FINAL TECHNICAL REPORT

PALEOSEISMIC INVESTIGATION OF THE NORTHERN SAN GREGORIO FAULT, HALF MOON BAY, CALIFORNIA

Recipient:
William Lettis & Associates, Inc.
1777 Botelho Drive, Suite 262
Walnut Creek, CA 94596
Phone (925) 256-6070; Fax (925) 256-6076

Principal Investigators:
Rich D. Koehler[1], Robert C. Witter[1], Gary D. Simpson[2], Eileen Hemphill-Haley[3], William R. Lettis[1]

Contributors:
Justin T. Pearce[1], Sean Sundermann[1], Ashley Streig[1]

William Lettis & Associates, Inc. [1]
1777 Botelho Dr., Ste. 262
Walnut Creek, CA 94596
Phone: (925) 256-6070;
Fax (925) 256-6076
koehler@seismo.unr.edu

SHN Consulting Engineers and Geologists[2]
812 W. Wabash
Eureka, CA 95501;
Phone (707) 441-8855
gsimpson@shn-engr.com

EHH Consulting Micropaleontology[3]
1871 Pickett Road
McKinleyville, CA 95519
(707) 840-9554
ehh@ehhmusic.com

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Rich D. Koehler[1], Robert C. Witter[1], Gary D. Simpson[2], Eileen Hemphill-Haley[3], William R. Lettis[1]

Recipient:
William Lettis & Associates, Inc., 1777 Botelho Drive, Suite 262, Walnut Creek, CA 94596
Phone (925) 256-6070; Fax (925) 256-6076; witter@lettis.com

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. The SGF accommodates at least 4.5 mm/yr and perhaps as much as 7 to 10 mm/yr of the slip budget along the San Andreas fault system. Despite its significance, the SGF has received relatively little attention regarding its late Holocene paleoseismic behavior because much of the fault lies offshore. This study, therefore, was designed to develop information on the timing of past earthquakes on the San Gregorio fault (SGF).

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. Based on the hypothesis that changes in the depositional environment are a function of sudden tectonic subsidence and gradual sea level rise, we performed a study of the Pillar Point Marsh (Koehler et al., 2004), that included analysis of seven vibra cores and twelve gouge augers. Diatom paleoecology and stratigraphic relations were used to evaluate the origin of abrupt changes in the depositional record associated with relative sea level rise. We inferred that the two to four earthquakes along the northern SGF had caused land level changes and burial of peat deposits in the marsh.

In order to confirm a tectonic subsidence mechanism for buried soils observed at Pillar Point, we initiated the verification studies presented in this report. We performed additional paleoecologic and radiometric analyses and evaluated the origin of stratigraphic contacts using a criteria matrix modified from Knudsen et al. (2002). We then performed a stratigraphic study of a marsh not affected by an active fault to determine whether the succession of deposits at Pillar Point marsh represent a unique response to tectonic subsidence. Finally, we performed a paleoseismic trench excavation on-land north of the marsh to document evidence for paleo earthquakes.

Stratigraphic relations in the marsh provide evidence of two and possibly three rapid relative sea level changes in the marsh that may be associated with large earthquakes along the SGF. Radiometric ages on subsided peat deposits indicate that these earthquakes occurred after 500 cal yr BP and between 3350 and 4080 cal yr BP. A third earthquake may have occurred between 3060 and 3330 cal yr BP. Our results also include stratigraphic evidence for two to four earthquakes observed in the trenches, providing independent verification that the observed land level changes in the marsh are synchronous with fault rupture. A reconnaissance study of China Camp marsh provided marginal evidence that the stratigraphic signature of coseismic land level changes at Pillar Point marsh is unique. We conclude that there have been at least two and possibly four earthquakes on the SGF in the last 4150-4410 cal yr BP, and estimate a preliminary recurrence interval of 1037-2205 years.

The results of this investigation will help mitigate earthquake losses by documenting the earthquake history of the SGF and providing recurrence estimates to evaluate segmentation models used in probabilistic seismic hazard assessments for the San Francisco Bay area.

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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 Pt. Ano Nuevo and San Gregorio, and between Pillar Point and Moss Beach (Figures 1 and 2). Despite geomorphic and paleoseismic evidence of Holocene activity (Koehler et al., 2004; Simpson and Knudsen, 2000; Simpson et al., 1998; 1997), 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 (Lewis, 1994) 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 formed by the right-stepover between the two fault strands (Figures 1 and 2). In a right-lateral strike-slip system, this produces a releasing geometry that may accommodate extension and subsidence within Half Moon Bay and Pillar Point marsh. We infer that stratigraphic sequences in the Pillar Point marsh reflect changes in the depositional environment of the marsh as 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; 1996; Abrahamson, 1998; Nelson et al., 1996; 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). During our first year investigation at Pillar Point marsh we identified five abruptly buried marsh soils and defined an apparent monoclinal warp in the marsh substrate along strike with the SGF. These observations, coupled with diatom evidence of rapid relative sea-level rise suggest that multiple earthquakes on the SGF caused abrupt coseismic subsidence of the marsh.

The intent of this study is to confirm and refine the timing of the MRE and older paleo-earthquakes identified in our first year study (Koehler et al., 2004) based on stratigraphic position, sedimentology, age, and microfaunal assemblages associated with abrupt changes in fresh-brackish marsh soils preserved beneath Pillar Point marsh. The geographic position of Pillar Point marsh between two active strands of the SGF that project on-land, makes the Pillar Point marsh area a unique location to study the possible synchroneity of the paleoseismic record between the marsh and an on-land trench exposure that provides an independent validation of the method of using marsh stratigraphy to identify earthquake-induced subsidence in strike-slip environments. An additional focus of this study is to conduct a stratigraphic investigation of another marsh in a non-tectonic environment to evaluate the uniqueness of the Pillar Point paleoseismic record.

This report includes new paleoseismic information for the northern SGF from a shallow stratigraphic core study of the Pillar Point marsh site and a trench investigation on the fault north of the marsh. Based on the results of our independent verification and validation studies, we infer that tectonic subsidence of Pillar Point marsh during earthquakes on the northern SGF has caused submergence and burial of peat soils two to four times in the last 4150-4410 cal yr BP. The results of the independent verification and validation studies demonstrate the utility of the marsh stratigraphic approach to paleoseismic studies on strike-slip faults.

2.0 TECTONIC SETTING AND REGIONAL GEOLOGY OF THE PILLAR POINT REGION

The San Gregorio fault zone extends approximately 110 km from the northern limit of the San Simeon fault near Monterey Bay to Bolinas Lagoon (Figure 1). In San Mateo County, the San Gregorio North segment (WGCEP, 2003; USGS, 2004) is exposed on land in two locations, 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). Using high-resolution aeromagnetic data and seismicity data, Jachens and Zoback (1999) interpret 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; Graham and Dickinson, 1978; Clark et al., 1984; Pampeyan, 1994), offset marine terraces (Lajoie et al., 1979; Weber, 1980; 1994; Weber et al., 1995), and offshore seismic reflection across the fault (Brocher, 1993; Lewis, 1994). Simpson et al. (1997), summarize these studies and characterize the late Holocene slip rate and earthquake history that provide the basis for the current state of knowledge on the San Gregorio fault.

The Seal Cove on-land trace of the SGF extends from Pillar Point to Moss Beach and consists 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 origin of this scarp is uncertain (CDMG, 1974; Weber and Lajoie, 1980).

Simpson et al. (1997; 1998) performed 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. The penultimate event was inferred to have occurred between A.D. 670 and 1400 based on upward fault terminations (Simpson et al. 1997). 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 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).

Nearshore marine, beach, and alluvial fan sediments comprise both the Half Moon Bay and Seal Cove Bluffs terraces that overlie wave-cut platforms beveled into nearshore marine sandstone and siltstone of the Pliocene Purisima Formation. The Half Moon Bay marine terrace (Lajoie et al., 1979; Lajoie, 1986) forms 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 (Figure 2). 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 (Figure 2). 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. (1997) 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).

Southeast of the Seal Cove Bluff, Pillar Point marsh is located adjacent to the SGF along the northern margin of Half Moon Bay, directly east of the Pillar Point headland (Figures 2, 3 and 4). In this area, the SGF forms a right-releasing stepover across Half Moon Bay and Seal Cove Bluffs and merges with a single off shore trace of the SGF west of Pillar Point. 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 and lies within an inferred pull-apart structure between the middle and eastern fault strands within this right-stepping right lateral fault system (Figures 2 and 3). The marsh basin suggests that the extensional fault geometry has caused local structural down-warping of the Stage 5a marine terrace. The presence of the topographically high Seal Cove Bluffs north of the marsh, may indicate that the fault evolves in a northerly direction to a more contractional geometry.

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. 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. These strata provide a relatively continuous record of episodic subsidence during paleoseismic events on the bordering SGF (Simpson and Knudsen, 2000; Koehler et al., 2004), similar to that observed in pull-apart basins along the San Andreas fault at Bolinas Lagoon and Bodega Bay (Knudsen et al., 1997).

2.1 Previous Marsh Studies at Pillar Point

Two recent studies of marsh stratigraphy at Pillar Point marsh have contributed information on the late Holocene depositional environments and possible earthquake chronology preserved in the marsh (Simpson and Knudsen, 2000; Koehler et al., 2004). These studies evaluated the hypothesis that earthquake induced subsidence was responsible for abrupt burial of tidal marsh soils and are summarized below.

Simpson and Knudsen (2000) extracted five gouge cores and four drive core samples to depths of two to three meters along the western margin of Pillar Point marsh. The four drive cores revealed laterally extensive stratigraphic relations, characterized by alternating thin to moderately thick beds of peat, mud, peaty mud, and sand. A distinct, sharp contact separating organic-poor mud from underlying peaty deposits approximately 1-2 m below the marsh surface was observed in every core. This relationship implies sudden submergence of a subaerially exposed paleo-marsh surface, and rapid burial by deeper-water estuarine deposits. Based on the presence of a fossil tidal flat diatom assemblage (from the mud above the event horizon) overlying a freshwater diatom assemblage (from the peat below the horizon), sudden relative sea level rise submerged the peat and led to subsequent burial by tidal mud. Simpson and Knudsen (2000) interpret this distinct stratigraphic relationship to represent an event horizon associated with coseismic subsidence during the most recent earthquake along the northern San Gregorio fault. Combination of 2-sigma calibrated ages for radiocarbon dates from materials directly above and below the inferred event horizon indicate that the event occurred between A.D. 1667 and A.D. 1802. This age is consistent with the age of the most recent earthquake (A.D. 1270-1775) at the Seal Cove trench site approximately 2.5 km north of the marsh (Simpson et al., 1997).

During field studies in 2002, we conducted a more detailed subsurface investigation at Pillar Point marsh consisting of twelve 2.5-cm-diameter gouge cores (02-1 to 02-12) and seven 7.6-cm diameter vibracores (02-V1 to 02-V7) along two transects oriented roughly east-west across the marsh (Figures 5 and 6) (Koehler et al., 2004). This study utilized vibra-core techniques to penetrate the entire marsh sequence, delineate the subsurface geometry of the marsh basin, and characterize the stratigraphic record above the marsh substrate. A dark gray gravelly clay loam soil observed in all the cores defines the base of the marsh. Based on similarities in the texture, color, and distribution of feldspar and granitic clasts, Koehler et al. (2004) correlate this soil with a soil exposed in the sea cliff 300-meters east of the marsh and developed into Denniston Creek alluvial fan sediments deposited on the 83 ka Stage 5a marine terrace (Figure 7). Beneath the marsh, the soil lies approximately 4.5 meters below the surface at the western margin of the marsh and gradually rises to the east creating a west-facing subsurface slope (Figure 6). This slope is continuous (northwest-southeast) and projects to the eastern on-land strand of the fault, adjacent to Seal Cove Bluffs.

Stratigraphic sequences identified in the marsh consist of buried peat soils, alluvial channel deposits, intertidal mud, and beach deposits. The buried peat soils are interpreted to represent former subareal marsh surfaces. Seven buried peat soils are preserved in the marsh (named Peats 1 to 7). Two well-developed peat soils occur within 2 meters of the marsh surface and are laterally continuous along a 130 meter transect. Five less-developed peat soils extend laterally over a 70 meter transect and occur between 3.2 to 4.1 meters depth. The buried peat soils have upper contacts that vary from sharp to gradational and are overlain by inorganic mud to peaty mud. Complete descriptions of sediments observed in the 2002 cores are provided in Appendices A and B.

Based on 15 diatom samples, stratigraphic data, and a criteria matrix modified from Knudsen et al. (2002), we interpreted the depositional environment for each buried marsh peat soil and interpreted the history of sediment accumulation and relative sea level changes that affected Pillar Point marsh. The sequence of marsh deposits and changes in the environment of deposition from subareal to shallow marine across abrupt contacts led Koehler et al. (2004) to infer a coseismic subsidence mechanism for the burial of Peats 1 and 6 and possibly Peats 3 and 4. Koehler et al. (2004) inferred that 2 to 4 earthquakes on the northern San Gregorio fault were responsible for rapid relative sea level rise that buried the peat soils, but did not provide ages for these soils.

3.0 APPROACH AND METHODS

Our approach involved three main activities designed to document the recent paleoseismic activity along the northern SGF. First, we performed focused paleoecologic, radiometric, and stratigraphic analyses of buried marsh soils preserved beneath Pillar Point marsh to evaluate the timing and recurrence of late Holocene paleo-earthquakes. Secondly, a comparative stratigraphic survey of a non-tectonic marsh was conducted to determine whether the tectonic events interpreted at Pillar Point marsh represent a unique stratigraphic signature. Lastly, we performed a conventional paleoseismic trench investigation of the SGF to provide independent verification of the paleoseismic record identified in the marsh and demonstrate synchroneity of events between the two sites.

The first phase of the project involved sampling cores extracted by Koehler et al. (2004) for radiocarbon and diatom analyses. Additionally, we extracted, described, and sampled a new vibra-core (PP04-V1) to extend our marsh cross section and obtain additional radiocarbon and sediment samples. Eleven samples consisting of seeds and bulk peat were submitted to Beta Analytic for radiocarbon analyses by accelerator mass spectrometry (AMS) method. Twenty-five sediment samples were submitted for diatom analysis at the sedimentology lab at Humboldt State University and were processed using methods outlined in (Hemphill-Haley, 1996).

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. Application of these criteria in detailed studies along the Cascadia margin has allowed the identification tectonic subsidence events in tidal wetlands (Nelson et al., 1998; Kelsey et al., 2002; Witter et al., 2003).

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 much less widespread than vertical deformation associated with subduction zone events and 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 criterion 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 criterion, in addition to those proposed by Knudsen et al. (2002).

Stratigraphic sequences in coastal marshes that closely resemble those produced by coseismic subsidence have been attributed to non-tectonic processes (Shennan, 1989; Nelson, 1992a; 1992b; Carver and McCalpin, 1996; Nelson et al., 1996). However, any buried soil formed by non-tectonic processes is unlikely to satisfy more than three of the co-seismic criteria proposed by Nelson et al. (1996) (Carver and McCalpin, 1996, as cited in Knudsen et al., 2002). Therefore, we evaluate the marsh stratigraphy within Pillar Point marsh with respect to the stratigraphic and micropaleontological data obtained in this study and criteria developed by Nelson et al. (1996) and Knudsen et al. (2002) to determine whether environmental changes within Pillar Point marsh occurred due to tectonic subsidence or other non-tectonic processes.

During the second phase of the project, we performed a reconnaissance survey consisting of three 2.5-cm diameter gouge cores (04-G1, 04-G2, and 04-G3 and one 7.6-cm diameter vibra-core (CC04-V1) oriented along a transect across China Camp marsh, a quiet water, relatively stable environment within San Pablo Bay, the northern lobe of the greater San Francisco Bay (Figures 1 and 8). This marsh was chosen to obtain stratigraphic data for a marsh not associated with an active fault and, thus, not likely to be influenced by vertical tectonic-related land-level changes. The purpose of obtaining marsh stratigraphic data from this non-tectonic marsh is to compare the stratigraphic record between a marsh responding to slow sea level rise (China Camp) and a marsh that responds to sea level rise overprinted by tectonic subsidence events (Pillar Point). Comparison of the marsh stratigraphy at these different tectonic settings is used to independently assess the tectonic subsidence mechanism for the buried marsh soils observed at Pillar Point Marsh.

During the third phase of the project two trenches located approximately one kilometer north of Pillar Point marsh were excavated to; (1) independently document geological evidence for prehistoric earthquakes, and (2) evaluate the possible relationship between paleoearthquakes on the San Gregorio fault and evidence for sudden marsh submergence at the Pillar Point marsh. The trenches were excavated by a backhoe to a depth of 2-3 meters orthogonal to the scarp at the base of Seal Cove Bluffs and orthogonal to a secondary trace approximately 50 m east of the main trace. Detailed logs drawn at 1:20 and 1:40 scales document the stratigraphic and structural relationships exposed in the trenches (Figures 10 and 11).

4.0 RESULTS

The results of this investigation include: (1) stratigraphic, radiometric and paleoecologic analyses from samples obtained from our 2002 cores and an additional core extracted in this study; (2) data on the paleoecology and stratigraphy of China Camp marsh, a marsh not affected by tectonics; and (3) stratigraphic and structural information from a nearby trench exposure.

4.1 Stratigraphic, Paleoecologic, and Radiometric Analyses of Pillar Point Marsh

In describing the buried marsh stratigraphy, we present lithologic, paleontologic, and radiometric data and use these data to determine the environment and timing of deposition. This information is then used to interpret the history of relative sea level and environmental changes that affected Pillar Point marsh. The implications of the stratigraphic record to a potential earthquake chronology are presented in the Discussion section below.

4.1.1 Marsh Stratigraphy and Depositional Environment

The stratigraphy observed in core PP04-V1 (this study) is consistent with the stratigraphy observed in our previous cores (Koehler et al., 2004) at the site. The marsh stratigraphy presented here, thus represents the combined description of twelve gouge cores and eight vibra-cores. Fifteen paleoecological samples from our previous investigation and 25 new samples are used to determine the depositional environment of the deposits. The stratigraphic, lithologic and biostratigraphic characteristics of the deposits are described below and summarized in Table 1, Figure 6, and Appendix A. Peat soils are labeled sequentially from oldest (Peat 7) to youngest (Peat 1).

Peat 7 is a massive, well-decomposed dark brown to reddish brown muddy peat. Diatom assemblages within Peat 7 indicate formation in a low 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. A dark gray, massive, silt loam to silty clay loam (mud) overlies Peat 7 and has a diatom assemblage indicative of a brackish middle to high marsh environment that periodically dried. Drying of the marsh may have been related to sediment aggradation and emergence of the marsh surface. The gradual (10 mm) upper contact of Peat 7 indicates that the environmental change occurred gradually.

Peat 6 is a well developed, fibrous, laminated, dark reddish brown peat. Diatom assemblages within Peat 6 indicate development in a fresh-brackish middle to 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. 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. Peat 6 is sharply overlain across the entire marsh by dark gray to dark olive brown silt loam to sandy silt loam (mud) that contains a brackish tidal flat or low marsh diatom assemblage. Diatoms indicative of a fresh-brackish stream in the upper portion of the mud above Peat 6 suggests that the fresh water stream that drains into the marsh migrated laterally over the tidal flat/low marsh deposit that buries Peat 6.

Peat 5 contains interbeds of peat, muddy peat and peaty mud. Individual peat layers range in color from reddish brown to black and peaty mud layers contain 3 to 4-mm-thick gray mud laminae. Diatom assemblages within Peat 5 indicate growth in a well-developed brackish low 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

Table 1. Fossil Diatom Data from the Pillar Point Marsh Site, Cores 02-V1, 02-V2, 02-V5, and 04-V1.

Core No.	Sample No.	Depth Interval (cm)[a]	Stratum/ Lithology	Paleo-environment	Comments
02-V5	Dia-1	59.5-60.5	Mud above Peat 1	Brackish low marsh or marsh/tideflat transition	Higher relative percentage of brackish species than below including, Gyrosigma spenceri, Achnanthes spp., Surirella gastuosa, Melosira moniliformis, and Amphora coffaeaformis.
04-V1	Dia-31	43-44	Mud above Peat 1	Brackish tidal flat	Diatoms common and diverse. Brackish benthic species found on muddy tidal flats are prevalent: Synedra fasciculate, Mastogloia exigua, Tryblionella apiculata, and various small intact frustules of Amphora spp. Also prominent Fragilaria construens f. subsalina, which is the only form of F. construens found in brackish environment.
02-V2	Dia-16	56-57	Mud above Peat 1	Brackish tidal flat or marsh/tidal flat transition (channel bank?)	Diatoms common but fragmentation severe. Sample dominated by small brackish pennates: T. apiculata and A. delicatula are prominent, but there are common small Naviculas, Fragilarias, Opephora spp. 99% of species are brackish. It is likely that this is a sand-rich lower intertidal deposit, because of occurrences of small Achnanthes and T. apiculata. Compared to Dia-2, this sample is less organic and more likely a bare mud environment (more conducive to small pennates).
02-V5	Dia-2	60.5-61.5	Peat 1	Fresh-brackish marsh	Dominant species are fresh-brackish.
04-V1	Dia-32	44-45	Peat 1	Fresh-Brackish marsh	Diatoms moderately preserved, dominated by fresh-brackish and fresh benthic diatoms, including Gomphonema spp., Epithemia turgida, Rhopalodia gibba and Eunotia pectinalis.
02-V2	Dia-17	57.5-58.5	Peat 1	Fresh-brackish marsh	Diatoms common but not well preserved, mostly large broken valves and numerous different kinds of small pennates. Species such as Navicula recens, N. salinarum, N. phyllepts, A. coffeaeformis and others are consistent with relatively dry (infrequently inundated) fresh-brackish marsh.
02-V5	Dia-3	102.5-103.5	Mud above Peat 2	Meadow or dune field	Coarse, dry environment, contains only residual reworked valves. Does not contain species indicative of an intertidal environment.
02-V5	Dia-4	103.5-104.5	Peat 2	Fresh to fresh-brackish marsh	Frequent periods of standing water at the surface, but very low salinities. Does not contain species that would be found in a salt marsh or tidal flat.
02-V5	Dia-5	247-248	Mud above Peat 3	Fresh-brackish pond or bog	Contains abundant diatoms, including a large percentage of planktonic species.
02-V5	Dia-6	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.
02-V5	Dia-7	275-276	Mud above Peat 4	Fresh marsh	Transition to even fresher conditions than sample Dia-8. Does not contain species indicative of a saline tidal flat environment.
02-V2	Dia-18	294-295	Mud above Peat 4	Brackish tidal flat or slough	Diatoms common but fragmented. Occurrences of Opephora spp., Gyrosigma balticum, Hyalodiscus sp.,

Core No.	Sample No.	Depth Interval (cm)[a]	Stratum/ Lithology	Paleo-environment	Comments
					Mastoglois exigua, and Rhopalodia acuminate. Formed at elevation lower than Dia-19 suggesting submergence.
02-V2	Dia-19	295-296	Peat 4	Brackish low marsh or marsh/tideflat transition	Diatoms abundant, but mostly fragmented and poorly preserved. Dominated by brackish species, Parsul common. Compared to core 02-V5, this sample compares better to the brackish paleoenvironment in Peat 4 than to the fresh environment in Peat 3
02-V5	Dia-8	276-277	Peat 4	Fresh-brackish marsh	Slight increase in numbers of fresh-brackish species from sample Dia-9 below, and probably formed higher in the intertidal zone than the sample below consistent with its stratigraphic position.
02-V5	Dia-9	280-281	Peat 4 below mud laminae	Low, brackish marsh	Diatoms consistent with a wet environment.
02-V5	Dia-37	283-284	Base of Peat 4	Brackish low marsh	Diatoms common and diverse, dominated by brackish benthic species common in low marshes such as Caloneis westii, C. bacillum and Nitzschia sigma. Compared to the underlying mud (Dia-38), there is evidence for more saline conditions, with little influence from fresh water flooding.
02-V5	Dia-38	285-286	Mud below Peat 4	Possible fresh-brackish to brackish marsh transition	Diatoms rare and not well preserved. The assemblage is a mix of brackish and fresh-brackish taxa, with prominent occurrences of the fresh species Synedra ulna. S. ulna is a large, freshwater diatom that occurs either as an epiphyte or massive blooms in the plankton. Its occurrence might be evidence for some kind of flooding by freshwater (stream outflow). The mix of brackish marsh species like Navicula slesvicensis and N. cincta, with species found in very wet, fresh-brackish to brackish sandy environments (like Epithimia turgida and Cocconeis placentula), would be consistent with a incipient marsh setting influenced occasionally by freshwater flooding.
02-V5	Dia-10	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
02-V2	Dia-20	330-331	Mud above Peat 5	Fresh-brackish marsh or bog	Diatoms are common and well preserved. Although not a peat sample, the assemblage is consistent with what would be found in a wet marsh or bog. Compared to Dia-21, this sample suggests a relative decrease in salinity and may indicate gradual emergence to an environment more influenced by fresh water flooding.
02-V5	Dia-11	309.5-310.5	Peat 5	Well-developed brackish marsh	Assemblage suggests a well-developed brackish marsh, not too low and not too wet.
02-V2	Dia-21	331-332	Peat 5	Brackish low marsh	Diatoms are very abundant, diverse and well-preserved, with dominant speciesMelosira spp. And Nitzschia sigma, and less frequent but prominent occurrences of taxa such as Fallacia pygmaea, N. elegans, N. peregrinopsis and C. westii.

Core No.	Sample No.	Depth Interval (cm)[a]	Stratum/ Lithology	Paleo-environment	Comments
02-V2	Dia-26	339-340	Base of Peat 5	Brackish low marsh	Diatoms very abundant. Dominant species: Milosira spp., N. peregrinopsis, N. sigma, N. fasciculate, R. acuminate, A. brevipes intermedia.
02-V2	Dia-27	340-341	Mud below Peat 5	Fresh-brackish stream outflow?	Diatoms rare and mostly poorly preserved, primarily broken frustules and fragments. Less saline than overlying Peat 5. fresh and fresh-brackish diatoms outnumber brackish species, and include taxa that might be found along stream banks. Species include: Synedra ulna, Gophonema spp., Achnanthes (Planothidium lanceolata, R. gibba, Eunotia pectinalis.
02-V5	Dia-12	334-335	Mud above Peat 6	Low marsh or tide flat	Represents a wetter, more saline environment than sample below.
02-V2	Dia-22	355-356	Mud above Peat 6	Indeterminate	Preservation is so poor in this sample that there is little evidence for an in situ assemblage.
02-V1	Dia-33	337-338	Mud above Peat 6	Brackish low to mid marsh?	Diatoms indicate change to wetter (possibly lower intertidal) marsh conditions but not tidal flat. Dominated by brackish marsh species Navicula peregrinopsis, and Epithimia turgida and Navicula elegans suggesting wetter conditions. There are occurrences of epiphytes such as Synedra ulna, Melosira varians and Rhoicosphenia abbreviate which may indicate episodic flooding from fresh water.
02-V5	Dia-13	336-337	Peat 6	Fresh-brackish high marsh	Marsh was probably inundated frequently.
02-V2	Dia-23	359-360	Peat 6	Brackish middle to high marsh	Diatoms abundant, but mostly fragmented. Dominant species are large Naviculas (N. peregrinopsis, N. rhyncocephala), Epithemia turgida, Nitzschia vitrea, and Caloneis westii. Brackish species are about 75% versus 25% fresh-brackish species.
02-V1	Dia-34	338-339	Peat 6	Brackish middle to high marsh	Diatoms common and well preserved. Dominated by brackish mid to high marsh taxa including Diploneis spp. And Navicula peregrinopsis. Similar to sample Dia-35
02-V5	Dia-35	346-347	Base Peat 6	Brackish middle to high marsh	Diatoms consist of well preserved brackish species, dominated by species of Diploneis (D. pseudovalis, D. smithii v. dilatata, D. smithii v. rhombica). Assemblage differs from that of Dia-36 (below) by indicating drier, less frequently inundated marsh conditions suggesting gradual development of brackish marsh.
02-V5	Dia-36	348-349	Mud below Peat 6	Brackish low marsh or marsh/tideflat transition	Diatoms common and moderately well preserved. Taxa include a mix of marsh and tidal flat species, particularly Gyrosigma eximium, Navicula peregrinopsis, Diploneis pseudovalis and Nitzschia sigma.
02-V5	Dia-14	371-372	Mud above Peat 7	High, dry aerophile	Not conducive to diatom productivity.
02-V2	Dia-24	372-373	Mud above Peat 7	Brackish middle to high marsh	Diatoms are well preserved, consisting of marsh species with little evidence of tidal flat taxa. Dominant species include: Navicula cincta, Caloneis bacillum, D. pseudovalis and D. smithii dilatata. Parsul absent.

Core No.	Sample No.	Depth Interval (cm)[a]	Stratum/ Lithology	Paleo-environment	Comments
02-V5	Dia-15	372-373	Peat 7	Low brackish marsh or marsh-tideflat transition	Diatoms consistent with a wet environment.
02-V2	Dia-25	373-374	Peat 7	Brackish low marsh or marsh/tideflat transition	Diatoms very fragmented, few intact specimens. Dominant species: Navicula peregrinopsis, D. smithii dilatata, D. pseudovalis, C. westii.

[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.

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 fresh-brackish marsh or bog environment that periodically dried. The gradual lower contact of Peat 5 indicates that the soil aggraded over time above tideflat/low marsh mud. The clear upper contact between Peat 5 and mud indicates that the marsh dried up periodically, possibly due to climatic variables such as a decrease in rainfall during a drought, but returned to a fresh-brackish environment evident by fossil diatoms in the mud below Peat 4.

Peat 4 is a massive, well-decomposed, dark brown peat deposit. Diatom assemblages within Peat 4 indicate initial development in a low, wet brackish marsh that gradually evolved to a fresh-brackish marsh and then to a fresh water marsh. The peat occurs in cores 02-V5, 02-V1, and 02-V2 and grades laterally over a distance of 70 m from a peat, to muddy peat, to organic mud in an eastward direction across the marsh. 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 mud overlying peat 4 was deposited in a fresh water marsh in the vicinity of core 02-V5 and a brackish tidal flat in the vicinity of core 02-V2. This interfingering of peat and mud laminae and different diatom assemblages at this horizon across the marsh may indicate that the mud accumulated close to the limit of tidal influence where depositional environments overlap.

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.

Peat 2 is a very well-decomposed dark reddish brown peat. The peat 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.

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). Peat 1 is overlain across the entire marsh 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.

4.1.2 Radiocarbon Results

A total of 21 radiocarbon samples were collected from the cores to assess the sedimentation rate in the marsh, the total age of the marsh, and the age of individual peat deposits. Eleven ages for peat deposits are presented in Table 2.

Table 2. Radiocarbon Data for the Pillar Point Marsh Site, Half Moon Bay, California

Core No.	Laboratory Sample No.[a]	Sample Material	Sample Interval (cm)[b]	Stratigraphic Unit	$\delta^{13}C$	Lab-Reported Age (14C yr BP at 1σ)[c]	Calibrated Age (cal yr BP at 2σ)[d]
02-V2	193939	Seeds	57.5-58.5	Peat 1	-26.2	170 +/- 40	0-290
02-V1	193940	Seeds	36-37	Peat 1	-24.2	210 +/- 40	0-310
02-V5	193941	Seeds	41.5-42.5	Peat 1	-28.3	400 +/- 40	300-500
02-V5	193942	Bulk Peat	84.5-85.5	Peat 2	-27.0	440 +/- 40	320-520
02-V5	193943	Bulk Peat	230-231	Peat 3	-27.7	2720 +/- 40	2750-2850
02-V5	193944	Bulk Peat	263-264	Peat 4	-22.7	2960 +/- 40	3060-3330
02-V5	193945	Bulk Peat	290-291	Peat 5	-26.0	3610 +/- 90	3650-4150
02-V5	193946	Bulk Peat	320-321	Peat 6	-23.7	3440 +/- 40	3630-3840
02-V1	193947	Bulk Peat	338-339	Peat 6	-27.5	3680 +/- 40	3850-4080
02-V2	193948	Bulk Peat	358-360	Peat 6	-25.3	3190 +/- 40	3350-3470
02-V5	193949	Bulk Peat	353-354	Peat 7	-26.6	3890 +/- 40	4150-4410

[a]Standard pretreatment of samples performed by Beta Analytic.
[b]Sample interval measured as depth below marsh surface.
[c]Conventional ages reported by radiocarbon laboratory based on the Libby half life (5570) for ^{14}C.
[d]Calibrated age ranges before AD 1950 reported to the nearest decade, calibrated by Beta Analytic using methods outlined in Stuiver and Reimer (1993) and Stuiver et al. (1998).

In general, the radiocarbon ages for the buried peat soils are consistent with stratigraphic position. The oldest peat soil (Peat 7) accumulated at the distal margin of the Denniston Creek alluvial fan presumably in a shallow basin. This soil represents the beginning of marsh deposition in Pillar Point and was deposited around 4150-4410 cal yr BP. The age of buried soil Peat 6 is broadly constrained by three radiometric ages at around 3350-4080 cal yr BP. Peat 5 accumulated around 3650-4150 cal yr BP. This age is slightly younger, but similar to the age of Peat 6, however the two deposits are close in elevation.

Stratigraphic position suggests that the ages of Peat 6 and Peat 5, may be better approximated by the older limit and younger limit of their age ranges, respectively. Peat 4 accumulated around 3060-3330 cal yr BP and Peat 3 accumulated around 2750-2850 cal yr BP. After the deposition of Peat 3, there was a long period of mud deposition with no peat accumulation. Peat 2 overlies this mud and was deposited around 320-520 cal yr BP. The age of Peat 1 is constrained by three radiometric ages on herbaceous seeds. Two of these ages range from modern to about 300 cal yr BP and a third age ranges between 300 and 500 cal yr BP, similar to the age of Peat 2. These two deposits are separated by a thin mud layer and probably represent sedimentation over time in the same depositional environment.

4.2 Comparison to a Non-Tectonic Marsh, China Camp, California

The China Camp marsh site (Figure 8) was chosen to obtain stratigraphic data for a marsh not associated with an active fault and, thus, not likely to be influenced by vertical tectonic-related land-level changes. The purpose of obtaining marsh stratigraphic and paleoecological data (Figure 9; Table 3) from this non-tectonic marsh is to compare the stratigraphic record between a marsh responding to slow sea level rise (China Camp) and a marsh that responds to sea level rise overprinted by inferred tectonic subsidence events (Pillar Point). This comparison is used to independently evaluate whether tectonic subsidence is the best explanation for the buried marsh soils observed at Pillar Point marsh.

Table 3. Fossil Diatom Data from the China Camp Marsh Site, Core CC-V1.

Depth Interval (cm)[a]	Stratum/ Lithology	Core No.	Sample No.	Paleo-environment	Comments
332-333	Mud above peat soil	CC-V1	Dia-26	Brackish tidal flat	Diatoms common and well preserved, dominated by Nitzschia scapelliformis and Tryblionella (Nitzschia) pararostrata.
333-334	Peat soil	CC-V1	Dia-27	Brackish (fresh-brackish?) marsh	Diatoms common and diverse, including Fragilarias, Surirella striatula, and Gyrosigma attenuatum. Diatom variety and abundance of small pennates is consistent with accumulation on a brackish marsh.
351-352	Mud below peat soil	CC-V1	Dia-28	Brackish low marsh or marsh/tideflat transition	Diatoms abundant and well-preserved. Assemblage contains prominent D. interrupta, D. stroemi, Hyalodiscus scoticus, plus less frequent occurrences of lower intertidal brackish-marine taxa such as Cyclotella meneghiniana and Tryblionella granulate.
499-500	Mud over peat laminae	CC-V1	Dia-29	Remnant or winnowed deposit	Diatoms well preserved but consists of relatively few species. Most common diatoms are intact valves of Diploneis interrupta, D. pseudovalis, Rhopalodia acuminate, and Caloneis bacillum. Winnowing out of lighter, less dense diatoms from an assemblage similar to Dia-30 (below) may have left behind these relatively denser and heavier taxa.
501-502	Peat laminae	CC-V1	Dia-30	Brackish low marsh or marsh/tideflat transition	Diatoms abundant and well preserved. Diverse collection of brackish low marsh and marsh tideflat transition species: Nitzschia sigma, Caloneis wewstii, C. bacillum, Rhopalodia acuminate, Melosira moniliformis, Achnanthes brevipes. Consistent with a frequently inundated, brackish low marsh or marsh/tideflat transitional environment.

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

The China Camp marsh site lies within China Camp State Park along the southeastern shore of San Pablo Bay, north of Buckeye Point, approximately 3 miles northeast of the city of San Rafael, Marin County, California (Figures 1 and 8). Directly west of the marsh the topography is dominated by San Pedro Ridge, a northwest trending ridge line characterized by steep, rugged hillslopes composed of northeast-southwest striking blocks of Cretaceous age sandstone and shale (Blake et al., 2000). The topography of the marsh is flat with the exception of four small hills named Jake's Island, Turtle Back Hill, Bullet Hill, and Chicken Coop Hill. These hills are composed of Jurassic Age Franciscan mélange consisting of sheared shale and sandstone with inclusions of greenstone, chert, greywacke, and serpentinite (Blake et al., 2000). Stream valleys directly north of Turtle Back Hill and directly south of Bullet Hill contain Holocene alluvium that has been incised by ephemeral streams that grade to the marsh surface and meander across it.

The stratigraphic sequence identified beneath the modern marsh consists of a continuous depositional record of intertidal mud interbedded with thin (<1-2 cm), tidal marsh peats (muddy peats and peaty muds), and sandy mud deposits (Figures 9 and Appendix C). Intertidal mud deposits consist of massive, olive gray to olive brown silt loam with common thin (< 3 mm) laminae. Laminae consist of black (charcoal) layers and muddy peat deposits. Tidal marsh peat observed in the cores are generally less than 1-2 cm thick and interbedded with intertidal mud. These deposits have relatively low peat concentration ranging from 20-30%, with the exception of Peat A, well developed peat soil (8-14 cm thick) with approximately 70% organic content. Peat A has a gradual dip towards San Pablo Bay and occurs at about 300 cm (core 04-G3), 333 cm (core CC04-V1), and 361 cm (core 04-G1).

Peat A has a clear upper contact (2-3 mm) and is overlain by approximately 40 cm of dark gray to olive silt loam with coarse fragments of peat and thin (<3-mm-thick) muddy peat laminae. The stratigaphy that brackets Peat A is characterized by a gradual increase in peat laminae below Peat A and a gradual decrease in peat laminae above the Peat A contact. Diatoms from mud and muddy peat laminae below Peat A indicate that the marsh was a brackish low marsh or marsh/tideflat transitional environment that was frequently inundated. Diatoms within Peat A indicate that the peat formed in a brackish marsh with slightly fresher conditions than the underlying deposits. Diatoms indicative of a brackish tidal flat characterize the mud overlying Peat A. Therefore, a brackish marsh environment persisted during deposition of Peat A, as well as during deposition of the mud deposits above and below Peat A. The slightly fresher conditions that existed during deposition of Peat A may be related to periodic flooding of the marsh or a slowing of the rate of sea level rise.

4.3 Trench Investigations

Trench 1 was located at the base of the prominent linear escarpment along the eastern margin of the Seal Cove Bluffs (Figures 10 and 11). The trench was about 30 m long and ranged from 3 to 5 m deep. We sited the excavation across a low-relief debris fan that periodically receives sediment evacuated from a colluvial hollow upslope to investigate possible deformation of latest Holocene colluvial strata. Prior trench investigations by Berlogar, Long & Associates in 1981 confirmed the presence of active fault-related deformation of deposits that underlie the debris fan. Unexpectedly, we encountered an archeological deposit within the upper 0.7 to 1.3 m of the exposure that was identified by California State Park archeologist Mark Hylkema as a prehistoric shell midden deposited by native Californians between AD 900 to AD 1100. This cultural deposit provides a useful chronostratigraphic datum to constrain the timing of the most recent deformation on the fault.

Trench 2 was located approximately 280 m northwest of trench 1 and approximately 50 m east of the escarpment (Figure 12). Trench 2 was about 22 m long and about 3.7 m deep at its deepest point. The trench was sited based on a consulting report by Berlogar, Long & Associates (1981) that concluded that a second fault traversed the broad alluvial plain east of Seal Cove Bluff and parallel to the primary fault at the base of the escarpment. The purpose of trench 2 was to investigate this secondary fault to evaluate the style of deformation and document possible evidence for the most recent earthquake. Sediments encountered in the trench are interpreted to be gravelly sands of the ca. 80 ka Half Moon Bay terrace and overlying poorly sorted, fine-grained Denniston Creek fan sediments.

4.3.1 Stratigraphic and Structural Relations

Trench T-1

Strata encountered in trench 1 are draped across the base of the east-facing escarpment of the Seal Cove Bluffs and include interbedded colluvial, marsh and archeological deposits (Figures 10 and 11; Appendix D). Trench exposures contained no bedrock. The oldest colluvium (unit 10) consists of massive, mottled sand and clay that is distinct from overlying younger colluvium (units 50 through 90) that are composed of silt with gravel. Because the older colluvium lacks sedimentary structure common in marine terrace deposits, we interpret that units 10A, 10B, and 10C composed the colluvial apron deposited at the base of Seal Cove Bluffs. The relative lack of soil development suggests that the colluvium was deposited rapidly. The lithology of the colluvial deposits ranges from sandy clay to clayey silt with gravel. Clasts within the colluvium consist predominantly of Purisima Formation fragments eroded from bedrock exposed in the escarpment directly to the west. Rarely, gravel-sized clasts included rounded chert pebbles, and angular feldspar and quartz crystals likely reworked from Pleistocene marine terrace deposits that mantle the top of the Seal Cove Bluffs. With the exception of several prominent stone lines, there was a notable lack of internal stratigraphy within the colluvium. A thick cumulative soil profile consisting of a series of A horizons developed in the upper 3.5 to 4 m of colluvium implies that the colluvium was deposited in the middle to late Holocene and suggests that periodic debris flows gradually built up the debris fan through time preventing the development of a mature soil profile.

In the deepest part of the trench, black, organic-rich mud (unit 20A) onlaps and interfingers with the colluvial deposits (Figures 10 and 11). On the basis of color, texture and the presence of coarse rock fragments, it is possible that unit 20A correlates with the prominent black soil observed in the base of cores from Pillar Point marsh. However, we have no conclusive stratigraphic evidence to support this correlation. The mud contains angular sandstone clasts of the Purisima Formation as well as some quartz and feldspar clasts likely derived from the escarpment to the west. The fine-grained lithology and rich organic nature of the mud suggests it was deposited in a marsh impounded on the west by the Seal Cove Bluffs. Colluvial deposits grade laterally, from west to east, into the marsh deposits and suggest that the western margin of the marsh migrated eastward as colluvial deposits prograded out over the marsh and eventually completely buried the marsh.

Archeological deposits encountered in the eastern end of trench 1 (unit 100A) range from 0.5 to 1.5 m thick and consist of silty colluvium with 10 to 30 percent fragmented shells of marine invertebrates and rarer fragments of mammal bone and stone artifacts (Figures 10 and 11). The shell debris is concentrated toward the base of the unit where evidence for bioturbation suggests that some mixing with the underlying units has occurred. The clear, subplanar lower contact of the midden is the youngest stratum offset by a fault observed in the trench. This shell midden shares many characteristics with native Californian cultural deposits dated at A.D. 1270 to 1400 at the Seal Cove trench site studied by Simpson et al. (1997).

Three thrust faults offset thick, poorly stratified Holocene colluvial deposits in Trench 1 (Figures 10 and 11). Each fault dips from 16° to 36°SW and shows an apparent reverse sense of slip with west-side-up vertical separation. No slickensides were observed on fault planes that would indicate the absolute slip direction. Based on a spring area directly west of the trench, we speculate that the thrust faults may represent a flower structure secondary to a main more vertical fault trace in this primarily strike-slip system. For clarity in the discussion, we assign each fault a letter from A to C. Fault A offsets only the oldest deposits exposed in the trench. Fault B offsets slightly younger deposits than fault A. Fault C, the fault with the largest amount of displacement, offsets the youngest deposits in the trench—a late Holocene archeological shell midden.

Fault A is a low-angle thrust fault that strikes N48°W and dips 21°SW (Figures 10 and 11). East-vergent apparent reverse slip on this structure places weathered, clayey colluvium over black marsh deposits. Measured displacement of the base of the marsh deposits provides an apparent dip-slip offset estimate of 0.6 to 1.0 m. Although the fault tip appears to terminate in the marsh deposits, it is possible that the fault either is continuous with or truncated by fault C. The massive, homogenous nature of the marsh mud obscures the structural relationship, if any, between fault A and fault C. Anticlinal folding of deposits directly above the fault tip also may be related to slip on fault A.

Fault B is a low-angle secondary fault in the hanging wall of fault A that strikes N27°W and dips 21°SW (Figures 10 and 11). The oldest colluvial deposits exposed in the trench are folded and possibly faulted over younger colluvial deposits. In the northern trench wall, offset of the base of unit 20B suggests about 0.6 m of apparent reverse displacement combined with possible kink folding of the base of unit 40B. The southern trench wall shows similar kink-fold deformation but no evidence for significant offset of the base of unit 20B. The observation that the kink fold coincides with the end of the western limb of the anticline overlying fault A suggests that deformation on the two structures was coeval.

Fault C has the largest amount of displacement of the three faults and offsets a shell midden that records prehistoric habitation by native Californians (Figures 10 and 11). This thrust fault strikes N62° to 70°W with a low-angle westward dip (16° to 36°SW) that becomes progressively steeper with depth. The fault plane was examined for evidence of oblique slip, but no slickensides were observed. Near the bottom of the trench, drag folding related to reverse slip along the fault deforms interbedded colluvial and marsh deposits. Apparent fault displacement of the base of unit 30 is at least 0.75 m, not including deformation by folding. Displacement of the base of unit 50, which shows less evidence for folding, is about 1.35 m. Vertical separation of unit 30, including both fault displacement and fold deformation, ranges between 1.5 to 1.8 m. The fault continues up section, offsetting a prominent stone line marking the base of unit 70. The fault is difficult to discern through massive colluvial deposits that are largely void of internal stratigraphy. Near the top, at the eastern end of the trench, the base of the shell midden is offset 0.5 to 0.7 m along the fault. Vertical separation of the base of the shell midden is about 0.4 m. At this location fault C strikes N35°W and dips 24°SW.

Stratigraphic and structural relationships in trench T-1 show evidence for at least two and possibly four slip events that offset probable Holocene and latest Holocene deposits. Evidence for at least two events is supported by progressively greater offset of strata along fault C with depth. For example, the vertical separation of the shell midden (0.4 m), the youngest unit offset by fault C, is about one third to one quarter times the vertical separation of the base of unit 30 (1.5 to 1.8 m). It is possible that the deformation related to slip on fault C records three or four earthquakes if each earthquake resulted in a characteristic amount of slip between 0.4 and 0.7 m. However, we observed no stratigraphic evidence that requires an interpretation of more than two events. The exposures allow the interpretation that slip on faults A and B may have occurred concurrently with slip on fault C and therefore may record only two events. Alternatively, if the three faults operated independently, the trench exposures could record at least four earthquakes. We prefer the interpretation that faults A, B and C operated concurrently because the limbs of the fold above the tip of fault A appear to be structurally controlled by faults B and C. Radiocarbon analysis of bulk sediment samples from marsh deposits (unit 20A) and the shell midden may provide age estimates that bracket the time of faulting.

Trench T-2

Strata exposed in trench 2 consist of coarse alluvial fan deposits overlain by fine-grained marsh deposits that are, in turn, overlain by 0.5- to 1-m-thick colluvial package derived from the Seal Cove Bluffs to the west (Figure 12 and Appendix D). Massive, poorly sorted gravelly sands and interbedded clay layers occur in the base of the trench. Coarse sand grains and gravel clasts include quartz and feldspar lithologies derived from the Cretaceous Montara granodiorite to the east. We interpret these sediments as interbedded littoral and alluvial deposits of the 83,000 year old Half Moon Bay terrace (Weber and Lajoie, 1980). Hard, massive clay deposited on top of the terrace sediments laps onto an east-facing buried fault scarp. We interpret this massive clay as distal fine-grained alluvial deposits of Denniston Creek that were impounded against the escarpment. Colluvial silt shed from the western bluffs overlies the clay. A prominent soil developed in both the colluvial and alluvial units suggests that the landscape at trench 2 has been relatively stable for perhaps several thousand years. The soil profile includes a prominent Bt horizon characterized by well-developed prismatic peds coated with thin clay films. No charcoal or other organic material was available for radiocarbon age analysis.

Two fault zones offset latest Pleistocene alluvium of the Half Moon Bay terrace based on exposures in trench 2. The eastern fault zone offsets the lower horizons of a soil developed into fine-grained alluvial deposits that may be early to middle Holocene in age. None of the faults appeared to offset or deform the youngest colluvial deposits. Evidence for the absence of deformation of the youngest deposits coupled with the absence of fresh geomorphic scarps overlying the faults suggest that the most recent surface deformation at the site of trench 2 occurred several thousand years ago.

The eastern fault zone consists of a low-angle thrust fault that strikes N31°W and dips 25° SW. Apparent dip-slip displacement on this primary fault ranges from 0.7 to 0.8 m in alluvial deposits of the Half Moon Bay terrace. Deformation caused by folding and faulting together accommodate approximately 1.7 m of vertical separation of terrace sediments. No slickensides were observed on the fault plane to indicate absolute slip direction. The single fault strand near the base of the trench divides into several fault splays that offset fine-grained clayey alluvial deposits and a soil that overlie the gravelly terrace sands. The youngest colluvial unit that overlies the fault splays appears to be undeformed. A secondary fault strand in the hanging wall of the primary thrust fault strikes N47°W and dips 65°SW. This secondary fault offsets clayey sand beds in the oldest exposed alluvium by about 0.2 m as apparent reverse dip-slip displacement. However, vertical separation of the clay marker bed due to faulting and folding reaches up to 0.7 m. The secondary fault terminates within the oldest exposed sediments of the Half Moon Bay terrace. The width of deformation related to the eastern fault zone spans about 4 m.

The western fault zone consists of multiple fault splays that show vertical separation of alluvial deposits of the Half Moon Bay terrace. The eastern-most fault within this zone strikes N25°W and dips 70°SW. Apparent reverse displacement on this fault (west-side up) caused about 0.5 m of vertical separation of a prominent zone of iron and manganese oxide staining. Splays of the western-most fault in the zone show evidence for east-side-up vertical separation along both apparent normal and reverse faults. The primary western fault splay strikes N45°W, dips 67°SW and juxtaposes coarse-grained sandy terrace deposits against fine-grained alluvial clay. A secondary splay to the west dips about 70°E and shows about 0.05 m of apparent vertical offset. Although we observed no slickensides on any fault planes in the western fault zone, the variety of deformation styles within the zone and mismatches within the stratigraphy suggest that a significant component of lateral displacement occurred. The western fault zone is about 2.5 m wide.

Together, the eastern and western fault zones exposed in trench 2 show evidence for east-vergent thrust and reverse faulting with corresponding hanging-wall folds and high angle faults that juxtapose different stratigraphic units. Evidence for a variety of faulting styles suggests that these structures accommodate transpressional deformation that include both right-lateral and reverse components of slip. If the western and the eastern fault zones connect at depth, the width of deformation across the entire zone is about 10 m.

5.0 DISCUSSION

5.1 Origin and Evolution 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 and is situated between the middle and eastern on-land strands of the SGF (Figures 2 and 3). The eastern on-land strand projects southeast from the Seal Cove Bluff into the marsh and coincides with the location of an apparent monocline along the eastern margin of the marsh (Figures 2, 3, and 4). This apparent monocline is delineated by the alluvial fan soil that marks the base of the marsh as mapped by our vibra core transect. Along the eastern side of the fault projection, the soil is exposed in tidal channels near the surface of the marsh. West of the fault, the soil dips steeply to the west to a depth of 4.5 meters where it is buried by marsh deposits. 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, 3, and 4). Based on the southerly divergent and right stepping geometry of the two fault strands within a right lateral system, we infer that the Pillar Point marsh basin is a pull-apart structure. We also infer that this releasing geometry accommodates extension and subsidence within Half Moon Bay and Pillar Point marsh.

Alternative mechanisms for the formation of the Pillar Point marsh basin include channel downcutting and wave erosion. We do not favor these explanations because (1) there are no channels of significant size upslope of the marsh and no channel deposits on the alluvial fan soil to support a channel downcutting mechanism; and (2) the rocky offshore reef complex and the Pillar Point headland protect the marsh location from strong ocean waves discounting a wave erosion mechanism.

We infer the following history of sediment accumulation and environmental change within Pillar Point marsh based on sedimentologic characteristics of the buried peat soils and their associated fossil diatom assemblages. In forming this interpretation we make the following assumptions: (1) sharp 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) gradual 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 a fresh-brackish environment indicate gradual aggradation and ponding.

The Pillar Point marsh basin was originally created by transtentional deformation along the marsh bounding faults. Sedimentation in the marsh began around 4150-4410 cal yr BP when sea level rose high enough to enter the basin 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 to 3 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 to a low, wet brackish marsh, Peat 7. Based on diatom ecology, this marsh surface dried up (high, dry aerophile environment) for a short period of time and then was buried by mud deposited in a brackish low marsh environment. This mud gradually aggraded to a fresh-brackish high marsh (Peat 6) by about 3350 to 4080 cal yr BP. Marsh aggradation is inferred to have kept pace with gradual sea level rise during this time. The abrupt transition from a fresh-brackish high marsh (Peat 6) to an interbedded tidal flat or low marsh environment indicates that rapid relative sea level rise caused submergence and burial of Peat 6.

Following the apparent submergence of Peat 6, interbedded sand, muddy peat, and tidal mud deposits accumulated in the low brackish marsh environment and a brackish marsh soil (Peat 5) developed between about 3650-4150 cal yr BP. Based on diatom ecology, Peat 5 may have intermittently dried, but was eventually buried by mud deposited in a fresh-brackish marsh environment that aggraded until the formation of Peat 4 around 3060-3330 cal yr BP. The sharp lower contact and transition from a fresh-brackish marsh (mud below Peat 4) to a brackish low marsh (base of Peat 4) may indicate that the site was submerged to a lower intertidal level that allowed marsh plants to become established forming Peat 4. Diatom assemblages from within Peat 4 indicate that the brackish low marsh environment became progressively fresher up-section. However, diatom species indicative of multiple depositional environments are also present including, fresh-brackish, marsh/tideflat transition, and brackish low marsh. Therefore, we infer that Peat 4 may have accumulated close to the limit of tidal influence and may have been close to the small alluvial channel that drained the marsh. Diatom analyses indicate that Peat 4 was abruptly buried by mud deposits that were deposited in a fresh water marsh environment or a brackish tidal flat environment. Because of this contrasting diatom signature it is inconclusive at this time whether the mud burying Peat 4 was deposited as a result of relative sea level rise or some other process such as increased flooding of the marsh.

After burial of Peat 4, sediment aggraded in the marsh until the marsh dried up around 2750-2850 cal yr. BP supporting a fresh-brackish aerophile soil (peat 3). A fresh-brackish pond or bog deposit was deposited on Peat 3 and probably initiated during flooding or a wetter year. 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 a long period of sedimentation that kept pace with gradual sea level rise. The marsh eventually aggraded to an elevation that allowed a fresh-brackish marsh soil (Peat 1 and Peat 2) to develop sometime within the last 500 yrs BP. Soil formation was interrupted briefly by deposition of a dark gray silt loam (mud) during a period of marsh drying. The abrupt transition from a fresh-brackish marsh (Peat 1) to a marsh tide flat environment indicates that rapid relative sea level rise caused submergence and burial of Peat 1. Tideflat mud with interbedded sand and peaty mud deposits accumulated until formation of the modern fresh-brackish marsh surface soil.

In summary, 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 subsidence associated with earthquakes on the northern SGF.

5.2 Independent Verification of Proposed Tectonic Model for Pillar Point Marsh Subsidence

The late Holocene evolution of the marsh proposed above 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 subsidence of Pillar Point marsh within a pull-apart basin. In evaluating whether the buried peat deposits were tectonically subsided or buried as the result of some other non-tectonic process, we employ three independent evaluation techniques including a criteria matrix (described below), a stratigraphic comparison to a non-tectonic marsh, and comparison to the late Holocene paleoseismic record exposed in our trenches north of the marsh.

<u>5.2.1 Criteria Matrix</u>

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 4, 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; (5) synchroneity with other

Table 4. Criteria Indicative of Coseismic Subsidence for Peat Soils (Peat 1 to 7), Pillar Point Marsh and Peat 1 China Camp Marsh.

Stratigraphic horizon	Abrupt Lithologic Contact	Diatom Evidence for Relative Sea Level Eise	Evidence for Sustained Submergence and/or Rapid Aggradation[c]	Wide Lateral Extent of Submergence (m)	Synchronous with other Paleoseismic Events	Located near an Active Fault	Number of Criteria Satisfied	Caused by Co-seismic Subsidence
Peat 1	Yes (2 mm)	Yes	Yes	Yes (130 m)	Yes	Yes	6	Yes
Peat 2	Yes (1 mm)	No	No	Yes (130 m)	?	Yes	3	No
Peat 3	Yes (3 mm)[a]	No	Yes	No	?	Yes	3	No
Peat 4 (upper contact)	Yes (1 mm)	Yes ?	Yes	Yes (70 m)	?	Yes	4-5	Possible
Peat 4 (lower contact)	Yes (1-5 mm)	Yes	No	Yes (70m)	?	Yes	4	Possible
Peat 5	Yes (1 mm)	No	No	Yes (70 m)	?	Yes	3	No
Peat 6	Yes (2 mm)[b]	Yes	Yes	Yes (70 m)	?	Yes	5	Yes
Peat 7	Yes (5 mm)	No	No	No	?	Yes	2	No
China Camp Peat Soil	Yes (2-3 mm)	Yes?	No	Yes (25 m)	No	No	2-3	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.

paleoseismic events; and (6) located near an active fault. 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 4), and present evidence supporting at least two (Peats 6 and 1) and possibly three (base of Peat 4 or top of Peat 4) marsh burial events caused by rapid relative sea level rise. These events are consistent with the hypothesis that surface rupture on the SGF caused coseismic subsidence and burial of peats at Pillar Point marsh.

Peat 6 satisfies five of the six criteria proposed to distinguish co-seismic from non-tectonic sea level change (Table 4). 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 lateral continuity and sharp upper contact (2 mm) of Peat 6 that is overlain by greater than 20 cm of 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. Based on the stratigraphic and paleontologic evidence for rapid submergence of Peat 6, we infer that an earthquake on the SGF caused coseismic land-level change within Pillar Point marsh around 3350-4080 cal yr BP.

The base and upper contacts of Peat 4 satisfy 4 and 4-5 coseismic criteria, respectively (Table 4). At the basal contact a coseismic subsidence interpretation is supported by lateral continuity, contact abruptness, proximity to an active fault. Additionally, the abrupt transition from a periodically dry fresh-brackish marsh environment below Peat 4 to a brackish low marsh environment at the base of Peat 4, is consistent with relative sea level rise that occurred early in the development of Peat 4. The transition occurred across the entire marsh, however Peat 4 continued to develop indicating that the amount of relative sea level rise was minor and did not result in a sustained period of aggradation. For the upper contact, a co-seismic subsidence interpretation is supported by a sustained period of aggradation (20 cm), abrupt contact, lateral continuity, and proximity to an active fault. Paleoecologic evidence from different cores indicate that the depositional environment above and below Peat 4's upper contact was both a fresh brackish marsh and a brackish low marsh. It is possible that an earthquake on the SGF may have caused minor subsidence of the marsh early in Peat 4's development and another earthquake may have caused a greater amount of subsidence and burial of Peat 4. However, because the diatom evidence for relative sea level rise is inconclusive, we infer that it is more likely that only one earthquake along the SGF affected Peat 4 sometime around 3060-3330 cal yr BP.

Peat 3 satisfies three of the stratigraphic criteria (Table 2). Criteria that satisfy a coseismic subsidence interpretation include an abrupt upper contact, a thick alluvial deposit that indicates a sustained period of aggradation, and proximity to an active fault. The change in diatom assemblage across the contact from a dry fresh-brackish soil to a fresh-brackish pond or bog suggests that deposition in the marsh responded to a shift to a wetter climatic period that flooded the marsh. It does not, however, indicate a land-level change. Alluvial channel deposits at the base of cores 02-V4 and 02-V6 occur at a similar stratigraphic level as Peat 3 (Appendix A) and may have eroded Peat 3 from the center of the marsh. Erosion of Peat 3 followed by aggradation of a thick sequence of interbedded mud and sand across the entire marsh could have been caused by a large land level change that resulted in erosion of the marsh surface and sustained aggradation. Based on the lack of diatom support, we consider this scenario unlikely. Thus, we conclude that Peat 3 was not buried as a result of tectonically induced subsidence.

Peat 1 represents the stratigraphically highest buried peaty soil and satisfies all six of the stratigraphic criteria. Rapid submergence and relative sea level rise is indicated by the sharp upper contact between Peat 1 and the overlying mud. The deposit is laterally continuous for over 130 m indicating that submergence affected the entire marsh. Sustained submergence is indicated by tide flat mud aggradation of ~0.5 m above Peat 1. The change in diatom assemblage from fresh-brackish species below the contact to brackish, low marsh/tideflat species above the contact is consistent with coseismic subsidence during an earthquake on the SGF. Finally, radiocarbon analyses above and below the contact indicate that the earthquake occurred within the last 500 cal yr BP and, thus supports synchroneity with a paleoseismic event (A.D. 1667 and A.D. 1802) observed in nearby trenches at Moss Beach (Simpson et al., 1997). Synchroneity is also supported by our 2004 trenches, which exposed an offset shell midden. This midden shares many characteristics with the native Californian cultural deposits dated at A.D. 1270 to 1400 at the Seal Cove trench site studied by Simpson et al. (1997).

5.2.2 Comparison to a Non-tectonic Marsh

For a second independent evaluation that the interpretation of tectonic subsidence is the best explanation for the buried marsh soils observed at Pillar Point marsh, we compare the marsh stratigraphic record from Pillar Point to China Camp marsh (a non-tectonic environment). The stratigraphic sequence documented at the China Camp site contains only one buried peat soil (named Peat A, Figure 9). We evaluate the environmental processes that buried Peat A, by considering the same criteria used to evaluate the Pillar Point marsh soils (above)(Table 4).

Peat A satisfies 2-3 of the criteria, including abrupt upper contact, possible diatom evidence for relative sea level rise, and lateral extent of submergence (observed in three cores). Paleoecologic evidence indicates that Peat A developed in a brackish marsh environment and was buried by mud deposited in a brackish tidal flat. These data suggest that relative sea level rose, however, we infer that this change was not caused by tectonic subsidence because the abundance of peat laminae gradually increases below Peat A and gradually decreases above Peat A. This observation indicates that the criteria of sustained submergence and/or rapid aggradation is not satisfied and that the stratigraphy is more consistent with a marsh that is responding to gradual fluctuations in the rate of sea level rise. Additionally, the marsh is not located adjacent to an active fault. The closest seismic sources to China Camp marsh are the Hayward fault (~8 km east), the San Andreas fault (~13 km west), and the Burdell Mountain Fault (~10 km north). We believe that the Hayward and San Andreas faults are too far away to produce the amount of land level change necessary for marsh submergence and burial. The Burdell Mountain fault projects beneath San Pablo Bay east of the marsh. Up to the west vertical motion associated with the Burdell Mountain fault is not consistent with subsidence of the marsh.

A few noteable differences exist between the Pillar Point marsh site and the China Camp marsh site. First, the number of buried peat soils is much greater in Pillar Point marsh, which contains seven buried soils in 4.5 meters of section. In comparison, the seven meter record from China Camp marsh contains only one buried peat soil. Secondly, the deposits within China Camp marsh are relatively homogenous, consisting of thinly laminated tidal mud with minor peat fragments and thin peaty mud to peat laminae. This is in contrast to the record observed at Pillar Point marsh, which shows multiple environmental shifts.

Based on the absence of a seismic source capable of subsiding the marsh, the presence of gradual stratigraphic changes, and relatively homogenous stratigraphy, we infer that the China Camp marsh surface has not experienced sudden coseismic subsidence. Although not compelling, we feel that the differences between the marsh at China Camp and the marsh at Pillar Point help to substantiate the tectonic subsidence mechanism for the buried marsh soils at Pillar Point.

5.2.3 Synchroneity Between the Marsh and Trench Site and Earthquake Chronology

For a third independent assessment of the coseismic subsidence model for Pillar Point marsh, we documented geologic evidence for prehistoric earthquakes in trench exposures north of the marsh and compared the number of events to the event record inferred from the marsh. Finally, based on the three independent verification tests, we present a preliminary earthquake chronology for the northern SGF.

Within Pillar Point marsh, an earthquake induced subsidence mechanism is strongly supported for Peat 1 and Peat 6. The subtle stratigraphic signature and contrasting diatom evidence associated with the deposit that buries Peat 4 provides possible support, but does not require a third tectonic subsidence event. Offsets of late Holocene deposits exposed in Trench T-1 provide compelling evidence for two earthquakes. Stratigraphic and structural relations also provide possible evidence for two additional earthquakes.

The number of paleo-earthquakes inferred from the marsh stratigraphy is consistent with the number of events documented in our trench exposures. Therefore, the stratigraphic, paleontologic, and structural data strongly support the occurrence of at least two and potentially support up to four Holocene earthquakes on the northern SGF.

The number of earthquakes is also consistent with the chronology 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 ages of the events inferred at Pillar Point and the Cascade Ranch site may provide information on rupture length and magnitude estimates for earthquakes on the northern San Gregorio fault.

Our data suggests that the most recent earthquake submerged peat 1 and occurred after 500 cal yr BP. The penultimate event may have occurred either directly before or directly after the deposition of Peat 4, around 3060-3330 cal yr BP, however the evidence supporting these events is not robust. The oldest earthquake recorded in Pillar Point marsh occurred following the deposition of Peat 6 around 3350 to 4080 cal yr BP. A preliminary recurrence interval can be estimated from this chronology. Assuming that marsh sediments began to accumulate around 4150-4410 cal yr BP, 2 to 4 earthquakes have subsided the marsh to a lower intertidal level, from which we estimate a preliminary recurrence interval of 1037-2205 years for large magnitude earthquakes on the northern San Gregorio fault. Future radiocarbon analyses of sediment and shell midden samples obtained in Trench T-1 may further refine our earthquake chronology and recurrence interval estimates.

6.0 CONCLUSIONS

The Pillar Point marsh site lies between two strands of the northern SGF on the north side of Half Moon Bay within an inferred pull-apart basin. The marsh is characterized by a small basin within which tidal and alluvial sediments have accumulated. Stratigraphic coring adjacent to the SGF within Pillar Point marsh and paleoseismic trenching of the fault on-land north of the marsh provides data on the late Holocene rupture history of the northern SGF. Stratigraphic and paleontologic analyses on cores extracted in 2002 and 2004 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 developed on the stage 5a 83 ka marine terrace. 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 that the slope is tectonically controlled.

Three independent verification tests were employed to evaluate whether abrupt changes in the late Holocene depositional record indicate tectonic subsidence during paleo-earthquakes. These test include a criteria matrix modified from Knudsen et al. (2002) and Nelson et al. (1996), a comparative stratigraphic study of a marsh not located adjacent to an active fault, and a paleoseismic trench investigation located approximately 1 km north of Pillar Point marsh.

Based on the paleontologic, stratigraphic, and criteria matrix, we interpret that two and possibly three earthquakes on the northern SGF produced subsidence within Pillar Point marsh and associated relative sea level rise. Radiometric analyses on buried peat soils interpreted to be tectonically subsided (Peats 1, 4, and 6) indicate that the most recent earthquake occurred between about 500 cal yr BP to the present and that the oldest earthquake recorded at the marsh occurred between 3350 and 4080 cal yr BP. A third earthquake may have subsided Peat 4 around 3060-3330 cal yr BP.

Comparison of the marsh stratigraphy in a relatively stable environment, China Camp marsh to Pillar Point marsh (adjacent to an active fault) provided marginal validation that the stratigraphic signature observed in Pillar Point is unique and related to tectonic subsidence associated with earthquakes on the SGF.

One trench (T-1) excavated across the scarp at the base of Seal Cove Bluffs north of the marsh provides a subsurface exposure of the fault and slope colluvial deposits overlying alluvial fan and marine terrace deposits. A second trench (T-2) excavated across a fault strand approximately 50 meters east of the base of the bluffs shows the fault and colluvial soils overlying marine terrace deposits. These exposures provide stratigraphic and structural evidence for 2 to 4 earthquakes, a similar number of events as interpreted from the stratigraphy beneath Pillar Point marsh, indicating possible synchroneity of events between the two sites. The structural style encountered in the trenches (thrust faults) was unexpected. We speculate that the structural style may evolve from a pull-apart basin caused by releasing geometry in the vicinity of Pillar Point marsh to a flower structure characterized by east-vergent thrust faults along the base of Seal Cove Bluffs where the middle and eastern strands of the SGF converge.

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 results also demonstrate the utility of using marsh stratigraphic techniques to evaluate paleoearthquakes along strike-slip faults where conventional paleoseismic methods may not be possible. The data developed in this study support the possibility that at least two and possibly up to four earthquakes are recorded in the marsh stratigraphy. Assuming the marsh began accumulating sediment around 4150-4410 cal yr BP and two to four earthquakes are recorded in the marsh, we estimate a preliminary Holocene recurrence interval of 1037-2205 years. Additional radiocarbon analyses on samples obtained from trench T-1 are necessary to better constrain the ages of the inferred paleo earthquakes and estimated recurrence interval.

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8.0 NON TECHNICAL SUMMARY

Pillar Point marsh lies within a right-releasing stepover between two active traces of the on-land northern San Gregorio fault. Earthquakes on the SGF may produce abrupt coseismic subsidence and tidal submergence of the freshwater marsh. This research was designed to better understand the timing and recurrence of paleo-earthquakes on the northern SGF by evaluating lithostratigraphic, biostratigraphic, and chronologic data on marsh sediments extracted in a series of vibra-cores and comparing the earthquake chronology to a nearby trench site. Additionally, this research provides an independent verification and validation of the approach of using marsh stratigraphy in paleoseismic studies on strike-slip faults. Our core analysis identified at least two and possibly four land level changes preserved as buried marsh soils. Paleoecologic and radiometric analyses indicate that at least two and possibly four land level changes are associated with tectonic subsidence within Pillar Point marsh related to earthquakes on the SGF. A similar number of events observed at a nearby trench site indicate synchroneity between the two sites.

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Figures

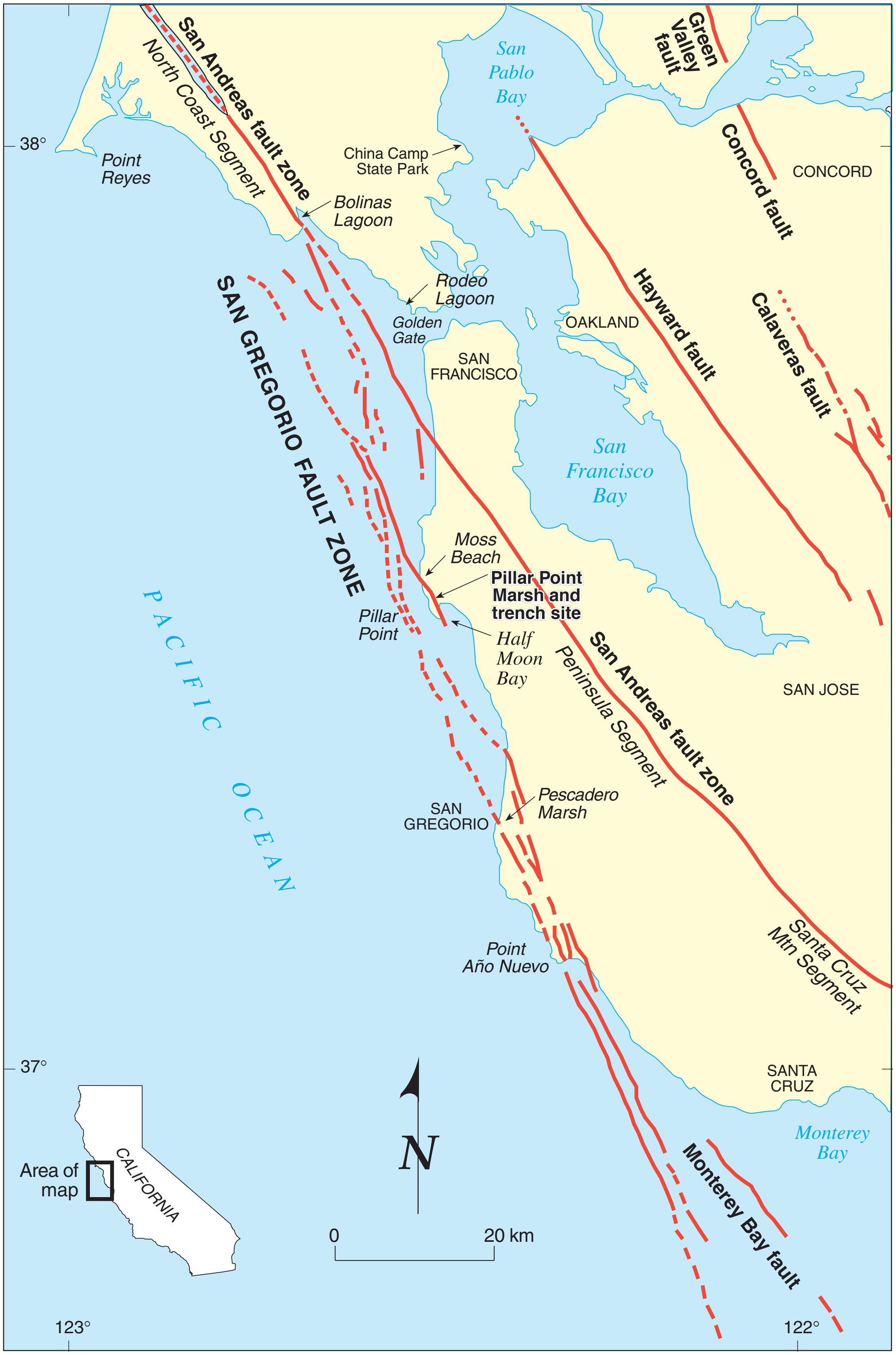
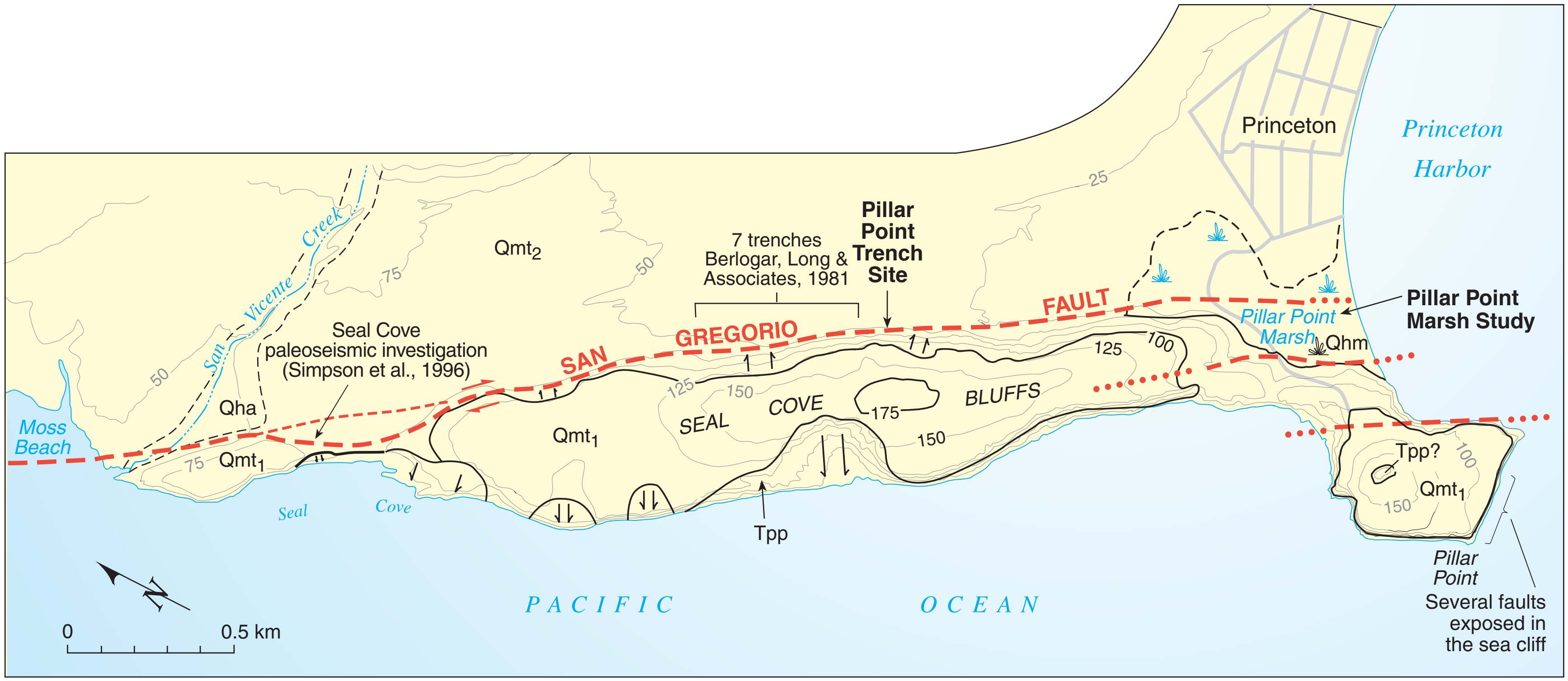


Figure 1. Map showing the San Gregorio fault zone and other principal Holocene faults in the San Francisco Bay area. Fault locations modified from Jennings (1994).



Explanation

Symbols

Northern San Gregorio fault

Previously mapped trace of San Gregorio fault

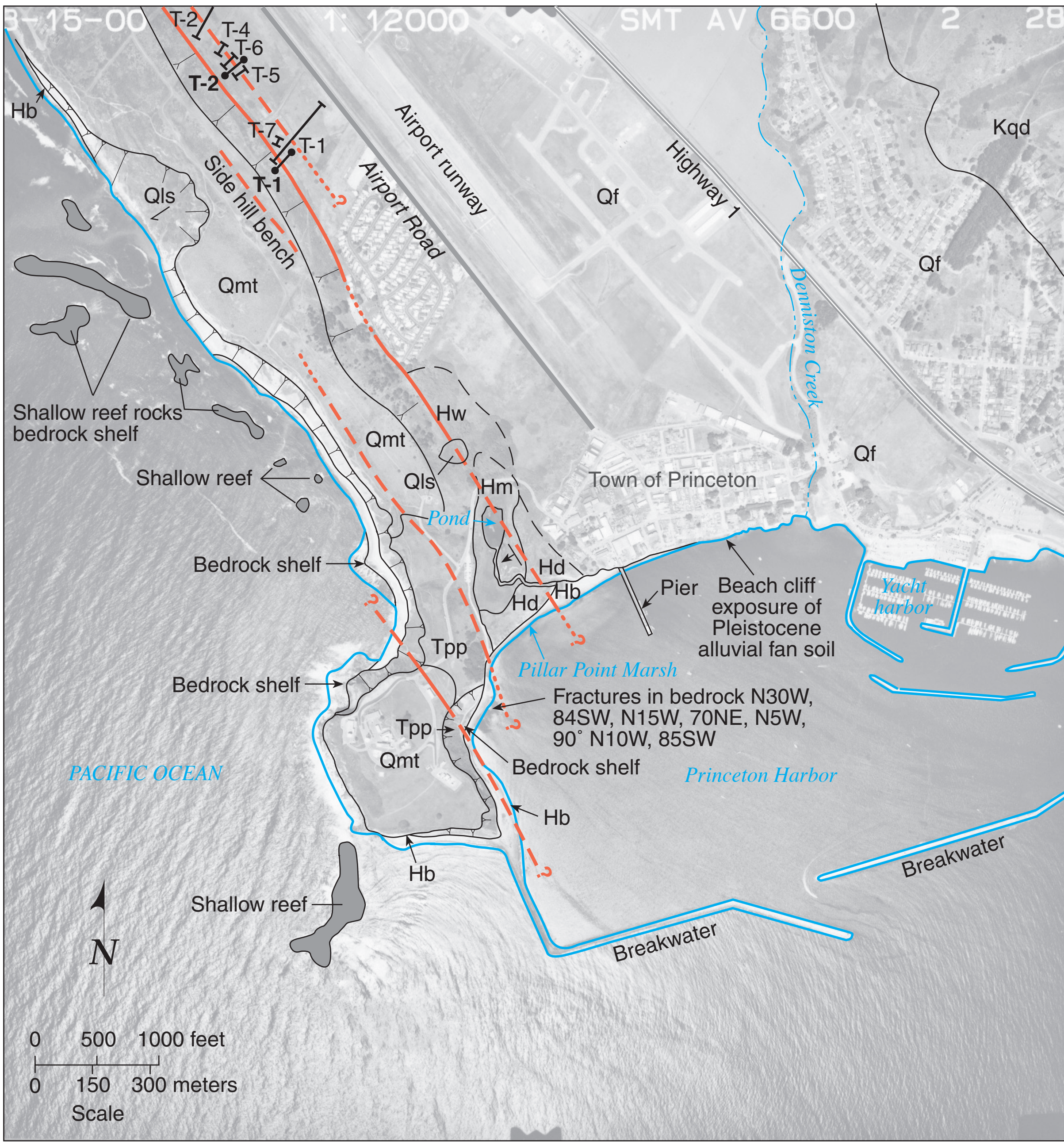
Geologic contact; dashed where approximate

Landslide

Geologic Units

Qha	Holocene alluvium
Qmt_2	Marine terrace, 83,000 years old (Half Moon Bay terrace)
Qmt_1	Marine terrace, 100,000 to 125,000 years old (Seal Cove Bluffs terrace)
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.



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		Dip of subsurface slope
Qf	Quaternary alluvial fan (deposited on 83,000-year-old marine terrace)		Slope
Qls	Quaternary landslide	T-2	2004 trench (WLA)
Qmt	Marine terrace (100,000 to 125,000 years old	T-4	Trench location Berlogar, Long & Associates (1981)
Tpp	Purisima Formation		

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

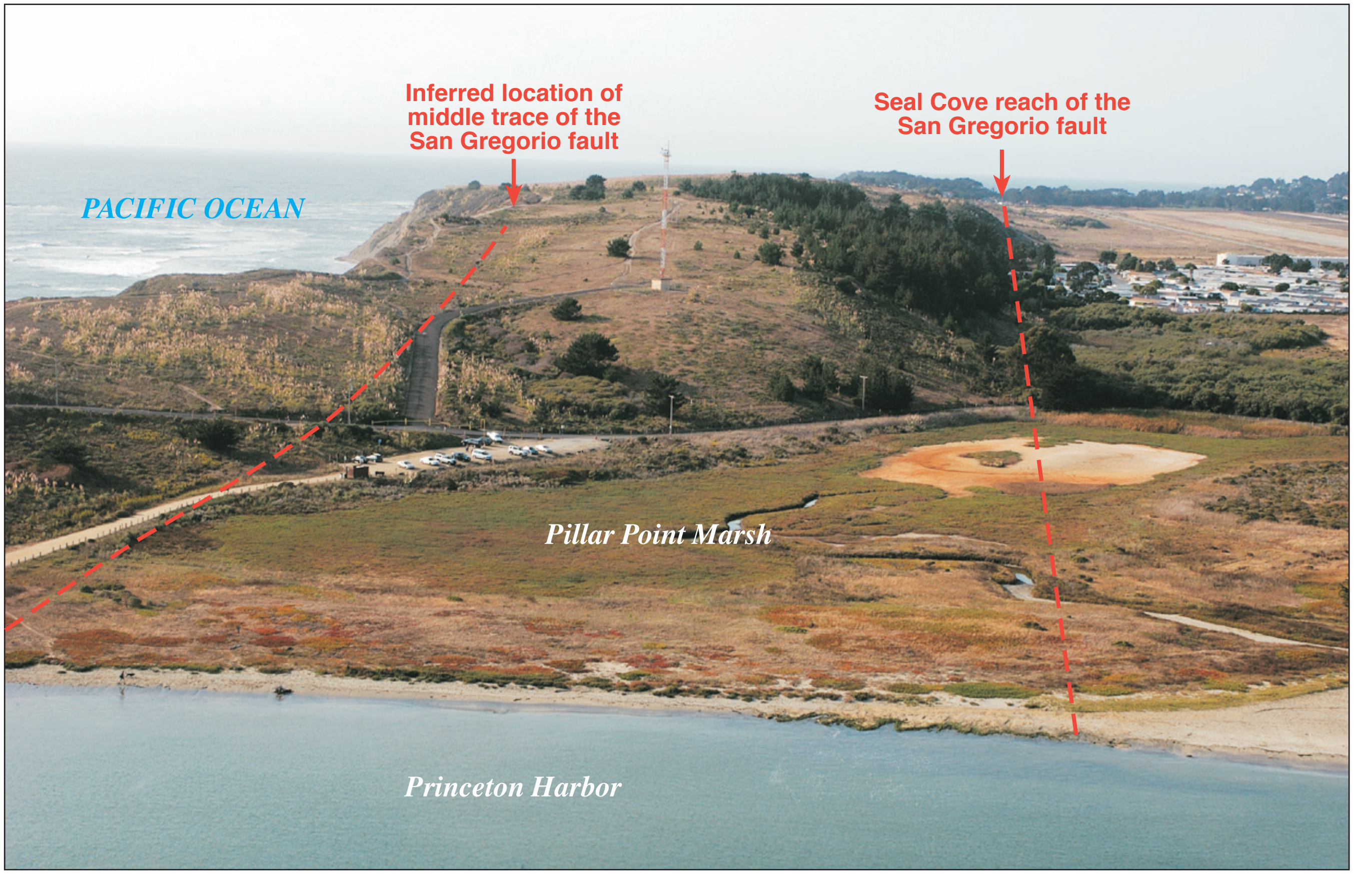
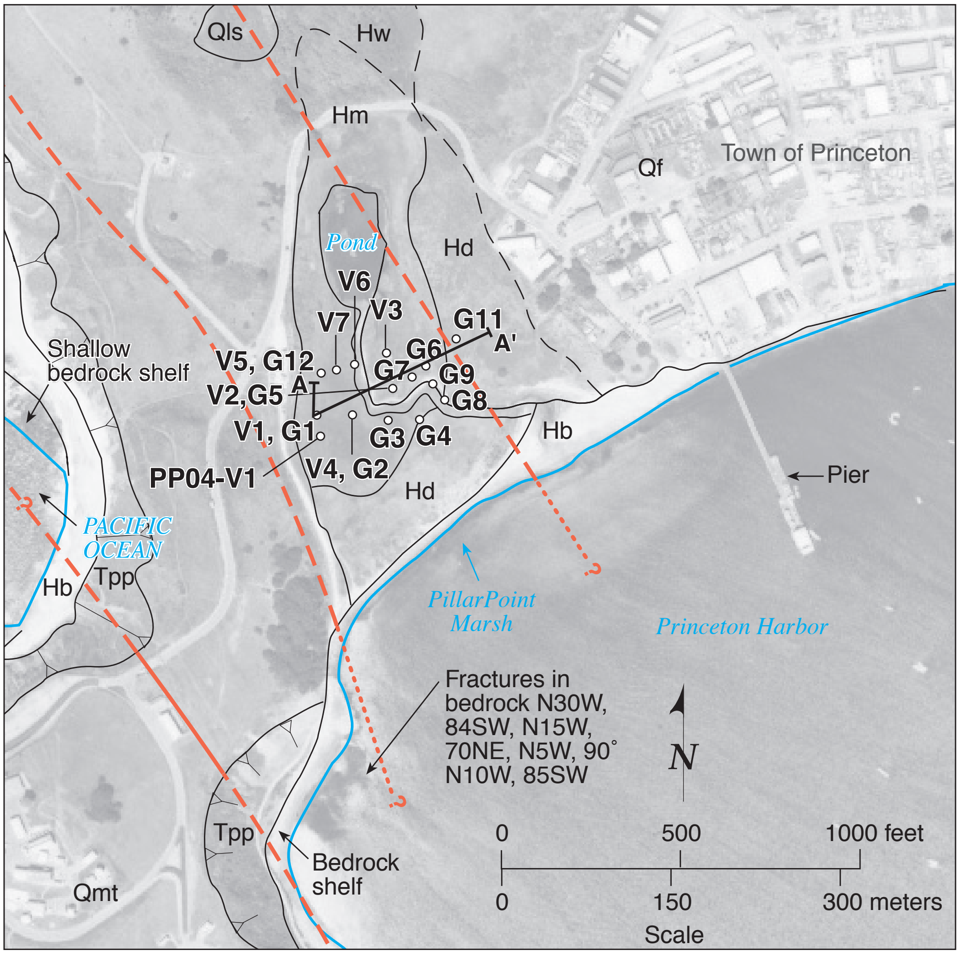


Figure 4. Fault locations superimposed on photo showing Pillar Point Marsh. Strands of the northern San Gregorio fault appear to border both sides of the marsh. The main eastern trace extends along the base of Seal Cove Bluffs towards Moss Beach. View to the northwest. Photo copyright (c) 2002-2003 Kenneth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



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 to 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.

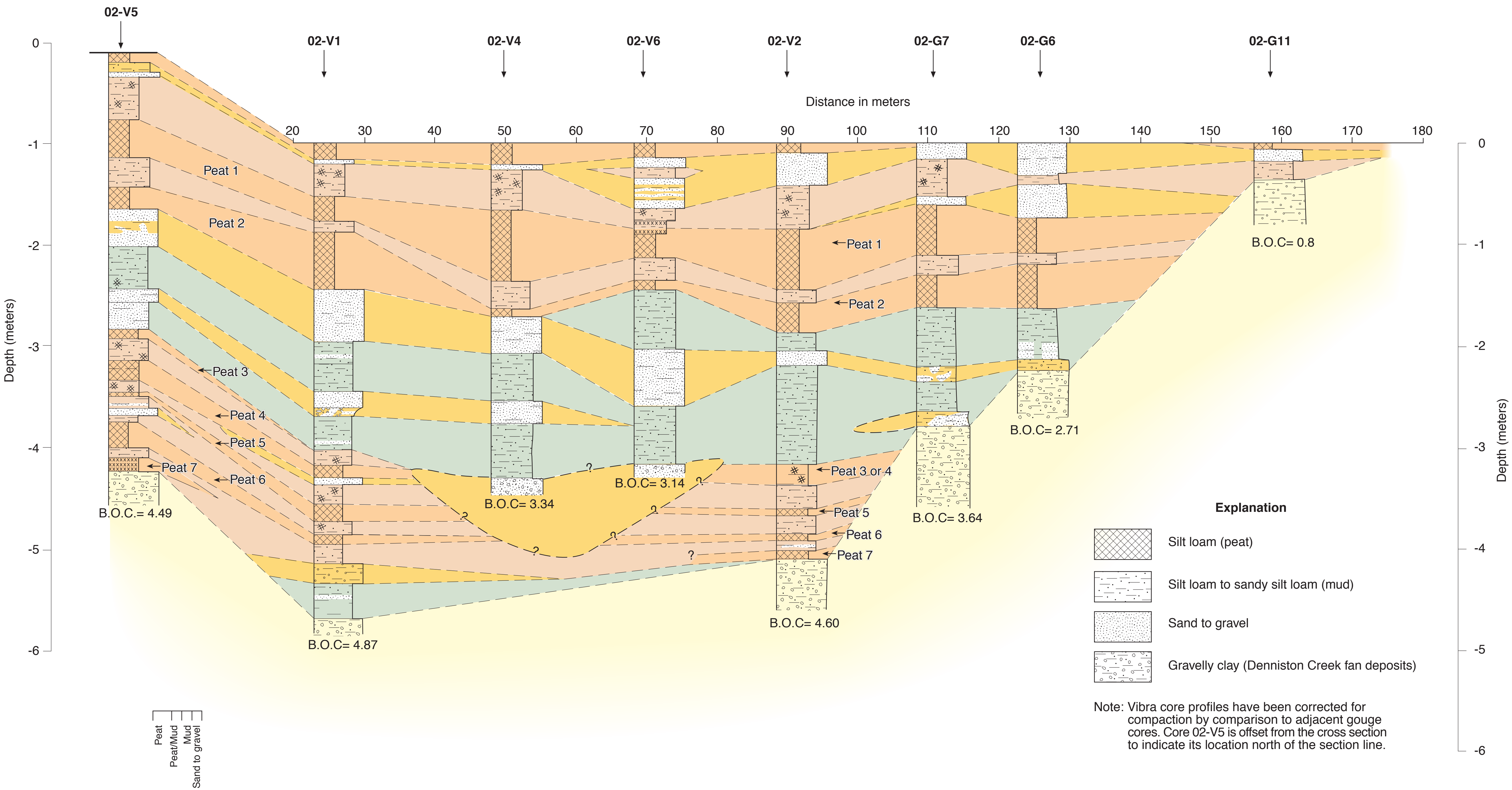


Figure 6. Cross section A-A' of Pillar Point Marsh showing stratigraphic unit correlations. Cross section location shown on Figure 5.

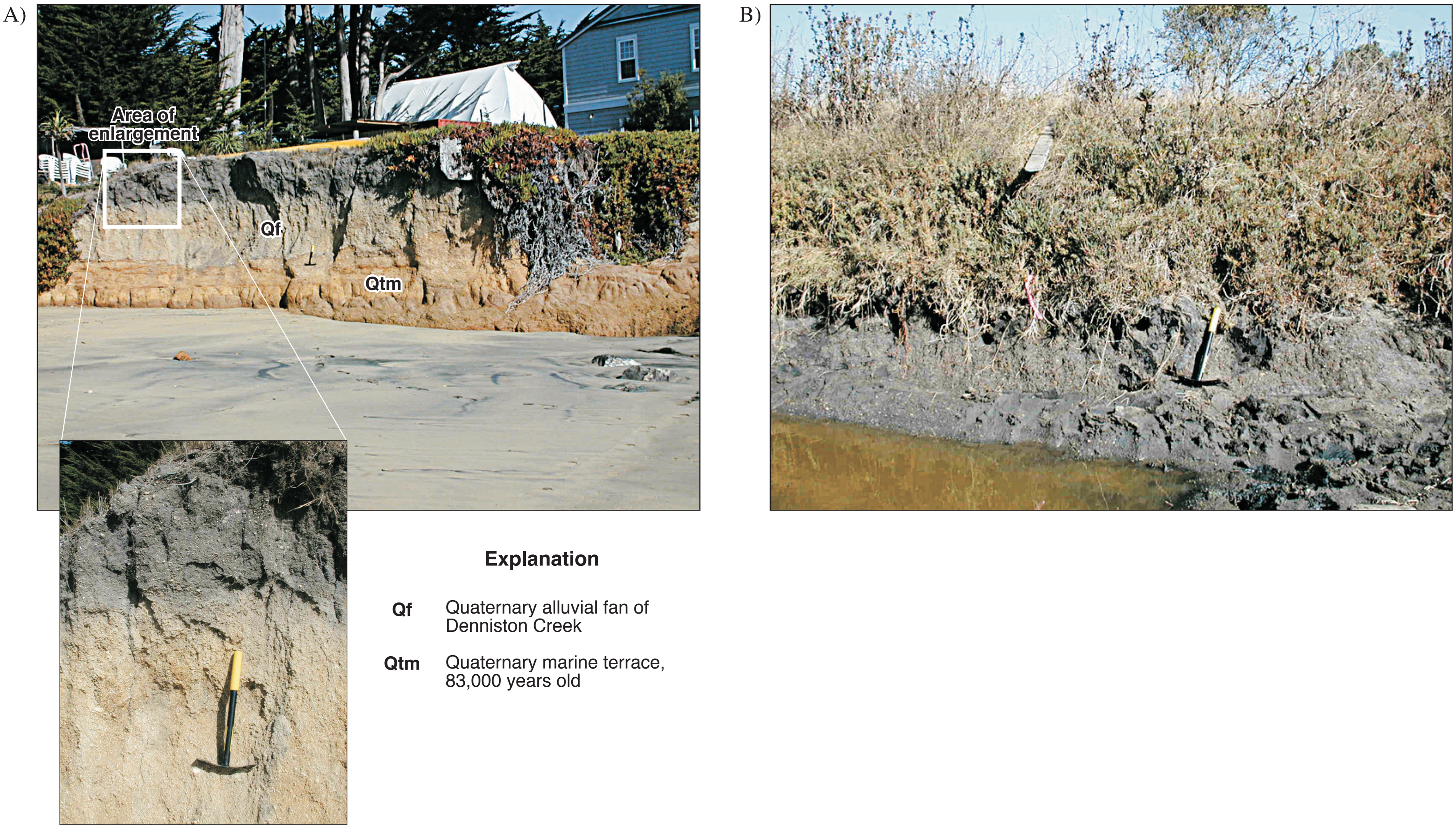


Figure 7. (A) Sea cliff exposure of the alluvial fan deposits overlying the Stage 5a 83 ka marine terrace, Princeton, California. Enlargement is a close up view of the soil developed in the alluvial fan. Angular granitic clasts within the soil are used to correlate the soil across the base of Pillar Point Marsh. (B) Alluvial fan soil exposed in a tidal channel outcrop overlain by dune sand at the eastern margin of Pillar Point Marsh. Note angular granitic clasts within soil at both locations.

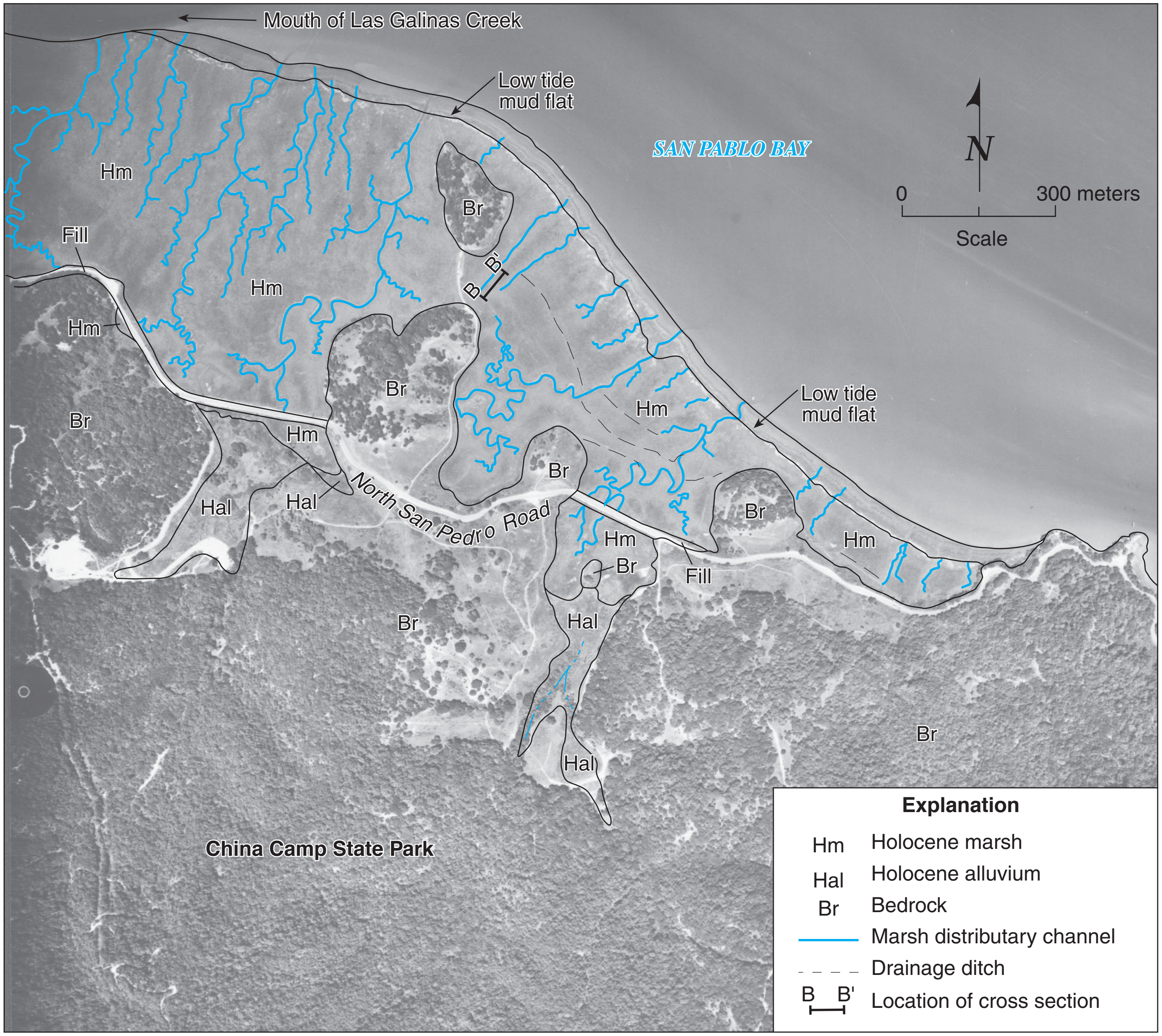


Figure 8. Map of northern part of China Camp State Park and tidal marsh located north of North San Pedro Road. Surficial geologic deposits were interpreted from 1:12,000-scale black and white aerial photography from 1992.

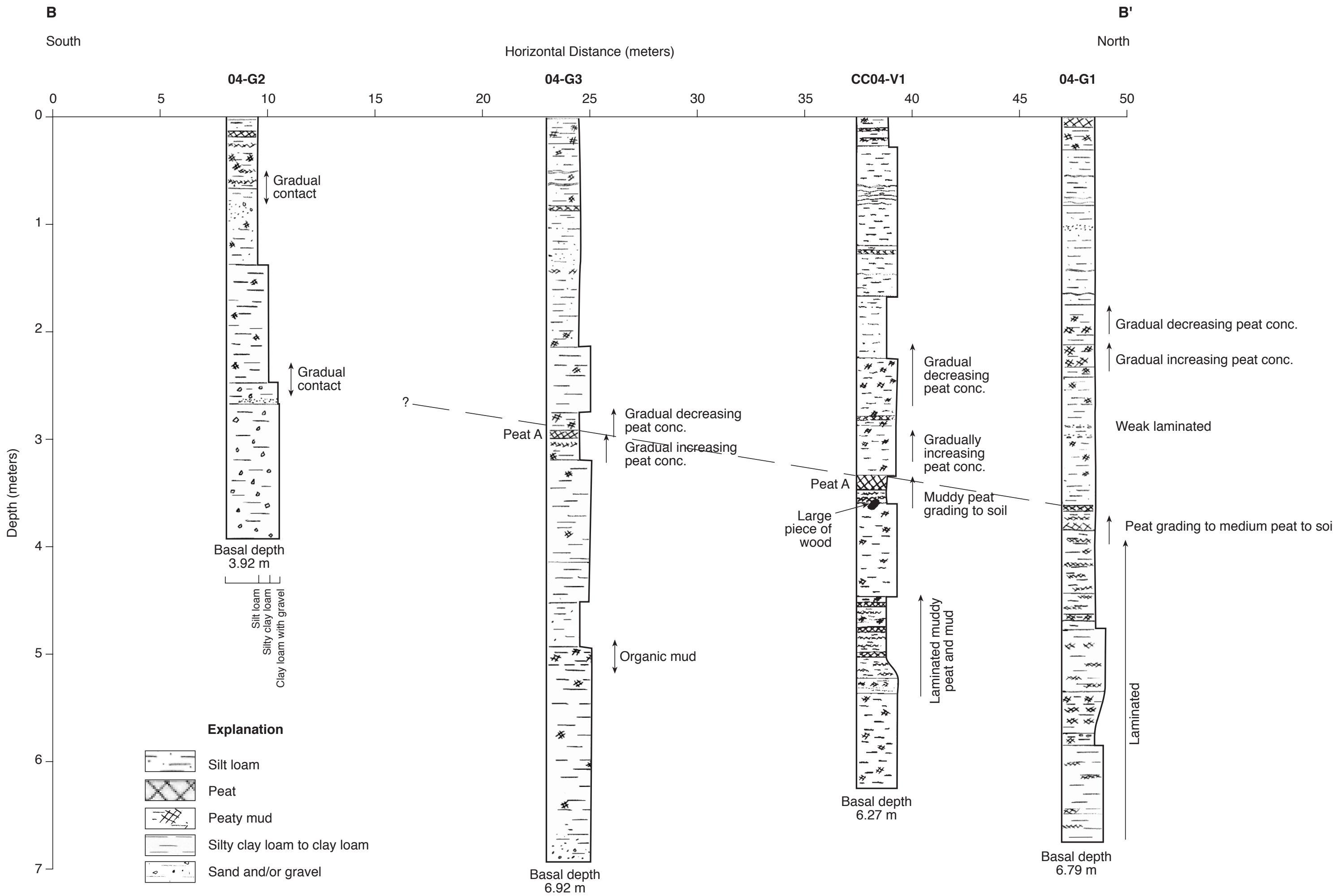


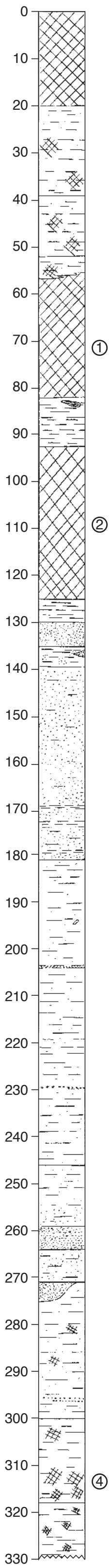
Figure 9. Stratigraphic cross section for B-B', China Camp Marsh. Location of cross section shown on Figure 8.

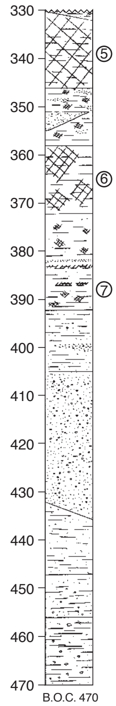
Appendix A

Detailed stratigraphic descriptions for Pillar Point marsh vibra-cores 02-V1 to 02-V7 and PP04-V1. The locations of buried marsh soils as described in text are numbered and shown on the right side of core log. Core locations shown on Figure 5.

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.

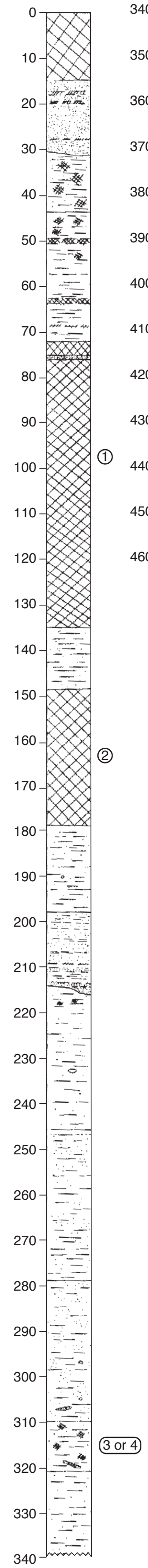
436-447
Silty clay loam w/ sand, dark gray brown, massive, sand is f. grained sub-angular quartz, ~25% clay, trace v.f. roots, trace med. plant fragments, no odor, lower contact over 5 mm.

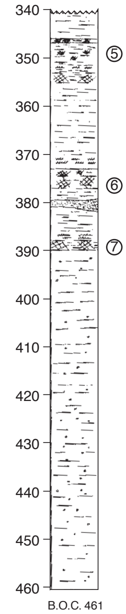
447-456
Sandy clay loam, dark gray brown, massive, similar gravels as above but more abundant, ~15-20% clay, gravels make up ~5% of unit, lower contact over 2-3 mm.

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,

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.

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.

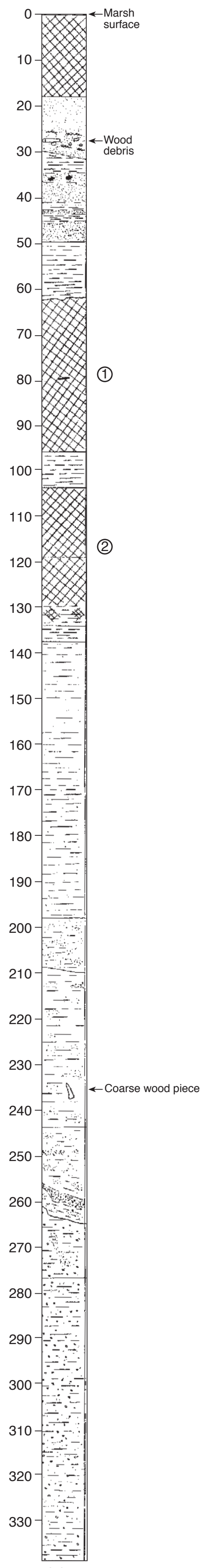
198-210
Sandy loam, dark olive brown, ~30-40% f. to v.f. sand w/ trace gravels up to 5 mm, massive, sand is distributed in patchy zones, quartz clast lithology, no roots, lower contact over 2 mm.

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.

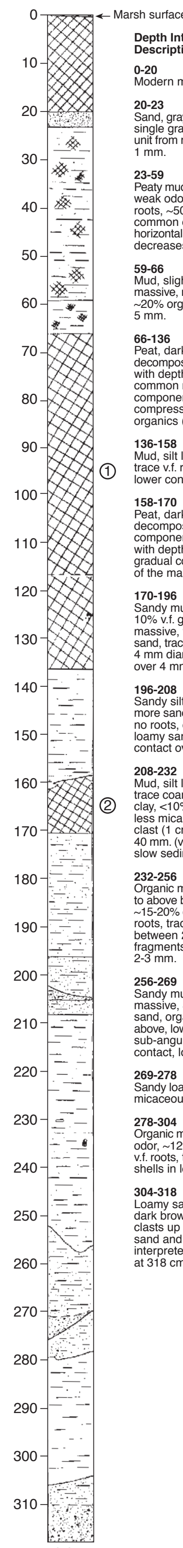
244-265
Sandy silt loam, dark olive brown, similar to above but more sand, ~15% clay, ~30% sand concentrated in patchy zones, sand is poorly sorted and ranges between v.f. and coarse grained, trace gravels up to 5 mm, <10% organics, lower contact over 2 mm.

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.

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.

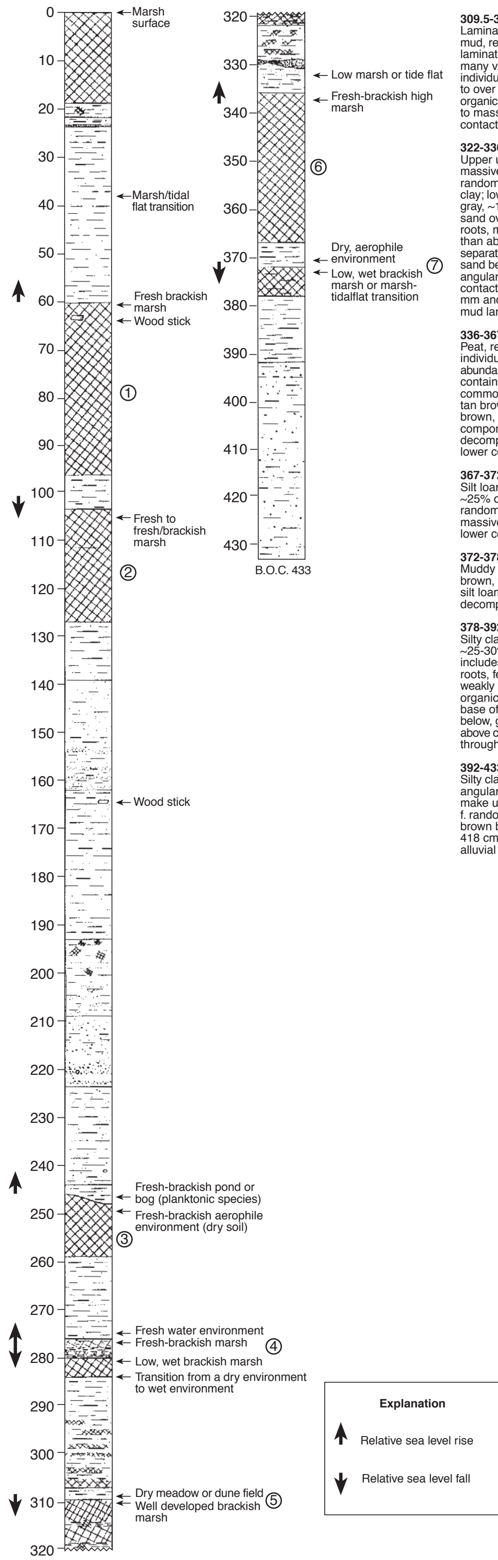
259-276
Mud, silt loam, dark olive gray grading downward to dark gray, massive weakly laminated (2 mm scale laminae), slight odor, ~15% organics above 269 cm, <10% organics below 269 cm, trace v.f. random roots, trace coarse plant fragments, trace to no mica, lower contact over 2-3 mm.

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.

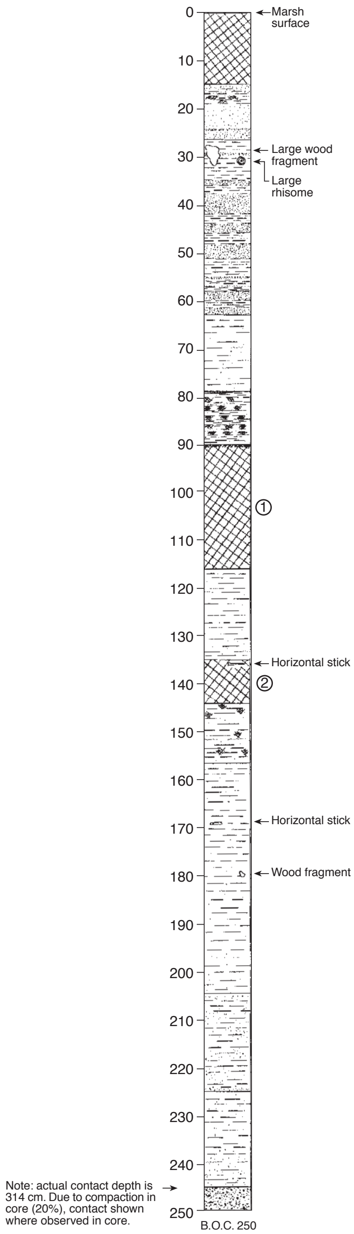
367-372
Silt loam to silty clay loam, dark gray, ~25% clay, ~10% mica, common v.f. random roots, trace f. random roots, massive, trace coarse peat fragments, lower contact over 10 mm.

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.

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.

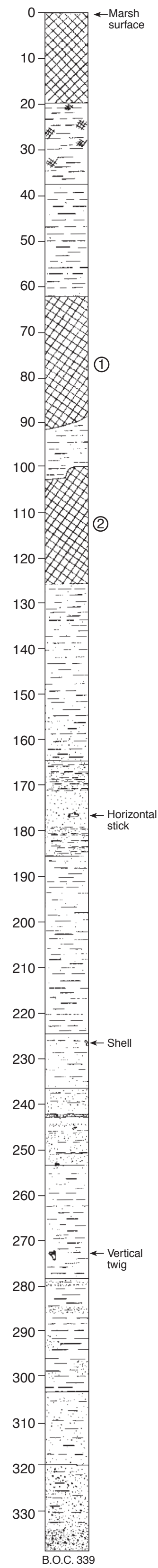
156.5-204.5
Mud, silt loam, dark olive brown, micaceous, ~7-12% clay, ~60% silt, ~30% organics, similar to unit above but more organics, contains horizontal stick 2.5 cm long at 169 cm, lower contact over 3-5 mm.

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.

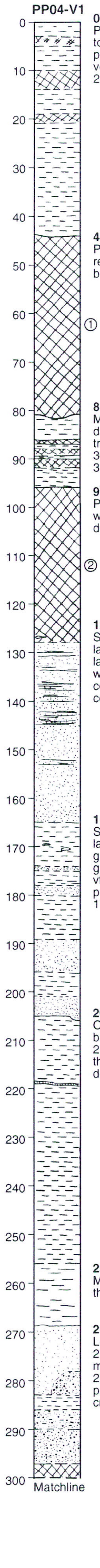
237-254
Loamy sand with gravel, dark gray to brown, >70% sand, trace woody debris, trace v.f. random roots, weakly laminated, individual laminae range from 0.5-1 cm thick, contains a 1 cm thick coarse sand layer, some pockets of silt near base suggest bioturbation, lower contact over 3 mm

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.



0-44
Peaty mud, silty clay loam, Gley 1 2.5/10Y greenish black, visually black to dark green, ~30% clay, massive to weakly laminated, generally 5% peat with occasional interlayers with up to 20-30% peat, many f and vf vertical and random roots, peat rich layers occur at 3-5, 10-14, and 19-21 cm, basal contact over 2 mm.

44-81
Peat, ~70% peat and 30% silt, 10YR 2/1 black, fibrous, visually dark reddish brown, many vf random roots, more decomposed with depth, basal contact over 2 mm with slightly wavy relief.

81-96
Mud, silt loam, Gley 1 2.5/10Y to 2.5/N greenish black to black, visually dark gray, contains <5% peat fragments, massive with peaty interbeds, trace med rhizomes, trace vf roots, peaty mud interbeds contain ~20-30% peat and occur at 86-87, 88-89, and 90-92 cm, basal contact over 3 mm.

96-125
Peat, ~70% peat, ~30% silt, 10 YR 2/2 very dark brown to dark brown, well decomposed, velvety, few vf roots, trace sticks and coarse woody debris, weak odor, basal contact over 10 mm.

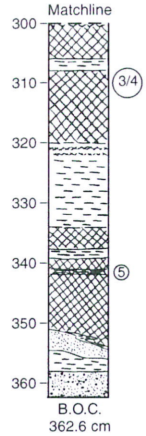
125-165
Sand, very fine grained, massive with weak 3-5 mm thick silty organic laminae, Gley 1 3/10Y dark gray with Gley 1 2.5/10Y greenish black laminae, visually dark gray with dark brown laminae, trace vf roots, weakly laminated near top (above 140 cm), trace woody debris concentrated in organic laminae at 142-145 and 152-153 cm, basal contact over 10 mm.

165-206
Sandy silt loam (80-90%) interbedded with very fine grained sand laminae (10-20%), Sandy silt loam zones are Gley 1 3/10Y dark greenish gray (visually dark gray), sand zones are Gley 1 2.5/10Y greenish black (visually dark brown), massive with weak laminae, trace vf roots, trace woody debris, organic laminae 3-4 to 30 mm thick, prominent sand laminae occur at 201-206, 189-196, 178-180, and 174-175 cm, basal contact over 2 mm.

206-256
Organic mud, silt loam, 2.5Y 3/1 very dark gray, visually dark olive brown, massive with trace sandy laminae, prominent sand laminae at 219 cm, trace vf random roots, contains trace med sand grains throughout, trace mica, strong odor, possibly as much as 20% well decomposed organics, basal contact over 5-10 mm.

256-269
Mud, silt loam, grayish brown, massive, no roots, much less organics than above, trace mica, basal contact over 3 mm.

269-297
Loamy sand to sandy gravel (coarse sand and angular gravel), 2.5Y 2.5/1 black, visually dark brown to gray, massive with weakly interbedded mud and sandy gravel, no roots, prominent beds of gravel occur at 278-283, and 290-297 cm, contains fine to med grained sand in upper part and coarsens downward, dark brown mud laminae at 283- 286 cm, interpreted as an alluvial deposit, basal contact over 5 mm.



97-320
Peat with silt loam mud laminae, dark reddish brown, ~60-70% peat, contains prominent mud interbed at 306-308 cm, fibrous, few med random rhizomes, trace vf random roots, strong odor, below 308 cm unit has more mud and peat content diminishes to 40-50%, basal contact over 20 mm.

320- 334
Mud, silty clay loam, 2.5Y 2.5/1 black, visually dark gray, massive, common med rhizomes, trace vf roots, gradual upper contact, upper 3 cm is weakly laminated as unit grades upward to peat, peaty laminae are dark brown, trace mica, basal contact over 1-4 mm.

334-354
Peat, ~60% peat, ~40% silt loam, dark reddish brown to black (10YR 2/1 black), fibrous, common med random rhizomes, common vf roots, contains dark black muddy peat interbed between 341 and 342 cm, basal contact over 5 mm.

354-356
Sand, greenish gray, sand is very fine grained, trace detrital peat, massive, no roots, interpreted as either tidal, beach, or storm wash-over deposit, basal contact over 1-2 mm.

356-358
Peaty mud, dark brown to black, massive, trace vf roots, basal contact over 4 mm.

358-362.6
Coarse sand and gravel, dark gray, massive, no roots, poorly sorted, contains grains of quartz (predominantly), contains mica and feldspar, trace woody debris, ~20% gravel (2-3 mm diameter and sub-angular), ~80% fine to coarse sand.

Appendix B

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

Stratigraphic description of 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

Stratigraphic description of 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

Depth Interval	Description
	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.

Stratigraphic description of 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

Stratigraphic description of 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

Depth Interval	Description
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

Stratigraphic description of 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.

Stratigraphic description of 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.

Depth Interval	Description
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

Stratigraphic description of 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.

Stratigraphic description of 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.

Stratigraphic description of 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.

Depth Interval	Description
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.

Stratigraphic description of 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.

Stratigraphic description of 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

Stratigraphic description of 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.

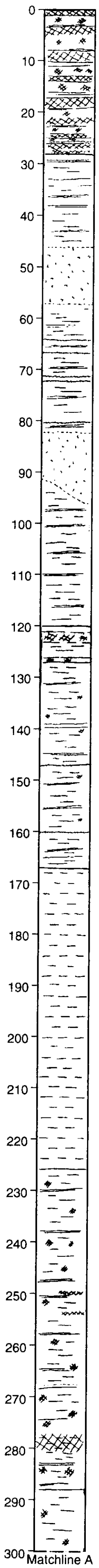
Depth Interval	Description
353-355	Organic mud, dark olive brown, trace f. roots.
355-363	Sand, med. to coarse grained, clean, angular to sub-angular rock fragments, no apparent bedding, lower contact over 2 mm., interpreted as a beach deposit.
363-366	Mud, dark olive gray
366-391.5	Peat, reddish brown, 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 C

Detailed stratigraphic description of China Camp marsh vibra-core CC04-V1
and gouge cores 04-G1 to 04-G3.

China Camp vibra core

CC04-V1



0-28
Mud to muddy peat to peat, silt clay loam with ~20-30% peat, 10Y 4/1 dark greenish gray, laminated, individual laminae up to 10 mm thick and average ~1 mm, mud layers are massive, mottled with orange oxidation, trace charcoal detritus, many vf and few f horizontal roots, basal contact over 10 mm.

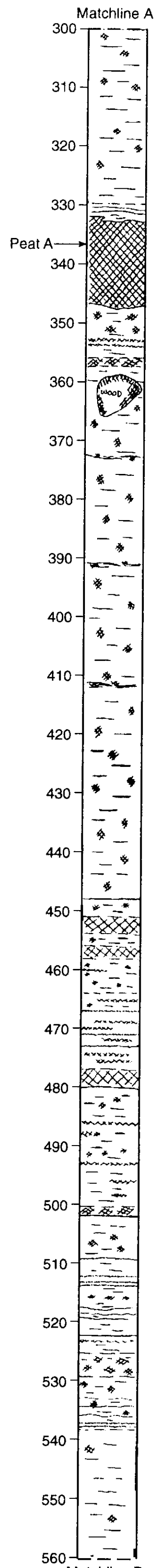
28-120
Mud, silt clay loam, 5GY 4/1 dark greenish gray, ~ 30 % clay, massive to weakly laminated, common vf and few f random roots, from 46 to 57 cm and 82-91 cm structure of mud has incipient granular structure, burn horizons approx 1 mm thick (charcoal?) occur at 64, 66.5 71, 72, and 80 cm, trace coarse peat makes up < 5%, basal contact over 10 mm.

120-167
Mud, silt clay loam to clay, 5GY 4/1 dark greenish gray, ~30-40 % clay, massive with sparse 1-4 mm thick laminae, many vf random and few med subvertical roots, black 3-4 mm thick laminae (charcoal) occur at 147 and 160 cm, peaty mud lams occur at 121-123 and 126-127 cm, peaty mud laminae are tan to light brown in color, basal contact over 20 mm.

167-226
Mud, silty clay, 5GY 4/1 dark greenish gray, ~ 40-45 % clay, massive, less organics than above and more massive, fewer laminae and less peat fragments than unit above, common vf random roots, less roots than above, trace coarse rhizomes subvertical, basal contact over 20 mm.

226-288
Mud with trace peat fragments, silt clay loam to clay, ~25-30 % clay, 5GY 4/1 dark greenish gray, massive to weakly laminated, many vf random roots, contains 5-10 % coarse peat fragments throughout, contains peaty mud laminae approx 1-2 cm thick at 250 and 254 cm, a 4 cm thick peaty mud laminae occurs between 277 and 281 cm, basal contact over 20-30 mm and noted by a decrease in peat fragments (<5%) and slightly lighter color below 288 cm.

288-333
Mud, silt clay loam, 5GY 4/1 dark greenish gray, ~25-30 % clay, < 5% peat fragments, massive, many vf random roots, very similar to unit above but has less peat fragments, lower 3 cm of unit is massive to microlaminated dark grey to greenish gray mud with trace roots, bioturbated, basal contact over 2-3 mm, wavy.



333-347
Peat, 10Y 2.5/1 greenish black, massive to velvety, trace med rhizomes horizontal, trace vf random roots, well decomposed peat, sulphur odor, contains abundant <1mm long white translucent shells?, paleosol, basal contact over 2 mm.

347-360
Laminated peaty mud and muddy peat, silt loam, mud is 10 Y 4/1 dark greenish gray, muddy peat is 2.5Y 3/2 very dark gray brown, approx. 20-30% peat in peaty mud layers, laminated but muds are massive, common med rhizomes random, mud laminae occur at 353 cm (4 mm thick), 354 cm (5 mm thick), and between 356-357.5 cm, basal contact over 10 mm.

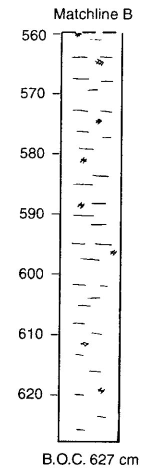
360-448
Mud, silt clay loam, 10Y 4/1 dark greenish gray, weakly laminated, approx. 5% peat fragments throughout, very few vf random roots, few med rhizomes random, discontinuous 1 mm thick tan organic mud laminae occur at 373, 392, and 412 cm, individual laminae are between 2-5 mm thick, basal contact over 3 mm.

448-480
Laminated mud, peaty mud, and peat, peats are 2.5Y 3/2 very dark grayish brown and muds are 10Y 4/1 dark greenish gray, texture of peats is silt loam, texture of muds is silt clay loam, laminated, common vf random roots, common med rhizomes random, peats have approx 50% organics, peaty muds have approx 30% organics, muds have < 5% organics, black laminae 2-3 mm thick (charcoal) occur at 467, 471, and 473 cm, basal contact over 10 mm.

480-502
Mud, silt clay loam, 5Y 4/2 olive gray, massive to weakly laminated, very few f rhizomes random, trace vf random roots, peaty mud laminae occur 486-487, 493-494, and 500-502, laminae are 2.5Y 4/2 dark grayish brown, basal contact over 10 mm.

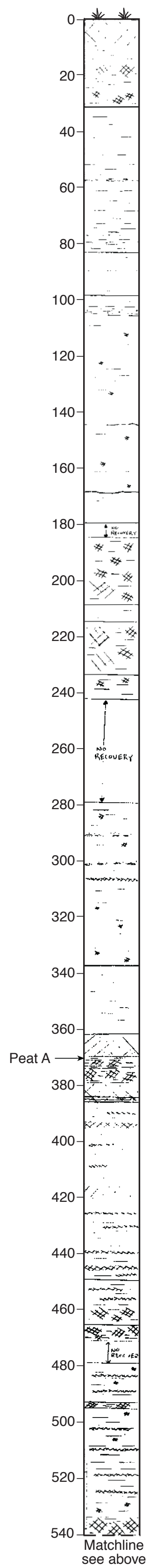
502-522
Organic Mud, 10Y 4/1 dark greenish gray, silt clay loam, weakly laminated, very few vf random roots, few med rhizomes random, contains 1-2 mm thick black laminae (charcoal) at 509, 512, 513, and between 517- 520 cm, contains one slightly darker organic mud between 515-516 cm, similar to unit above only darker, basal contact over 10 mm.

522-538
Mud and peaty mud, silt clay loam, laminated, mud laminae are 10Y 4/1 dark greenish gray, peaty mud laminae are 2.5Y 3/2 very dark grayish brown, common vf random roots, trace med rhizomes random, contains peaty mud laminae at 523 cm (3 mm thick) and between 525-529 cm, below 528 cm unit is predominantly massive to weakly laminated mud with trace peat fragments, contains two black charcoal layers (1 mm thick) at 537 and 537.5 cm, basal contact over 10 mm.



538-627
Mud, silt clay loam, 10Y 4/1 dark greenish gray, massive with thin laminations in upper 10 cm, <5% peat fragments, laminae decrease downward, trace med rhizomes, common vf random roots.

04-G1



Depth Interval Description

0-31
Interbedded muddy peat and mud, silt, upper peat reddish brown, lower muddy peats brownish gray, massive, many f. and med. roots, mud layers are dark gray with trace roots, upper peat contains gray mud mixed in with the peat consistent with gradual mud accumulation, basal contact over 1 cm.

31-82.5
Mud, silt loam, gray, massive, trace f. and med. random roots, contains burned layers at 57, 77, and 79 cm (~3 mm to 0.5 cm thick), upper burn layer contains sticks, basal contact over 5 cm.

82.5-98
Mud, silt loam, olive gray, massive many f. and vf roots, similar to above but darker color.

98-179
Mud, silt loam, olive gray, massive, trace med subvertical and many f. random roots, contains a layer of silt loam with trace fine sand and coarse sand (~5 %) between 102 and 104.5 cm, contains 0.5 cm thick burn layers at 168 and 144 cm, contains trace peat fragments (2-3 mm) throughout (~<5%).

179-184
No recovery.

184-208
Muddy peat grading to peaty mud above 195 cm, dark olive brown to brown, massive, many f and med random roots, lower part has trace coarse rhysomes, basal contact over 3 cm.

208-214
Mud, silt loam, olive gray, massive, trace coarse rhysomes, many vf roots, basal contact over 1 cm.

214-233
Muddy peat, silt loam, olive brown, massive, many vf random roots, basal contact over 2 cm.

233-242
Mud, silt loam, olive gray, massive, many vf random roots.

242-279
No recovery

279-337
Mud, silt loam, olive gray, massive to weakly laminated, many vf random roots, contains layers of sticks, burned wood and vf sand (~ 1 cm thick) at 291 and 301 cm, contains dark brown peat layer (2 mm thick) at 306.5 cm, contains peat fragments throughout that are about 2-3 mm, individual laminae are alternating olive gray mud and olive brown mud with trace peat, interpret as slow aggradation of marsh, peat content in olive brown mud is much less than entire core below 362 cm, basal contact over 2 cm.

337-361
Mud, silt loam, dark gray, massive no roots, similar to above but no roots, basal contact over 1 cm.

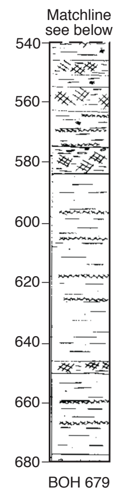
361-369
Peat, silt loam to silty clay loam, very dark brown, massive, fibrous in upper 2 cm, many vf random roots at base, roots diminish up section, contains trace f to med grained sand throughout, approx 70% organics, lower 1 cm has approx 10% sand, basal contact over 2 mm, interpreted as buried soil.

369-386
Peat grading upwards to muddy peat, reddish brown, massive, trace vf roots, silt, 80% organics at base, stinky, contains gray mud laminae at 373 and 369 cm, contains two 2 mm thick burn layers at base, basal contact over1 cm.

386-449
Mud interbedded with dark reddish brown muddy peats, peats occur as laminae that are generally 1 to 3 mm thick, 2 cm thick peat layers occur at 393 and 444 cm, 5 cm thick peat layer at 415 cm, 1 cm thick peat layer at 439, mud is olive gray, massive, many vf and f roots, laminated, basal contact over 3 cm.

449-465
Mud with thin peaty mud laminae, silt loam, olive brown,massive to laminated, common vf random roots, peat content diminishes up section, represents very gradual transition from muddy peat below to laminated mud and muddy peat above.

465-473
Muddy peat, reddish brown, massive to weakly laminated, common vf random roots.



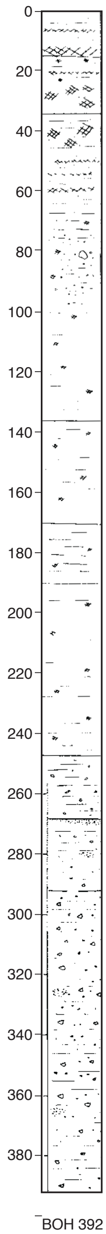
473-479
No recovery

479-577
Interbedded mud, peaty mud, silt loam to silt clay loam, reddish brown, olive gray, and tan brown, laminated, common vf random roots, individual laminae range from 1-2 mm and up to 8 cm, contains 1 mm thick burn layers occurring approx every 5 cm, muddy peats are weakly laminated with gradual upper and lower contacts, contains trace peat fragments throughout (1-2 mm).

577-586
Peaty mud, silt loam, olive gray to brownish gray, massive, trace vf. random roots, basal contact over 2 cm

586-679
Mud interbedded with brown peaty mud, silty clay loam, olive gray to light gray, massive and locally laminated, slightly more clay content below 610 cm, peaty mud laminae are 3-5 mm thick with coarse peat fragments.

04-G2



Depth Interval Descriptions

0-34
Interbedded mud, muddy peat and peaty mud, silt loam, tan brown, laminated, individual laminae are 1-2 mm thick, many vf and f roots, contains coarse wood fragments, trace sand, coarse rhysomes, peat fragments gradually diminish up section being more abundant at base, basal contact over 2 cm.

34-64
Interbedded mud, peaty mud, and muddy peat, similar to above but olive brown color, silt loam, laminated, many vf random roots, few med roots, contains common 3 mm thick burn layers, and trace fine sand, muddy peat layers are not well developed, slightly mor peat in upper part of unit, basal contact over 2 cm.

64-136
Mud, silt loam, olive gray, massive to weakly laminated, many vf roots, below 80 cm unit becomes dark olive gray, contains concentration of gravel (~ 5%) between 77 and 97 cm, gravels are 2-3 mm with rare clasts up to 2 cm, subrounded, contains trace wood and coarse peat fragments, trace med roots in lower part of unit, basal contact over 1 cm.

136-170
Mud, silt clay loam, stiffer than above, brownish gray, reduced ?, massive, trace to no roots, much less roots than above, trace peat fragments (less than above), basal contact over 3 cm.

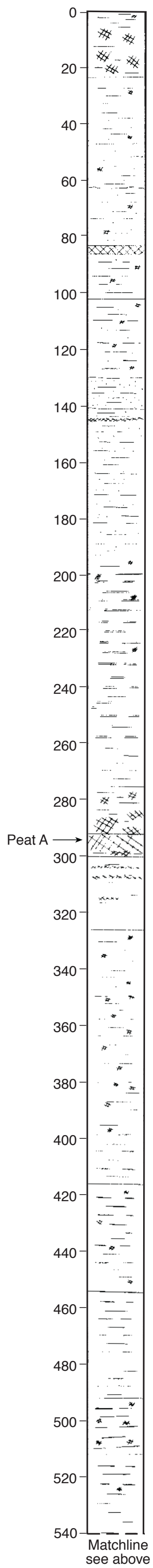
170-192
Same as above but slightly darker color, basal contact over 2 cm.

192-247
Mud, silt clay loam, olive gray, massive, trace coarse rhysomes, contains approx 5% coarse peat fragments, basal contact over 3 cm.

247-268
Clay loam with trace gravel, olive gray, massive, no roots, contains discontinuous pockets of sand (0.5 cm thick) that are probably weathered sandstone bedrock clasts, contains 5-10% subangular to angular gravel up to 1 cm long, gravels are sandstone and siltstone derived from Franciscan Formation bedrock to the west, clasts are green, tan, and yellow color, contains sand lens at 168 cm, interpreted as soil developed in weathered Franciscan Formation bedrock overlain by Holocene marsh sediments, probably reflects mixing of both marsh deposits and soil, basal contact over 2 cm.

268-392
Gravelly clay loam, dark olive gray, massive, no roots, contains gravels similar to unit above but more abundant, gravel makes up approx 15% above 292 cm and approx 30% below 292 cm, gravels are up to 2 cm, contains pockets of sand that represent weathered Franciscan Formation clasts.

04-G3



China Camp gouge core 04-G3
Depth interval (cm)

Description

0-24
Peaty mud, silt loam, tan brown to brownish gray, massive, many f and vf roots, contains wood sticks up to 2 cm, upper 5 cm is pure mud with small peat fragments, common coarse rhysomes, basal contact over 2 cm.

24-102
Mud, silt loam to silt clay loam, olive gray, massive to weakly laminated, contains coarse peat fragments, trace coarse rhysomes, laminations include black burn layers and alternating layers of olive gray and olive brown mud (< 0.5 cm thick), few f and common vf roots, contains a dark brown, well decomposed peat layer between 83 and 86 cm.

102-130
Mud, silt loam with trace sand, olive gray, massive common f and vf roots, trace peat fragments, similar to above but has trace sand.

130-141
Mud, silt loam, olive gray, massive, trace vf roots, contains a very fine sandy silt loam between 130 and 141 cm, upper and lower contacts of this layer are over 1 cm, contains trace vf roots in sany bed, roots diminish below sand bed to very few f and vf roots.

141-192
Mud, sandy silt loam to silt loam, olive gray, massive, very few f and vf roots, slightly less sand than above, contains dark brown peaty mud layer approx 1 cm thick at 145 cm.

192-275
Mud, silt loam to silt clay loam, olive gray, similar to above but less sand, massive, common vf roots, trace subvertical rhysomes, trace peat fragments, below 212 cm peat fragments are less (trace to none), basal contact over 1 cm.

275-292
Peaty mud, tan brown, silt loam, massive, few f roots, < 5% coarse peat fragments, very stinky, gradually becomes peatier with depth, base of unit becomes muddy peat with approx 30% organics.

292-300
Peat, silt loam, reddish brown to olive brown, massive, many vf roots, approx 60% organics, becomes muddy peat in basal 2 cm.

300-326
Mud, silt loam, olive gray, massive to weakly laminated, common vf and trace f roots, contains 0.5 cm thick brown peaty mud laminae concentrated at top of unit and diminishing downward, basal contact over 2 cm.

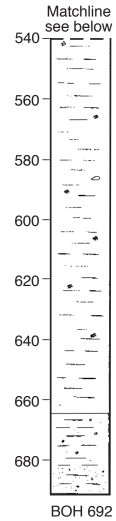
326-392
Mud, silt loam to silt clay loam, olive gray, massive to weakly laminated, common vf roots, trace peat fragments (1-2 mm diameter) throughout (approx 25%).

392-416
Mud, silt loam to silt clay loam, olive gray, massive, generally same texture as above except no roots, and few to no peat fragments, basal contact over 2 cm.

416-454
Mud, clay loam, olive gray (lighter than above), massive, few very fine roots, trace subvertical rhysomes, trace peat fragments (1-2 mm diameter), basal contact over 2 cm.

454-492
Mud, silt loam, dark olive brown, massive, trace vf random roots, similar to unit above but darker color, less clay, and no peat fragments

492-665
Mud, silt clay loam, olive gray, massive, trace vf roots, contains approx 5% coarse peat fragments and subvertical rhysomes down to 512 cm, below 512 cm peat fragments diminish to trace, contains trace 2 cm long pieces of wood (redwood), basal contact over 2 cm.



665-692
Mud, silt clay loam with gravel, grading to sandy clay loam in lower 10 cm of core, gravels are subrounded to subangular up to 0.5 cm, olive gray, massive, no roots, interpret lower 10 cm as possible tidal channel based on zones of f and med sand that are grain supported, unit is not the soil developed in Franciscan Formation observed in core 04-G2 based on lack of large angular siltstone clasts (bedrock may not be much deeper).

Appendix D

Detailed unit descriptions for trench T-1 and trench T-2 excavated across the San Gregorio fault approximately 1-km north of Pillar Point Marsh.

Trench 1

UNIT LITHOLOGICAL DESCRIPTION

10A CLAY, sandy with trace angular gravel (CL); light yellow brown (2.5Y 6/3) matrix with strong brown (7.5YR 5/6) mottles and black (7.5YR 2.5/1) clay films lining pores; damp; very stiff to stiff; 60 to 70% clay, 30 to 40% poorly sorted angular sand, 5 to 10% silt, trace coarse angular clasts include quartz and feldspar grains and clasts of Purisima Formation sandstone. Massive structure with common oxidized strong brown to black root casts. Lower contact not observed. [Buried soil Btb horizon developed in COLLUVIUM]

10B SAND, clayey (SC); greenish gray (Gley 1 5/10GY) with strong brown (7.5YR 5/8) mottles and black (7.5YR 2.5/1) clay films lining pores; damp; stiff; 50 to 60% fine-to-medium grained, angular sand, 40 to 50% clay, and minor silt. Sand consists predominantly of quartz and feldspar grains. Massive structure with oxidized root mottles. Reduced greenish gray color possibly due to groundwater barrier along fault. Lower contact not observed. [COLLUVIUM]

10C CLAY, sandy (CL); light olive brown (2.5Y 5/3) matrix with strong brown (7.5YR 5/8) mottles and black (7.5YR 2.5/1) clay films lining pores; damp; very stiff to stiff; 60 to 70% clay, 30 to 40% sand, and 5 to 10% silt. Sand consists predominantly of subangular quartz and feldspar grains. Massive structure with slightly less oxidation, fewer root mottles and thinner clay films lining pores compared to unit 10A. Lower contact gradual to diffuse, smooth. [COLLUVIUM]

20A CLAY, silty with trace fine sand to gravel (CL); black (2.5Y 2.5/1 to 10YR 2/1); moist; soft; 45 to 55% clay, 40 to 50% silt, and 5 to 10% sand and gravel. Subangular, cube-like clasts up to 1 cm long consist of sandstone (Purisima Fm.), quartz and feldspar lithologies. Massive; medium to high plasticity; low toughness. Lower contact with unit 10 is diffuse and wavy. [MARSH DEPOSITS]

20B CLAY, sandy, silty with gravel (CL); very dark grey (10YR 3/1) matrix with dark yellow brown (10YR 3/6) mottles; damp; stiff; 35 to 45% clay, 25 to 35% silt, 20 to 25% sand and ~5% gravel. Subangular sandstone clasts of the Purisima Fm. up to 4 cm long; subangular quartz and feldspar clasts typically <0.5 cm long. Lower contact with unit 10 gradual and wavy to undulatory. [Soil A-horizon developed in COLLUVIUM]

30A SILT, clayey with sand and gravel (ML); black (2.5Y 2.5/1); moist; soft; 40 to 50% silt, 30 to 40% clay, 10 to 25% sand, trace gravel. Subangular sandstone (Purisima Fm.) clasts up to 7 cm long; quartz and feldspar clasts also present. Weathered greenish-grey sandstone clasts concentrated in layer that is offset by fault C and deformed by drag folding. Massive structure. This unit, interpreted to be colluvium deposited in a marsh environment, is laterally equivalent to the colluvium of unit 30B. Lower contact clear to sharp, smooth. [COLLUVIUM deposited in marsh environment]

30B SILT, clayey with sand and gravel (ML); black (10YR 2/1) with dark yellow brown (10YR 4/6) mottles; moist, soft; 40 to 50% silt, 20 to 30% sand and gravel and 20 to 30% clay. Common, large 10- to 12-cm-long, subangular sandstone (Purisima Fm.) clasts; clay films visible within pores of matrix. Interpreted as a clastic debris flow deposit that grades laterally (eastward) into unit 30A. Lower contact clear to sharp, smooth. [COLLUVIUM]

40A CLAY, silty with gravel (CL); black (2.5Y 2.5/1 to 10YR 2/1); damp to moist; medium stiff; 40 to 50% clay, 35 to 45% silt, 10 to 20% coarse sand and gravel. Gravel consists predominantly of sandstone (Purisima Fm.) clasts. Similar to unit 20A: massive structure, medium plasticity, and medium to high toughness. Lower contact diffuse, smooth. [MARSH DEPOSITS]

40B CLAY, silty with gravel (CL); black (7.5YR 2.5/1) with faint very dark brown (10YR 2/2) mottles; dry to damp; medium stiff; 35 to 45% silt, 35 to 45% clay, 15 to 25% coarse sand and gravel. Gravel consists predominantly of sandstone (Purisima Fm.) clasts. Massive structure, thin (black) clay films line pores. This unit grades laterally (eastward) into unit 40A. Lower contact very diffuse and smooth. [COLLUVIUM]

50 SILT, clayey with gravel (ML); black (7.5YR 2.5/1) with weak, very dark brown (10YR 2/2) oxidation mottles; damp to dry; medium stiff; 40 to 50% silt, 30 to 40% clay and 5 to 15% coarse sand and gravel; rare rounded chert pebbles less than 1 cm diameter. Massive structure with the exception of a discontinuous stone line between meters 1 and 3; subangular sandstone (Purisima Fm.) clasts up to 10 cm long and completely weathered. At the base of the stone line, which marks the base of the unit, is a 10- to 12-cm-thick rust-colored oxidized zone. Lower contact very diffuse, smooth. [COLLUVIUM, fine facies]

60 SILT, with gravel (ML); very dark grey (7.5YR 3/1); dry; stiff; 50 to 60% silt, 20 to 30% clay, 10 to 25% coarse sand and gravel. Notable increase in, some up to 15 cm long; rare chert pebbles less than 1 cm diameter. Massive to weak granular/blocky structure, common pores, no clay films. Lower contact diffuse, smooth. [COLLUVIUM, coarse facies]

70 SILT, with gravel (ML); very dark grey (7.5YR 3/1); dry; stiff; 50 to 60% silt, 20 to 30% clay, 10 to 25% coarse sand and gravel. This unit is marked by a prominent but discontinuous stone line documented in the eastern end of the trench. Subangular sandstone (Purisima Fm.) clasts that comprise the stone line show weak imbrication with slight westward dips. Individual clasts reach up to 12 cm long within a 10- to 15-cm-thick layer. Lower contact diffuse, smooth. [COLLUVIUM, stone line]

80 SILT, with gravel (ML); very dark grey (7.5YR 3/1); dry; stiff; 45 to 55% silt, 20 to 30% clay, 15 to 30% coarse sand and gravel. A discontinuous stone line marks the base of this unit evident in the central part of the north wall of trench 1. This unit was not evident in the south wall of the trench. Subangular sandstone (Purisima Fm.) clasts up to 16 cm long are concentrated within a zone 0.2 to 0.3 cm below unit 100A. Long axes of individual clasts appear to have a subhorizontal orientation indicating weak imbrication. Lower contact diffuse, smooth. [COLLUVIUM, stone line]

90 SILT, with gravel (ML); very dark grey (7.5YR 3/1); dry; stiff; 45 to 55% silt, 20 to 30% clay, 15 to 30% coarse sand and gravel. This unit, evident in both the northern and southern walls of the trench consists of a concentration of subangular sandstone (Purisima Fm.) clasts up to 20 cm long. This unit directly underlies unit 110 in the central and western part of the trench. Lower contact diffuse, smooth. [COLLUVIUM, stone line]

100A SILT, clayey with sand (ML); black (10YR 2/1); dry; medium stiff; 45 to 55% silt, 30 to 40% clay, 5 to 10% sand, <5% gravel consisting predominantly of subangular sandstone (Purisima Fm.) clasts. Weak blocky to granular structure with abundant pores and common fine roots. Abundant shell debris comprises 10 to 30% of unit. Shell material comes from species including mussels (*Mytilus californianus*), barnacles (*Semibalanus cariosus*), turban snails (*Tegula* sp.), chiton (*Nuttallina*), abalone (*Haliotis*), and possibly some unidentifiable gastropods. Additional artifacts present include probable pinniped (seal) bones, stone tools (e.g., pitted stones, pestles) and thermal spall. The concentration of shelly debris increases toward the base of the unit. In the eastern part of the trench, the shell-rich material grades upward into unit 120 that contains some reworked shell debris from bioturbation. Lower contact is clear to gradual (where extensively bioturbated) and smooth. [ARCHEOLOGICAL SHELL MIDDEN]

100B SILT, clayey with sand (ML); black (10YR 2/1); dry; medium stiff; 40 to 50% silt, 25 to 35% clay and 10 to 25% sand with several large, angular sandstone clasts up to 11 cm long. Massive to week granular structure, abundant pores and fine rootlets. The sandstone clasts are red and have concoidal fractures interpreted to reflect thermal spalling from heating. Rare bone fragments were observed, however, the unit contained no shelly debris. Lower contact diffuse. [ARCHEOLOGICAL HEARTH MIDDEN]

110 SILT, with sand (ML); black (10YR 2/1); dry; medium stiff; 50 to 60% silt, 20 to 30% sand, 15 to 20% clay, <5% coarse sand and gravel, rare weathered angular sandstone clasts. Weak to moderate prismatic structure with few fine to medium roots and pores. Lower contact gradual and slightly wavy. [Buried soil A horizon developed in COLLUVIUM]

120 SILT, sandy (ML); black (10YR 2/1); dry; soft to medium stiff; 50 to 60% silt, 25 to 35% clay and 5 to 10% sand. Granular soil structure, abundant pores with many fine to medium roots. Shell fragments (reworked?) common (5 to 10%) but significantly less than in unit 100A. Lower contact gradual and wavy. [modern soil A horizon developed in COLLUVIUM]

130 GRAVEL, silty, sandy (GW); very dark grey (10YR 3/1); dry; medium stiff; 50 to 90% gravel with sandy silt matrix. Largest disintegrated sandstone clasts are >20 cm long and angular. Parts of unit appear to completely consist of crushed sandstone. Lower contact clear to gradual, smooth. [ROAD FILL]

140 SILT, sandy (ML); very dark grey (10YR 3/1); dry; soft to medium stiff; 50 to 60% silt, 20 to 30% sand; 15 to 20% clay, <5% coarse sand and gravel (angular sandstone (Purisima Fm.) clasts). Moderate granular structure with abundant pores and many fine to medium roots. Shell debris occurs where this unit overlies unit 100A. Lower contact clear and smooth. [Soil A horizon developed in COLLUVIUM]

Trench 2

UNIT LITHOLOGICAL DESCRIPTION

10 SAND, gravelly (SW); pale brown (10YR 6/3) with strong brown (7.5YR 5/8) mottles; damp; medium dense; ~70% fine to coarse sand; 15 to 25% gravel; 5 to 10% clay. Poorly sorted gravelly sand consists primarily of angular quartz and feldspar grains. Largest feldspar clasts reach up to 1 cm in length. Lower contact not observed. [ALLUVIUM of the upper Half Moon Bay terrace]

10A-C CLAY, silty (CL); strong brown (7.5YR 5/8); damp; soft; 55 to 65% clay; 20 to 30% silt; 5 to 10% fine sand. Massive clay interbeds within unit 10. Secondary clayey texture interpreted to reflect weathering of feldspar sand and silt grains. Lower contact clear and smooth to wavy. [ALLUVIUM of the upper Half Moon Bay terrace]

20 SAND, gravelly, clayey (SW); pale olive (5Y 6/4) with dark reddish brown (5YR 3/4) mottles; damp; medium dense; 50 to 60 % sand, 15 to 25% clay, and 15 to 20% gravel. Very poorly sorted, angular gravelly sand consisting of predominantly quartz and feldspar clasts up to 1 cm long. Base of unit marked by a distinctive discontinuous layer of manganese oxide 1 to 3 cm thick. Lower contact sharp to clear, smooth. [ALLUVIUM from Denniston Creek fan]

30 CLAY (CH); pale olive (5Y 6/3); damp to dry; hard; >80% clay, 10 to 15% silt, <5% coarse sand. Well-developed, large prismatic structure; weak clay films coat ped surfaces; dark organic staining along root pores; abundant fine rootlets. Clay texture interpreted to be primary; however, some secondary translocated clay appears to be related to soil development. Strong prismatic structure extends through entire unit and, in some places, into top of unit 20. Lower contact clear and smooth. [Soil Bt horizon developed in MARSH DEPOSITS]

40 SILT (ML); dark grey (10YR 4/1); dry; hard to very stiff; ~90% silt; ~5% clay, ~5% coarse sand to fine gravel. Well-developed blocky prismatic structure with common pores and very fine rootlets. Lower contact clear and smooth. [Soil AB horizon developed in COLLUVIUM]

50 SILT (ML); very dark grey (10YR 3/1); dry; medium stiff to stiff; ~90% silt; ~5% clay, ~5% coarse sand to fine gravel. Moderate subangular blocky to granular structure with abundant pores and fine rootlets. Lower contact clear and smooth. [Soil A horizon developed in COLLUVIUM]

Explanation

Symbols

- Fault, dashed where inferred; dotted where covered; arrow shows direction of movement
- Fracture
- Depositional contact
  - solid: sharp contact
  - dashed: gradual contact
- Soil horizon boundary
- Burrow or krotovina
- RC-5 Radiocarbon sample (not submitted)
- S-7 Bulk soil sample

Lithologic Descriptions
(See Appendix D)

Notes

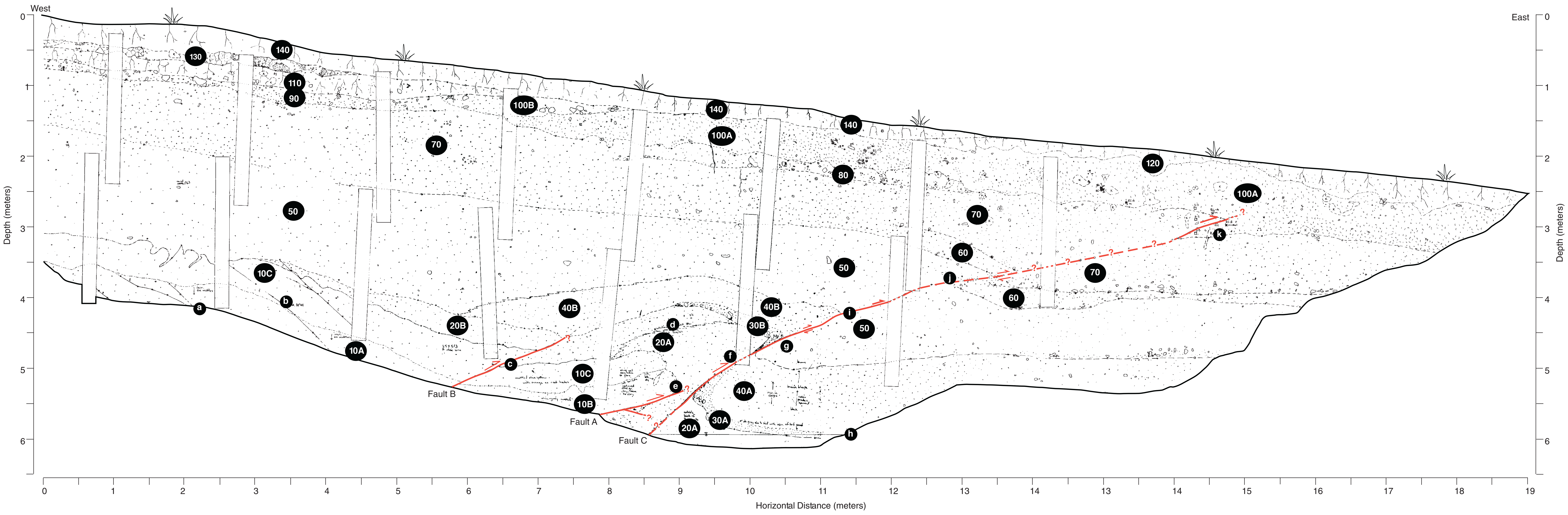
- a Shell debris concentrated in 25-cm thick zone at base of unit 100A
- b Fault C attitude: N35˚W, 24˚SW
- c Fault C attitude: N70˚W, 16˚SW
- d Fault C attitude: N62˚W, 32˚SW
- e Fault C attitude: N66˚W, 36˚SW
- f Fault A attitude: N485˚W, 21˚SW
- g Fault B attitude: N27˚W, 21˚SW
- h Groundwater elevation, 9/29/04

PILLAR POINT

Log of Trench T-1
Southeast Wall

William Lettis & Associates, Inc. | Figure 10

1639 San Gregorio



Explanation

Symbols

Fault, dashed where inferred; dotted where covered; arrow shows direction of movement

Fracture

Depositional contact
solid: sharp contact
dashed: gradual contact

Soil horizon boundary

Burrow or krotovina

RC-5 Radiocarbon sample (not submitted)

S-7 Bulk soil sample

Lithologic Descriptions
(See Appendix D)

Notes

a. Groundwater encountered during excavating on 9/16/04 west of this point. No groundwater occurred at this elevation to the east of this point.

b. Fracture attitude: N30˚W,38˚NE

c. Fault B attitude: N27˚W, 21˚SW

d. Gradational contact between laterally adjacent facies (units 20B abd 20A)

e. Fault A attitude: N48˚W, 21˚SW

f. Fault C attitude: N66˚W, 36˚SW

g. Fault C attitude: N62˚W, 32˚SW

h. Groundwater elevation, 10/1/04

i. Fault C attitude: N70˚W, 16˚SW

j. Anomalous soil structure along projection of fault C characterized by open voids, angular blocky structure and friable consistency

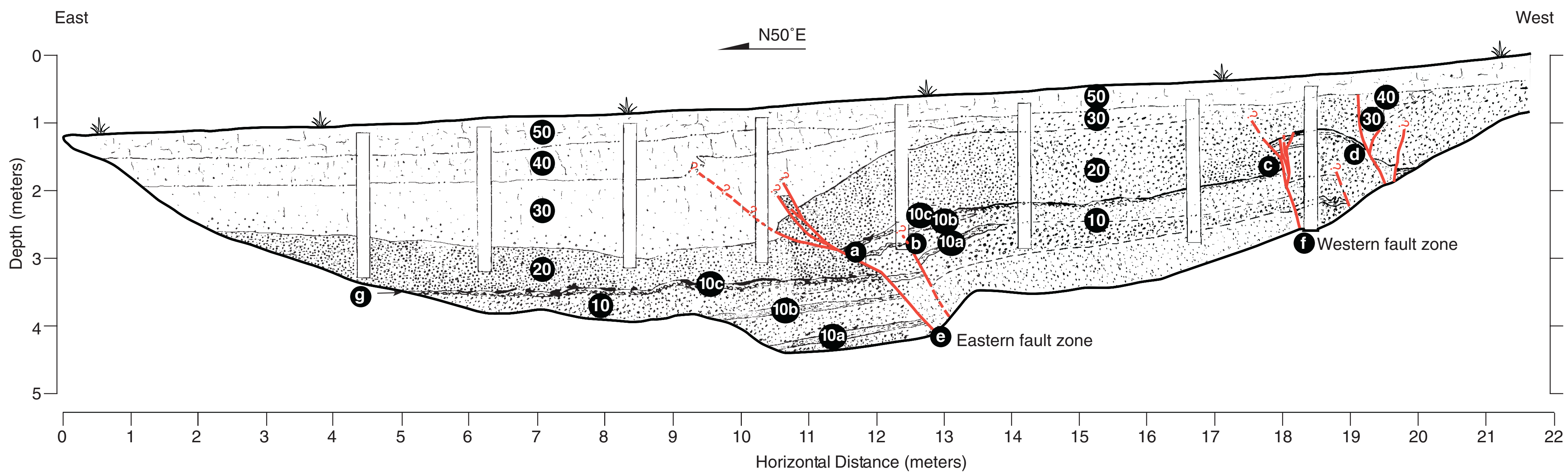
k. Fault C attitude: N35˚W, 24˚SW

PILLAR POINT

Log of Trench T-1
North Wall

WLA William Lettis & Associates, Inc. | Figure 11

1639 San Gregorio



Explanation

Symbols

Fault, dashed where inferred; dotted where covered

Fracture

Depositional contact
- solid: sharp contact
- dashed: gradual contact

Soil horizon boundary

Lithologic Descriptions

10 SAND, gravelly (SW); pale brown (10YR 6/3) with strong brown (7.5YR 5/8) mottles; damp; medium dense; ~70% fine to coarse sand; 15 to 25% gravel; 5 to 10% clay. Poorly sorted gravelly sand consists primarily of angular quartz and feldspar grains. Largest feldspar clasts reach up to 1 cm in length. Lower contact not observed. [ALLUVIUM of the upper Half Moon Bay terrace]

10a to **10c** CLAY, silty (CL); strong brown (7.5YR 5/8); damp; soft; 55 to 65% clay; 20 to 30% silt; 5 to 10% fine sand. Massive clay interbeds within unit 10. Secondary clayey texture interpreted to reflect weathering of feldspar sand and silt grains. Lower contact clear and smooth to wavy. [ALLUVIUM of the upper Half Moon Bay terrace]

20 SAND, gravelly, clayey (SW); pale olive (5Y 6/4) with dark reddish brown (5YR 3/4) mottles; damp; medium dense; 50 to 60 % sand, 15 to 25% clay, and 15 to 20% gravel. Very poorly sorted, angular gravelly sand consisting of predominantly quartz and feldspar clasts up to 1 cm long. Base of unit marked by a distinctive discontinuous layer of manganese oxide 1 to 3 cm thick. Lower contact sharp to clear, smooth. [ALLUVIUM from Denniston Creek fan]

Lithologic Descriptions (continued)

30 CLAY (CH); pale olive (5Y 6/3); damp to dry; hard; >80% clay, 10 to 15% silt, <5% coarse sand. Well-developed, large prismatic structure; weak clay films coat ped surfaces; dark organic staining along root pores; abundant fine rootlets. Clay texture interpreted to be primary; however, some secondary translocated clay appears to be related to soil development. Strong prismatic structure extends through entire unit and, in some places, into top of unit 20. Lower contact clear and smooth. [Soil Bt horizon developed in MARSH DEPOSITS]

40 SILT (ML); dark grey (10YR 4/1); dry; hard to very stiff; ~90% silt; ~5% clay, ~5% coarse sand to fine gravel. Well-developed blocky prismatic structure with common pores and very fine rootlets. Lower contact clear and smooth. [Soil AB horizon developed in COLLUVIUM]

50 SILT (ML); very dark grey (10YR 3/1); dry; medium stiff to stiff; ~90% silt; ~5% clay, ~5% coarse sand to fine gravel. Moderate subangular blocky to granular structure with abundant pores and fine rootlets. Lower contact clear and smooth. [Soil A horizon develop]

Notes

- **a** Fault attitude: N31˚W, 25˚SW
- **b** Fault attitude: N47˚W, 65˚SW
- **c** Fault attitude: N25˚W, 70˚SW
- **d** Fault attitude: N45˚W, 67˚SW
- **e** No slickensides on fault plane
- **f** No slickensides on fault plane
- **g** Iron and manganese oxide layer marks base of unit 20

PILLAR POINT

Trench T-2

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