contains coarse mica grains (0.5 mm) and pebbles up to 2 mm, trace coarse woody debris, 2-cm long redwood bark (?), 1 cm-long wood fragment on lower contact, lower contact over 5 mm.
192-245	Organic mud w/ trace mica grains and v. fine sand, dark olive brown, massive, v. few v. fine horizontal roots, stiffer with depth, sulfur odor, 2 mm-thick f. sand laminae @ 204 cm, 5 mm-thick f. sand laminae @ 205.5 cm, lower contact over 1 mm.
245-248.5	Sand, v. fine to fine grained, dark gray, clean single grained structure, no roots, lower contact over 2 mm.
248.5-254.5	Gravelly clay loam w/sand, dark olive brown, massive, trace v. fine roots, common subangular pebbles up to 2-3 mm, approx. 20-30% pebbles and fine sand, lower contact over 5 mm
254.5-262	Loamy fine sand w/trace pebbles to coarse sand, dark gray, massive, no roots, trace mica grains, trace coarse sand up to 2 mm w/ pods of clay loam, lower contact over 5 mm.
262-301	Silty clay loam w/trace v. fine and coarse sand, olive brown to dark olive brown, massive, no laminae, few v. fine horizontal roots, trace chunks of coarse peat, trace stems of marsh plants, grades downward to organic mud w/ darker brown color, lower contact over 10 mm.
301-320	Silty Clay loam w/ patches of peat, dark gray w/ dark brown patches, massive, slightly sticky, slightly plastic, many fine random roots in brown zones, common roots in gray zones, contains med. vertical rhizomes, peat zones make up approx. 20-50% of unit, contains f. grained mica sand and silt, lower contact over 10 mm.
320-348	Muddy Peat grading down to peaty mud, 50% Silty clay loam, 50% well to mod. decomposed peat, dark brown to black, massive to fibrous, many very fine horizontal and few coarse vertical roots, faint sulfur odor, trace mica, peat concentration decreases below 338 cm, lower contact over 10 mm.
348-358	Peaty mud w/ patches of sand and trace pebbles up to 5mm (long axis), trace v. fine mica, dark brown to black, massive, few v. fine random roots, similar to unit above but with more sand, lower contact over 3 mm.
358-373	Muddy peat, dark olive brown, 70% organics, moderately decomposed, fibrous, many v. fine horizontal and common med. sub-vertical roots, trace woody debris (sticks/bark),lower contact over 5 mm.
373-387	Silt loam and loam, dark olive brown to black, 20-25% sand, very soft, wet, goopey, lower contact not observed
387-396.5	Muddy peat dark olive brown, 60% organics, 40% silt loam and loam, fibrous, mod. to well decomposed (more than above), many f. random and few med sub-vertical roots, trace mica, lower contact over 5 mm.
396.5-416	Peaty mud, silty clay loam w/trace coarse sand, dark gray to dark olive brown, 10-15% organics, massive, few v. fine and few med random roots, trace mica, lower contact over 20 mm.
416-433	Coarse sand w/gravel, dark grey w/white granite rock fragments, single grained structure, no roots, subangular gravels up to 4 mm, unit fines upward, top 5 cm is loamy sand w/less gravel, lower contact over 1 mm.
433-446	Silty clay loam w/trace gravel, dark gray to black, contains med to coarse sand, 5-10% decomposed peat, massive, v. few v. fine roots, f. med. rhizomes, lower contact over 1 mm.
446-448	Clean sand
448-470	Clay w/coarse sand and gravel, dark gray to black w/ blue-green mottles, massive trace f. to med. vertical roots, 5-10% sand, blue-green clay rip ups throughout, weakly laminated between 457-462 cm, transitional unit between younger marsh unit above and older surface below, lower contact over 30 mm.
470-487	Clay, blue-green w/ dark rust brown root hallows, trace sand, very stiff, sticky, plastic, massive, v. few coarse vertical rhizomes, no roots, Pleistocene soil

Appendix A. (continued)

Core 02-2

Depth Interval	Description
0-13	Peat, dark brown, fibrous, 100% organics, many vf., f. and med. horizontal roots, lower contact over 1 mm.
13-14	Sand, tan, clean, v. fine to fine grained, single grained structure, common vf. vertical roots penetrate down from above, lower contact over 1 mm.
14-57.5	Peaty mud, silty clay, dark gray to black, 15% organics, massive w/fibrous roots, common vf. horizontal and trace coarse horizontal roots, lower contact over 5 mm.
57.5-65	Peaty mud, dark grayish brown, 80% silty clay loam, 20% well decomposed peat, massive, common vf. horizontal and trace vertical roots, lower contact over 5 mm.
65-139	Muddy peat, dark brown, 60-70% organics, silt loam mineral component, fibrous, common vf. horizontal roots, becomes well decomposed toward base of unit, trace coarse sand up to 1 mm., lower contact over 2 mm
139-212	Mud, silt loam, dark gray to dark olive brown, trace organics, trace mica grains, velvety, soft, trace vf. roots, lower contact over 1 mm.
212-226	Sand w/peaty mud laminae, dark gray w/dark brown laminae, sand: v. fine grained, single grained structure, trace roots, lower contact over 1 mm.
226-295	Silt loam and loam, dark olive brown, 10-15 % organics, trace mica, trace coarse sand, massive, velvety, v.few v.f. roots, trace woody debris, stinky odor, white coarse sand concentrated at base from 285-295 cm., lower contact over 10 mm.
295-331	Silty clay loam, dark olive brown, massive, v. few v.f. roots, sand laminae from 298-299 cm., contains 3-4 mm diameter twigs and woody debris, lower contact over 3 mm.
331-347	Sand w/ sub-angular gravel, dark gray, grain supported structure, sand is med. to coarse grained, gravels up to 1 cm, fines upward to loamy texture in upper part, lower contact not observed, core refusal in dense pebbly sand at 366 cm.

Core 02-3

Depth Interval	Description
0-4	Fine sand, rusty color, single grain structure, common fine horizontal roots, lower contact over 1 mm.
4-11	Sandy peat, dark tan brown, 70% organics, massive to fibrous, common fine horizontal and few coarse horizontal roots, contains large (5-6 mm) woody rhizomes, lower contact over 2 mm.
11-54	Fine sand, tan to gray w/ rust mottles, clean, grain supported, color becomes bluer with depth (reduced), interpreted as tidal channel sand, lower contact over 3 mm.
54-80	Peaty mud, silt loam and loam, very dark brown to black, 20% organics, well decomposed, massive, trace med. horizontal roots, lower contact over 1 mm.
80-81	Very fine sand, dark gray, clean, trace mica grains, single grained to massive, lower contact over 1 mm.
81-87	Peaty mud, dark olive brown, 50% organics, mineral component silt loam, massive, many v.f. horizontal roots
87-112	Peat, dark reddish brown, 70% organics, fibrous, many fine to v.f. random roots, lower contact over 10 mm.
112-149	Peat, dark reddish brown, 70%organics, velvety, moderately decomposed, many v.f. horizontal and trace med. rhizomes, similar to above but more decomposed, lower contact over 10 mm.
149-170	Silty clay loam, dark olive brown, massive, no roots, trace coarse redwood fragments, lower contact over 2-3 mm.
170-193	Muddy peat, dark brown, 60% organics, 40% silt loam and loam, well decomposed, massive to velvety texture, many v.f. horizontal and trace med. vertical roots, lower contact over 5 mm.
193-312	Silt loam, dark olive brown, trace mica and coarse sand, massive, trace v.f. random roots, lower contact not observed, core refusal @312cm on dense gravelly sand w/sub-angular pebbles up to 3 mm diameter

Appendix A. (continued)

Core 02-4

Depth Interval	Description
0-5	Peat
5-10	Fine sand w/trace peat
10-20	Dark brown peaty mud
20-50	Fine sand, interpreted as a beach deposit
50-58	Mud
58-70	Peat, dark reddish brown
70-100	Contaminated core from rodding, contains some sand, presumably this interval is peat (same as above and below)
100-110	Peat, reddish brown
110-117	Silty clay loam, no roots
117-126	Peat, reddish brown, 100% organics, large rhizomes
126-187	Peat, well decomposed, strong organic odor
187-318	Mud, silt loam, dark olive brown, trace to 5% decomposed organics, trace sand w/mica
318-463	Clayey mud, silty clay loam, dark gray, downward increase in coarse sand and angular pebbles up to 10 mm diameter

Core 02-5

Depth Interval	Description
0-6	Sandy peat, dark brown, common coarse and v.f. roots
6-41.5	Sand, gray w/ orange oxidation mottles, contains some peat, sand is bluish gray at base, few v.f. and few med. roots, lower contact over 1 mm.
41.5-84	Peaty mud, silt loam, dark brown to black, soft, sulfur odor, 40% organics, many v.f. horizontal and common f. random roots, lower contact over 2 mm.
84-87	V. fine sand w/trace mica, gray, contains woody debris (acorn ?) and trace peat, weakly bedded, lower contact over 2 mm.
87-108	Peat, reddish brown, 70% $^{+}$ organics, few med. and common f. roots, moderately decomposed, distinct coarse red rhizome (rare), lower contact over 10-20 mm.
108-142	Peat, reddish brown, well decomposed, sulfur odor, few v.f. random and trace med sub-vertical roots, trace woody debris, similar to above, lower contact over 4 mm.
142-151.5	Organic mud, silt loam, gray, sulfur odor, trace coarse peat (rhizomes), lower contact over 2 mm
151.5-183.5	Peat, dark brown, well decomposed, 60% organics, less organics than peat between 108-142 cm, silt loam mineral component, sulfur odor, v. few v.f. random roots, lower contact over 5 mm.,
183.5-201	Mud, silt loam, dark olive brown, trace mica grains, trace woody debris, v. few v.f. roots, massive, lower contact over 2 mm.
201-218	Sand w/mud laminae, sand is dark gray, v.f. grained, 10% med. grained, mud laminae are sandy silt loam, olive brown, generally < 2 cm thick, lower contact over 2 mm.
218-290	Silt loam, dark olive brown, trace mica, 10% organics, v. few v.f. horizontal roots, slight increase in fine mica near base, lower contact over 30 mm.
290-319	Silt loam, dark olive brown, 10% fine sand, trace coarse sand up to 1 mm diameter, 10% organics, massive to patchy, increase in sand from unit above, lower contact over 5 mm.
319-333.5	Organic mud, silt loam, dark brown, slightly more organics than above, 15% organics, massive, micaceous, trace v.f. horizontal roots, sulfur odor, lower contact over 2 mm.
333.5-387	Interbedded dark gray and dark brown mud, silt loam to silt clay loam, micaceous, less organics than above, <10% organics in brown beds, contains a brown peaty mud bed at 360-361 cm, 5 mm thick laminae between 361-365 mm, lower contact over 2 mm.
387-390.5	Muddy peat, olive brown, well decomposed, common v.f. random roots, 60% organics, lower contact over 2 mm.
390.5-406	Silty clay loam interbedded w/ organic brown mud laminae, contains a sand layer (1 cm thick) at 395 cm., between 403 and 406 cm is a peaty mud bed olive color, 40% organics, silt loam, trace v.f. roots, lower contact over 3 mm.
406-454	Silty clay loam, dark bluish grey, trace sand and angular to sub-angular pebbles up to 5 mm diameter, v. few f. roots, massive, much stiffer than all units above, interpreted as Pleistocene soil, base of core @454 cm.

Appendix A. (continued)

Core 02-6

Depth Interval	Description
0-76	Fine sand, tan brown w/ orange oxidation mottles, few med. and common v.f. roots, single grain supported, black mud laminae 5-10 mm thick occur at 14, 35,37, and 40 cm, below 40 cm sand fines to v.f., lower contact over 3 mm.
76-110.5	Peat, dark reddish brown, >70% organics (peat), contains macro coarse marsh plant remains, sulfur odor, becomes more decomposed toward base, fibrous, lower contact over 2 mm.
110.5-118	Silt loam, gray, massive, smells, v. few v.f. horizontal roots, lower contact over 1 mm.
118-161	Peat, dark reddish brown, >70% organics, fibrous, similar to peat between 76-110.5 cm, below 131 cm peat more decomposed, many v.f. horizontal roots, few med. rhizomes, lower contact over 10 mm.
161-215	Mud, silt loam, dark olive brown, trace mica, trace v.f. roots, 1 cm thick peaty mud laminae at 190 cm., patchy sand below 190 cm., lower contact not observed.
215-225	Gravelly sand, pebbles up to 5 mm diameter make up 10 % of unit, predominantly coarse sand, lower contact over 10 mm.
225-271	Gravelly clay loam, dark blackish gray, poorly sorted, angular to sub-angular gravel clasts include serpentine (Franciscan) and granitic rock fragments (Montara Mountain), interpreted as Pleistocene fan soil

Core 02-7

Depth Interval	Description
0-14	Fine sand, tan with orange oxidation, common f. roots, 5 mm. thick mud laminae at 11 cm., lower contact over 3 mm.
14-50.5	Peaty mud, silt loam, black, 10-20 % organics, massive to weakly laminated, coarse woody debris, common v.f. horizontal and f. vertical roots,1 cm. thick tan sand laminae at 23.5 cm., 1-2 mm thick sand lamiae at 31 and 34 cm.
50.5-53	Sand to loamy sand, dark gray, v.f. sand to coarse silt, clean, single grain supported, few fine random roots, lower contact over 2 mm.
53-109	Peat, dark reddish brown, slightly darker at top, horizontally matted coarse peat, common v.f. random roots, fibrous, >70% organics, contains macro plant remains, less fibrous and more decomposed below 78 cm., lower contact over 10 mm.
109-124	Silt loam, dark gray, massive, v. few v.f. roots, no mica, lower contact over 1 mm.
124-160	Peat, reddish brown, >70% organics, moderately fibrous to well decomposed, common v.f. random roots, woody debris includes; sticks and macrofossils, redwood fragments, lower contact not recovered and not observed.
160-220	Mud, silt loam, dark olive brown, micaceous, massive, trace coarse sand, few v.f. random roots, lower contact over 10 mm.
220-239	Mud, silt loam, dark olive brown, micaceous, massive, coarse woody debris, patchy v.f. sand (approx 10% of unit), lower contact over 10 mm.
239-280	Mud, silt loam grading downward to a loamy sand (lower 10 cm.), dark olive brown, micaceous, slightly grayer than above, similar to unit between 160-220 cm., lower contact over 1 mm.
280-364	Clay w/coarse sand and gravel to clay loam, bluish gray, contains granitic pebbles, interpreted as Pleistocene fan soil, bottom of core at 364 cm.

Appendix A. (continued)

Core 02-8

Depth Interval	Description
0-100	Very fine to fine sand, tan, dry, clean, well sorted, common v.f. random roots in upper 20 cm., orange oxidation between 50 and 60 cm., coarsens downward to med to f. sand, interpreted as a beach berm or dune deposit, refusal at 100 cm.

Core 02-9

Depth Interval	Description
0-78	Fine sand, well sorted, tidal channel exposure, interpreted to be a beach bar or dune deposit, lower contact not observed,
78-118.5	Peat, dark reddish brown, fibrous, >70% organics, many v.f. horizontal roots, common med. rhizomes, tidal channel exposure for upper half lower half observed by coring the bed of tidal channel, lower contact over 2 mm.
118.5-120	Peaty mud, silt loam, dark gray, no sand, lower contact over 1 mm.
120-125.5	Peat, dark brown, well decomposed, >70% organics, smelly, trace v. f. roots, lower contact over 10 mm.
125.5-138	Interbedded peaty mud and peat, abundant coarse plant remains, brown mud laminae range from 2-10 mm, lower contact over 5 mm.
138-152	Silt loam, dark gray, no roots, massive, very stinky, lower contact over 1 mm.
152-161	Muddy Peat, dark olive brown, 60% organics, few v.f. and few med. horizontal roots, sulfur odor, well decomposed, lower contact over 5 mm.
161-168	Silt loam, dark olive brown, contains v.f. sand (<5-10%), micaceous, lower contact over 2 mm.
168-172	Coarse sand and gravel, angular to sub-angular clasts up to 4 mm., interpreted as an alluvial channel deposit, lower contact not observed.
172-223	Clay loam, dark bluish gray, contains angular to sub-angular granitic and serpentine rock clasts, interpreted as Pleistocene fan soil.

Outcrop 02-10

Depth Interval	Description
0-82	Sand, tan, well sorted, clean, single grain supported, interpreted as a beach bar or dune deposit
82-160	Gravelly clay loam, dark bluish gray, contains granitic and serpentine rock clasts, interpreted as Pleistocene fan soil.

Core 02-11

Depth Interval	Description
0-4	Sandy peat, black, fibrous
4-7	V. fine sand, clean, tan
7-35	Mud, stiff sandy clay, black, dry, interbedded with clean v.f. sand, sand laminae range in thickness from 4-10 mm.
35-80	Clay w/ coarse sand and granitic rock clasts, clasts are sub-angular and highly weathered, interpreted as Pleistocene fan soil

Appendix A. (continued)

Core 02-12

Depth Interval	Description
0-10	Peat with mud, modern marsh, fibrous
10-24.5	Mud, gray to tan-gray, orange mottles, common v.f. roots, increasing peat concentration towards base, well sorted sand laminae at base between 24 and 24.5 cm., possible tsunami or storm surge deposit.
24.5-68	Peaty mud, black, massive, increasing roots above 50 cm., f. orange roots between 46-50 cm., rare roots below 50 cm., flat, 3 cm. long wood fragment at 46 cm., lower contact over 3 mm.
68-103	Peat, dark reddish brown, >60% organics, lower contact over 20-30 mm.
103-131	Mud, silt loam, dark gray,concentration of peat between 116 and 118 cm., lower contact over 1 mm.
131-154	Peat, dark brown, well decomposed, velvety, 60% organics, no visible roots, lower contact over 20 mm.
154-190.5	Sandy loam to loamy sand, dark olive gray, coarsens downward, abundant mica grains, contains fine to v.f. sand and silt, basal 8 cm. is very sandy and abruptly overlies micaceous mud, lower contact over 1 mm.
190.5-232	Mud, silt loam, dark olive brown, lower contact over 5 mm.
232-247	Homogeneous mixture of sand and mud with 20% med to fine sand between 232 and 239 cm., clean med to f. sand between 239 and 240 cm., v. fine sand laminae interbedded with dark olive brown mud between 240 and 247 cm., lower contact over 5-10 mm.
247-272	Mud, silt loam, dark olive brown, micaceous, contains trace sand laminae <1 cm thick possible tidal laminae
272-286	Muddy peat to peaty mud, dark brown, 40-50% organics, well decomposed, smells, micaceous, below 280 cm becomes less organic, lower contact over 10 mm.
286-304.5	Mud, silt loam, dark olive gray, massive trace med. roots, faintly laminated, contains peaty mud laminae, no mica, lower contact over 2-3 mm.
304.5-322	Peaty mud, dark brown, contains coarse plant fragments, dark gray mud laminae between 306.5-307 cm. and 307.5-308 cm, top of unit more organic than base, slightly more mud than peat between 272-286 cm., lower contact over 3 mm.
322-338	Silty clay loam, dark olive gray, massive, abundant mica grains, contains interbedded 3 mm thick laminae of coarse peat, total of 5 laminae between 322 and 326 cm, below 326 cm. unit has more peat than laminated interval above, lower contact over 5 mm.
338-343	Peaty mud, dark brown, massive, well decomposed, lower contact over 3 mm.
343-349	Silty clay loam, dark brown gray to black, smells, lower contact over 1 mm.
349-353	Fine sandy loam, dark gray to black, abundant mica, 5 mm thick mud laminae at 351 cm., lower contact sharp.
353-355	Organic mud, dark olive brown, trace f. roots.
355-363	Sand, med. to coarse grained, clean, angular to sub-angular rock fragments, no apparent bedding, lower contact over 2 mm., interpreted as a beach deposit.
363-366	Mud, dark olive gray
366-391.5	Peat, reddish brown, slightly muddy, 60-70% organics, macro peat fragments, lower contact over 3 mm.
391.5-413	Mud, Silty clay loam, dark olive brown to dark gray, between 400 and 413 cm unit is laminated with 2-3 mm. thick brown peaty layers, increasingly black with coarse sand at base, lower contact over 20 mm.
413-449.5	Sandy to silty clay loam, black, contains coarse granite rock clasts, interpreted as Pleistocene fan soil.

APPENDIX B

Diatom species counts for samples DIA-1 to DIA-15, core 02-V5
Diatom analyses performed by EHH Consulting Micropaleontology,
McKinleyville, California

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #1	DIA #2	DIA #3	DIA #4
	100	**100**	**18**	**100**
per traverse	157	151	10	480
ml/area traversed	6.7E-04	6.7E-04	6.7E-04	6.7E-04
valve concentration/cc	2.36E+05	2.27E+05	1.50E+04	7.20E+05
BRACKISH SPECIES				
Achnanthes haukiana	4	2		
Achnanthes brevipes	2			
Amphora coffeaeformis	8			
Amphora holsatica				
Bacillaria paradoxa				
Caloneis bacillum				
Caloneis westii	6	1		
Cocconeis scutellum				
Cosmioneis pusilla				
Denticula subtilis				
Diploneis cf. Boltdiana				
Diploneis interrupta				
Diploneis pseudovalis				
Diploneis smithii v. dilatata				
Frustulia vulgaris				
Gyrosigma eximium				
Gyrosigma spenceri	11			
Gyrosigma wansbeckii				
Mastogloia exigua				
Melosira moniliformis	4			
Melosira nummuloides				
Navicula cf. Decussis				
Navicula cf. Halophila				
Navicula cincta		2		
Navicula cryptotenella				
Navicula digitoradiata				
Navicula eidrigiana				
Navicula menisculus				
Navicula peregrina				
Navicula salinarum	3			
Navicula slesvicensis				
Navicula viridula rostellata				
Nitzschia commutata				
Nitzschia fasciculata				
Nitzschia nana				
Nitzschia scalproides				
Nitzschia sigma				
Nitzschia vitrea			1	
Paralia sulcata				
Rhopalodia acuminata	8	2		
Rhopalodia musculus		1		
Surirella fastuosa	5			
Surirella ovalis/brebisonnii	1			
Synedra fasciculata	1			
Tryblionella apiculata	2	8		
Tryblionella coarctata	2	2		

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #5	DIA #6	DIA #7	DIA #8
	100	**100**	**100**	**100**
per traverse	1310	132	240	720
ml/area traversed	6.7E-04	6.7E-04	6.7E-04	6.7E-04
valve concentration/cc	1.97E+06	1.98E+05	3.60E+05	1.08E+06
BRACKISH SPECIES				
Achnanthes haukiana		4		
Achnanthes brevipes				4
Amphora coffeaeformis				
Amphora holsatica			2	5
Bacillaria paradoxa				
Caloneis bacillum		2	6	7
Caloneis westii				6
Cocconeis scutellum				
Cosmioneis pusilla			4	7
Denticula subtilis				
Diploneis cf. Boltdiana			2	3
Diploneis interrupta				
Diploneis pseudovalis			14	1
Diploneis smithii v. dilatata				
Frustulia vulgaris			1	2
Gyrosigma eximium			10	7
Gyrosigma spenceri			1	
Gyrosigma wansbeckii				
Mastogloia exigua				6
Melosira moniliformis				
Melosira nummuloides				
Navicula cf. Decussis				1
Navicula cf. Halophila				2
Navicula cincta		3	1	
Navicula cryptotenella		1	3	5
Navicula digitoradiata				
Navicula eidrigiana				
Navicula menisculus				
Navicula peregrina		9	1	1
Navicula salinarum				
Navicula slesvicensis				
Navicula viridula rostellata				
Nitzschia commutata			2	2
Nitzschia fasciculata			3	2
Nitzschia nana			2	
Nitzschia scalproides				
Nitzschia sigma			6	3
Nitzschia vitrea				
Paralia sulcata				
Rhopalodia acuminata		2	3	15
Rhopalodia musculus			1	9
Surirella fastuosa				
Surirella ovalis/brebisonnii			4	
Synedra fasciculata				
Tryblionella apiculata			1	
Tryblionella coarctata				

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #9	DIA #10	DIA #11	DIA #12
	100	**100**	**100**	**100**
per traverse	240	12	162	172
ml/area traversed	6.7E-04	6.7E-04	6.7E-04	6.7E-04
valve concentration/cc	3.60E+05	1.80E+04	2.43E+05	2.58E+05
BRACKISH SPECIES				
Achnanthes haukiana		1		
Achnanthes brevipes				
Amphora coffeaeformis				
Amphora holsatica	2			5
Bacillaria paradoxa		1		
Caloneis bacillum	8		4	4
Caloneis westii	13			
Cocconeis scutellum				1
Cosmioneis pusilla		4	9	1
Denticula subtilis	1			
Diploneis cf. Boltdiana	3			3
Diploneis interrupta				
Diploneis pseudovalis	1	4	17	15
Diploneis smithii v. dilatata				2
Frustulia vulgaris				3
Gyrosigma eximium	10	1	7	13
Gyrosigma spenceri				1
Gyrosigma wansbeckii				
Mastogloia exigua				
Melosira moniliformis	1			
Melosira nummuloides				
Navicula cf. Decussis				
Navicula cf. Halophila				
Navicula cincta	1	2		1
Navicula cryptotenella	22		3	2
Navicula digitoradiata			1	
Navicula eidrigiana		1		
Navicula menisculus		1		
Navicula peregrina				
Navicula salinarum				
Navicula slesvicensis				3
Navicula viridula rostellata		1	14	
Nitzschia commutata				
Nitzschia fasciculata				
Nitzschia nana	1	3	2	
Nitzschia scalproides	1			
Nitzschia sigma	6	6	3	6
Nitzschia vitrea		1	6	1
Paralia sulcata	1			
Rhopalodia acuminata		1	2	1
Rhopalodia musculus	6	2		
Surirella fastuosa				
Surirella ovalis/brebisonnii		1		
Synedra fasciculata	1			
Tryblionella apiculata		3		
Tryblionella coarctata				

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #13	DIA #14	DIA #15
	100	**100**	**100**
per traverse	197	38	650
ml/area traversed	6.7E-04	6.7E-04	6.7E-04
valve concentration/cc	2.96E+05	5.70E+04	9.75E+05
BRACKISH SPECIES			
Achnanthes haukiana	1		2
Achnanthes brevipes	1		5
Amphora coffeaeformis			
Amphora holsatica	1		1
Bacillaria paradoxa			3
Caloneis bacillum	5		7
Caloneis westii	1		4
Cocconeis scutellum			
Cosmioneis pusilla	3	2	2
Denticula subtilis		2	
Diploneis cf. Boltdiana		1	2
Diploneis interrupta	2	1	5
Diploneis pseudovalis	5	2	
Diploneis smithii v. dilatata			
Frustulia vulgaris			
Gyrosigma eximium	1		7
Gyrosigma spenceri			
Gyrosigma wansbeckii		1	4
Mastogloia exigua		1	
Melosira moniliformis			1
Melosira nummuloides	2		12
Navicula cf. Decussis			
Navicula cf. Halophila			
Navicula cincta	1		1
Navicula cryptotenella			1
Navicula digitoradiata			1
Navicula eldrigiana			
Navicula menisculus			
Navicula peregrina			1
Navicula salinarum			
Navicula slesvicensis			
Navicula viridula rostellata	3		
Nitzschia commutata			
Nitzschia fasciculata			1
Nitzschia nana			
Nitzschia scalproides			
Nitzschia sigma			1
Nitzschia vitrea	1		
Paralia sulcata	2		
Rhopalodia acuminata	12	12	13
Rhopalodia musculus	2	6	3
Surirella fastuosa			
Surirella ovalis/brebisonnii			
Synedra fasciculata			
Tryblionella apiculata	1		
Tryblionella coarctata			

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #1	DIA #2	DIA #3	DIA #4
Tryblionella debilis				
Tryblionella granulata				
Tryblionella navicularis				
Tryblionella littoralis				
Tryblionella vexans				
Tryblionella victorae		1		
FRESH-BRACKISH SPECIES				
Achnanthes lanceolata			2	2
Amphora veneta		4		
Aulacoseira cf. Islandica	4	2		
Caloneis molaris				
Cocconeis placentula		1	4	22
Cyclotella meneghiniana				3
Cymbella amphicephala				1
Cymbella pusilla				
Epithemia argus	1			2
Epithemia turgida	4	12	6	16
Eunotia flexuosa				6
Fallacia cryptolyra				
Fallacia pygmaea		5		
Fragilaria brevistriata				3
Fragilaria pinnata	30	28		
Fragilaria leptostauron				2
Gomphonema acuminatum				
Gomphonema angustatum				4
Gomphonema gracilie				1
Gomphonema parvulum		1		
Hantzschia amphioxys			1	
Luticola mutica				
Luticola muticoides				
Mastogloia smithii				
Melosira varians		2		3
Meridian circulare				
Navicula gregaria				
Navicula phyllepta	2	5		
Navicula radiosa				
Navicula rhyncocephala	2	4		1
Nitzschia amphibia				4
Nitzschia brevissima			2	
Nitzschia dissipata				
Nitzschia palea				
Nitzschia terrestris				
Pinnularia lagerstedtii				1
Pinnularia viridis				
Rhoicospphenia abbreviata		2		8
Rhopalodia gibba				1
Sellaphora pupula				1
Surirella angusta				
Surirella ovalis				
FRESH SPECIES				

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #5	DIA #6	DIA #7	DIA #8
Tryblionella debilis			3	1
Tryblionella granulata				5
Tryblionella navicularis				
Tryblionella littoralis				1
Tryblionella vexans				
Tryblionella victorae			1	
FRESH-BRACKISH SPECIES				
Achnanthes lanceolata	2	12		
Amphora veneta				
Aulacoseira cf. Islandica			2	
Caloneis molaris		5		
Cocconeis placentula	2	8	3	
Cyclotella meneghiniana	3			
Cymbella amphicephala	1	2		
Cymbella pusilla				
Epithemia argus		2		
Epithemia turgida			4	1
Eunotia flexuosa				
Fallacia cryptolyra		1		
Fallacia pygmaea		1		
Fragilaria brevistriata				
Fragilaria pinnata				
Fragilaria leptostauron				
Gomphonema acuminatum				
Gomphonema angustatum	2			
Gomphonema gracilie				
Gomphonema parvulum		4		
Hantzschia amphioxys		1		
Luticola mutica			9	
Luticola muticoides				
Mastogloia smithii				
Melosira varians	30			
Meridian circulare		1		
Navicula gregaria	6			
Navicula phyllepta				
Navicula radiosa				
Navicula rhyncocephala	18	10	7	4
Nitzschia amphibia				
Nitzschia brevissima				
Nitzschia dissipata				
Nitzschia palea		1	2	
Nitzschia terrestris		2		
Pinnularia lagerstedtii				
Pinnularia viridis	2			
Rhoicospphenia abbreviata		2		
Rhopalodia gibba	8			
Sellaphora pupula		2		
Surirella angusta				
Surirella ovalis	6			
FRESH SPECIES				

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #9	DIA #10	DIA #11	DIA #12
Tryblionella debilis	3		10	3
Tryblionella granulata	17			
Tryblionella navicularis				
Tryblionella littoralis				
Tryblionella vexans				
Tryblionella victorae				
FRESH-BRACKISH SPECIES				
Achnanthes lanceolata				
Amphora veneta				
Aulacoseira cf. Islandica				
Caloneis molaris		2	1	3
Cocconeis placentula		2	2	6
Cyclotella meneghiniana				
Cymbella amphicephala				
Cymbella pusilla				
Epithemia argus			1	
Epithemia turgida		17	8	7
Eunotia flexuosa				
Fallacia cryptolyra				
Fallacia pygmaea			2	
Fragilaria brevistriata				
Fragilaria pinnata				
Fragilaria leptostauron				
Gomphonema acuminatum		2		
Gomphonema angustatum				
Gomphonema gracilie				
Gomphonema parvulum		1		2
Hantzschia amphioxys		10		4
Luticola mutica	2	1	2	1
Luticola muticoides				
Mastogloia smithii				
Melosira varians				
Meridian circulare				
Navicula gregaria				
Navicula phyllepta				
Navicula radiosa		1		
Navicula rhyncocephala		8		1
Nitzschia amphibia			1	1
Nitzschia brevissima		1		
Nitzschia dissipata		3		
Nitzschia palea		1	2	
Nitzschia terrestris				
Pinnularia lagerstedtii		1	3	1
Pinnularia viridis		1		
Rhoicospphenia abbreviata				
Rhopalodia gibba				
Sellaphora pupula				
Surirella angusta				1
Surirella ovalis				
FRESH SPECIES				

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #13	DIA #14	DIA #15
Tryblionella debilis	3		1
Tryblionella granulata		1	14
Tryblionella navicularis	1		2
Tryblionella littoralis	1		
Tryblionella vexans		2	
Tryblionella victorae			2
FRESH-BRACKISH SPECIES			
Achnanthes lanceolata			
Amphora veneta			
Aulacoseira cf. Islandica			
Caloneis molaris			
Cocconeis placentula	9	3	
Cyclotella meneghiniana			
Cymbella amphicephala			
Cymbella pusilla		7	
Epithemia argus	1	1	1
Epithemia turgida	15	7	
Eunotia flexuosa			
Fallacia cryptolyra			
Fallacia pygmaea			
Fragilaria brevistriata			
Fragilaria pinnata			
Fragilaria leptostauron			
Gomphonema acuminatum	1		
Gomphonema angustatum			
Gomphonema gracilie			
Gomphonema parvulum	2	2	
Hantzschia amphioxys	2	13	
Luticola mutica	8	3	1
Luticola muticoides			1
Mastogloia smithii			1
Melosira varians			
Meridian circulare			
Navicula gregaria			
Navicula phyllepta			
Navicula radiosa			
Navicula rhyncocephala	1		
Nitzschia amphibia			
Nitzschia brevissima			
Nitzschia dissipata			
Nitzschia palea	2		
Nitzschia terrestris	2		
Pinnularia lagerstedtii	1		
Pinnularia viridis			
Rhoicospphenia abbreviata		3	
Rhopalodia gibba		1	
Sellaphora pupula			
Surirella angusta			
Surirella ovalis			
FRESH SPECIES			

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #1	DIA #2	DIA #3	DIA #4
Achnanthes minutissima v. affinis				
Amphora normanii		2		3
Eunotia pectinalis			2	2
Fragilaria virescens		6		3
Pinnularia divergens				
Pinnularia microstauron		1		1
Stauroneis kreigeri				6
Stauroneis phoencenteron				
Synedra ulna		6		4
ECOLOGY UNKNOWN				
Achnanthes cf. expressa				
Achnanthes cf. brevipes	30			
Gomphonema cf. abbreviatum		1		
Navicula cf. cincta		4		
Navicula cf. libonensis				
Nitzschia sp. large straight				
total	**100**	**100**	**18**	**100**
total brackish	57	19	1	0
total fresh-brackish	43	66	15	81
total fresh	0	15	2	19
total ecology uncertain	30	5	0	0
aerophile species	0	3	3	5
planktonic species	4	16	0	13

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #5	DIA #6	DIA #7	DIA #8
Achnanthes minutissima v. affinis		8		
Amphora normanii				
Eunotia pectinalis		5	2	
Fragilaria virescens				
Pinnularia divergens		4		
Pinnularia microstauron	8	1		
Stauroneis kreigeri		2		
Stauroneis phoencenteron				
Synedra ulna	12	5		
ECOLOGY UNKNOWN				
Achnanthes cf. expressa		5		
Achnanthes cf. brevipes				
Gomphonema cf. abbreviatum				
Navicula cf. cincta				
Navicula cf. libonensis				
Nitzschia sp. large straight				
total	**100**	**100**	**100**	**100**
total brackish	0	21	71	95
total fresh-brackish	74	54	27	5
total fresh	20	17	2	0
total ecology uncertain	0	5	0	0
aerophile species	8	8	0	0
planktonic species	45	5	2	0

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #9	DIA #10	DIA #11	DIA #12
Achnanthes minutissima v. affinis				
Amphora normanii				
Eunotia pectinalis		3		2
Fragilaria virescens				2
Pinnularia divergens				
Pinnularia microstauron				
Stauroneis kreigeri				
Stauroneis phoencenteron		1		
Synedra ulna		12		4
ECOLOGY UNKNOWN				
Achnanthes cf. expressa				
Achnanthes cf. brevipes				
Gomphonema cf. abbreviatum				5
Navicula cf. cincta				
Navicula cf. libonensis			3	
Nitzschia sp. large straight			1	
total	**100**	**100**	**100**	**100**
total brackish	98	33	78	65
total fresh-brackish	2	51	22	27
total fresh	0	16	0	8
total ecology uncertain	0	0	4	5
aerophile species	0	12	3	5
planktonic species	0	12	0	6

PILLAR POINT DIATOM ANALYSES: CORE 02-V5

Sample #	DIA #13	DIA #14	DIA #15
Achnanthes minutissima v. affinis			
Amphora normanii		22	
Eunotia pectinalis		1	
Fragilaria virescens		3	
Pinnularia divergens	2		
Pinnularia microstauron		2	
Stauroneis kreigeri			
Stauroneis phoencenteron		1	
Synedra ulna	5		
ECOLOGY UNKNOWN			
Achnanthes cf. expressa		16	
Achnanthes cf. brevipes			
Gomphonema cf. abbreviatum	3	4	
Navicula cf. cincta			
Navicula cf. libonensis			
Nitzschia sp. large straight			
total	**100**	**100**	**100**
total brackish	49	31	96
total fresh-brackish	44	40	4
total fresh	7	29	0
total ecology uncertain	3	20	0
aerophile species	7	44	0
planktonic species	5	3	0