# 7. Field Trip to the Skyline Ridge Area in the Central Santa Cruz Mountains

**Trip highlights:** San Andreas Fault scarps, sag ponds, vegetation and bedrock contrasts, regional vistas, Quaternary gravels, Tertiary marine rocks, ancient submarine landslide deposits, volcanic rocks (Mindego Basalt), Native American mortar holes in sandstone

This field-trip guide includes a collection of stops that may be selected to plan a geology field trip. The field-trip stops are along Highway 9 (Saratoga Road) and Highway 35 (Skyline Boulevard) between Castle Rock State Park and La Honda on Highway 84. Most stops are on lands maintained by the Midpeninsula Regional Open Space District. Outcrop and natural areas along the ridgeline crest of the Santa Cruz Mountains west of the San Andreas Fault are featured. Stops also include excursions to the fault itself in the Los Trancos and Monte Bello Open Space preserves. The inclusion of all stops listed below might be possible only with an early start and plans for a long day in the field. Stop descriptions below include information about interesting geologic features in the vicinity, but they may require additional hiking to visit (fig. 7-1).

Note that rattlesnakes can be encountered anywhere. Poison oak is prevalent, and ticks can be encountered any time of year, but mostly in the spring. The area is also mountain lion habitat. It is advisable to contact the Midpeninsula Open Space District before planning group visits to the preserves; maps and information are available on their website at http://www.openspace.org.

Geologic maps with descriptions of this region include Brabb and others (1997, 1998, and 2000). These maps are ideal for field-trip discussions. PDF format versions of the maps are available for downloading, plotting, or graphic modi-

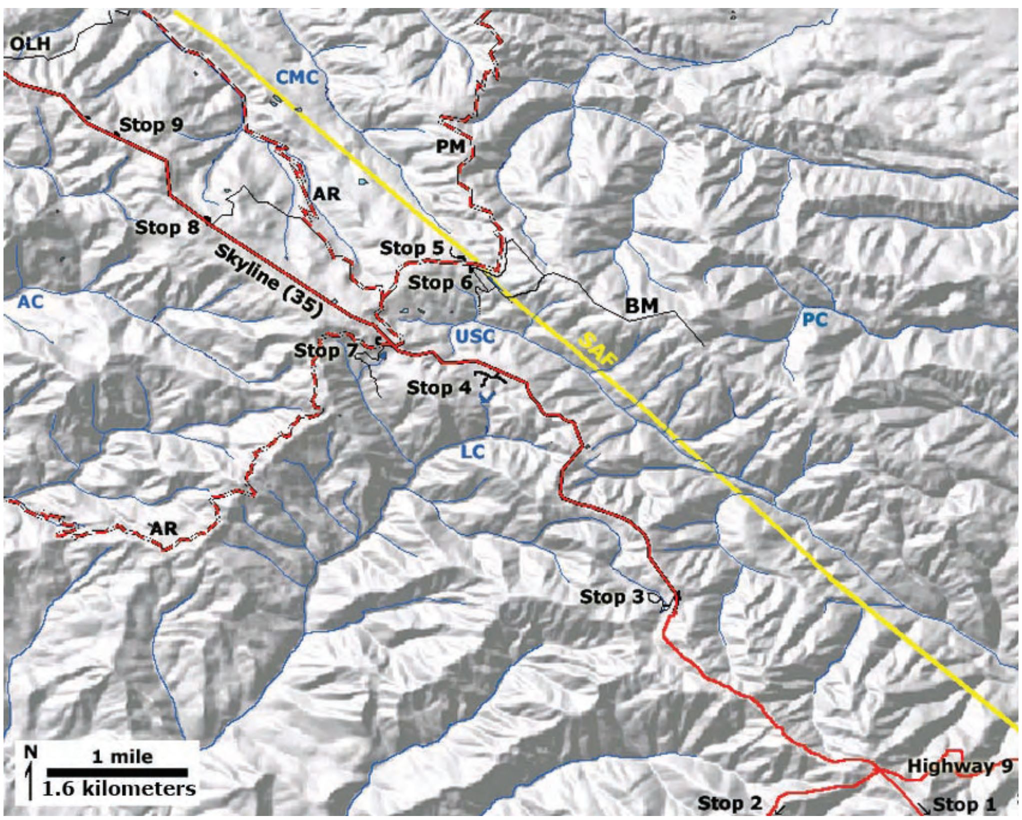


**Figure 7-1.** Map of the Skyline Ridge region of the north-central Santa Cruz Mountains along Highway 35 (Skyline Boulevard). The yellow line labeled SAF is the main trace of the San Andreas Fault. Stop 1 is at Castle Rock State Park. Stop 3 is a scenic overlook on Highway 9 west of Saratoga Gap. Stop 3 is the Long Ridge Open Space Preserve. Stop 4 is the Skyline Open Space Preserve. Stop 5 is the Los Trancos Open Space Preserve. Stop 6 is the Monte Bello Open Space Preserve. Stop 7 is the Russian Ridge Open Space Preserve. Stop 8 is a vista area near Clouds Rest. Stop 9 is Windy Hill Open Space Preserve. PM is Page Mill Road; AR is Alpine Road. BM is Black Mountain. Selected streams include Upper Stevens Creek (USC), Permanente Creek (PC), Corte Madera Creek (CMC), Lambert Creek (LC), and Alpine Creek (AC).

fication into handout at the *USGS San Francisco Bay Region Geology* website (http://sfgeo.wr.usgs.gov/).

The San Andreas Fault defines the boundary to two distinct geologic terranes in the north-central Santa Cruz Mountains. The east side of the San Andreas Fault is characterized by the Permanente Terrane, a belt of ancient oceanic crustal rocks (volcanic and sedimentary) of Cretaceous age that are part of the Franciscan Complex. The Permanente Terrane contains pillow basalt, sandstone, mudrocks, chert, and limestone in varying degrees of metamorphic grade, hydrothermal alteration, and structural shearing from both ancient and modern fault movement. Economic production of limestone is ongoing in the Permanente Creek area on the southeastern flank of Black Mountain in this field-trip area. The mine in the Permanente Creek area is about 2 miles directly east of Stop 6 (shown on fig. 7-1).

West of the San Andreas Fault is the Santa Cruz Mountain Block, a complex terrane composed of granitic and mafic igneous basement rocks that have intruded older Paleozoic and Mesozoic metamorphic rocks. These rocks are collectively called Salinian Complex. Salinian rocks are exposed to the southwest on Ben Lomond Mountain and in the north on Montara Mountain. In the Ben Lomond Mountain area, marble was historically mined for lime, and hard-rock aggregate is still actively mined. These crystalline basement rocks are overlain by a thick blanket of latest Cretaceous to late Tertiary sedimentary rocks and some basaltic volcanic rocks. In southern San Mateo and northern Santa Cruz counties this complexly faulted and folded sequence of sedimentary rocks is as much as 13,000 feet (4,000 m) thick and consists of rocks of Eocene, Oligocene, and Miocene age. Miocene-age volcanic rocks (Mindego Basalt) also occur in the Santa Cruz Mountain Block. These rocks of the Santa Cruz Mountains Block are bounded on the east by the San Andreas and Pilarcitos Faults and to the west by the San Gregorio Fault (rocks west of the San Gregorio Fault are part of the Pigeon Point Block). Oil production in the Half Moon Bay area was some of the first in California. Today, there is no active oil production in the region, however, some unrecovered oil (albeit small) may exist, as is suggested by a number of oil seeps in the region, perhaps most noteworthy being seeps along Tarwater Creek, a tributary in the greater Pescadero-Alpine Creek drainage area west of Skyline Ridge.

Page Mill Road generally defines the boundary between the Peninsula segment of the San Andreas Fault to the north and the Santa Cruz Mountains segment to the south. The Peninsula segment extends northward of Page Mill Road to offshore of San Francisco. It is characterized by very little seismicity since the massive magnitude 7.9 1906 San Francisco earthquake ruptured this section of the fault. The Peninsula segment also experienced an estimated magnitude 7.0 earthquake in 1838. Studies of offset alluvial fan deposits near San Andreas Reservoir suggest other major seismic events occurred at 1,810±50 years BP (before present) and 2,790±60 years BP as indicated by carbon 14 ages (Prentice and others, 1991). The average recurrence interval of major earthquakes on the Peninsula segment is estimated to be about 225 years. However, it must be stressed that earthquakes do not occur at regular preset intervals. Hall and others (1999) report an estimated overall slip rate of 17±4 mm/year for the Peninsula section, but the fault is currently displaying locked behavior. The modern Peninsula section of the San Andreas Fault runs parallel to, or slightly orthogonal to, the Pilarcitos Fault, which is an inactive ancestral strand of the San Andreas Fault. Although more than 185 miles (300 km) of offset is estimated for the San Andreas Fault in the San Francisco Bay region, only about 16 miles (26 km) of offset is accommodated by the modern Peninsula segment of the San Andreas Fault as determined by the offset of a belt of Cretaceous limestone within the Permanente Terrane of the Franciscan Complex (Griscom and Jachens, 1989). The rest of the offset occurred along the Pilarcitos Fault and other faults in the region.

In contrast to the Peninsula segment, the more seismically active Santa Cruz Mountains segment, which extends southward from Page Mill Road to the San Juan Bautista area, has experienced nearly a dozen magnitude 4 to 5 range earthquakes in the two decades proceeding the magnitude 6.9 1989 Loma Prieta earthquake. This seismicity shows that the plane of the San Andreas Fault dips at a steep angle approaching 75 degrees toward the west in the Santa Cruz Mountains.

# Road Log to the Skyline Ridge Region of the Central Santa Cruz Mountains

| Distance | Description |
|---|---|
| **0.0 mi (0.0 km)** | Intersection of Saratoga Road with Highway 85. |
| **1.7 mi (2.7 km)** | Intersection of Saratoga Road with Saratoga-Sunnyvale Road and Saratoga-Los Gatos Avenue (Highway 9) at downtown Saratoga. Proceed south on Highway 9 through downtown Saratoga. |
| **3.5 mi (5.6 km)** | The Mountain Winery is to the right (uphill about 1.2 miles to the parking area).<br><br>The Mountain Winery was originally the Paul Masson Winery. The old Paul Masson Winery building is now the back stage area for a 1,000 seat outdoor concert facility and party grounds. The grounds of the winery provide exceptional views of the South Bay region. The hilltop facility is built on a ridge between linear valleys defined by the Berrocal Fault to the east and the San Andreas Fault to the west. |
| **4.2 mi (6.7 km)** | Bridge over Sanborn Creek. Sanborn Road (to Sanborn Park) is on the left. |
| **5.0 mi (8.0 km)** | Savannah-Chanelle Vineyards is on the left. Highway 9 crosses the San Andreas Fault in this vicinity (it is not apparent along the road due to plant and colluvial cover). |
| **9.0 mi (14.5 km)**<br><br><br>**0.0 mi (0.0 km)** | Intersection of Highway 9 and Skyline Boulevard (Highway 35) at Saratoga Gap. Proceed south on Highway 9. **Reset the odometer mileage to zero**.<br>Saratoga Gap Vista Area is a convenient gathering area at the intersections of Highway 9 and 35. Although the area is frequently patrolled, take things of value with you. |
| **2.6 mi (4.2 km)** | **Stop 1—Castle Rock State Park** (see stop description below). Restrooms are available here, albeit primitive.<br><br>After the stop, return north to Highway 35 at Saratoga Gap. |
| **0.0 mi (0.0 km)** | Intersection of Highway 35 northwest of Highway 9 at Saratoga Gap; **Reset the odometer mileage to zero** at the intersection. |
| **1.7 mi (2.7 km)** | **Stop 2—Highway 9 Vista Point at Castle Rock State Park** (see stop description below). The overlook is on the left (east) side of the road. A restroom is available at this stop.<br><br>After the stop, return north to Highway 35 at Saratoga Gap. |
| **0.0 mi (0.0 km)** | Intersection of Highway 35 northwest of Highway 9 at Saratoga Gap; **Reset the odometer mileage to zero** at the intersection. |
| **0.7 mi (1.3 km)** | Saratoga Summit Fire Station is on the left. |
| **1.3 mi (2.1 km)** | **Stop 3—Long Ridge Open Space Preserve** (see stop description below).<br><br>After the stop continue north on Highway 35. |
| **5.4 mi (8.7 km)** | **Stop 4—Skyline Ridge Open Space Preserve** (see stop description below). |
| **6.3 mi (10.1 km)** | Intersection of Skyline Boulevard (35) with Page Mill Road and Alpine Road. Turn right on Page Mill Road. |
| **7.6 mi (12.2 km)** | **Stop 5—Los Trancos Open Space Preserve** (see stop description below).<br><br>A restroom is available at this stop. Continue to the Monte Bello Preserve across Page Mill Road. |

**Continued.**

| | |
|---|---|
| **7.7 mi (12.3 km)** | **Stop 6—Monte Bello Open Space Preserve** (see stop description below).<br><br>A restroom is available at this stop. Return to the intersection of Page Mill and Highway 35. The parking area to the Russian Ridge Open Space Preserve is just across Highway 35 on Alpine Road. |
| **8.9 mi (14.3 km)** | **Stop 7—Russian Ridge Open Space Preserve** (see stop description below).<br><br>A restroom is available at this stop. |
| **0.0 mi (0.0 km)** | Return to the intersection of Alpine Road and Highway 35. Turn left (north) on Skyline Boulevard. **Reset the odometer mileage to zero**. |
| **1.1 mi (1.8 km)** | **Stop 8—Vista Point along Skyline Boulevard** (see stop description below).<br><br>After this stop continue north on Highway 35. |
| **4.8 mi (7.7 km)** | **Stop 9—Windy Hill Open Space Preserve** (see stop description below). A restroom is available at this stop. **End of field trip**.<br><br>**For location reference only:** north-bound travelers will find the intersection of Skyline Boulevard with La Honda Road (Highway 84) 2.2 miles north of the Windy Gap Open Space Preserve. Highway 84 connects between I-280 at Woodside and Highway 1 along the coast at San Gregorio State Beach. Alice's Restaurant is at located the intersection of Skyline Boulevard and Highway 84. Highway 84 provides a better return route to Highway 280 than the narrow, steep, and winding Page Mill Road. |

## Stop 1—Castle Rock State Park

**Stop highlights**: Massive Tertiary marine sandstone outcrops, tafoni-style weathering, vistas along Castle Rock Ridge

East of Highway 9, Skyline Boulevard follows Castle Rock Ridge; home of Castle Rock State Park. Castle Rock State Park is most famous for its massive outcrops of arkosic (feldspar-rich, lithic-poor) sandstone (lower to middle Eocene age). The Butano Sandstone forms the ridgeline of Castle Rock Ridge and much of Skyline Ridge and other ridges in the Santa Cruz Mountains west of the San Andreas Fault. The Butano Sandstone Formation contains as much as 10,000 feet (3,000 m) of marine rocks that are mostly sandstone but that also include interbedded shale and conglomerate.

It is advisable to call the park office in advance of a field trip to ensure that there is no conflict with other scheduled events and to inquire about park access fees for educational field trips. Parking within the State park lot requires a day use fee. Along the road parking is free; however, it can be quite limited on weekends and holidays.

The shortest route to see massive outcrops of Butano Sandstone is a 0.1 mile (0.2 km) trail to Indian Rock on the east side of the road. Indian Rock provides a view of Sanborn Creek Valley (along the San Andreas Fault). Be aware that the sandstone is slippery when wet and climbing on the rocks without appropriate equipment can be hazardous!

Slightly longer hikes include an uphill, about 0.3 mile (0.5 km) walk to Castle Rock itself. The trail starts in the main parking area. Castle Rock also displays spectacular cave-like tafoni weathering. Goat Rock Overlook along the Ridge Trail provides spectacular views of the San Lorenzo River Valley to the west. Goat Rock is perhaps the highest cliff in the park (about 200 feet or 65 meters) and involves a more strenuous hike of about 1 mile (1.6 km). In addition, Castle Rock Falls overlook is worth the detour from the Ridge Trail.

Note the tafoni-style weathering of the sandstone (fig. 7-2). Tafoni forms from differential weathering of sandstone over time. Precipitation soaks into the sandstone and dissolves mineral cements that then migrate to the rock surface as the rock dries. This produces a hardened patina crust on rock surfaces. The sand that has lost its cement inside the rock easily

**Figure 7-2.** Goat Rock is a popular hiking destination in Castle Rock State Park. It is deeply pocketed by tafoni-style weathering.

crumbles when exposed, resulting in the cave-like holes in the sandstone.

## Stop 2—Highway 9 Vista Point

**Stop highlights:** Vista of the Monterey Bay region, Ben Lomond Mountain (a fault-bounded block of Salinian basement)

The vista point is located 1.8 miles south of the intersection of highways 9 and 35 at Saratoga Gap. The stop provides views south and west of Castle Rock Ridge toward the southwestern Santa Cruz Mountains and the drainage basin of the San Lorenzo River (fig. 7-3). Distant views on a clear day include Monterey Peninsula and Monterey Bay. The valley of the San Lorenzo River is underlain by a complexly folded and faulted sequence of marine sedimentary rocks, mostly shale, of Eocene, Oligocene, and Miocene age. To the west is Ben Lomond Mountain, a massive block of Salinian crystalline basement rock overlain by a discontinuous cover of late Tertiary sedimentary rocks that are bounded on the northeast by the Ben Lomond Fault. Closer by is the southern end of Butano Ridge, a ridge of resistant Butano Sandstone bounded on the northeast by the Butano Fault. Castle Rock Ridge along Highway 35 is also a ridge composed of Butano Sandstone bounded on the northeast by the San Andreas Fault. All three faults, and others in the San Lorenzo River Valley, display evidence of Quaternary offset and may be capable of producing earthquakes.


**Figure 7-3.** View looking southwest from the vista area along Highway 9, located 1.8 miles (3 km) south of Saratoga Gap. MB is Monterey Bay; BLM is Ben Lomond Mountain, and BR is Butano Ridge. The entire visible landscape is part of the San Lorenzo River basin. The valley is typically shrouded in fog in the morning hours.

The Skyline to the Sea Trail passes through the vista area. The uphill end of the trail begins at Saratoga Summit in Castle Rock State Park. The-18-mile long trail passes through Big Basin State Park and ends at Waddell Creek near Año Nuevo State Park along Highway 1 at the border between Santa Cruz and San Mateo Counties.

## Stop 3—Long Ridge Open Space Preserve

**Stop highlights:** Tertiary sandstone outcrops, vista of fault-bounded Butano Ridge, oak and mixed evergreen forest

Long Ridge Open Space Preserve offers trails through grassland bald areas and mixed evergreen forests (consisting of moss-covered live oaks, bay laurels, madrone, and Douglas fir). A 0.25 mile (0.4 km) walk from the trail head leads to a rocky outcrop on the ridgeline consisting of Butano Sandstone of Eocene age (fig. 7-4). The view to the west encompasses the straight valley of Pescadero Creek where it follows the trace of the Butano Fault at the base of Butano Ridge. This region is the most extensive wilderness areas left in the Peninsula region and encompasses Portola, Pescadero Creek, and Butano State Parks. Although the region was heavily lumbered in the late 19th and early 20th centuries, many of the redwood groves are returning. Efforts are now underway to restore the Pescadero Creek salmon population.

From the parking area proceed west and then north on the main trail (Hickory Oaks Trail). Butano Sandstone outcrops can be seen on a foot trail that cuts off to the left near the top of the hill. Watch out for rattlesnakes and poison oak. An additional distraction is a walk through an amazing oak grove on a spur trail that leads to the left (south) a short distance from the trail head. About 10 vehicles can fit if parked closely along the roadside parking area on Highway 35. Additional space for 6 more vehicles are a short distance north along the road.

## Stop 4—Skyline Ridge Open Space Preserve

**Stop highlights:** Ancient submarine landslide deposits (Lambert Shale), restored upland habitats

This stop involves a 0.6 mile (1 km) round-trip walk to Horseshoe Lake at the head of Lambert Creek (fig. 7-5). Upon entering the preserve, turn right and park in the northernmost parking area. A sign at the trail head says "Ridge Trail to Horseshoe Lake 0.3 mi."

The area along the road was once a Christmas tree farm (soon to be restored to its original oak woodlands and grasslands setting). Horseshoe Lake has a beautiful setting amongst mixed evergreen and Douglas fir forests. Bobcats are frequently seen here, and the area is mountain lion habitat. On warm days, the air around the pond can be crowded with dragonflies. A small trail next to a wooden bridge leads to the dam spillway and a small outcrop area of Lambert Shale (the destination of this field-trip stop). Be cautious handling rocks and plant material because scorpions, black-widow spiders, and poison oak are found here. Also note that the creekbed exposures may not be accessible during the wet winter season.

The Lambert Shale is of Oligocene to lower Miocene age and is about 4,800 feet (1,460 m) thick in the Santa Cruz Mountains. It only occurs west of the San Andreas Fault. The formation consists of dark-gray to pinkish-brown, moderately well cemented siliceous mudstone, claystone, and siltstone. Sandstone bodies as much as 100 feet (30 m) thick, glauconitic sandstone beds and microcrystalline dolomite are present

**Figure 7-4.** This view looking toward the northwest shows small outcrops of Butano Sandstone in a grassy "bald" area along Long Ridge. The valley of Pescadero Creek and Butano Ridge are in the distance.

**Figure 7-5.** View of Horseshoe Lake in the headwaters of Lambert Creek. A mixed evergreen and Douglas-fir forest grows on the cooler, wetter, north-facing slopes. Chaparral grows in the foreground on the drier south-facing slopes.

in places. The upper part of the section contains chert. In outcrop, it resembles the Santa Cruz Mudstone and parts of the Purisima Formation (exposed along the coast between Santa Cruz and Half Moon Bay); (Brabb and others, 2000).

This small outcrop at the dam spillway is a typical Lambert Shale outcrop in the Santa Cruz Mountains; there isn't much to see at first. However, closer inspection reveals curious features about this mudrock formation. Note the character of the small sandstone bodies in the outcrop area. The sandstone bodies have unusual shapes ranging from smooth and rounded to elongate or jagged. They suggest that the Lambert Shale accumulated, in part, as massive chaotic units, possibly as massive submarine landslide deposits. The siliceous nature also suggests deposition in offshore areas of upwelling marine currents where siliceous diatom blooms occurred.

## Stop 5—Los Trancos Open Space Preserve

**Stop highlights**: Fault scarps, pull-apart basin with sag pond, view of the San Andreas Rift Valley, Pliocene- and Pleistocene-age alluvial gravels (Corte Madera facies)

Volunteers from Foothill College developed and maintain the San Andreas Fault Trail at Los Trancos Open Space Preserve. The trail follows the trace of the San Andreas Fault and associated slump escarpments throughout oak woodlands. Posts have been placed along the lines of ground rupture from the 1906 earthquake. A popular destination along the Los Trancos Fault Trail is a historic fence line offset by the strike-slip rupture of the fault has been restored to its original orientation; the original fence has long since deteriorated. Other features include trees that fell during the 1906 earthquake and have since regrown and scenic vistas along the trace of the San Andreas Fault (fig. 7-7). The Midpeninsula Open Space District provides a brochure for the San Andreas Fault Trail that describes nine stops along a 1.5 mile (2-4 km) hiking route (http://www.openspace.org/preserves/pr_los_trancos.asp). This field trip only utilizes hiking two stops from the San Andreas Fault Trail brochure.

Just to the north of the parking area in a chaparral-covered saddle between two hills. During wet periods water accumulates in a low area here. The saddle represents a small pull-apart basin (with sag pond). Low white-capped posts show the location of surface rupture caused by the 1906 earthquake. However, this is not considered the main trace of the San Andreas Fault. It is one of many areas throughout the Santa Cruz Mountains where intense earthquake shaking caused gravity driven ridge-crest spreading and slumping. The main trace of the San Andreas Fault is several hundred feet to the east of this location.

**Hiking Stop One** is located at an overlook a short distance beyond the trailhead at the west end of the Los Trancos parking area. This overlook provides a similar vista of the Upper Stevens Creek valley as the one described below at the Monte Bello Preserve. The overlook is along a section of trail lined with boulders of conglomerate containing clasts of volcanic rock (andesite porphyry, diorite, and gabbro) imbedded in a tightly cemented sandy matrix. These boulders were derived from Cretaceous-age conglomerates exposed along the Sierra Azul Ridge from Mount Umunhum and Loma Prieta Peak, nearly 23 miles (37 km) to the south (and visible on a clear day from this location). The poorly consolidated sandy gravel bearing the conglomeratic boulders are named the "Corte Madera facies" of the Santa Clara Formation, named after Corte Madera Creek, the drainage just north of this location along the San Andreas Fault. These poorly consolidated sediments are estimated to have been deposited roughly 2 million years ago on an alluvial fan draining from the Sierra Azul and Loma Prieta Peak summit region. Right-lateral movement of the fault has offset these materials from their sediment source area by a minimum distance of about 19 miles (30 km), providing an average long-term rate of offset at about 15 mm per year. These ancient deposits are preserved in a massive sliver-like trough within San Andreas Fault Zone that extends from Upper Stevens Creek Valley into the Corte Madera Creek drainage. The Corte Madera facies deposits are well drained and preferentially support grasslands and chaparral habitats in contrast to the surrounding rocks that host mixed evergreen forests and oak woodlands.

**Hiking Stop Two** is several hundred feet farther along the trail and is located at a monument in a grassy field with a spectacular view of the central San Francisco Bay region. This stop provides a view northward along the San Andreas Fault along the Corte Madera Creek drainage and onward to Crystal Springs Reservoir and San Andreas Lake, two reservoirs built in the San Andreas Rift Valley that can be seen from here on a clear day. The San Andreas Fault was named for a natural sag pond along the fault that was inundated by the construction of San Andreas Reservoir dam. This overlook provides an opportunity (on a clear day) to reflect on the setting and natural history of San Francisco Bay region.

On a clear day Mount Diablo, the East Bay Hills, and the Diablo Range are visible east of the bay. The Hayward Fault runs along the base of the western slope of the East Bay Hills. The bay itself floods an ancient valley system associated with the stream and river system that drains through the bay. During the climax of the last ice age about 18,000 years ago, sea level was as much as 400 feet (120 m) lower, and these river systems merged and flowed into a canyon that is now the Golden Gate.

Return to the parking area and cross the road to the parking lot for the Monte Bello Preserve to continue this walking excursion.

**Figure 7-6.** Boulders of conglomerate like this one are common along the trails near the parking area for Los Trancos and the Monte Bello Preserves. The conglomerate boulders consist of tightly cemented gravels dominated with clasts of andesite porphory and are part of the Corte Madera facies of the Santa Clara Formation, with an original source area in the Loma Prieta and Mount Umunhum summit region. The boulders are within alluvial deposits that filled a combination erosional and structural trough along the San Andreas Fault zone. These deposits are now exposed in a geographic high in a saddle between the Upper Stevens Creek and Corte Madera Creek drainages (see also figures 3-4 and 3-5).

## Stop 6—Monte Bello Open Space Preserve

**Stop highlights:** Sag pond, fault scarps, vegetation and bedrock contrasts, Franciscan Complex, limestone, conglomerate

**Hiking Stop One** is at the trail head in the Monte Bello Preserve parking area. Maps of the preserve are on display.

**Figure 7-7.** Trees like this oak along the San Andreas Fault Trail are a living reminder of the damage caused by the 1906 earthquake. Many older trees in both the Los Trancos and adjacent Monte Bello Open Space Preserve display damage from falling over or being broken during the earthquake.

Blocks of locally derived serpentinite and conglomerate are around the trail head. The blocks are from the Corte Madera facies of the Santa Clara Formation. Vegetation contrasts in the Upper Stevens Creek Valley partially reveal that the Corte Madera facies fill a structural graben in the San Andreas Rift Valley. In the Monte Bello Preserve, the Corte Madera facies contains a interesting mix of rock types—cobbles and boulders of serpentinite, conglomerate, and mollusk-bearing marine sandstone can be found amongst the blocks and pieces of andesite porphyry-bearing conglomerate that dominate the deposit. These rocks are also well exposed nearby as blocks, boulders, and cobbles in the creekbed of Upper Stevens Creek. The fossils include turritellid gastropods, crepidula, clams, and other bivalves encased in coarse sandstone probably of Late Miocene age. The fossiliferous sandstone derived from an unknown source along the rift valley, possibly the upper Lambert Shale.

**Hiking Stop Two** is at the intersection of two paths approximately 0.1 miles (0.2 km) south of the trailhead. This location provides an excellent view to the south along the straight valley of Stevens Creek with Mount Umunhum and Loma Prieta Peak in the distance (fig. 7-8). The trail to the right descends to Upper Stevens Creek (a good place to observe a mixture of rocks and bedrock exposures along the west side of the valley). A change in vegetation along the east side of this grassy area probably marks the boundary between the Santa Clara Formation gravels under the grasslands and the forest-covered Tertiary sedimentary formations that lie west of the San Andreas Fault (mostly Lambert Shale of Oligocene to Miocene age in this area). This vegetation boundary probably defines the trace of the Pilarcitos Fault, an ancient strand of the San Andreas Fault that splays off the current main strand of the San Andreas Fault at this point. The Pilarcitos Fault extends northward to the Rockaway Beach area on the San Mateo Coast before going offshore (see chapter 8). However, evidence of a fault in this area is not clear beyond a change in bedrock and vegetation. No fault plane is seen in the stream bed outcrops. In contrast, the active main trace of the San Andreas Fault is clearly visible on the east side of the valley where surficial offset, fresh fault scarps, and other features associated with the fault are obvious.

Four distinct plant communities reflect the underlying geology and soil conditions: mixed evergreen and oak woodlands and chaparral cover the ancient bedrock east of the San Andreas Fault on Black Mountain. Grasslands cover the alluvial gravels of the Santa Clara Formation under the central valley area, and Douglas fir forest covers the marine shale and sandstone that underlie Skyline Ridge on the west side of the fault valley.

**Hiking Stop Three** is along the San Andreas Fault. From the trail intersection follow the trail to the west through the old walnut orchard to the Monte Bello Road (trail). Monte Bello Road follows the escarpment of the 1906 rupture of the San Andreas Fault. The size and extent of this escarpment and associated sag pond that fills the fault zone here suggests this fault trace has been experiencing episodic earthquakes for

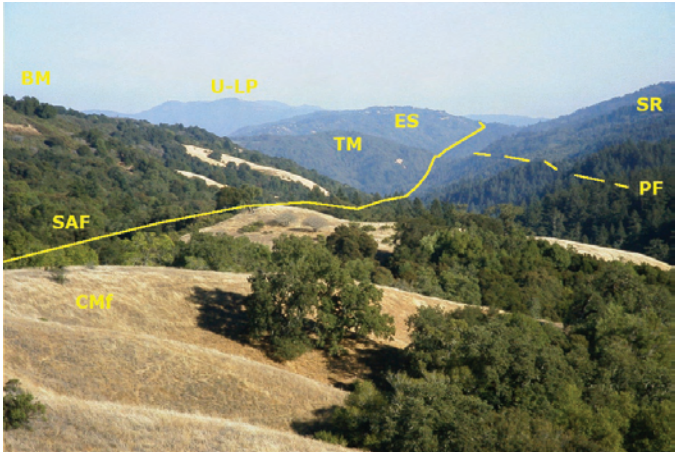


**Figure 7-8.** This view is looking southeast along the straight valley of Upper Stevens Creek that basically follows the trace of the San Andreas Fault (SAF). Black Mountain (BM) is on the left, and Skyline Ridge (SR) is on the right. Table Mountain (TM) and El Sereno Ridge (ES) near Saratoga Gap are in the middle of the image. The fault passes to the right (west) of the Mount Umunhum Loma Prieta summit area (U-LP) and in the distance. The conglomerate boulders in the Corte Madera facies gravels (CMf) that underlie the grasslands in this vicinity were derived from outcrops in the ancestral summit areas of those two mountains. The Pilarcitos Fault (PF) probably follows the drainage of Upper Stevens Creek on the right.

many thousands of years. It also implies that there is a vertical component to fault motion (hence the escarpment). Walk to the south along Monte Bello Road to a park bench adjacent to the sag pond and several large Bay Laurel trees (fig. 7-9). An interpretive plaque describes the succession of pond formation and filling along the fault. A large boulder of serpentinite is visible next to the shore of the pond a short distance south of the park bench. South of the Sag Pond the landscape along the fault zone displays an unusual topography, hinting of a series of fault-bounded grabens and horsts within the fault zone. About 0.8 mile (1.3 km) south of the sag pond is a small abandoned quarry in Franciscan limestone.

**Hiking Stop Four** is located near the intersection of Monte Bello Road (trail) and Page Mill Road. Return by the Monte Bello Road toward the parking area. The outcrop is near where the fault crosses Page Mill Road and is on the east side of the fault. This small outcrop consists of highly sheared greenstone (altered basaltic rock) with pods of dolomitic limestone. These are likely ancient pillow basalt (now sheared and altered) with calcareous marine ooze deposits (dolomitic limestone) of Early Cretaceous age. Massive limestone deposits on Black Mountain and the surrounding area are interpreted as ancient oceanic atoll deposits that were accreted onto the continental margin rather than being subducted during formation of the Franciscan Complex in the region east of the San Andreas Fault. Surficial weathering of these limestone deposits has produced an unusual karst landscape on the top of nearby Black Mountain (fig. 7-10).

Return to the parking area via the dirt path along the south side of Page Mill Road. Cobbles and boulders of conglomerate of the Corte Madera facies are exposed along the trail.

## Stop 7—Russian Ridge Open Space Preserve

**Stop highlights:** Outcrops of Tertiary marine rocks (Vaqueros Sandstone and Lambert Shale), Native American grinding mortar holes, oak woodlands

Follow the Old Page Mill Trail to the spillway area of Alpine Lake about 0.1 mile (0.2 km) south of the Russian

**Figure 7-9.** Bay Laurels grow on an up-thrust escarpment of the San Andreas Fault next to a long, linear sag pond that fills the fault zone. This view is along the Monte Bello Road (trail).

**Figure 7-10.** These limestone outcrops on the top of Black Mountain display karst weathering. This limestone is mined in the Kaiser-Permanente (Stevens Creek) Quarry on the southeastern flank of Black Mountain.

**Figure 7-11.** These mortar holes made by prehistoric Native Americans are in a Vaqueros Sandstone outcrop along Alpine Creek below the dam at Alpine Lake.

Ridge Open Space parking area at the intersection of Alpine and Skyline roads. Below the dam is a massive outcrop of Vaqueros Sandstone (Oligocene to Early Miocene age, or roughly 30 to 20 million years old). Examine the outcrop to determine the orientation of the graded bedding of the sandstone and the structural strike and dip of the beds.

Oak woodlands and a perennial supply of water made this an attractive area to prehistoric people who carved many mortars (round holes) in the sandstone of natural stone ledge of a waterfall along the streambed below Alpine Lake (fig. 7-11). These ancient people probably used the mortars to grind and process acorns and other seeds harvested from the surrounding area.

**Figure 7-12.** Laminated beds in sandstone and shale in the Lambert Shale along the loop trail at Russian Ridge Open Space Preserve.

An optional loop walk of about 0.4 mile (0.7 km) is to continue west on Old Page Mill Trail and take a foot trail to the right that loops around to the main trail. This trail junction is less than 0.1 mile (0.2 km) west of the dam. This trail provides vistas of the redwood and mixed evergreen forests in the Alpine Creek drainage basin. The trail leads through mature oak woodlands and grass-covered slopes to an outcrop of interbedded sandstone and shale (fig. 7-12). This rock is part of the Lambert Shale, also of Oligocene to Early Miocene age, or roughly 30 to 20 million years old. Return via the Old Page Mill Trail to Alpine Lake. A visitor center next to the pond has nature exhibits, an interesting collection of stuffed animals, and at least one snake.

## Stop 8—Vista Point along Skyline Boulevard (Highway 35)

**Stop highlights**: Vista of the San Francisco Bay region, boulders of Mindego Basalt, a soil profile

Near this vista parking area is a local road named Clouds Rest. The vista area provides a spectacular view of the midpeninsula region of San Francisco Bay. On a clear day, visibility extends to Mount Diablo, the highest peak in the northern end of the Diablo Range in Contra Costa County. This area is frequently shrouded in morning fog, especially when a thick marine layer moves in from offshore. The entire Highway 35 passage through the Santa Cruz Mountains can become immersed in dense fog with miserable wet and windy conditions any time of year. It is best to avoid this high section of highway when these conditions persist.

The stop also provides an exposure of a thick soil profile in the cut on the opposite side of the road from the overlook parking area. Here, a thick blanket of colluvium bearing basaltic boulders overlies deeply weathered shale bedrock. The basalt is derived from local sources in the surrounding uplands. The Mindego Basalt and related volcanic rocks occur in the northern Santa Cruz Mountains. These basaltic rocks are both intrusive and extrusive and are of Oligocene and Miocene age. The Mindego Basalt has yielded a radiometric age of 20.2 (±1.2) million years (Brabb and others, 2002). The intrusive igneous rock is medium to coarsely crystalline and is dark greenish gray to orange brown. As in the vista point outcrop, the basalt commonly weathers spheroidally and crops out as tabular bodies intruding older sedimentary rocks. Minor amounts of sandstone and mudstone are also locally exposed in the road cut (fig. 7-13).

## Stop 9—Windy Hill Open Space Preserve

**Stop highlights:** Vistas of the San Francisco Bay region, the San Mateo Coast, and the San Andreas Rift Valley

The grass covered hilltops along Highway 35 at Windy Hill Open Space Preserve provide unhindered observation of the northern Santa Cruz Mountains from the Pacific Ocean to San Francisco Bay and beyond. A short trail (about 0.2 mile) starts at the parking area and winds around the side and eventually to the top of the hill just to the north of the parking area. From here, the trace of the San Andreas Fault can be seen from the Monte Bello Preserve area northward to Crystal Springs Reservoir and beyond. Shale and sandstone of the San Lorenzo Formation and the Butano Sandstone underlie the grasslands and oak woodlands along this section of Skyline Boulevard (fig. 7-14).

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**Figure 7-13.** A thick blanket of colluvium bearing spheroidally weathered boulders of basalt overlies deeply weathered shale bedrock at the Highway 35 vista point near Clouds Rest.

**Figure 7-14.** The San Andreas Fault follows the valley of Corte Madera Creek on the north side of Black Mountain (the high point in this image).

# 8. Field-Trip Guide to Faults and Geology in San Mateo County—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.

## Planning Your Field Trip

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

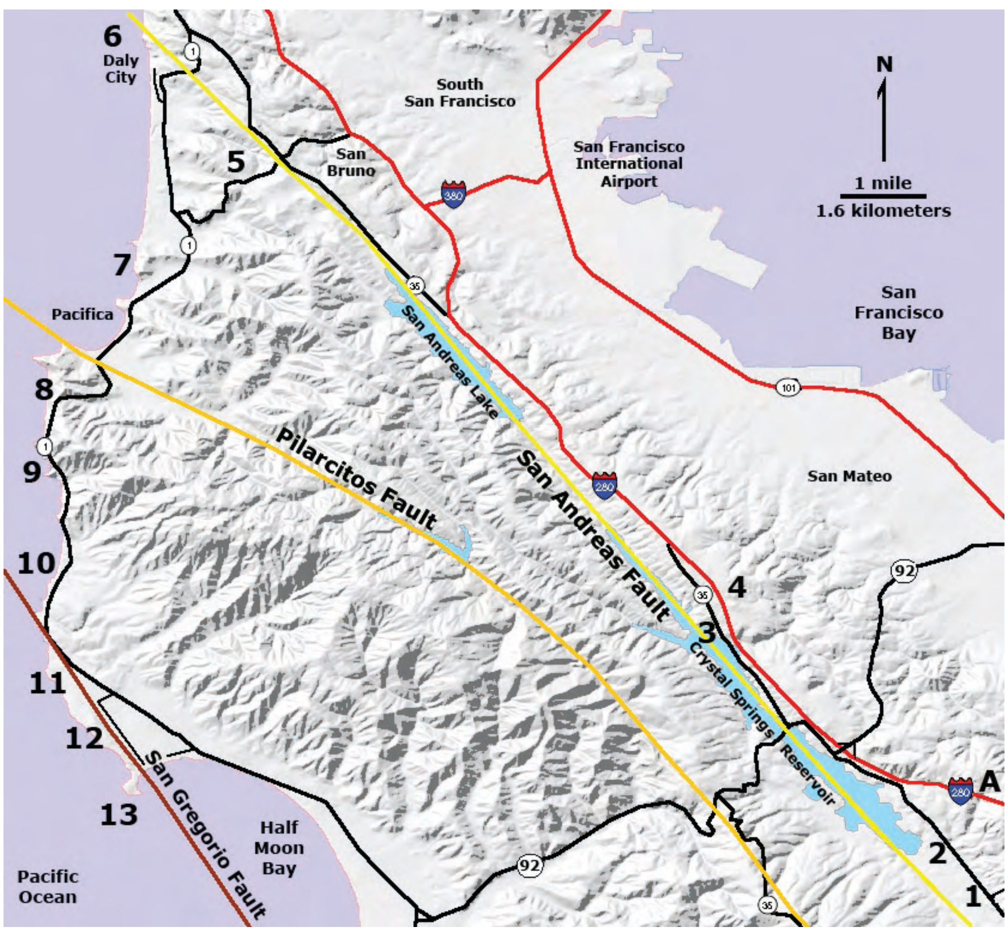


**Figure 8-1.** Map of the southern San Francisco Peninsula showing major faults in the northern Santa Cruz Mountains in San Mateo County. Stops include: (A) I-280 Vista Point, (1) Filoli Center, (2) Pulgas Water Temple, (3) Crystal Springs Dam, (4) I-280 Rest Area, (5) Milagro Ridge, (6) Mussel Rock 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.

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 Road 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

| Distance | Description |
|---|---|
| **0.0 mi (0.0 km)** | **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 (7 km) north of Woodside Road (Highway 84) and is 6 miles (10 km) south of the Highway 92 exit for Half Moon Bay.<br><br>Drive west on Edgewood Road. |
| **0.7 mi (1.1 km)** | Turn right (north) on Cañada Road.<br><br>Note that Cañada Road runs roughly parallel to the San Andreas Fault through its rift valley. Outcrops of Franciscan sandstone (graywacke), greenstone, and some serpentinite can be seen along the road and in bedrock exposures along the shoreline of Crystal Springs Reservoir. |
| **2.0 mi (3.2 km)** | **Stop 1—Filoli Center** (optional stop; see description below).<br><br>Continue north on Cañada Road. |
| **2.4 mi (3.9 km)** | **Stop 2—Pulgas Water Temple** (optional stop; see description below).<br><br>Continue north on Cañada Road. |
| **4.7 mi (7.6 km)** | Intersection of Cañada Road and Highway 92. Bear left (west at the stoplight). |
| **5.4 mi (8.7 km)** | Turn right (north) on Skyline Boulevard (Highway 35).<br><br>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 mi (10.1 km)** | Intersection of Bunker Hill Drive. Continue north on Skyline Boulevard. |
| **6.8 mi (10.9 km)** | Cross Crystal Springs Dam and proceed to the parking area to the left on the north side of the dam. |
| **6.9 mi (11.1 km)** | **Stop 3—Crystal Springs Dam** (see description below). |
| **7.5 mi (12.1 km)** | Return south on Skyline Boulevard to Bunker Hill Drive. Turn left on Bunker Hill Drive. |
| **7.6 mi (12.2 km)** | Turn left (north) on I-280. |

**Continued.**

| | |
|---|---|
| **8.0 mi (12.9 km)**<br><br>**0.0 mi (0.0 km)** | **Stop 4—I-280 Rest Area [northbound only] (see description below).** Restrooms are available.<br><br>**Reset the odometer mileage to zero.** Continue north on I-280. |
| **5.5 mi (8.8 km)** | Exit on Skyline Boulevard (Highway 35—Pacifica exit). |
| **6.0-7.0 mi (9.7-11.3 km)** | 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, originally 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 mi (14.4 km)** | Turn left on Sharp Park Drive. |
| **9.7 mi (15.6 km)** | Turn right to the park access lane to Milagra Ridge just past College Drive. |
| **9.9 mi (15.9 km)** | **Stop 5—Milagra Ridge** (part of Golden Gate National Recreation Area; see description below).<br><br>Return east to Skyline Boulevard (Highway 35). Turn north on Skyline. |
| **14.4 mi (23.2 km)** | Exit on Highway 1 South. |
| **15.9 mi (25.6 km)** | Exit at Palmetto Drive. It is a hard-right turn onto Palmetto Drive. |
| **16.7 mi (26.9 km)** | Bear left of Westline Drive. |
| **17.2 mi (27.7 km)**<br><br>**0.0 mi (0.0 km)** | **Stop 6—Mussel Rock Park** (see description below).<br><br>**Reset the odometer mileage to zero.** Return north on Westline Drive. Bear Right on Palmetto. |
| **1.3 mi (2.1 km)** | Continue straight on Palmetto past the McDonald's restaurant. |
| **1.8 mi (2.9 km)** | Take Highway 1 South. |
| **4.3 mi (6.9 km)** | Mori Ridge (part of Golden Gate National Recreation Area) parking area on the right; however, continue south on Highway 1 past the large field in the abandoned Pacifica limestone quarry on the right. |
| **5.7 mi (9.2 km)** | 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 mi (9.5 km)**<br><br>**0.0 mi (0.0 km)** | **Stop 7—Rockaway Beach and Pacifica Quarry** (see description below). Restaurants and public restrooms are available in the Rockaway Beach Shopping Center.<br><br>**Reset the odometer mileage to zero** at the main intersection for the shopping center on Highway 1. Continue south on Highway 1. |
| **1.1 mi (1.8 km)** | Highway 1 crosses San Pedro Creek. The creek follows the approximate trace of the Pilarcitos Fault. |
| **1.1-3.2 mi (1.8-5.1 km)** | **Rolling Stop 8—San Pedro Mountain and the Devil's Slide** (see description below). (Note: "rolling stop" means continue driving to recommended stop locations described below, but observe features in the surrounding landscape as you carefully drive by.) |
| **3.2 mi (5.1 km)** | **Rolling Stop 9—Montara Mountain** (see description below). |

**Continued.**

| | |
|---|---|
| **4.1 mi (6.6 km)** | 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 10. |
| **5.5 mi (8.8 km)** | **Stop 10—Montara State Beach** (see description below). Restrooms are available.<br><br>Continue south on Highway 1. |
| **7.5 mi (12.1 km)** | Turn right (west) on California Avenue. |
| **7.9 mi (12.7 km)** | **Stop 11—James V. F itgerald Marine Preserve** (see description below). Restrooms are available.<br><br>Return by California Av enue to Highway 1 and continue south. |
| **8.6 mi (13.8 km)** | Turn right (west) on Cypress Avenu e. |
| **9.1 mi (14.6 km)** | Turn left (south) on Airport Avenu e. |
| **9.2-11.2 mi (14.8-18.0 km)** | **Rolling Stop 12—Seal Cove Fault along Airport Ave nue** (see description below).<br><br>Continue south on Airport Avenue into Princeton on Half Moon Bay. |
| **11.3 mi (18.2 km)** | Turn right on Harvard Avenue. |
| **11.4 mi (18.3 km)** | Turn right on West Point Avenue. |
| **11.7 mi (18.8 km)** | Turn left into the Pillar Point Marsh Preserve (GGNRA) just before the entrance to the Pillar Point Air Force Station. |
| **11.8 mi (19.0 km)** | **Stop 13—Pillar Point and Mavericks** (see description below). Restrooms are available.<br><br>Return north into Princeton. Follow Harvard Avenue east. |
| **12.8 mi (20.6 km)** | Turn right on Capistrano Road. |
| **12.9 mi (20.8 km)** | Half Moon Bay Brewing Company is on left.<br>Continue south on Capistrano Road. |
| **13.0 mi (20.9 km)** | Turn right on Highway 1 South. |
| **17.3 mi (27.8 km)** | Turn left (east) on Highway 92. |
| **22.4 mi (36.0 km)** | Turn right (south) on I-280. |
| **26.5 mi (42.6 km)** | Exit at Edgewood Road to return to the Park and Ride. **End of field trip**. |

## San Andreas Rift Valley in San Mateo County

The San Andreas Fault runs diagonally in a northwestward direction through San Mateo County in the eastern foothills of the northern Santa Cruz Mountains. From the south, the fault runs through the rural watershed of Corte Madera and upper San Franciscito Creeks, passes through the town of Woodside, and through open space, parklands, watershed reserves around Crystal Springs and San Andreas Reservoirs (fig. 8-2). North of San Andreas Lake, the San Andreas Fault runs through urbanized portions of San Bruno and Daly City before running offshore into the Gulf of the Farallones at Mussel Rock Park. This field-trip guide only focuses on selected public localities and avoids areas within neighborhoods. Unfortunately, many of the urbanized areas underlain by the fault were developed before modern earthquake laws, code, and regulations affecting building construction and neighborhood development were established. The epicenter of the magnitude 7.9 Great San Francisco Earthquake of 1906 is located only several miles offshore of the coast to the northwest of San Mateo County, and the fault ruptured throughout its extent in the county locally causing severe damage in what was mostly a rural region at the time of the earthquake.

## Optional Stop A—Interstate 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 (0.8 km) north of the Edgewood Road exit. The Edgewood Road exit is located 2 miles (3.2 km) 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.

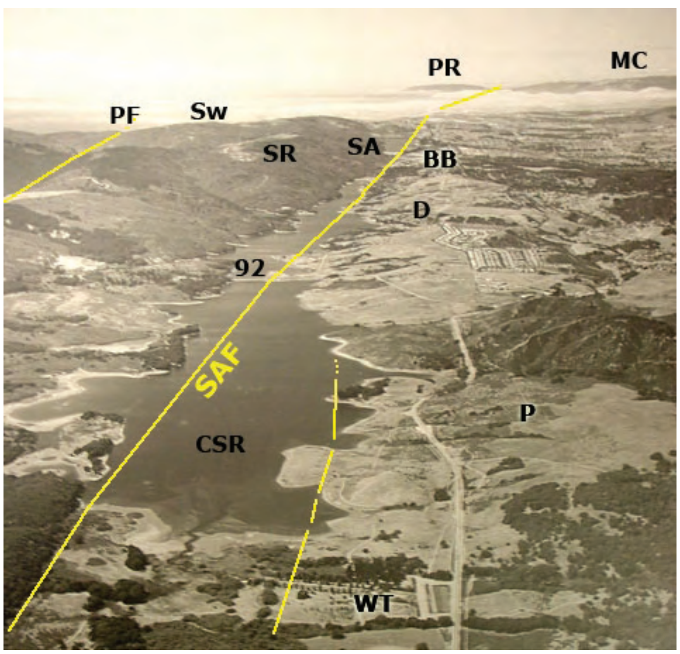


**Figure 8-2.** This oblique aerial view looks north along the rift valley of the San Andreas Fault (SAF) in the vicinity of Crystal Springs Reservoir (CSR). The photograph was taken from about a mile above the Filoli Estate. The Pulgas Water Temple (WT) is in the foreground. The Highway 92 causeway (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 (P) and Buri Buri Ridge (BB) near San Andreas Reservoir (SA). 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).

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 186 miles (300 km) of offset has 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 108 miles (174 km) of offset in the Bay Area has occurred along the East Bay fault system, whereas 62 miles (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 13.5 miles (22 km) has been absorbed on the modern Peninsula segment of the San Andreas Fault after about 65 miles (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 miles 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, graywacke sandstone, and limestone. Some of these deposits eventually were metamorphosed into metachert, slate, schist, metasandstone (including metagraywacke), and marble. Over a 100-million-year period, these rocks migrated great distances

**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. Interstate 280 is not shown in the foreground. The Pilarcitos Fault is in the valley on the west side of Sawyer Ridge.

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 and 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.

## 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 earthquake disaster of 1906. The failures of the water system in San Francisco contributed to the massive fire damage after the earthquake. The Bourns had their country mansion built 10 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 William 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 past human activity. The Filoli Estate provided an ideal area to study the fault because in some identified areas sediments have been accumulating for thousands of years in wetlands and along stream floodplains that are cut by the fault. Seismologists dig trenches in undisturbed ground across fault zones in search of clues in the sediments that might reveal information about the frequency and intensity of past earthquakes. Dates of past seismic events can be estimated by using radiocarbon dating methods to determine the age of organic material extracted from sediment that were either cut by faulting or overlie breaks or features associated with past fault movements.

The main trace of the fault passes through the undeveloped Filoli Center grounds several hundred feet 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 prehistoric 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 others, 1996; Hall and others, 1999). Hall and others (1995) interpreted a total slip from the 1906 earthquake in the range of 8 feet (2.5 m) in the fault zone in the Filoli area. The magnitude 7.0 earthquake of 1838 that occurred on the San Francisco Peninsula also produced about 5 feet (1.5 m) of offset along the San Andreas 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 by the general public at the estate and gardens area of the Filoli Center. However, the hillslope associated with the east-facing escarpment along the west side of the San Andreas Rift Valley is visible from the estate grounds (fig. 8-4). 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 (fig. 8-5). The Pulgas Water Temple was designed by San Francisco architect Willis Polk and has a Roman temple style. The temple was constructed in 1934. It 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 the 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 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.

## Stop 3—Crystal Springs Reservoir Dam

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

**Figure 8-5.** The Pulgas 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.

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 Camp 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 (14.5 km) 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 (120 billion liters) of water. The dam is made of concrete and was originally about 120 feet (37 m) high. The dam was raised to 145 feet (44 m) in 1890 and to 149 feet (46 m) in 1911. It is 120 feet (37 m) thick at its base and about 20 feet (6 m) 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 construction of Crystal Springs Dam.

## 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 field-trip stop that provides a sweeping vista of the San Andreas Rift Valley, Sawyer Ridge, and Crystal Springs Reservoir (fig. 8-7). A

**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.

walkway leads to an overlook area around a statue of Father Junipero Serra, the founder of the California missions. The 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 credited 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 looks like it points across the interstate toward the San Andreas Fault.

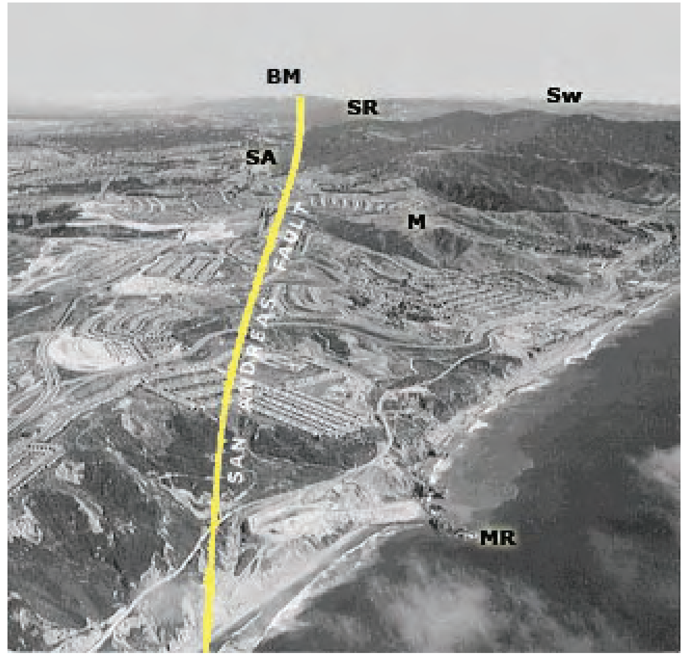


**Figure 8-8.** Aerial view of the San Andreas Fault in the northern Santa Cruz Mountains in San Mateo County. This view is looking south toward the coast at Mussel Rock Park and neighborhoods of Daly City. Labeled features include Mussel Rock (MR), Milagra Ridge (M), San Andreas Lake (SA), Sawyer Ridge (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.

## Northern San Mateo County

### 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 (see fig. 8-8). 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 missile 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 reached by 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 Sweeney Ridge (http://www.nps.gov/goga/clho/swri/).

## 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 just north of Mussel Rock (figs. 8-8, 8-10, and 8-11). 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 Fort Funston at 37°70’N, 122°50’W (location data from the website *Anniversaries of Notable California Earthquakes* at http://www.consrv.ca.gov/cgs/rghm/quakes/eq_calender.htm). The northern end of the Peninsula segment of the San Andreas Fault experienced about 13 feet (4 m) of right-lateral displacement and experienced near the full intensity of the 7.9 magnitude 1906 San Francisco 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

**Figure 8-9.** View of the San Andreas Rift Valley on the west side of Milagra Ridge. Milagra Ridge is protected habitat within Golden Gate National Recreation Area. In the distance, a housing development runs along the hillsides east of the rift valley.

**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 County 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 condemned 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 magnitude 5.3 earthquake on March 22, 1957, the route was once again abandoned. Today only a trace of the highway cut can be seen about midway up the sea cliff. See figure 8-8 for comparison.

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)(fig. 8-12). The Merced Formation consists of interbedded sandstone and shale and contains some fossiliferous marl (calcareous mudstone) 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 (229 m) 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/.

## 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, field-trip participants should be given a time to meet at the northwest end of the rip-rap beach wall because the beach and shops grow more crowded during mid-day, and 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 consists 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 road cuts along Highway 1 south of Pacific Beach and in the San Pedro Point headlands (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 (figs. 8-14 and 8-15). Small-scale limestone mining began in the Pacifica area in the early 19th century, when lime was used primarily for whitewash for buildings at the Presidio in 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. 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 230 feet (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).

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

**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 headlands of Rockaway Point. 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 8-15.** The Calera Limestone was mined in the Pacifica Quarry. The rock is 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.

The Calera Limestone formed by the accumulation original lime ooze sediments (including planktonic foraminifera and coccoliths) deposited on the ocean floor. Over time these sediments became compacted and lithified, and later underwent a moderate degree of metamorphism during deep burial and accretion onto the North American continental margin. Fossils found in the Calera Limestone 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 about 2.5 miles (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.

## 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 pulloffs 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 as you drive.

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 (fig. 8-17). Paleocene-age conglomerate and granitic breccia in the road cut 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 fan 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 (1.3 km) along Highway 1 on the northwest flank of Montara Mountain (fig. 8-18). 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 (46 m) below the surface. The landslide extends from 900 feet (275 m) high on the mountain down to sea level (Williams, 2001).

**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 field-trip 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.

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 the road 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 it 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

**Figure 8-17.** Pedro Rock at the south end of Point San Pedro consists of steeply dipping beds of 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 offs 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 World War II-era gun emplacement is visible on top of a headland at the south end of Devil's Slide.

Highway 1 today. However, landsliding and road closures have constantly plagued the route, and millions of dollars have been expended in endless repairs. CalTrans (California Department of Transportation) is currently evaluating plans to construct a 4,000-foot (1,220 m) 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.

## 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 (Lawson, 1895a, Lawson, 1895b, and Lawson, 1914).

The Salinian Block is a 15,500 square mile (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 about 200 miles (320 km)

**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.

of movement 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. 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).


**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.

**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.**

## Stop 10—Montara State Beach

**Stop highlights:** Salinian granite, offset Quaternary marine terraces, shore dune and 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 and 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 by a lack of datable materials.

**Figure 8-21.** This image shows a small fault where Montara granitic rock has been thrust over younger 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.

## 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 (61 to 170 m) 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 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): (1) a well sorted wind-blown sand facies [eolianite], (2) a lignite bed, (3) an upper arkosic, alluvial gravel facies (containing Montara Mountain granodiorite), and (4) 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 (5.5 m) elevation north of the fault and 95 feet (29 m) south of the 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 50,000 to 150,000 years.

## 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 field trips, and for good reason. The preserve is one of the closest tide pool areas to the San Francisco and other Bay Area cities. 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,

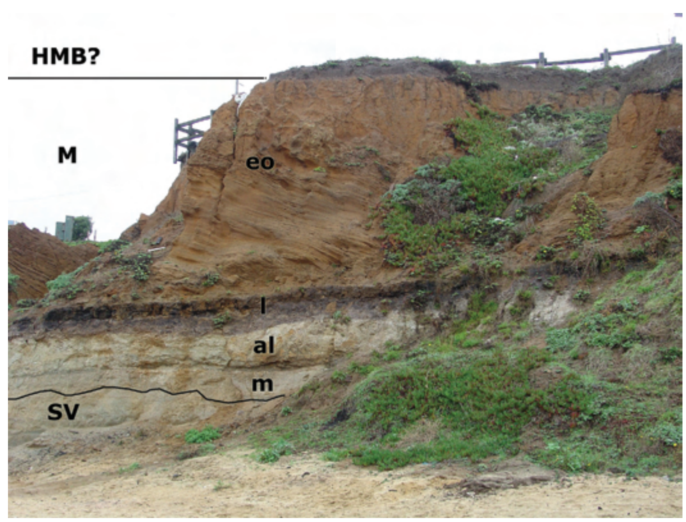


**Figure 8-22.** Quaternary terrace deposits are exposed in the beach cliff below the Montara State Beach parking area. San Vicente marine terrace deposits (SV) are unconformably overlain by the Montara terrace deposits (M). The Montara terrace deposits consist of a thin lower marine gravel layer (m), 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.

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 2 miles (3.2 km) 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 33 feet (10 m) and 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 about 300 to 2,300 feet (100 to 700 m). 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 range of 3 to 5 million years.

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.

## 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 onshore 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 143 miles (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 about 70 miles (115 km) (Graham and Dickenson, 1978) and 100 miles (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 10 to 16 feet (3 and 5 m) occurred in the pre-Colonial era (sometime between A.D. 1270 and 1775). These fault ruptures probably produced earthquakes of magnitude 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 (12 m), whereas the high point west of the fault scarp is about 175 feet (53 m) (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

**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 fossiliferous 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.

**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.

to rise. The Half Moon Bay marine 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 (43 m) 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.

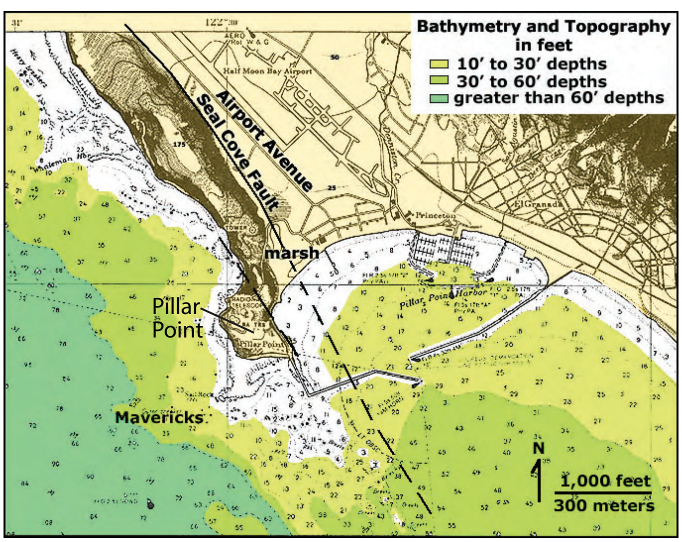


**Figure 8-25.** Bathymetry and topography along the Seal Cove Fault at Half Moon Bay. The Seal Cove Fault runs along the east side of a linear ridge along the coast between Moss Beach to the north (not shown) and near Pillar Point to the south. Rolling stop 12 is along Airport Avenue, and the parking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

## Stop 13—Pillar Point and Mavericks

**Stop highlights:** Offset marine terrace, San Gregorio Fault system, small faults in sea cliffs, the geology associated with surfing large waves at Mavericks

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, high wave action, or 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 1500 feet (450 m) 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; 18 m) 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 (fig. 8-25).

**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 (3 m).

Mavericks is considered one of the most challenging 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 (6 to 9 m) are not uncommon, and waves in the 40-foot (12 m) and higher range occur on rare occasions. Local legend tells that waves as high as 100 feet (30 m) 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, surfers traditionally 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. However, many videos and films document the history of surfing at Mavericks.

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