INSTRUCTOR'S LIST OF TOPICS
HALF MOON BAY FIELD TRIP

DRIVE TO HALF MOON BAY:

Serpentine and landslides on Hwy 280
San Andreas Fault valley
Franciscan rocks in quarry near reservoir
Pilarcitos fault just as we come over the crest of the mountains is in the N-S valley:
   separates Franciscan on E from Montara granodiorite on W
   western boundary of the San Andreas fault zone and therefore now on Pacific plate

DRIVE FROM HALF MOON BAY TO MOSS BEACH:

Surface doesn't slope gently to sea; we are on a marine terrace (shallow marine sediments and river sediments deposited on a wave-cut platform)
Edge of hills marks the old sea cliff
Pillar Point and the Seal Cove Fault: why does Pillar Point stand high?
Trace of Quaternary fault in cultivated fields east of the Hwy 1 visible if light is right.

STOP 1: MOSS BEACH:

- Overview from near Sunshine Creek:
  - Different wave patterns due to storms
  - Wave-cut platform in Purisima formation (Pliocene)
  - How do you know large rocks at base of sea cliff did not get there naturally?
  - Stratigraphy: Montara granodiorite overlain by Purisima overlain by marine terrace deposits. Two unconformities.
- Measurements in the plunging syncline:
  - Take strikes and dips, showing the students how (get them to do it if you can).
  - Help them locate themselves and plot the strikes and dips on the map.
  - In places where you can't actually get to, help the students visualize the strikes and dips and put them crudely on their maps.
- Walking over to the unconformity between Montara granodiorite and Purisima:
  - Fossil clams. Can they have been transported far?
  - Graded beds.
  - Filled clam burrows and modern ones
  - Coarse grits: minerals present? rounding? sorting? Has this material been transported far? Why the alternation of coarse and fine sediments? What sort of environment could this occur in?
  - Formation of potholes
- Unconformity between Montara granodiorite and Purisima:
  - Note large boulders in some of the debris flows just above the unconformity.
  - Looking north, how can you tell it is granite outcropping beneath terrace deposits even though we are not looking at it with a handlens? (color, massive, lack of bedding, jointing)
- Walking back to Seal Cove fault:
  - Look at terrace deposits: minerals? what is the parent material? transported far?
  - Channels in terrace deposits
  - Soil developed on terrace deposits
  - As you move away from the syncline, what happens to the dip of the Purisima? (gets steeper--consistent with drag on fault)
- Seal Cove fault:
  - Even though the fault is covered with rip rap, how do you know it is there?
  - What is the obvious sense of motion? (up on the west)
  - Can you determine if motion is pre- or post-terrace deposits? (probably post but not for sure)

How about pre- or post-cutting of wave-cut platform? (Obviously post)
How does the lack of outcrop above sea level tell you where the fault goes even though you can't actually see it? Why would the rocks be lower?
Looking at the rocks west of the fault, how are they different from those on the other side (more massive, all siltstone)? Can you see bedding (hard because all chopped up, but probably dipping to west)? Do these large differences in lithology seem consistent with the apparently small vertical displacement on the fault? (No; suggests there must be lateral movement as well. Can't tell what direction, but a good guess would be right lateral given that the fault is part of the San Andreas system.)

DRIVE FROM MOSS BEACH TO MONTARA BEACH:

Point out that terrace is completely eroded away north of town of Moss Beach but reappears at Montara Beach.

STOP 2: MONTARA BEACH

Walk down to south end of beach:
- Look at terrace deposits, noting mineralogy and that they are coarser than at Moss Beach. Eroded from where?
- Conglomerate with rounded chert pebbles from the Franciscan. Can't be eroded from present-day exposures of Franciscan, therefore something that moved away on a fault or reworking of sediments that once overlay the Montara granodiorite.
- Montara granodiorite: sheared due to proximity of fault; pegmatites
- Reverse faults, drag on faults, fault gouge
- Channel in conglomerate

Walking back to buses:
- Two old soil horizons
- Tilting of terrace deposits
- Is sand in the beach eroded from the cliffs?
- Look at red-colored cross-bedded dune sands, helping them to guess what kind of deposit they are.

STOP 3: EL GRANADA BEACH

Walk out onto breakwater:
- Discuss rock types as you go; some nice granite with pink kspar and white plag
- Discuss why marine terrace is higher at Pillar Point
- Point out the increase in height of the surface of the terrace deposits as you go south along Half Moon Bay
- Contrast the beach to the north of the breakwater with that to the south; also contrast the position of the sea cliff.

Walk onto beach north of breakwater:
- Magnetite lag on beach
- Small-scale dunes on beach: discuss formation of dunes, slip face, saltation, armored with mica flakes because hard to pick up by wind, perpendicular to wind direction.
- Good time for them to collect some rock samples for scavenger hunt homework.

DRIVE FROM EL GRANADA BEACH TO MARTIN'S BEACH (ABOUT 30 MINUTES):

- Stream valleys cut deeply into terrace surface
- Eroded old alluvial fans that proably were deposited on the emergent seafloor soon after it was exposed.
- Hills getting closer to coast, so we are getting closer to shoreline angle as we travel south (one of the reasons the terrace surface is higher)

. SARATOGA GAP TO SKEGGS POINT

At Saratoga Summit (mile 7.5), turn right (north) on the Skyline Boulevard highway 35). For the next 25 miles, the route lies along the drainage divide etween the bayside and the coastside of the San Francisco Peninsula. For the irst 12 miles (mile 7.5 to 19.5), the route traverses exposures of complexly olded Oligocene and lower Miocene marine mudstones, themselves about 5000 ft. 1250 m.) thick, with additional thicknesses of sandstone and interbedded vol- anics, including basaltic lavas and volcaniclastics, with feeder sills and ikes of diabasic rocks. The sandstone beds are distal tongues of Vaqueros, hich interfingers gradationally between Oligocene mudstones of the San Lorenzo ormation below and Miocene mudstones of the Lambert Shale above. The Mindego olcanics, mainly pillow lavas and pillow breccias with aquagene tuffs and nterstratified marine mudstones, are distal tongues of a submarine volcano tructure centered near La Honda, within the marine depositional basin, where he volcanics are more than 2000 ft. (750 m) thick.

Between miles 12.0 and 13.5, an open ridge crest affords views to the ortheast (right) across the San Andreas fault, down in Stevens Creek below, to xposures of Franciscan greenstone, with associated cherty limestone lenses, n Monte Bello Ridge. One of the larger of the limestone bodies is the site of aiser's Permanente cement quarry, out of view on the far side of the ridge. etween 15.0 and 16.5 are views of Coal Mine Ridge, a fault sliver of anta Clara Formation caught in the acute angle between the merging Pilarcitos nd San Andreas faults. The Pilarcitos is a splay fault of the San Andreas ystem, and lies west of the main fault zone. Near mile 17.5, views to the outh (left) afford glimpses of Langley and Mindego hills underlain by Mindego olcanics, and views to the west (left) near mile 18.5 look past La Honda to he coast. The shoreline lies beyond a broad tract of rolling hills underlain y gently folded lower and middle Pliocene strata of the Purissima Formation, hich is about 5500 ft. (1750 m.) thick and rests unconformably on Miocene nd older strata of the Santa Cruz Mountains.

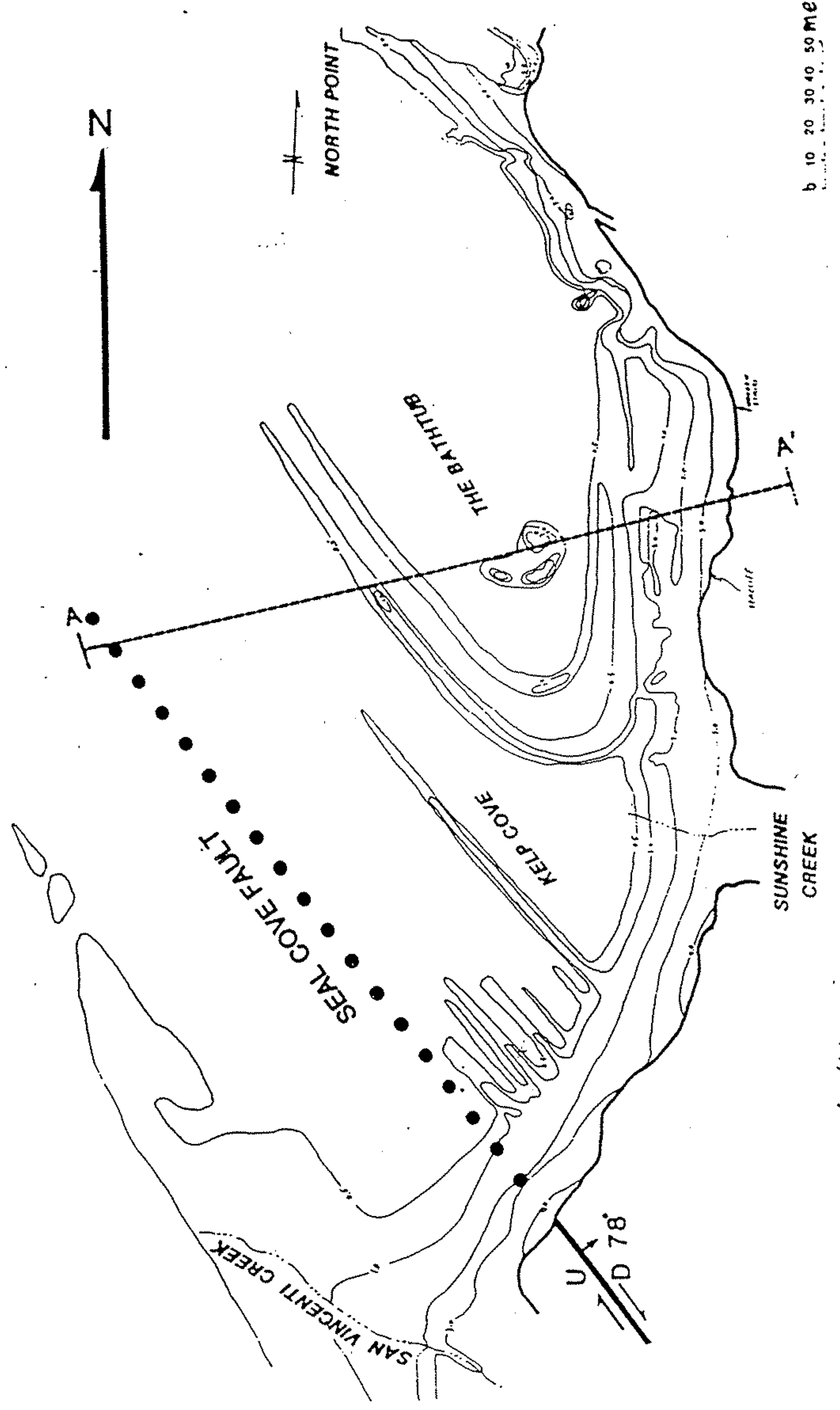
Near Windy Hill (mile 19.5), the route passes from open grasslands, char- cteristic of the mudstone bedrock, into woodlands underlain by the Eocene utano Sandstone, a unit of buff-weathering gray arkosic turbidite sandstones nd siltstones deposited by north-moving paleocurrents. We traverse only the pper part of this formation near Skylonda (mile 21.0), but farther south it s 6000-9000 ft. (2-3 km.) thick. Near mile 23.0, the route crosses again into ocene strata among which massive, probably neritic, sandstones are prominent mong dominantly finer grained strata.

STOP AT SKEGGS POINT (mileage 25.0) for panorama of San Andreas rift valley, n Francisco Bay lowland, and Diablo Range beyond.

SKEGGS POINT TO HALF MOON BAY

Continuing north, we soon cross the Pilarcitos fault (mile 26.5 on a rve just south of Kings Mountain), where we pass from exposures of the Miocene rata to exposures of sandy Eocene strata commonly correlated with the Butano rmation, as are similar rocks in the foothills across the San Andreas fault ar Palo Alto. From miles 30.5 to 32.5, open brushlands on this bedrock afford ews of the Crystal Springs reservoirs in the San Andreas rift valley. At le 33.5, in Franciscan exposures, turn left (west) on highway 92.

Figure 5. Map of Moss Beach stop.



Contours are meters above mean low tide.

On the big curve at mile 34.5, the route re-crosses the Pilarcitos fault, and isses into exposures of Miocene strata west of the fault. Between miles .0 and 35.5, just before reaching the valley of Pilarcitos Creek, large road its expose Cretaceous granitic rocks of Montara Mountain. The granitic rocks e unconformably beneath the Tertiary strata of the Santa Cruz Mountains, it are in fault contact with the broadly coeval Franciscan assemblage along ie Pilarcitos fault.

From mile 35.5 to mile 38.5, the route is down the Pilarcitos Valley, iose alluviated floor is graded to the level of a marine terrace, about 100,000 ears old, on Half Moon Bay. At mile 38.7 - 38.8, turn right (north) on highway 1, iich is built on the surface of this terrace. Two older terraces are plainly sible in the hills north of the intersection, and at least two more terraces, en higher, have also been recognized locally.

STOP AT HALF MOON BAY HARBOR (mileage 42) to view breakwater (built of ocene calcareous arkose from the southern Santa Cruz Mountains), and terrace atures (warping, soil cover, faulting). Prominent heavy minerals in the beach nd include epidote, garnet, hornblends, ilmenite, magnetite, pyroxene, sphere, d zircon.

HALF MOON BAY TO SAN FRANCISCO

Continuing north, views to the left (west) across the airport, display e Seal Cove fault scarp breaking the marine terrace surface between Princeton ile 43.0) and Moss Beach (mile 45.0). From Montara Beach (mile 46.5) to vils Slide (mile 49.0), the route crosses exposures of granitic rocks on the gged shore of Montara Mountain. At Devils Slide, and on the ridge beyond, e flysch-like Paleocene strata, including basal conglomeratic beds that st nonconformably (?) on the granitic rocks near Devils Slide (mile 49.0) and sconformably(?) on similarly flysch-like late Late Cretaceous strata over e hill (mile 50.0). At Pedro Valley (mile 50.7-50.8), the route again osses the Pilarcitos fault and passes back into exposures of the Franciscan semblage east of the fault. Pedro Valley was the camp site from which outs of Portola's expedition first glimpsed San Francisco Bay in 1769.

At Rockaway Beach (mile 52.0) is the Calera Valley quarry in Franciscan estone. Local pods of limestone a few tens or hundreds of feet thick are espread in the Franciscan assemblage of the Santa Cruz Mountains. All are se, fine-grained biomicrites, or pelagites, containing early Late Cretaceous aminifers and palynomorphs, and most are associated with greenstone bodies t were probably seamounts. Beyond the quarry, varied Franciscan rocks exposed through Pacifica to beyond Edgemar (mile 55.0), but are covered by er Pliocene beds of the Merced Formation in the vicinity of the San Andreas lt (mile 56.0) and the junction with Skyline Boulevard (mile 56.5). Continue San Francisco on hiway 35 (mileage, approx. 66.5).

(Total mileage of entire trip is about 150 miles.)

Geologic Events Along San Mateo County Coast

Event	Evidence
Intrusion and long erosion of granite Meso.	Granite is exposed at Montara Beach; oth formations lie unconformably on eroded granite surface
Deposition of Purísima sediments in a shallow sea, with shoreline near present north end of Moss Beach Pla	Coarse conglomerate with granite boulder at Moss Beach, grading to finer sedime south to Martin's Beach. Marine fossil at many places in Purísima beds
Folding and faulting of Purísima beds	Plunging syncline at north end of Moss B tilted beds at Redondo and Martin's Be Faults in cliff at Pillar Point
Long erosion of granite at Montara Beach, followed or accompanied by beach and near-shore deposition of sands and gravels. (Age of these beds uncertain; may be equivalent to next item.)	Beds of sand and gravel with well rounded pebbles of chert and other rocks from Franciscan formation; beds fairly even, but some small-scale cross-bedding; imp nated with tar in places
Long erosion of Purísima by waves and currents, producing a wave-cut terrace on which marine sediments (sands and gravels) were deposited in some places	Old sea cliff on landward side of terrace Redondo and Martin's Beach, less clear farther north. Unconformity on Purísim at all beaches except Montara, overlain sand beds with fair sorting and small-s cross-bedding at Redondo (and possibly
Local erosion of marine sands and gravels, then deposition of alluvium from a granitic source	Local unconformity and channeling at Mont Beach. Elsewhere marine deposits grade into stream-deposited sand and gravel w abundant granite fragments. Alluvium probably deposited directly on eroded Purísima surface at Pillar Point and Mo Beach
Uplift and tilting of terrace gravels	Terrace surface slopes gradually downward from Martin's Beach to Half Moon Bay, t upward to Moss Beach. Terrace beds are tilted to about 20° at Montara Beach
Faulting of terrace deposits and underlying rocks	Thrust fault and vertical fault at Montar Beach extend upward at least into the l beds of terrace gravel. Seal Cove faul extends along east side of Pillar Point ridge, and cuts completely thru terrace deposits at Moss Beach
Local erosion of terrace and formation of soil, followed by development of coastal marshes and beach dunes	Red sand at Montara Beach with excellent sorting and large-scale cross-bedding, underlain by peat-like material contain plant fragments, then by terrace gravel with granite debris
Erosion by streams and waves, continuing today	Gullies in terrace, sea cliff on coast. Beach sand consisting largely of granit debris all along coast, evidently carri southward by long-shore currents

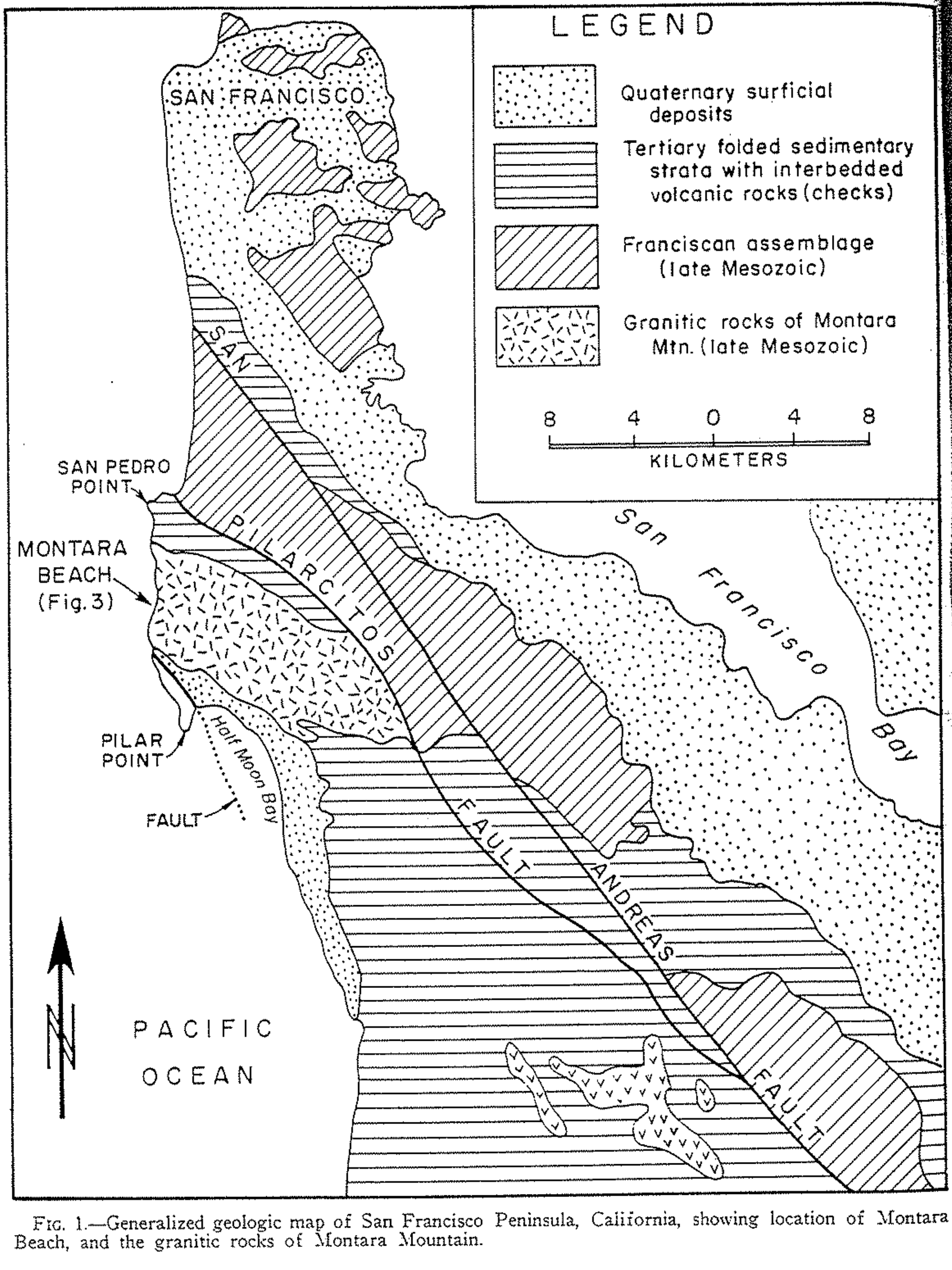


FIG. 1.—Generalized geologic map of San Francisco Peninsula, California, showing location of Montara Beach, and the granitic rocks of Montara Mountain.

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The Northern San Gregorio Fault Zone: Evidence for the Timing of Late Holocene Earthquakes near Seal Cove, California

by Gary D. Simpson, Stephen C. Thompson,[1] J. Stratton Noller,[2] and William R. Lettis

Abstract The San Gregorio fault is the principal active fault west of the San Andreas fault in central coastal California, yet it remains the largest known fault in the region whose seismogenic potential is not known. In this study, we integrate traditional paleoseismic and archaeologic investigations to define the location, style, and timing of slip events on the northern San Gregorio fault at a site near Seal Cove in Moss Beach, California. The on-land portion of the San Gregorio fault at Seal Cove is a late-Holocene active dextral slip fault. Trench excavations revealed a broad zone of faulting, at least 22 m wide, consisting of five Holocene-active strands. These include a single mid-Holocene east-vergent reverse fault and four late-Holocene near-vertical strike-slip faults. The most recent event occurred after the deposition of a native Californian cooking hearth dated A.D. 1270 to A.D. 1400, but prior to the arrival of Spanish missionaries ca. 1775. The penultimate event at the site is less well constrained but appears to have occurred between A.D. 620 and A.D. 1400. The penultimate event was associated with horizontal displacement on the order of 3 m, based on reconstruction of a thrust wedge within the fault zone. The geometry of midden deposits shows a 5 (−2, +6) m deflection along the projection of faults associated with the most recent event (MRE). All or part of this deflection may be associated with the MRE. These displacements are consistent with M_w 7 to 7¼ earthquakes and show that the San Gregorio fault is an active seismogenic source that should be considered in seismic hazard assessments in the San Francisco Bay area.

Introduction

The San Gregorio fault zone is the principal tectonic structure west of the San Andreas fault in the coastal region of central California between Monterey Bay and Bolinas Lagoon. The fault is located primarily offshore, with strands intersecting the coastline at only two locations: between Pt. Año Nuevo and San Gregorio, and between Pillar Point and Moss Beach (Fig. 1). The northern on-land portion of the fault zone is sometimes referred to as the Seal Cove fault, but we do not make this distinction in this article. Because of its limited onshore extent, few detailed geologic studies have been conducted to evaluate the style and rate of late Quaternary deformation along this complex fault zone. Thus, wide disparities exist in published estimates of the location, character, and paleoseismic behavior of the fault. For example, estimates on the style of deformation range from predominantly right-lateral strike slip based on offset bedrock lithologies (e.g., Hall, 1975; Graham and Dickinson, 1978; Clark *et al.*, 1984) and offset Quaternary marine terraces (e.g., Weber, 1994) to west-vergent reverse slip based on fault geometry interpreted from offshore seismic reflection data (e.g., Brocher, 1993; Lewis, 1993, 1994). Published slip-rate estimates for the San Gregorio fault range from 1 to 3 mm/yr (Sedlock and Hamilton, 1991), to 4 to 10 mm/yr (Weber, 1994), to 13 to 16 mm/yr (Clark *et al.*, 1984). There are no published estimates on the timing or number of late Holocene events. Thus, the San Gregorio fault represents the largest known active fault in the San Francisco Bay area whose seismogenic potential (i.e., slip rate, displacement per event, sense of slip, recurrence, and maximum earthquake potential) is not well known.

In this article, we provide results from a paleoseismic investigation conducted along the northern onshore reach of the San Gregorio fault near Seal Cove, in Moss Beach, California (Fig. 2). At this location, the fault trace transects a previously identified archaeological site (California registered site CA-SMA-134) and is well defined by a 1.5- to 3-m-high, east-facing fault scarp and associated sag pond. Our studies consisted of two interrelated tasks: (1) definition of the distribution and character of archaeological deposits at

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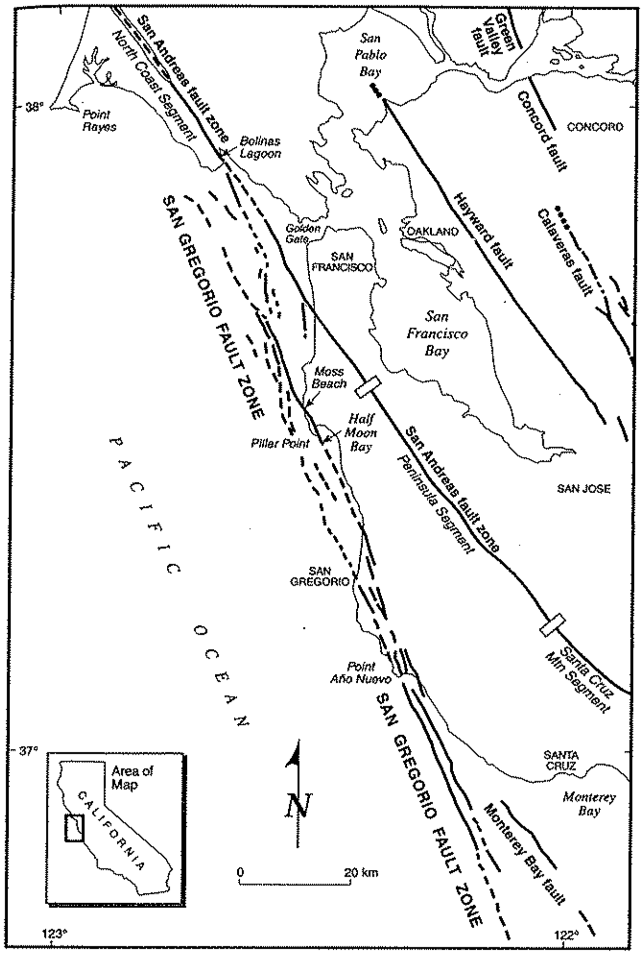

Figure 1. Map showing the San Gregorio fault zone and other major Holocene faults in the western San Francisco Bay area. Modified from Jennings (1994), segment boundaries (rectangles) along the San Andreas fault after WGCEP (1990).

the site, and (2) a paleoseismic trench investigation to document the character, number, and timing of surface-faulting events.

These investigations document primarily right-lateral strike-slip displacement along the fault with two large surface rupturing earthquakes during the past 700 to 1300 yr. Estimates on the amount of displacement during the most recent and penultimate events, combined with published estimates of slip rate, allow us to assess the amount of accrued strain on the fault since the most recent event. These data are important for estimating earthquake probabilities in the San Francisco Bay area (WGCEP, 1990), assessing regional strain-rate budgets (e.g., Kelson *et al.*, 1992), and evaluating local seismic hazards for general community planning. In addition, these data provide important constraints on the tectonic setting of the San Gregorio fault and the role of the fault in accomodating deformation along the Pacific–North American plate boundary.

Tectonic Setting

The San Gregorio fault zone is the northern part of a system of coast-parallel strike-slip faults extending from Point Conception in the south to the Marin Peninsula in the north. The southern part of the system includes the Sur, San Simeon, and Hosgri faults (Hall, 1975; Graham and Dickinson, 1978). The San Gregorio fault extends from Monterey Bay to the north, where it merges with the San Andreas fault at a complex, poorly understood intersection or right-releasing step-over between the Golden Gate and Bolinas Lagoon (Fig. 1). Because the fault zone is complex and lies primarily offshore, its rate of deformation and relative components of strike, slip, oblique slip, and/or reverse slip remains poorly understood.

The physical and behavioral connection of the San Gregorio fault with the San Andreas fault is inferred from offshore geophysical data and tectonic models based on onshore paleoseismic studies. Recent paleoseismic data from the North Coast segment (Niemi and Hall, 1992; Noller *et al.*, 1993) and Peninsula segment of the San Andreas fault (Clahan *et al.*, 1995) show an increase in slip rate of 3 to 10 mm/yr on the San Andreas fault north of the intersection with the San Gregorio fault. This increase in slip rate suggests that the San Gregorio fault is, at least in part, a strike-slip fault accomodating dextral offset at the Pacific–North American plate margin. To fully understand the partitioning of dextral slip between the Peninsula segment of the San Andreas fault and the San Gregorio fault, additional data on the Holocene slip rate of the San Gregorio fault are needed.

Available geologic, geomorphic, and geophysical data indicate that the San Gregorio fault zone is a broad, complex system of high-angle dextral strike-slip and west-vergent reverse faults. The relative distribution of strike-slip and reverse-slip displacement on the San Gregorio fault remains largely unknown however. Onshore stratigraphic and geomorphic evidence suggests the system is dominated by significant dextral slip along high-angle faults, although the rate of this movement is poorly constrained. Offset Cretaceous and Tertiary bedrock units suggest up to 115 km of dextral offset at an average late Cenozoic slip rate of 7 to 9 mm/yr (Graham and Dickinson, 1978). Clark *et al.* (1984) correlate bedrock units between Point Reyes and the Santa Cruz Mountains and estimate up to 150 km of offset, yielding an average late Cenozoic slip rate on the order of 13 to 16 mm/yr. Where the fault zone comes onshore at Point Año Nuevo, it deforms late Pleistocene marine terraces at a poorly constrained dextral slip rate of 4 to 10 mm/yr (Weber and Lajoie, 1980; Weber, 1994). In addition, there is a consistent component of west-vergent reverse faulting along the San Gregorio fault. At Point Año Nuevo, the broad fault zone is present that contains two principal dextral-slip traces and a west-vergent reverse fault. Offshore seismic reflection data suggest that the San Gregorio fault is part of a system of west-vergent thrust faults (Lewis, 1993, 1994).

The timing and recency of movement along the San highstand (Kennedy *et al.*, 1981). East of the fault, the Half Moon Bay marine terrace surface is laterally continuous for several kilometers. The terrace is warped in a broad northeast-plunging syncline whose axis intersects the San Gregorio fault several km south of Seal Cove (Lajoie *et al.*, 1979). Remnants of a marine terrace are also preserved on the Seal Cove Bluffs west of the San Gregorio fault. The age of this terrace has not been documented, and correlation of the terrace to the Half Moon Bay terrace east of the fault is uncertain. Jack (1969) interprets the terrace on Seal Cove Bluffs (which he calls the Montara terrace) to be older than the Half Moon Bay terrace. This interpretation requires that Seal Cove Bluff was an island during development of the Half Moon Bay terrace. Lajoie *et al.* (1979) correlate the Seal Cove Bluff terrace west of the fault with the Half Moon Bay terrace to the east and suggest that the Seal Cove Bluff has been uplifted via tectonic deformation. They use an analysis of boreholes and bathymetry to conclude that the abrasion platform west of the fault has been warped and uplifted into a relatively steep-sided structural dome, which is truncated on its eastern side by the San Gregorio fault, forming the high escarpment along the Seal Cove Bluffs. If the uplifted abrasion platform west of the fault is the Half Moon Bay terrace, the platform has been displaced vertically some 50 m in the past 83,000 years based on the depth of the Half Moon Bay terrace abrasion platform east of the fault (Weber and Lajoie, 1980). This scenario suggests a vertical separation rate of up to 0.6 mm/yr. Uplift or shortening along the fault indicates a localized restraining bend or step-over along the San Gregorio fault.

Across the Seal Cove gap, the abrasion platform west of the fault (e.g., Seal Cove Bluff terrace) may extend or be eroded beneath sea level, based on observation of seacliff exposures (Jack, 1969) that are presently obscured by landslides. The gap therefore appears to represent either an infilled paleochannel or, alternatively, represents a sharp structural down-warping of the Seal Cove Bluff terrace surface. The alluvial character of the sediments west of the fault exposed in our trench and in limited exposures in the sea cliff at Seal Cove support the interpretation that the Seal Cove gap is a paleochannel. These alluvial deposits are distinct from marine/littoral sediments exposed in the sea cliff just northwest of the gap.

Prior to this study, the precise location of the San Gregorio fault within the Seal Cove gap was poorly constrained because of the lack of a large, distinct scarp or other well-defined geomorphic features. In this study, we refine the location of the fault across the gap based on the results of our trenching study, a compilation of previous trenching studies, and detailed assessment of subtle geomorphic features. Previous mapping of the San Gregorio fault (Glen, 1959; Jack, 1969; Weber and Lajoie, 1980; Brabb and Pampeyan, 1972; Pampeyan, 1994) shows the fault as a straight projection across the Seal Cove gap between the large east-facing scarps to the north and south (Fig. 2). This inferred projection was adopted as the active fault trace for the State of California's Alquist-Priolo Earthquake Fault Zone map. Our review of consultant reports (e.g., Wood, 1983; JCP Associates, 1987; Cleary Consultants, 1990), however, suggests that the main trace of the fault arcs westward across the topographic gap at Seal Cove (Fig. 2). This alignment is coincident with a 1.5- to 6-m-high east-facing scarp that can be traced across the entire gap. Our trench, as well as previous consultant trenches across this scarp, shows a distinct lithologic break across the fault indicative of significant cumulative displacement. Conversely, consultant trenches across the previously mapped straight-line projection of the fault revealed only fractures and secondary faults with minor displacements that do not juxtapose dissimilar strata. Based on the results of our study, we conclude that the main San Gregorio fault follows an arcuate path across the Seal Cove gap marked by a distinct, yet relatively low, east-facing scarp.

Additional strands of the northern San Gregorio fault may cross Pillar Point and extend just offshore of Seal Cove (Fig. 2). This interpretation would be consistent with the character of the fault at Point Año Nuevo and offshore, where it is a broad zone consisting of multiple active traces. If the on-land fault trace described herein is part of a broader fault zone at Seal Cove, it would represent the eastern limit of the zone, and other faults would lie offshore to the west. With the possible exception of a small west-facing scarp across the Holocene alluvial fan of Denniston Creek 1 km to the east (Weber and Lajoie, 1980), there are no significant traces within the fault zone east of the main on-land trace of the northern San Gregorio fault shown in Figure 2. The distribution, level of activity, and sense of displacement of offshore faults are not known.

Site Description

Our study area is located on the bluff-top directly east of Seal Cove, at the southern edge of the Fitzgerald Marine Reserve within the community of Moss Beach (Figs. 2 and 3). At this site, the fault trace is marked by a low, 1.5- to 3.0-m-high east-facing scarp across a previously identified archaeological site (CA-SMA-134). The eastern, downthrown side of the fault at this site is bordered by a broad depression, probably a tectonic sag, that contains hydrophytic vegetation. The 2500-m^2 archaeological site is a midden containing shell, bone, cooking stones, tools, and other debris from prehistoric human occupation (Hylkema, 1996). The archaeological site extends from the sea cliff eastward across the fault scarp and into the depression.

The study area is within the Seal Cove gap described above, at an elevation of 18 to 21 m (60 to 65 ft) above mean sea level. Seacliffs 20 m northwest of the gap expose approximately 10 m of marine terrace deposits consisting of bedded, well-sorted sand, clayey sand, and gravel overlying an abrasion platform eroded into sheared Purisima mudstone. Within Seal Cove itself, however, active landsliding and slumping of the cliff face have obscured exposures of

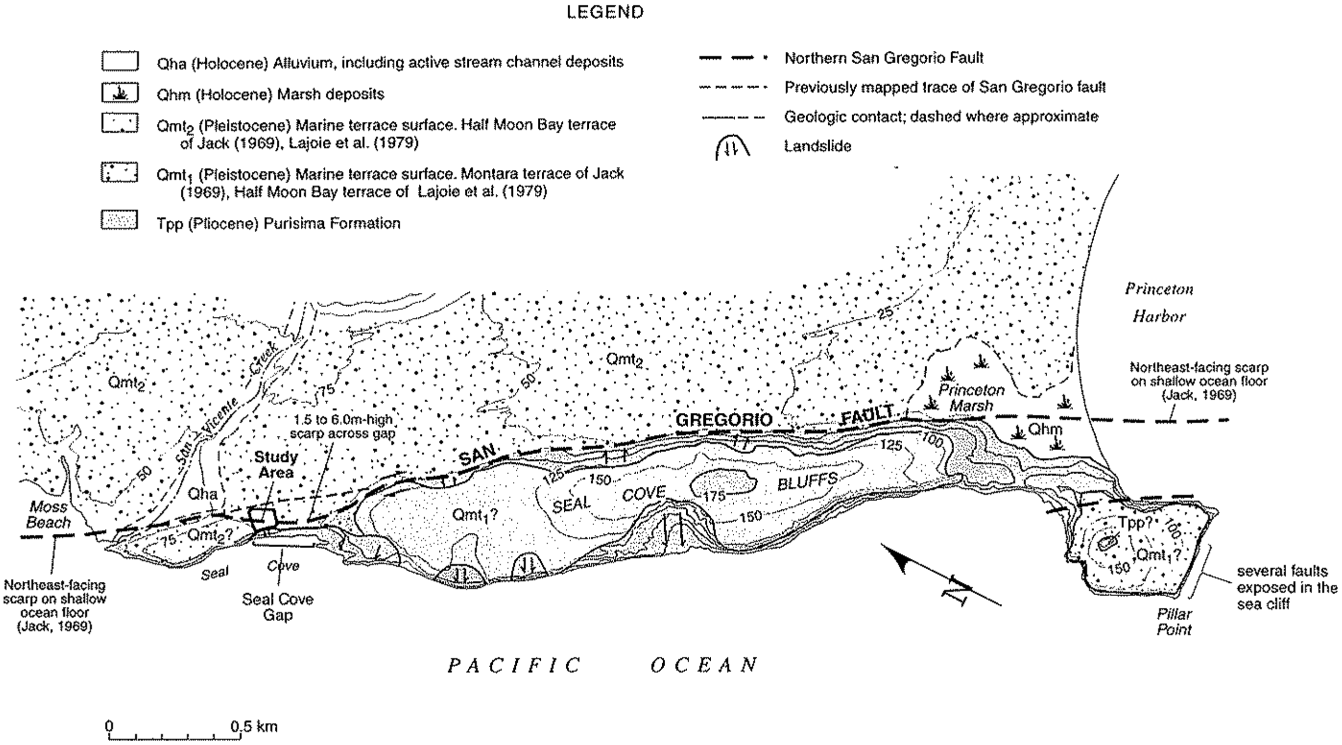

Figure 2. Generalized geologic map of the northern on-land portion of the San Gregorio fault, showing the study area and both the previously mapped and the revised fault locations.

Gregorio fault is poorly constrained. The fault trace is geomorphically well-expressed onshore by scarps, deflected drainages, offset marine terrace back-edges, and linear topographic features (this study; Weber, 1994; Weber and Lajoie, 1980; Bedrossian, 1979) and offshore by topographic and geomorphic features on the sea floor including scarps (Jack, 1969; Reed *et al.,* 1992), dewatering structures (Greene *et al.,* 1994), and aligned linear hills (Reed *et al.,* 1992). Displacement of Holocene deposits has been reported at Año Nuevo (Weber and Lajoie, 1980; Weber and Cotton, 1981; Weber, 1994), and on the alluvial fan at Denniston Creek (Weber and Lajoie, 1980). However, geodetic data do not show strain accumulating across the fault (Coppersmith and Griggs, 1978), the fault is not creeping at the surface (Galehouse, 1995), and only sparse, diffuse microseismicity is associated with the fault (Hill *et al.,* 1991). There has been no large surface faulting event on the San Gregorio fault since the arrival of Spanish missionaries ca. 1775, although Toppozada *et al.* (1981) describe two historic earthquakes that might have occurred on the San Gregorio fault, an M 5 to 5½ event near Pillar Point in 1856, and an M 5¾ to 6 event southeast of Point Año Nuevo in 1884.

Geologic and Geomorphic Setting

The northern on-land portion of the San Gregorio fault is 3 km long, extending from Pillar Point to Moss Beach (Fig. 2). The fault was exposed until recently in the sea cliff at Moss Beach (Fig. 2), where it juxtaposes sheared mudstones of the lower Pliocene Purisima Fm on the west against marine terrace sands (Half Moon Bay terrace, described below) on the east. The principal fault surface within the 30- to 40-m-wide zone at this location strikes N18-35W and dips 65 to 80E (Leighton and Associates, 1971). The steep dip and clear west-side-up vertical separation of Purisima Fm observed in the sea cliff shows that the fault is a high-angle oblique slip fault at this location.

Tectonic geomorphology of the on-land portion of the northern San Gregorio fault is consistent with west-side-up right-oblique displacement. The fault forms an east-facing escarpment up to 30 m high along the eastern margin of the Seal Cove Bluffs (Fig. 2). To the north, between Seal Cove and Moss Beach, the fault is expressed as an 18-m-high east-facing escarpment adjacent to San Vicente Creek, which appears to be deflected right laterally to the northwest. At Seal Cove, the high fault scarp is interrupted by an approximately 200-m-wide windgap, which we informally refer to as the Seal Cove gap. The fault is expressed across the gap by a small east-facing scarp 1.5 to 6 m high. Our study area is located within the Seal Cove gap.

The fault displaces and deforms the principal geomorphic surface in the area, the Half Moon Bay marine terrace (Lajoie *et al.,* 1979; Lajoie, 1986). The Half Moon Bay terrace has been correlated to the stage 5a (83 ka) sea-level