The San Andreas and San Gregorio Fault Systems in San Mateo County

Selected Field Trip Destinations in the Northern Santa Cruz Mountains and Along the Coast

Trip Highlights: San Andreas Fault along the I-280 and Skyline Boulevard corridor, and at Mussel Rock Park; Calero Limestone at Rockaway State Beach; Devil's Slide; Montara Mountain granite; Seal Cove Fault, the San Gregorio Fault System, and geologic structures exposed along the coast at Montara State Beach, James V. Fitzgerald Marine Reserve, and at Pillar Point on Half Moon Bay

This field trip focuses on the geology in the northern Santa Cruz Mountains and the coast in San Mateo County. Selected stops highlight landscape features and bedrock along the San Andreas and San Gregorio fault zones, and other localities that reveal information about the geologic evolution of the landscape. The field trip follows a loop route that begins near Crystal Springs Reservoir on I-280. The route follows I-280 and Highway 35 (Skyline Boulevard) north, then follows Highway 1 south along the San Mateo Coast before returning east on Highway 92. back to I-280.

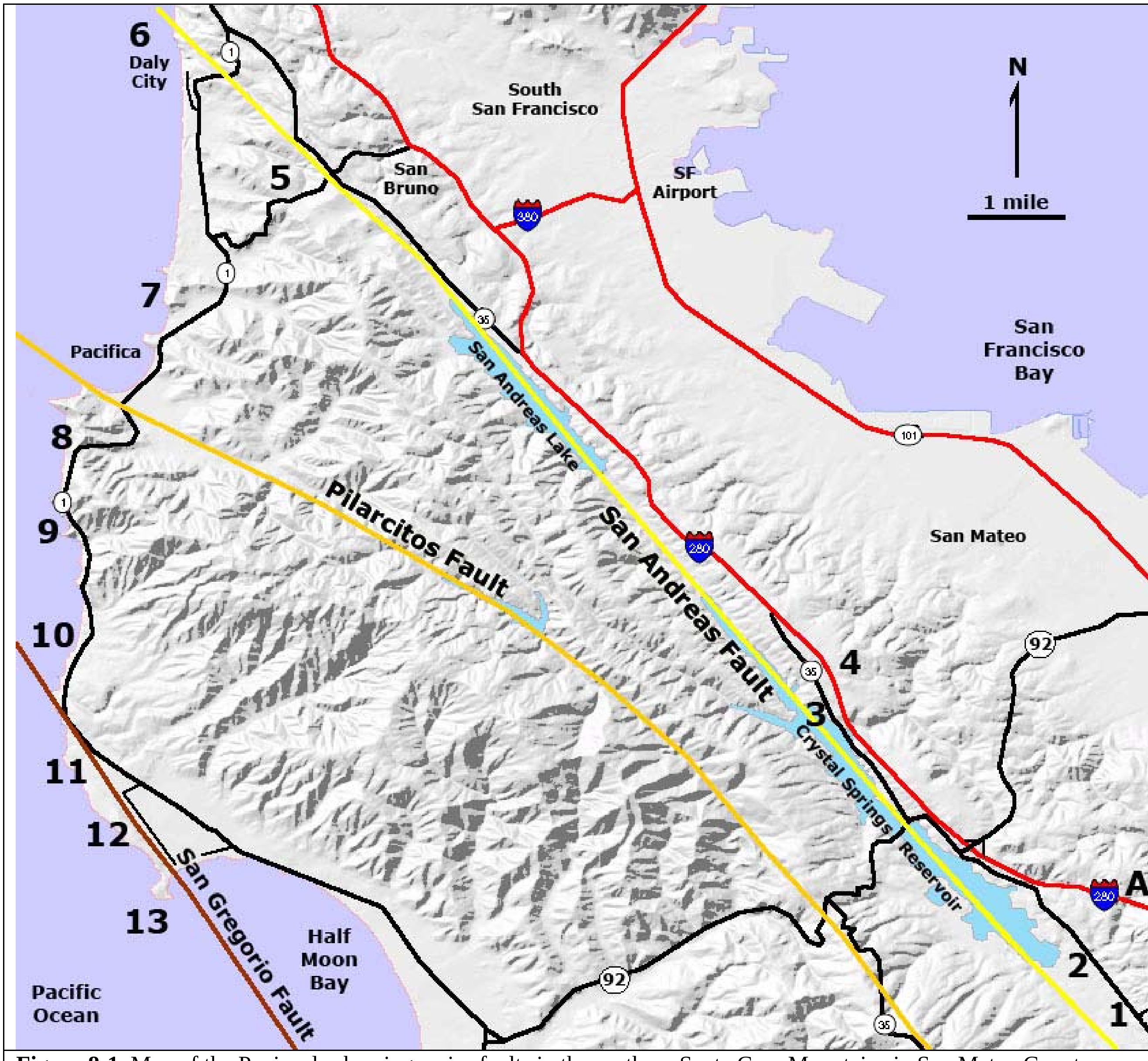

Figure 8-1. Map of the Peninsula showing major faults in the northern Santa Cruz Mountains in San Mateo County. Stops include: A) I-280 Vista Point, 1) Filoli Center, 2) Pulgas Water Temple, 3) Crystal Springs Dam, 4) I-280 Rest Area, 5) Milagro Ridge, 6) Mussel Rock Park, 7) Pacifica Quarry, 8) San Pedro Mountain and Devil's Slide, 9) Montara Mountain, 10) Montara Beach, 11) James V. Fitzgerald Marine Preserve, 12) Half Moon Bay Airport, and 13) Pillar Point and Mavericks.

Planning Your Fieldtrip

A field trip along the San Andreas Fault and to the coast in San Mateo County should be planned according to time limiting factors: tide conditions and trip destination interests. You will not want to attempt to visit coastal localities described in this guide during high tide or during inclement weather. The field trip described here starts at the Park and Ride at the Edgewood Road exit on I-280 where extra cars can be left during the field trip. The road log presented below follows a recommended route for **when low tide occurs in the mid afternoon.** Many websites provide tide information; search “tides” and “Half Moon Bay” on the World Wide Web to find a reasonable low tide estimate for the coast. Also, be sure to check weather forecasts and projected wave heights. The San Mateo beaches and tide pool areas are extremely dangerous places during high surf. High waves can occur unexpectedly.

More stops are provided than could be reasonably visited in one day without rushing. Optional stops are included in this guide to help plan the best trip for specific group interests or time constraints. For instance, although the Filoli Center is a wonderful trip destination, it is both fairly expensive and a time consuming venture that requires advanced planning and should be considered for a separate trip. Groups in a hurry might consider at least one stop along I-280 for the first part of the trip. The recommended northbound route presented below includes the all-important restroom stop at the northbound I-280 Rest Area (Stop 4 described below).

If low tide occurs in the morning, plan to head directly to Half Moon Bay, but consider stopping first at the I-280 Vista Area (Optional Stop A) just north of the Edgewood exit before taking Highway 92 west. Be sure to take a detailed map of San Mateo County with you on the trip. Two other geology and engineering field trips in this region include Andersen and others (2001), and Williams (2001); Brabb and others (1998) provide a geologic map of the area.

Road Log to Northbound Trip: San Andreas Rift Valley and San Mateo Coast

Mileage	**Description**
0.0	**Park and Ride** (east side of I-280 at Edgewood Road). This is a good location to carpool from (but do not leave valuables in cars). The Edgewood Road/Cañada Road exit on I-280 is located 4 miles north of Woodside Road (Highway 84) and is six miles south of the Highway 92 exit for Half Moon Bay. Drive west on Edgewood Road.
0.7	Turn right (north) on Cañada Road. Note that Cañada Road runs roughly parallel to the San Andreas Fault through its rift valley. Outcrops of Franciscan sandstone (greywacke), greenstone, and some serpentinite can be seen along the road and in bedrock exposures along the shoreline of Crystal Springs Reservoir.
2.0	**Stop 1 – Filoli Center** (optional stop; see description below). Continue north on Cañada Road.
2.4	**Stop 2 – Pulgas Water Temple** (optional stop; see description below). Continue north on Cañada Road.
4.7	Intersection of Cañada Road and Highway 92. Bear left (west at the stoplight).
5.4	Turn right (north) on Skyline Boulevard (Highway 35). The San Andreas Fault crosses the west end of the Highway 92 causeway. A small east-facing scarp reveals the trace of the fault along a low hill on the eastern shore of the reservoir just north of Highway 92.
6.3	Intersection of Bunker Hill Drive. Continue north on Skyline Boulevard.
6.8	Cross Crystal Springs Dam and proceed to the parking area to the left on the north side of the dam.
6.9	**Stop 3 – Crystal Springs Dam** (see description below).
7.5	Return south on Skyline Boulevard to Bunker Hill Drive. Turn left on Bunker Hill Drive.
7.6	Turn left (north) on I-280.
8.0	**Stop 4 – I-280 Rest Area [northbound only] (see description below).** Restrooms are available. **Reset mileage to zero.** Continue north on I-280.

5.5	Exit on Skyline Boulevard (Highway 35 – Pacifica exit).
6.0-7.0	Note the topography along this scenic route between I-280 and San Bruno Boulevard. Skyline Boulevard follows Buri Buri Ridge along the east side of the San Andreas Rift valley northward to Daly City. Look to the west to get a glimpse of San Andreas Reservoir, the original home of San Andreas Lake, a historic natural sag pond from which the name of the San Andreas Fault was derived. Sweeney Ridge is on the west side of the Reservoir. Skyline Boulevard follows and crosses the San Andreas Fault (or splay of faults) in a number of places along the route.
9.0	Turn left on Sharp Park Drive.
9.7	Turn right to the park access lane to Milagra Ridge just past College Drive.
9.9	**Stop 5 – Milagra Ridge** (part of Golden Gate National Recreation Area [GGNRA]) (see description below). Return east to Skyline Boulevard (Highway 35). Turn north on Skyline.
14.4	Exit on Highway 1 South.
15.9	Exit at Palmetto Drive. It is a hard-right turn onto Palmetto Drive.
16.7	Bear left of Westline Drive.
17.2	**Stop 6 – Mussel Rock Park** (see description below). **Reset mileage to zero.** Return north on Westline Drive. Bear Right on Palmetto.
1.3	Continue straight on Palmetto past the McDonald's.
1.8	Take Highway 1 South.
4.3	Mori Ridge (GGNRA) parking area on the right; however, continue south on Highway 1 past the large field in the abandoned Pacifica limestone quarry area on the right.
5.7	Turn right on San Marlo Way (this small road takes you into the Rockaway Beach Shopping Area). Proceed to a parking area at the north end of Rockaway Beach.
5.9 0.0	**Stop 7 - Rockaway Beach and Pacifica Quarry** (see description below). Restaurants and public restrooms are available in the Rockaway Beach Shopping Center. **Reset mileage to zero** at the main intersection for the shopping center on Highway 1. Continue south on Highway 1.
1.1	Highway 1 crosses San Pedro Creek. The creek follows the approximate trace of the Pilarcitos Fault.
1.8-3.2	**Rolling Stop 8 – San Pedro Mountain and the Devil's Slide** (see description below). (Note: "rolling stop" means keeps driving to a more recommended stop locations described below, but observe features in the surrounding landscape as you drive by.)
3.2-	**Rolling Stop 9 – Montara Mountain** (see description below).
4.1	McNee Ranch State Park/Gray Whale Cove State Beach parking area is on the east side of Highway 1. An old railroad cut near the parking area is a good place to look at the weathered Montara Granite. An even better place to look at the Montara Granite is at Stop 11.
5.5	**Stop 10 – Montara State Beach** (see description below). Restrooms are available. Continue south on Highway 1.
7.5	Turn right (west) on California Avenue.
7.9	**Stop 11 – James V. Fitgerald Marine Preserve** (see description below). Restrooms are available. Return via California Avenue to Highway 1 and continue south.
8.6	Turn right (west) on Cypress Avenue.
9.1	Turn left (south) on Airport Avenue.
9.2-11.2	**Rolling Stop 12 – Seal Cove Fault along Airport Avenue** (see description below). Continue south on Airport Avenue into Princeton on Half Moon Bay.
11.3	Turn right on Harvard Avenue.
11.4	Turn right on West Point Avenue.
11.7	Turn left into the Pillar Point Marsh Preserve (GGNRA) just before the entrance to the Pillar Point Airforce Station.
11.8	**Stop 13 – Pillar Point and Mavericks** (see description below). Restrooms are available. Return north into Princeton. Follow Harvard Avenue east.

12.8	Turn right on Capistrano Road.
12.9	**Half Moon Bay Brewing Company** (and restaurant) is on left. Continue south on Capistrano Road.
13.0	Turn right on Highway 1 South.
17.3	Turn left (east) on Highway 92.
22.4	Turn right (south) on I-280.
26.5	Exit at Edgewood Road to return to the Park and Ride. **End of field trip**.

San Andreas Rift Valley in San Mateo County

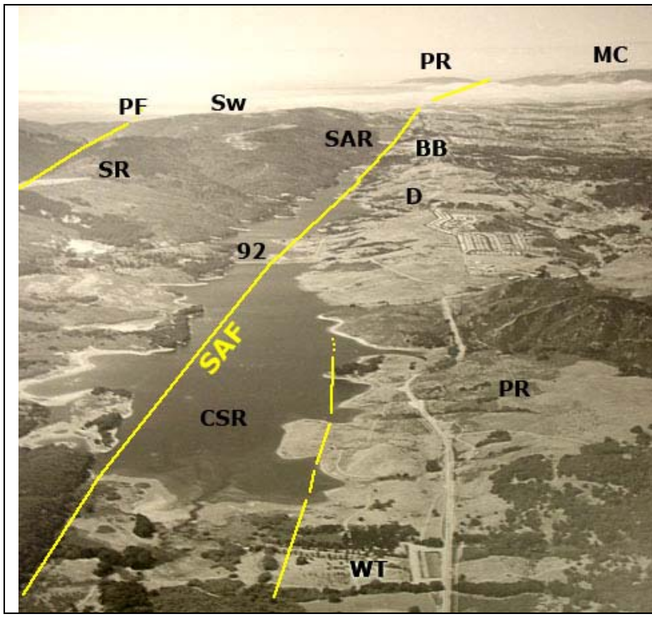

Figure 8-2. This oblique aerial view is looking north along the rift valley of the San Andreas Fault (SAF) in the vicinity of Crystal Springs Reservoir (CSR). The photograph was taken from about a mile above the Filoli Estate. The Pulgas Water Temple (WT) is in the foreground. The Highway 92 causeway (92) bisects the reservoir (*Lower* and *Upper* reservoirs, with Upper in the foreground). Sawyer Ridge (SR) and Sweeney Ridge (Sw) run between the San Andreas Rift valley and a valley along the Pilarcitos Fault (PF) in the northern Santa Cruz Mountains. Crystal Springs Dam (D) was built across a narrow gorge cut by San Mateo Creek through the eastern shutter ridge along the San Andreas Fault. This gap divides Pulgas Ridge [PR] and Buri Buri Ridge [BB] near San Andreas Reservoir [SAR]. Fog covers the Golden Gate. Higher peaks of Point Reyes (PR) and Marin County (MC) are in the distance beyond the Gulf of the Farralones. This photograph was taken before the construction of I-280. A similar view appears in Wallace, 1990.

Optional Stop A. I-280 Vista Point of Crystal Springs Reservoir

Stop highlights: San Andreas Rift Valley, shutter ridge, serpentinite, greenstone

For groups in a hurry, to take advantage of morning low tide along the coast, consider taking a brief orientation stop at the I-280 Vista Point located 0.5 miles north of the Edgewood Road exit. The Edgewood Road exit is located 2 miles south of the Highway 92 (Half Moon Bay exit). Note that the Vista Point is accessible only on the north-bound lane of I-280. Southbound travelers should take the Edgewood Road exit on I-280, cross to the other side of the Interstate, then return northward to the Vista Point exit. Parking for about a dozen vehicles is typically available.

The I-280 Vista Point provides an excellent location for an introductory overview about the regional geology of the San Andreas Fault and the northern Santa Cruz Mountains. The Vista Point provides a sweeping view of the San Andreas Rift Valley along the central portion of the Peninsula segment of the fault. Crystal Springs Reservoir floods the lower portion of the linear rift valley (see figs. 8-1, 8-2, and 8-3). Although published estimates vary, and are often disputed, roughly 300 km of offset occurred along the mid-section of the San Andreas Fault (south of the Bay Area). In the Bay Area, this amount of offset is divided by the regional fault system. About 174 km of offset in the Bay Area has occurred along the East Bay fault system, whereas 127 km of offset has occurred along the San Andreas Fault/Pilarcitos fault system in the Santa Cruz Mountains on the San Francisco Peninsula. Only about 22 km has been absorbed on the modern Peninsula segment of San Andreas after 100 to 105 km of offset occurred on the Pilarcitos Fault (McLaughlin and others, 1996; Jachens and others, 1998). Pilarcitos Fault (or Pilarcitos/Montara Fault) is located in the valley on the west side of Sawyer Ridge—shown in figs. 8-1, 8-2 and 8-3. Additional regional right-lateral fault displacements that may total in the range of hundreds of kilometers occurred along the San Gregorio Fault and other fault systems along the west side of the Santa Cruz Mountain and offshore.

Boulders of serpentinite and greenstone can be viewed along the paths and in the walls around the Vista Point. Serpentinite (or more technically, serpentinized-ultramafic rock) is derived from the mantle or lower oceanic crust and probably originally formed beneath a mid-ocean ridge spreading center. Massive serpentinite bodies in the Bay Area are part of the Coast Range Ophiolite of Jurassic age. The greenstone is from the Franciscan Complex of Cretaceous age and is abundant throughout the northern Santa Cruz Mountains. The Franciscan Complex represents rocks from the upper ocean crust and consists of rocks formed from submarine volcanism and from deep marine sediments. Greenstone forms from the low-temperature metamorphic alteration of basalt. The original basalt probably accumulated as intrusions or flows on ancient submarine volcanoes on the seafloor. Other sediments that accumulated on the sea bed became layered chert, shale, greywacke sandstone, and limestone. Some of these deposits eventually were metamorphosed into metachert, slate, schist, metasandstone (including metagreywacke), and marble. Over a 100-million year period, these rocks migrated great distances from their place of origin, carried by the tectonic plates on which they were deposited. These rocks were wedged against the North American plate along the subduction zone that existed here at the time amd were accreted onto the western North American continental margin. Slivers of serpentinite are found within the Franciscan Complex. Wahrhaftig and Murchey (1987), and Elder (2001), provide discussions about the geology of the Franciscan Complex in Marin County in the headlands west of the Golden Gate.

Figure 8-3. View of Crystal Springs Reservoir in the rift valley of the San Andreas Fault. This view is from the northwest end of the I-280 Vista Point looking northwest toward Sawyer Ridge beyond the reservoir. The Interstate is not shown in the foreground. The Pilarcitos Fault is in the valley on the west side of Sawyer Ridge.

Stop 1. Filoli Center (optional stop on Cañada Road)

Stop highlights: San Andreas Rift Valley, offset alluvial fan deposits, sidehill bench, historic estate and gardens

The Filoli Center is a 654-acre estate with a Georgian-style mansion surrounded by 16 acres of formal gardens. The Filoli Estate was built for the family of William Bowers Bourn II. The building was designed by Mr. Bourn’s friend and San Francisco architect, Willis Polk, who also designed the nearby Pulgas Water Temple. Mr. Bourn amassed a fortune from the Empire Gold Mine, a bedrock gold mine in the Mother Lode in Grass Valley, California. He was also owner and president of the Spring Valley Water Company that comprised Crystal Springs Lake and surrounding lands (now managed by of the San Francisco Water Company). The Bourns were supposedly severely traumatized by the San Francisco’s great disaster of 1906. The failures of the water system in San Francisco contributed to the massive fire damage after the earthquake. However, the Bourns had their country mansion built ten years after the 1906 disaster, probably without the knowledge of the proximity of the great earthquake fault nearby. After Mr. Bourn’s death in 1936, the estate was purchased by the Willam P. Roth family (owners of the Matson Navigation Company). Mrs. Lurline B. Roth donated 125 acres of the estate (including the mansion and gardens) to the National Trust for Historic Preservation in 1975, and it is now operated by the Filoli Center.

Many geologic and paleoseismic investigations have been conducted in the Filoli area because landscape features and sedimentary deposits along the San Andreas Fault are well preserved and relatively undisturbed by human activity. The main trace of the fault passes through the undeveloped Filoli Center grounds several hundred meters to west of the mansion and gardens. The fault created an escarpment and sidehill bench in the area southeast of the mansion where the fault runs through a pre-historic Ohlone (Native American) habitation site. Nearby, Spring Creek crosses the fault where an embankment reveals alluvial fan sediments that are offset by the fault, including slip from the 1906 earthquake. In 1993 to 1994, trenches were dug in a meadow and sag pond area near the creek about a half mile south of the mansion. The trenches were dug to evaluate the fault and its paleoseismicity (Wright and Hall, 1996). Hall and others (1995) interpreted a total slip from the 1906 earthquake in the range of 2.5 m in the fault zone in the Filoli area. The M 7.0 earthquake of 1838 also produced about 1.5 m of offset along the fault. Nearby in vicinity of a ranger’s residence, a row of mature cypress trees is offset where it crosses the fault.

Please note that the significant geologic features associated with the San Andreas Fault are not accessible via the general public estate and gardens area of the Filoli Center. Guided trips to look at natural features on the non-public grounds require an escort by Filoli volunteer staff and reservations are required well in advance. See the Filoli website for hours, access fees, and other information (http://www.filoli.org).

Figure 8-4. The Filoli Center (estate and formal gardens) is located on Cañada Road west of I-280 near the Edgewood Road exit. The San Andreas Fault runs through the forest west of the developed estate grounds where it offsets alluvial fan deposits. Skyline Ridge is in the distance.

Stop 2. Pulgas Water Temple (optional stop on Cañada Road)

Stop highlights: San Andreas Rift Valley, Franciscan Complex sandstone, greenstone, serpentinite

The Pulgas Water Temple is located along Cañada Road between the Filoli Estate and the southern end of Crystal Springs Reservoir. The Pulgas Water Temple was designed by San Francisco architect, Willis Polk and has a Roman temple style. The temple was constructed in 1934. The temple marks the western terminus of the water pipeline and tunnel system that drains from the Hetch Hetchy Reservoir in the Sierra Nevada and supplies the City of San Francisco and other municipalities with water stored in Crystal Springs Reservoirs and San Andreas Lake. The Pulgas Water Temple was renovated in 2004; the parking area serves as a trailhead for Fifield-Cahill Ridge Trail. Note that the parking area is closed on the weekends except for special events.

The drive northward along Cañada Road provides a less-stressful way of viewing the San Andreas Rift Valley and Crystal Springs Reservoir than driving along along Highway 280. Outcrops of Franciscan sandstone, greenstone, and some serpentinite can be seen in the field and road cuts along Cañada Road between Filoli and Highway 92, and along the shore of Crystal Springs Reservoir.

Figure 8-5. The Water Temple is located along Cañada Road just north of the Filoli Center. The trace of the San Andreas Fault that ruptured in the 1906 earthquake runs along the base of the mountainside in the distance.

Stop 3 – Crystal Springs Reservoir Dam

Stop Highlights: a high dam constructed near the San Andreas Fault, shutter ridge, Crystal Springs Canyon

Crystal Springs Dam is accessible along Skyline Boulevard between the Half Moon Bay exit for Highway 92 (west) and Haynes Road exit on I-280. Skyline Boulevard runs parallel to I-280 on the east side of Crystal Springs Reservoir. Parking for the dam and the shoreline Sawyer Trail is located along Skyline Boulevard just north of the dam. Outcrops of serpentinite can be seen along the road near the dam. Serpentinite soils in the vicinity host a manzanita scrub forest along the shore of the reservoir. Note that the reservoir shoreline and surrounding watershed area is closed to public access.

Construction of Crystal Springs Reservoir began in the 1870s with removal of all vegetation and manmade structures from a 9 mile stretch along upper San Mateo Creek valley. The reservoir was part of the extensive water system designed by the Spring Valley Water Company of San Francisco to help quench the demands of the rapidly growing city. Construction of the dam across Crystal Springs Canyon was completed in 1889 and heavy rains of the following year filled the reservoir to capacity in a little over a year (nearly a decade sooner than was anticipated). At the time of its construction the dam was the largest in the world, designed to hold back 32 billion gallons of water. The dam is made of cement and was originally about 120 feet high. The dam was raised to 145 feet in 1890 and to 149 feet in 1911. It is 120 feet thick at its base and about 20 feet thick at the top. Crystal Springs Reservoir is bisected into Lower and Upper reservoirs by the causeway traversed by Highway 92. The Crystal Springs Dam is on the Lower Reservoir.

Crystal Springs Dam is located ominously close to the San Andreas Fault; the fault trace runs parallel to the dam several hundred feet to the west and submerged beneath the reservoir. Crystal Springs Canyon is a narrow gorge cut through the eastern shutter ridge of the San Andreas Fault. Buri Buri Ridge is north of the canyon and Pulgas Ridge is south of the canyon. The dam survived both the 1906 and 1989 earthquakes with no apparent damage. The drainage tunnel of the San Andreas Lake (reservoir) dam to the north and upstream of Crystal Springs Reservoir was offset and severely damaged by motion along the San Andreas Fault during the 1906 earthquake, but the earth-fill dam itself survived undamaged. It is interesting to note that the significance of the San Andreas Fault was unknown at the time of the dam's construction.

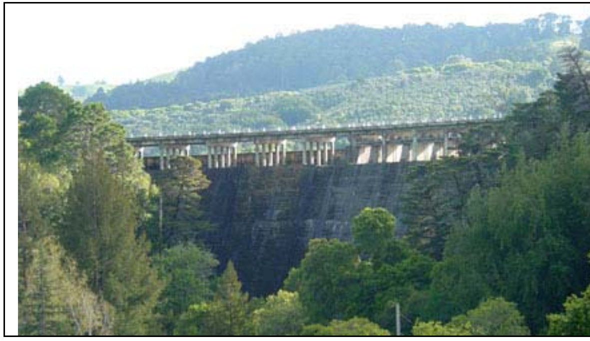

Figure 8-6. This view of Crystal Springs Reservoir Dam is from along Crystal Springs Road beneath the I-280 bridges over Crystal Springs Canyon. Skyline Boulevard crosses the dam. Sawyer Ridge is in the distance.

Stop 4. I-280 Northbound Rest Area

Stop Highlights: San Andreas Rift Valley overlook, Crystal Springs Reservoir, serpentinite

The northbound I-280 is another optional fieldtrip stop that provides a sweeping vista of the San Andreas Rift Valley, Sawyer Ridge, and Crystal Springs Reservoir. A walkway leads to an overlook area around a statue of Junipero Serra, the founding father of the California Missions. Walls along the path and of the restroom facility are made of serpentinite and greenstone from local sources (see discussion for Stop A above).

Figure 8-7. Franciscan Padre Junipero Serra (1713-1784) is accredited for founding the Mission which led to the Spanish colonization of California. He was appointed to establish the Missions in *Alta* (upper) California in 1767 and spent the rest of his life pursuing that effort. He aided an expedition in locating San Francisco Bay, and before he died he founded nine of the California missions.

Although Serra's statue at the rest area on northbound I-280 should probably be pointing at the bay, instead it points across the Interstate toward the San Andreas Fault!

Northern San Mateo County

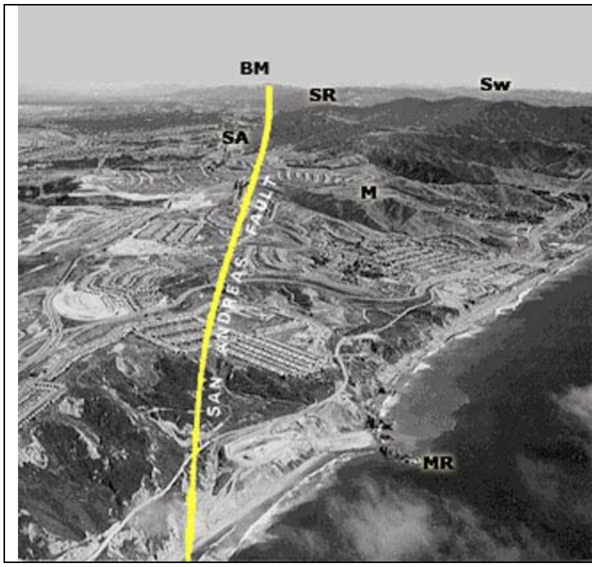

Figure 8-8. Aerial view of the San Andreas Fault in the northern Santa Cruz Mountains in San Mateo County. This view is looking south toward the coast at Mussel Rock Park and neighborhoods of Daly City. Labeled features include Mussel Rock (MR), Milagra Ridge (M), San Andreas Lake (SA), Sawyer Ridge (SR) and Sweeney Ridge (Sw). Black Mountain (BM) in northern Santa Clara County is in the distance. This photograph was probably taken in the early 1960s when most of the residential construction was nearly completed in the Daly City region. Note the trace of Highway 1 along the sea cliffs in the Mussel Rock area. A massive landslide is near the “SAN” of the San Andreas Fault label on the image. Today, very little remains of the trace of the highway due to coastal erosion and landsliding (see fig. 8-10). The landscape east of Mussel Rock is underlain by the Merced Formation. The Merced Formation is a mile thick sequence of poorly-consolidated sedimentary materials that accumulated in coastal and nearshore marine environments during the late Pliocene and Pleistocene epochs.

Stop 5 – Milagra Ridge (Golden Gate National Recreation Area)

Trip highlights: San Andreas Rift Valley, coastal view of Pacifica region, butterfly preserve

Milagra Ridge offers a good view of the urbanized area along the San Andreas Fault and along the coast. The preserve is a “habitat island” – a remnant of coastal prairie now surrounded by urban development. In the past, the area was used by native Ohlone people. The land was then later claimed by Spanish settlers and Mexican rancheros. A gun battery was installed on the ridge during World War II, and a Nike missle station was installed during the Cold War. Extensive urban development of the surrounding area began in the late 1950s. In 1984 the land was added to the Golden Gate National Recreation Area. The parkland is a preserve for threatened and endangered species—the Mission blue and San Bruno elfin butterflies, and the California red-legged frog.

Parking is extremely limited on a small access road via Sharp Park Road opposite the College Drive access to Skyline College. A short uphill trail that starts at the parking area leads to an overlook of the Pacifica area and headlands along the coast. On the east side of the ridge, the rift valley of the San Andreas Fault is clearly visible as it runs through the urban setting adjacent to Skyline Boulevard. Sweeney Ridge to the south is also part of the Golden Gate National Recreation Area. It was on Sweeney Ridge in 1769 that Spanish explorer Captain Gaspar de Portola recorded in his diary an account of the first sighting of what would become the busy seaport harbor and metropolitan region around San Francisco Bay. For more information, see the National Park Service websites for Milagra Ridge (http://www.nps.gov/goga/clho/miri/) and for Sweeney Ridge (http://www.nps.gov/goga/clho/swri/).

Figure 8-9. View of the San Andreas Rift Valley on the west side of Milagra Ridge.

Stop 6 – Mussel Rock Park

Trip highlights: Quaternary Merced Formation, Franciscan greenstone, landslides, coastal erosion, urban geohazards

Mussel Rock Park is situated along the northern San Mateo Coast at Daly City. The Peninsula segment of the San Andreas Fault runs out to sea at just north of Mussel Rock (figs. 8-7, 8-8, and 8-10). The fault trace is obscured by landslide deposits and an old garbage dump, now filled, in the park area. However, the presence of the fault can be seen in the bedrock contrast from Cretaceous age greenstone of the Franciscan Complex of Mussel Rock itself located west of the fault, and the late Pliocene to Quaternary-age sediments of the Merced Formation west of the fault. Current theory is that the epicenter of the 1906 earthquake probably occurred along the offshore segment of the San Andreas Fault several miles north of Mussel Rock in the region offshore from Ft. Funston at 37°70'N, 122°50'W (location data from California Geological Survey website: *Anniversaries of Notable California Earthquakes*): http://www.consrv.ca.gov/CGS/rghm/quakes/eq_calendar.htm). The northern end of the Peninsula segment of the San Andreas Fault experienced about 4 meters of right-lateral displacement and experienced near the full intensity of the ~8 M of the 1906 earthquake. However, the area along the fault was essentially undeveloped at the time of the great earthquake.

The San Andreas Fault runs through urbanized areas of San Bruno and Daly City. Although developers were probably aware of the fault's location, construction of many residential homes and businesses proceeded because earthquake fault zone assessment and zoning laws were not yet established. The Alquist-Priola Earthquake Zoning Act of 1973 set forth the minimum fault investigation and approval requirements for all California cities and counties. The Act requires fault investigations for developments of four or more houses and subdivisions of five or more parcels. No structure subject to the provisions can be placed closer than 50 feet to a fault unless studies approved by a local authority support a lesser setback, but no structure can cross the trace of a fault with established earthquake potential. An additional hazard to property and structures in this area is from landsliding. A number of homes have been destroyed or severely damaged because they were built too close to the sea cliff on unstable ground.

Use caution when exploring the landslide area, the greenstone outcrops near Mussel Rock, or the beach below the sea cliffs. Do not attempt to go on the beach during high tide or during high surf. There is not enough space along the upper beach to escape from rogue waves, and material is constantly sloughing off the cliff. The same is true of the cliffs along the upper landslide escarpment. Open fractures occur throughout the landslide area and may not be visible beneath vegetation cover.

Only the lower part of the Merced Formation crops out in the Mussel Rock Park area. These sandstone beds are steeply dipping near the fault zone, but dip more gently northward along the coast at Thornton State Beach (north of Mussel Rock Park). The Merced Formation consists of interbedded sandstone and shale and contains some fossiliferous marl and conglomeratic beds. These deposits accumulated in marine shelf, intertidal, and coastal sedimentary environments as sea level rose and fell during the ice ages of the Quaternary Period. As the modern strand of the Peninsula segment of the San Andreas Fault developed, the land steadily rose in late Quaternary time, eventually elevating the once marine sediments to their present elevation of 750 feet in the bluffs along the San Andreas Fault Zone at Mussel Rock Park. A better place to visit the Merced Formation is at Fort Funston located several miles north of Mussel Rock Park. The geology of the Merced Formation is described by Clifton and Hunter (1987) and Andersen and others (2001). For more information about Fort Funston, see the National Park Service website at http://www.nps.gov/goga/fofu/.

Figure 8-10. Mussel Rock is part of a large outcrop belt of greenstone that forms a small promontory and sea stacks on the San Mateo coast in Daly City. This belt of greenstone of the Cretaceous Franciscan Complex is on the west side of the San Andreas Fault.

Figure 8-11. A massive landslide complex at Mussel Rock Park masks the main trace of the San Andreas Fault. Note the high, barren slump escarpment in the background. Ongoing coastal erosion at the toe of this slide area promotes the landward migration of the high wall of the landslide escarpment. Numerous homes have been destroyed, damaged, or condemmed along this coastal slide area of Daly City.

Figure 8-12. View looking northward from Mussel Rock Park along the sea cliffs at Thornton Beach State Park. The rolling hill slope in the foreground is part of the toe area of the large landslide complex at Mussel Rock Park. The sea cliffs are exposures of the Merced Formation. The Ocean Shore Railroad built along this section of coast in 1905 to 1906 was severely damaged by the 1906 earthquake. Because of ongoing troubles due to landsliding, the rail line was abandoned in 1920. In the 1930s, the rail line was widened to accommodate Highway 1. However, shortly after the M 5.3, March 22, 1957 earthquake the route was once again abandoned. Today only a trace of the highway cut can be seen about midway up the sea cliff. See fig. 8-8 for comparison.

Stop 7 – Pacifica Quarry and Rockaway Beach

Stop highlights: Permanente Terrane, Calera Limestone, Pilarcitos Fault, coastal headlands

Rockaway Beach is a good place to view the headlands along the northern San Mateo Coast and to access the Pacifica Quarry. The Rockaway Beach Shopping Center usually has ample parking. However, fieldtrip participants should be given a time to meet at the northwest end of the rip-rap beach wall (as the beach and shops grow more crowded during the mid-day it will probably not be possible to park vehicles together near the beach).

From the rip-rap seawall area it is possible to see a geomorphic expression of the Pilarcitos Fault along the north facing flank of the San Pedro Point headlands to the south of Rockaway Beach (see fig. 8-13). Unfortunately, there are no bedrock exposures along the Pilarcitos Fault that are accessible to the public. The presence of the fault is revealed by a change in bedrock lithology. On the east side of the fault, the bedrock conisits of Franciscan Complex (mostly greenstone and sandstone exposed in the Rockaway Point headlands). The bedrock on the west side of the fault consists of interbedded sandstone and shale (turbidites) of Paleocene age. These turbidites are exposed in Highway 1 road cuts south of Pacific Beach and in the San Pedro Headlands and (see figs. 8-16 and 8-17 described in Stop 8).

Pacifica Quarry is an inactive limestone and greenstone mine on the south end of the Mori Point headlands at the north end of Rockaway Beach. Small-scale limestone mining began in the Pacifica area in the early 19th century when lime was used primarily for whitewash for buildings in the Presidio district of San Francisco. The larger quarry began operation in 1904, a year before the Ocean Shore Railroad was established. Much of the limestone mined at the site was probably used for cement in San Francisco's reconstruction after the 1906 earthquake. Shortly after the city of Pacifica was incorporated in 1957, the community voted to donate much of the undeveloped coastal land, including Mori Point, to the National Park Service (Golden Gate National Recreation Area) in an effort to prevent further development. Efforts in the late 1990s were made to develop the abandoned quarry into housing and a convention center, but local environmental groups have so far prevented this effort. The restored Calera Creek is considered habitat for the endangered California red-legged frog. The Rockaway Beach Quarry Trail crosses through the quarry area.

The Calera Limestone Member of the Franciscan Complex is about 70 m thick. The Calera Limestone is part of the Permanente Terrane, a split-up block of Franciscan rocks that also crops out in the foothills along the San Andreas Fault in Santa Clara County, including at El Toro Peak in Morgan Hill, Calero County Park, and in the Permanente Quarry in the Permanente Creek area of the larger Stevens Creek watershed near Cupertino, California. The Calera Limestone Member consists mostly of a dark gray, fine-grained (micritic) limestone locally recrystallized to crystalline calcite masses and contains interbedded nodular layers of chert. The Calera Limestone is also locally cut by greenstone dikes (originally of basalt composition).

The Calera Limestone formed by the diagenetic and metamorphic alteration of the original lime ooze sediments (including planktonic forams and coccoliths) deposited on the ocean floor. Fossils indicate a middle Cretaceous age (Albian to mid-Cenomanian stages, about 105 to 94 million years ago). The presence of tropical microfauna suggests that the calcium-carbonate deposits of the Calera Limestone have been transported a significant distance from their place of origin by plate-tectonic movement (Tarduno, 1985). In the modern ocean, the carbonate-compensation depth (CCD) is typically around 4 km deep in tropical latitudes. Below the CCD, carbonate material (such as plankton skeletal material) tends to dissolve in cold water conditions before it can be incorporated into sediments. However, in low-latitude regions carbonate sediment generation is more rapid, and carbonate ooze accumulates on the deep-ocean seabed, particularly on elevated platforms or seamounts and is purest where it is far from terrigenous sediment sources. Calcium carbonate is also generated by ocean-derived fluids reacting with ultramafic rocks in the formation of serpentinite, and large modern deposits of deep-sea carbonates associated with seafloor springs have been discovered in association with warm-water vents on the sea bottom (Fruh-Green and others, 2003; Schroeder, 2002). However, these deep-sea vent deposits are typically associated with rough ocean bottom terranes and have a different microfossil and invertebrate fauna than those observed in the more evenly-bedded Calera Limestone, and have a high concentration of magnesium carbonate.

Figure 8-13. View looking south along Rockaway Beach towards Rockaway Point and the more distant San Pedro Point headlands and Pedro Rock (a sea stack in the distant right). Cretaceous-age sandstone and greenstone of the Franciscan Complex crop out on the Rockaway Point headlands. Pacifica State Beach is in the bay to the south of Rockaway Point. San Pedro Creek, at the south end of Pacifica Beach, follows the trace of the Pilarcitos Fault and runs out to sea along the north side of the San Pedro Point headlands (far distance, right).

Figure 8-14. Calera Limestone forms the Mori Point headlands at the north end of Rockaway Beach. Calera mean *limestone quarry* or *limekiln* in Spanish. Mori Point is now part of Golden Gate National Recreation Area.

Figure 8-15. The Calera Limestone was mined in the Pacifica Quarry. The rock is a dark, layered limestone and marble, with interbedded layers of chert. Locally, the rock contains some small greenstone dikes and veins of calcite. Large blocks of this material can also be examined in the rip-rap seawall at the parking area at Rockaway Beach.

Stop 8 – San Pedro Mountain and the Devil's Slide (rolling stop)

Stop highlights: Paleocene turbidites, coastal headlands, landslide hazards

In the Devil's Slide area, most of the roadside pull offs along Highway 1 are posted "no stopping" for good reason. The spaces are too narrow and small, and the traffic is too heavy and fast to be considered safe for a field trip stop. However, notable geologic features can be seen along the highway.

South of Pacifica State Beach, Highway 1 crosses the Pilarcitos Fault (near San Pedro Creek) and climbs to the crest of San Pedro Ridge through a eucalyptus forest. Near the crest of the ridge, steeply dipping and folded layers of shale, sandstone, and calcareous marl of Paleocene age crop out in road cuts along the highway (fig. 8-16). These same units are exposed in Pedro Rock at the northwest end of San Pedro Point. Paleocene-age conglomerate and granitic megabreccia in the roadcut rests unconformably on Mesozoic-age granitic rocks and gneiss of Montara Mountain (Salinian basement complex) to the south. The sedimentary units formed as deep-sea fans deposits (inner- and mid-fan channels, channel margin, and interchannel settings) that accumulated as turbidity flows into a restricted, deep, tectonically active basin setting (Nilsen and Yount, 1987). Mineral clasts in arkosic, lithic, and unusual calcareous marl and sandstones within the turbidite sequence suggest that sediments were derived from Salinian basement, with the calcareous material derived from marble roof pendant structures in the granitic terrane, similar to carbonate rocks exposed in the Ben Lomond Mountain and Fremont Peak areas to the south.

The Devil's Slide area begins just west of the pass on the west side of San Pedro Ridge and extends for about 0.8 mile along Highway 1 on the northwest flank of Montara Mountain. The landslide is occurring where steeply dipping, faulted, and folded Paleocene rocks are slipping above a steeply inclined surface of underlying weathered Mesozoic granitic bedrock of Montara Mountain. Several landslide chutes and failure zones are present in the area, and the glide planes of the slump blocks extend as much as 150 feet below the surface. The landslide extends from 900 feet high on the mountain down to sea level (Williams, 2001).

The landslide complex at Devil's Slide has a long and expensive history. Landslide failures disrupted travel along the first road built across the slide area in the late 1890s and was eventually abandoned. Starting in 1905, the Ocean Shore Railroad attempted to operate a rail line across the area below the present road level, but was abandoned in the 1920s because of the chronic troubles with landsliding at Devil's Slide and elsewhere along this coastal route. The State Department of Highways completed the first version of the coastal highway along the abandoned rail line in 1936, and this route in part is Highway 1 today. However, landsliding and road closures have constantly plagued the route, and millions of dollars have been extended into endless repairs. CalTrans is currently evaluating plans to construct a 4,000 foot tunnel through Montara Mountain to bypass the slide area. For more information, see the discussion by Williams (2001) about the engineering geology of the Devil's Slide.

Figure 8-16. Road cuts along Highway 1 expose interbedded layers of Paleocene-age deep sea fan deposits (turbidites). This view is looking east from a small pull off at the top of the ridge of San Pedro Mountain. Note that this pull off is not recommended as a fieldtrip stop because of high traffic volume along the highway. Coastal travelers can more safely access similar deposits of Cretaceous age at Bean Hollow State Beach or near Pigeon Point south of Half Moon Bay.

Figure 8-17. Pedro Rock at the south end of Point San Pedro consists of steeply dipping beds Paleocene-age sandstone and shale (covered locally with bird guano). Darrow (1963) described unconformable relations between the Paleocene sedimentary rocks and sedimentary rocks of late Upper Cretaceous beds on San Pedro Point (to the right). Whether these Upper Cretaceous sediments are in conformable contact with the Salinian granite is unclear. A remnant of the old Ocean Shore Railroad bed is visible along the shore (lower right).

Figure 8-18. Devil's Slide. This view is looking south from one of the small roadside pull off along Highway 1. Portions of the San Mateo Coast south of Shelter Cove (including San Pedro Rock) have been incorporated in the Golden Gate National Recreation Area. A ruin of a WWII era gun emplacement is visible on top of a headland at the south end of Devil's Slide.

Stop 9 – Montara Mountain (rolling stop)

Stop highlights: Salinian granite, coastal headlands

Cretaceous-age granitic rocks of the Salinian Block are exposed in coastal headlands and cuts along Highway 1 on Montara Mountain. Granitic rock is exposed along the shore at Gray Whale Cove State Beach and along trails and in a historic Ocean Shore Railroad cut in McNee Ranch State Park. Note that the granitic rock is deeply weathered except in eroding exposures along the beaches. This gives the Montara Mountain granitic bedrock a rusty-orange appearance, whereas the fresh exposures along the beach are pale gray (fig. 8-19). Quartz-rich dikes and dark mafic dikes cross cut the granitic rock in many locations. The rock was originally named the Montara Granite, and later renamed the Montara Quartz Diorite (by Lawson, 1895a, Lawson, 1895b, and Lawson, 1914).

The Salinian Block is a 40,000 km^2 fault-bounded block of granitic and metamorphic basement along California's coastline, west of the San Andreas Fault (fig. 8-20). The block is structurally isolated from other Cordilleran granitic terranes of the West Coast by large-scale, right-lateral movements including at least 300 km on the San Andreas Fault System. The Salinian Block is surrounded by oceanic crust basement (Franciscan Complex and Coast Range Ophiolite) along most of its length. The Salinian Block is in itself split into several smaller, structurally complex blocks. The granitic exposures on Montara Mountain are part of a northern block that includes disjointed exposures such as the Farallon Islands, Point Reyes, and Bodega Head. The granitic exposures on Ben Lomond Mountain, the Monterey Peninsula, Santa Lucia Range, and the Gabilan Range are within a central block. chemical and petrographic characters of the Salinian Block granitic rocks and their metamorphic frameworks suggest that the crystalline basement rocks originated somewhere within the Cordilleran volcanic arc in southern California or possibly from a similar setting much farther to the south. These rocks moved northward to their present location along fault systems that predate the San Andreas Fault, and then along the San Andreas Fault from its time of inception starting about 23 million years ago to the present. Radiometric ages of the granitic rocks in the Salinian Block range from about 70 to 120 million years (within the Cretaceous Period), but radiometric ages of granitic samples from Montara Mountain are in the range of about 82 to 95 million years (Ross, 1983; Mattinson, 1990, Kistler and Champion, 1997).

Please note that it is advised not to stop along the Highway 1 on Montara Mountain or attempt to cross the busy highway into parking areas. Instead, consider using the Stop 10 (Montara State Beach) locality described below.

Figure 8-19. Headlands along the coast side of Montara Mountain. Cretaceous-age Salinian granitic rocks make up the core of Montara Mountain. This view is looking north from a small pull off on Highway 1 north of Gray Whale Cove State Beach.

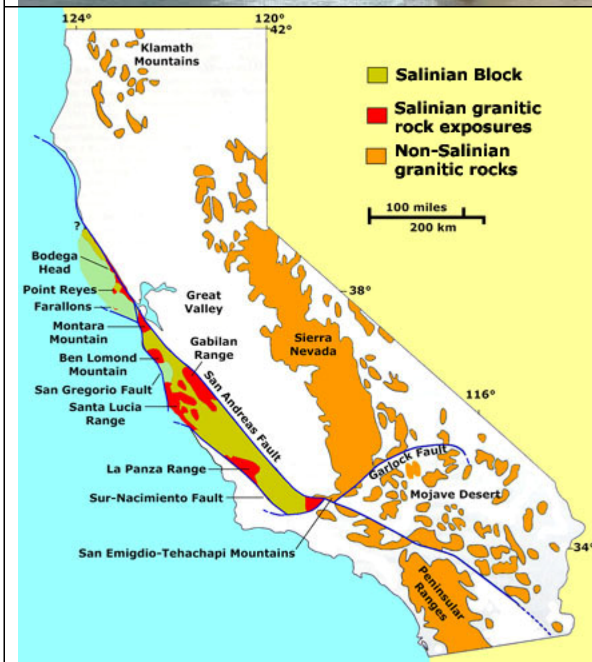

Figure 8-20. Map showing granitic bedrock provinces of California highlighting the extent of the Salinian Block. Exposures of granitic bedrock in the Salinian Block are shown in red. The Salinian Block extends offshore to the shelf margin to some undetermined extent north and west of the San Francisco Bay Area. The block is bounded on the east by the San Andreas Fault and on the west in the southern part by the Sur-Nacimiento and San Gregorio Fault Systems. The western side of the northern Salinian Block is probably bounded by faults in the offshore region along the continental shelf margin.

Stop 10 – Montara State Beach

Stop highlights: Salinian granite, offset Quaternary marine terraces, lignite deposits

Montara State Beach is in a cove between the Montara Mountain headlands to the north and headlands by the town of Montara to the south. A northwest trending fault zone runs offshore at the northern end of Montara Beach along the southwest side of Montara Mountain. Another northwest trending fault, the Montara Fault, extends offshore in the rocky headlands at the south end of the beach. A small fault with some apparent thrust offset is exposed in the sea cliff displaces Salinian granite over marine terrace deposits of Quaternary age (fig. 8-21).

Three marine terraces are recognized along the coast between Montara Beach and Half Moon Bay (to the south) and were described by Jack (1969). These marine terraces are, from oldest to youngest, the San Vicente, the Montara, and the Half Moon Bay. The ages of the terraces are still being debated, and their correlation to terraces elsewhere along the coast is made difficult by the complexity of fault motion relative to marine terrace development in the area, as well as a lack of datable materials.

San Vicente Terrace Deposits

The San Vicente marine terrace deposits are exposed in a faulted block near sea level at the south end of Montara State Beach (see fig. 8-21). These deposits rest unconformably on an irregular wave-cut bench surface on underlying Salinian granitic rocks. The terrace deposits consist of a basal pebble conglomerate of marine origin that contains clasts (pebbles to cobbles) of mafic volcanic rock and other materials derived from the Franciscan Complex (these are not present in the younger terrace deposits). It also contains material derived from the local granite with some pieces ranging to boulder size. Some cobbles in the San Vicente preserve marine pelecypod (*Pholad*) borings.

Terrace deposits with pebbles of Franciscan derivation also occur 200 to 560 feet above sea level in the region south of Montara Beach. This variation in elevation suggests that the San Vicente terrace has experienced significant post-depositional tectonic tilting and/or faulting. In addition, erosion has highly degraded any surface expression reminiscent of younger marine terraces, such as those preserved along the coast near the Davenport area in Santa Cruz County (Weber and Allwardt, 2001). Cross-cutting relationships in the sea cliff exposures suggest that some of the tectonic tilting and faulting took place before deposition of the next younger Montara marine terrace. The age of the San Vicente marine terrace is not well determined, but is likely older than 300,000 to 500,000 years.

Montara Terrace Deposits

Deposits of the Montara marine terrace are well exposed in the sea cliff below the parking area at Montara State Beach (fig. 8-22). The terrace deposits consist of (from youngest to oldest):

a well sorted eolian sand facies,
a lignite bed,
an upper arkosic, alluvial gravel facies (containing Montara Mountain granodiorite),
a lower beach and shallow marine member containing material of local granitic rock derivation.

At Montara State Beach the Montara terrace deposits rest unconformably on San Vicente terrace deposits. At Montara Point (about a mile south of the beach), slip along the Point Montara Fault displaces the Montara marine terrace at 18 feet elevation north of the fault, and 95 feet south of this fault (Jack, 1969). The age of the Montara Terrace is also disputed, but is probably in the range of 200,000 to 300,000 years.

The Half Moon Bay Terrace

The Half Moon Bay terrace is only clearly preserved south of Point Montara. The terrace is only slightly dissected by subsequent stream erosion. Terrace deposits consist of reworked material from the Montara Terrace. The Half Moon Bay marine terrace is likely equivalent in age to the Highway 1 terrace on Ben Lomond Mountain described by Weber and Allwardt (2001) that has a disputed age in the range of 50-150 thousand years.

Figure 8-21. An apparent thrust fault places Montara granitic rock over Quaternary marine terrace deposits. The basal conglomerate of the San Vincente terrace deposits rests unconformably on an irregular wave-cut bench surface of weathered granite. Thrust faulting (with possibly more significant strike-slip offset) occurred after the San Vicente terrace deposits had accumulated.

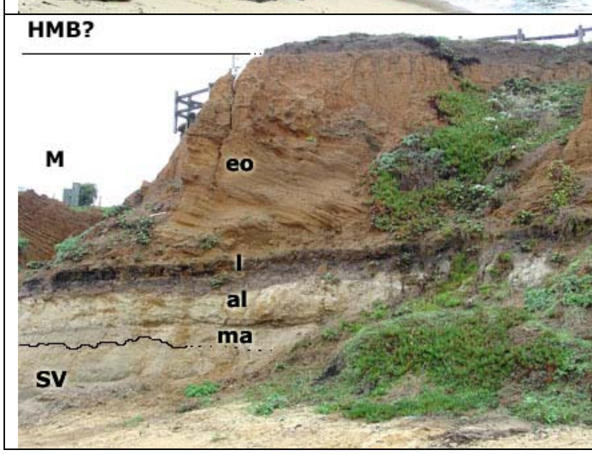

Figure 8-22. Quaternary terrace deposits are exposed in the beach cliff below the Montara State Beach parking area. San Vicente marine terrace deposits (SV) are unconformably overlain by the Montara terrace deposits (M). The Montara deposits consist of a thin lower marine gravel layer (ma), a layer of alluvial channel gravels (al), a lignite [coastal swamp] layer (l), and cross-bedded eolian dune sand (eo). Whether the upper surface along Highway 1 is the Half Moon Bay terrace (HMB?) is unclear. This is unlike the Ben Lomond Mountain area, where Marine terraces grow progressively older higher on the mountain. At Montara Beach, the marine terrace deposits are stacked on top of each other. To the south at Ben Lomond Mountain the land has been rising, but at Montara State Beach the land has been relatively stationary relative to sea level.

Stop 11 – James V. Fitzgerald Marine Preserve

Stop highlights: Seal Cove Fault, San Gregorio Fault System, syncline, Purisima Formation, fossils, tide pools

The tide pools at the James V. Fitzgerald Marine Preserve are an extremely popular destination for fieldtrips, and for good reason. The preserve is one of the closest tide pool areas to the city. Steeply dipping, folded rock layers are exposed on a broad wave-cut bench. At low tide an extensive network of tidal channels and pool areas are exposed. Because of the popularity of this destination, the area is highly protected. Please read the preserve's rules to help reduce impact on the fragile tide pool environment. Collecting of any kind of natural materials is prohibited. Rangers and volunteer naturalists are usually available for assistance. It is advisable to bring a wildlife field guide such as the *Audubon Guide to Seashore Creatures* or the *Audubon Guide to California* to help enjoy wildlife observation. The tide pools contain a diverse fauna including seaweed, crabs, urchins, sea anemones, mollusks, starfish, fish, and other shelled and soft-bodied invertebrates.

The James V. Fitzgerald Marine Preserve is also a special geologic preserve. The Seal Cove Fault, considered by many geologists to be a strand of the greater San Gregorio Fault System, crosses the shoreline in the preserve at Moss Beach. The fault cuts through sedimentary rocks of the Purisima Formation of late Miocene to Pliocene age. The fault goes offshore just south of the parking area on California Avenue. Unfortunately, the fault is covered by rip-rap on the cliff and cannot be seen. Bathymetry shows a submerged ridge bounded on the northeast by the Seal Cove Fault. The submerged ridge extends northward along the coast for about two miles north of Moss Beach.

In the tide pool area north of the Seal Cove Fault, the Purisima Formation consists of greenish gray sandstone, marl, mudrock, and some conglomeratic beds. The beds are only accessible during low tide; they locally contain an abundance of fossil mollusk shells, mostly large clams. Powell (1998; 2003) suggests that the layered rock units of the Purisima Formation north of the fault were deposited in intertidal depths to about 10 meters and the the rocks are about 2 to 4 million years old (Pliocene) based on a comparison with modern species. South of the fault, the rock formation has a more massive character and shell fossils are not as abundant. The rocks on the southwest side of the fault are part of an older unit within the Purisima Formation and were probably deposited in subtidal water depths of 100 to 700 meters. Bones of marine mammals, microfossils and rare invertebrate remains have been recovered from this portion of the Purisima Formation. They are older than the rocks to the north, but in the 3 to 5 million-year range.

Ongoing tectonic activity associated with the Seal Cove (San Gregorio) Fault System is responsible for the Moss Beach Syncline, a large fold that is exposed at low tide (fig. 8-23). Deposits of the Half Moon Bay Terrace are also exposed along the sea cliffs at Moss Beach (with an age of roughly 125,000 years). These elevated marine terrace deposits unconformably overlie the Purisima Formation. Boulders in the basal unit of the marine terrace display boring from marine pelecypods (*Pholad*). Look for fault offsets in the marine terrace deposits.

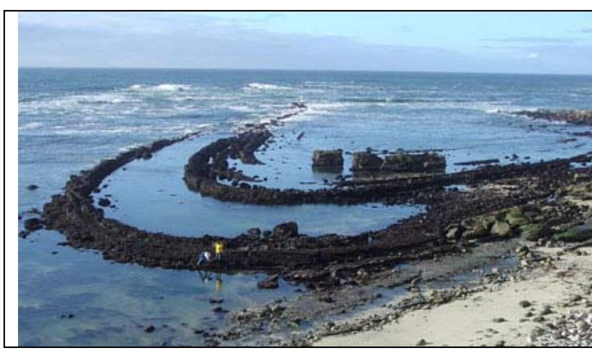

Figure 8-23. The Moss Beach Syncline, a broad fold, is exposed at low tide in the James V. Fitzgerald Marine Preserve. Folded sedimentary layers of the plunging syncline consist of fossilerous sandstone and mudrocks of the Purisima Formation (Miocene to Pliocene age). The Seal Cove Fault scarp is associated with a submerged ridge located near where the waves break just offshore of the syncline.

Stop 12 – Seal Cove Fault Near the Half Moon Bay Airport (rolling stop)

Stop highlights: fault scarp, offset Quaternary marine terrace, San Gregorio Fault System

The Seal Cove Fault is considered by many geologists to be an on-shore strand of the greater San Gregorio Fault System. Many questions remain unresolved about the San Gregorio Fault System; it is one of the least understood major fault systems in California partly because so little of it is exposed onshore. Geophysical and oceanographic data suggest it is part of the greater fault system that bounds the western margin of the Salinian Block (see fig. 8-20). The San Gregorio Fault System extends for about 230 km from the Big Sur region south of Monterey Bay and northward to where it merges with the San Andreas Fault System near Bolinas Bay north of San Francisco. Strands of the fault come onshore only in San Mateo County between Año Nuevo and Pescadero, and again between Pillar Point and Moss Beach (the latter is the Seal Cove Fault). Like the San Andreas Fault, the San Gregorio Fault displays significant late Quaternary offset. Based on geologic and geophysical evidence, total right-lateral offset along the fault from late Miocene time to the present is estimated between 115 km (Graham and Dickenson, 1978) and 156 km (Clark and others, 1984). Paleoseismicity studies show that the fault is still active. Trench studies along the Seal Cove Fault show that displacements of between 3 and 5 m occurred in the pre-Colonial era (sometime between 1270 and 1775 AD). These fault ruptures probably produced earthquakes of M=7 or greater (Simpson and others, 1997).

Continuing activity along the Seal Cove Fault is ominously revealed by a fault scarp that offsets the young Half Moon Bay Terrace near the Half Moon Bay Airport (fig. 8-24). The elevation of the airport runway is about 40 feet, whereas the high point west of the fault scarp is about 175 feet (fig. 8-25). The Half Moon Bay marine terrace formed when coastal erosion cut a broad bench during a Late Quaternary marine transgression. The flat, wave-cut surface of the marine terrace became exposed as sea level fell and the shoreline retreated seaward about 85,000 years ago. The marine terrace has remained exposed as the coastline (and the entire Santa Cruz Mountains) has progressively continued to rise. The Half Moon Bay Terrace is actually folded into a northwest trending, gently-plunging syncline (Lajoie, 1986). Since the marine terrace became exposed, the vertical component of offset along the Sea Cove Fault has produced the 140 foot high scarp that is visible today. The fault places latest Quaternary deposits adjacent to Pliocene-age marine mudstones of the Purisima Formation. Note that the rate of horizontal slip on the fault is probably ten to twenty times as great compared to the vertical offset during the same time period.

Figure 8-24. Scarp of the Seal Cove Fault, a strand of the San Gregorio Fault System, forms a linear ridge along the west side of the Half Moon Bay Airport.

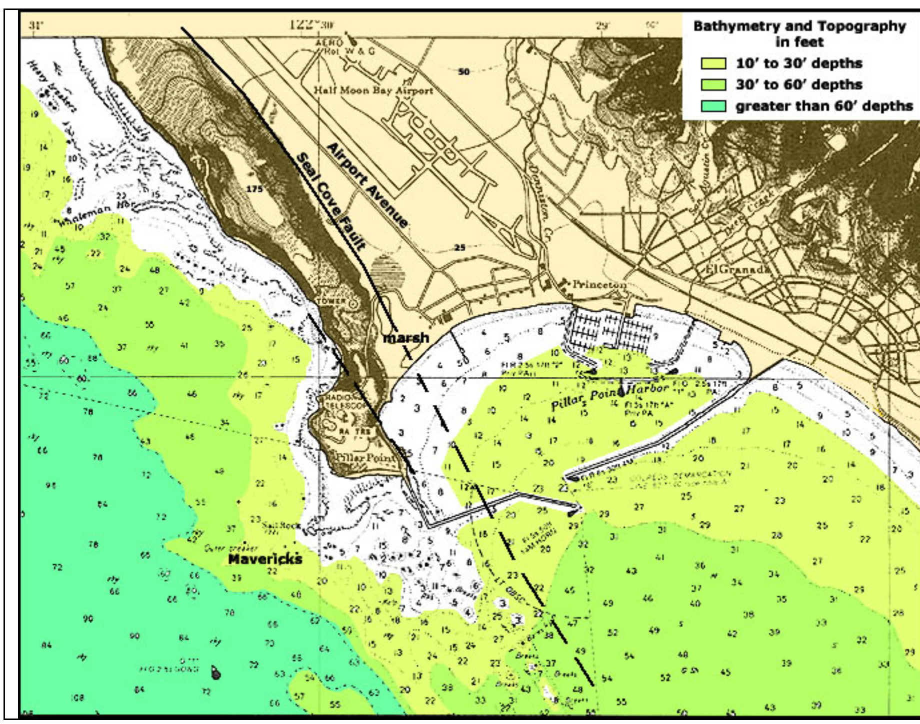

Figure 8-25. Bathymetry and topography along the Seal Cove Fault at Half Moon Bay. The Seal Cove Fault runs along the east side of a linear ridge along the coast between Moss Beach to the north (not shown) and near Pillar Point to the south. Rolling stop 12 is along Airport Avenue, and the parking area for stop 13 is located near the marsh label on the map. The map base is modified from NOAA Chart 18682.

Stop 13 – Pillar Point and Mavericks

Stop highlights: offset marine terrace, San Gregorio Fault System, small faults in sea cliffs, surfing large waves

Pillar Point is a headlands promontory that juts seaward at the west end of Half Moon Bay Harbor. A coastal access trail begins at a parking area next to Pillar Point Marsh. The trail provides access to an extensive wave cut bench with tide pools that extend seaward of the Pillar Point headlands. The marsh and the tide pool area are part of the James V. Fitgerald Marine Preserve. The marsh itself is part of a pull-apart basin (sag) associated with the Seal Cove Fault (labeled "marsh" on fig. 8-25). The marsh is a famous bird watching locality, especially during migration periods. **Warning!** Do not attempt to climb around the point beyond the end of the trail during high tide or during inclement weather.

The sea cliffs at Pillar Point consist of sand and mudstone of the lower Purisima Formation (late Miocene to Pliocene age). Rare fossils, mostly mollusks and marine mammal bone, have been observed in the rock (Powell, 1998, 2003). Pillar Point proper lies west of a fault that runs parallel approximately 450 meters to the southwest of the Seal Cove Fault. Other small faults that offset sandstone beds are exposed in the sea cliffs along the trail and around the point (fig. 8-26). Seaward of Pillar Point, a broad wave-cut platform and submerged rock reef extends seaward. A break in slope roughly follows the 10 fathom (60 feet) contour offshore (fig. 8-25). This rock reef extends offshore nearly a mile on the south side of the point. The high wave belt known in the surfing world as Mavericks is located along this westward-extending submerged promontory.

Mavericks is considered one of the most challenging wave surfing areas of the world, and professional surfers fly in from around the world to attempt to catch monster waves that frequently develop along the outer reef track area offshore of Pillar Point (labeled "Mavericks" on fig. 8-25). Typically several times a year, large weather systems in the northern Pacific Ocean create large wave trains that propagate across the ocean. Buoy and weather satellite data are used to make predictions as to when large wave conditions may occur, giving surfers and the watchful media time to gather at Pillar Point to catch the action. During high seas, waves in the 20 to 30 foot range are not uncommon, and waves in the 40 foot and higher range occur on rare occasions. Local legend tells of waves as high as 100 feet have been observed. Other hazards to surfing at Mavericks, in addition to at least one documented shark attack, are large rocks exposed along the reef or just below the surface where waves curl and crash, or in the chaotic surf shoreward of Mavericks. Although traditionally, surfers will paddle out to catch waves, many professional surfers attempt the higher and most dangerous waves only by being towed into harm's way behind a jet ski. However, despite the danger, very few people have been killed or severely injured at Mavericks. It is difficult to see surfers in action in the high waves from the shore. Movies featuring big wave surfing at Mavericks, however, are playing constantly at the nearby Half Moon Bay Brewing Company in Princeton by Half Moon Bay Harbor.

Figure 8-26. Sea cliffs on the south side of Pillar Point consist of mudstone and sandstone of the lower Purisima Formation. A high angle reverse fault in the middle of this image offsets a massive sandstone layer by about 10 feet.

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