# 9. Field-trip Guide to Point Reyes National Seashore and Vicinity—A Guide to the San Andreas Fault Zone and the Point Reyes Peninsula

**Trip highlights:** San Andreas Fault, San Gregorio Fault, Point Reyes, Olema Valley, Tomales Bay, Bolinas Lagoon, Drakes Bay, Salinian granitic rocks, Franciscan Complex, Tertiary sedimentary rocks, headlands, sea cliffs, beaches, coastal dunes, Kehoe Beach, Duxbury Reef, coastal prairie and maritime scrublands

Point Reyes National Seashore is an ideal destination for field trips to examine the geology and natural history of the San Andreas Fault Zone and the northern California coast. The San Andreas Fault Zone crosses the Point Reyes Peninsula between Bolinas Lagoon in the south and Tomales Bay in the north. The map below shows 14 selected field-trip destinations where the bedrock, geologic structures, and landscape features can be examined (fig. 9-1). Geologic stops highlight the significance of the San Andreas and San Gregorio Faults in the geologic history of the Point Reyes Peninsula. Historical information about the peninsula is also presented, including descriptions of the aftermath of the Great San Francisco earthquake of 1906.

## Planning Your Trip

The Bear Valley Visitor Center (Park Headquarters) near Olema is about an hour drive north of the Golden Gate Bridge. Point Reyes is located approximately 35 miles north of San Francisco on Highway 1. The park is accessible from San Rafael by Sir Francis Drake Boulevard or from Lucas Valley Road (the latter is discussed in the road log presented below). Although a trip to Point Reyes from anywhere in the Bay Area can be accomplished on a long day, field-trip planners should consider spending a night camping or utilizing overnight accommodations either inside or near the park to have more time to enjoy the experience. However, there is no car camping in the park. Call the Bear Valley Visitor Center well in advance to inquire about group overnight accommodations. It is advisable to check weather forecasts and tide conditions before traveling to Point Reyes. The weather can be very windy and cold along the coast, particularly near the lighthouse on the Point Reyes headlands. More information can be found on the Point Reyes National Seashore website at http://www.nps.gov/pore/.

The park is open daily from sunrise to sunset throughout the year. The Bear Valley Visitor Center is open weekdays, 9:00 a.m. to 5:00 p.m., weekends and holidays 8:00 a.m. to 5:00 p.m.; the Lighthouse Visitor Center is open Thursday through Monday, 10:00 a.m. to 4:30 p.m. Lighthouse stairs and exhibits (weather permitting) are accessible 10:00 a.m.

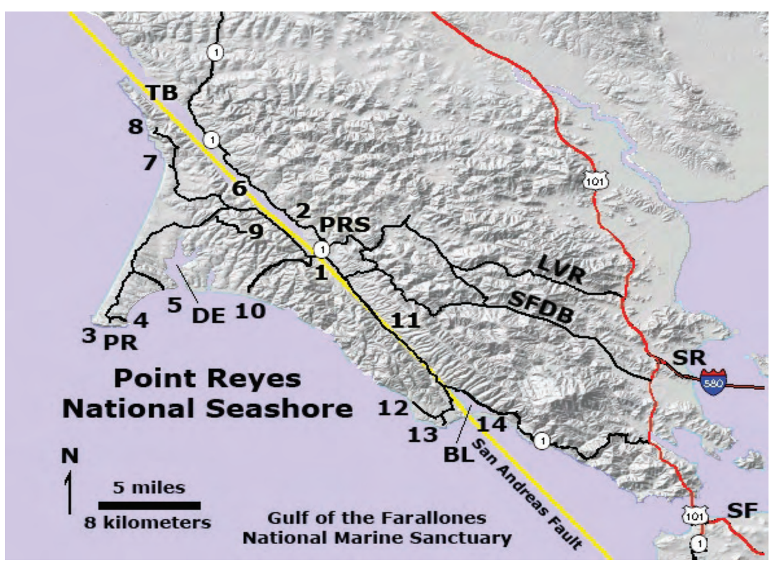


**Figure 9-1.** Map of the Point Reyes National Seashore area. Numbered stops include (1) Visitor Center and Earthquake Trail, (2) Tomales Bay Trail, (3) Point Reyes Lighthouse, (4) Chimney Rock area, (5) Drakes Beach, (6) Tomales Bay State Park, (7) Kehoe Beach, (8) McClures Beach, (9) Mount Vision on Inverness Ridge, (10) Limantour Beach, (11) Olema Valley, (12) Palomarin Beach, (13) Duxbury Reef, and (14) Bolinas Lagoon/Stinson Beach area. Features include Point Reyes headlands (PR), Tomales Bay (TB), Drakes Estero (DE), Bolinas Lagoon (BL), Point Reyes Station (PRS), San Rafael (SR), and San Francisco (SF), Lucas Valley Road (LVR), and Sir Francis Drake Boulevard (SFDB).

to 4:30 p.m., and the Lens Room is open as weather and staffing permit. All Lighthouse facilities are closed Tuesdays and Wednesdays; Ken Patrick Visitor Center, weekends and holidays, 10:00 a.m. to 5:00 p.m. On weekends during whale watching season (December to April) the road to Point Reyes is closed to private vehicles, but shuttle bus transport is provided.

## Geology of Point Reyes—An Overview

Point Reyes National Seashore is an exceptional geologic observatory for many reasons, but it is perhaps most notable for its association with the San Andreas Fault Zone and Great San Francisco earthquake of 1906. The San Andreas Fault Zone is a dividing line between rocks of disparate origin and represents the classic boundary between the North American and Pacific Plates—with the Point Reyes Peninsula residing on the Pacific Plate and the rest of Marin County being part of the North American Plate. Olema Valley and the submerged valleys flooded by Tomales Bay and Bolinas Lagoon are part of the San Andreas Rift Valley (fig. 9-2).

Rocks on the east side of the fault are those of Franciscan Complex, a mix of oceanic crustal rocks that formed in late Mesozoic time (Jurassic and Cretaceous) and were gradually accreted onto the North American continental margin by plate-tectonic motion. Bolinas Ridge along the east side of the rift valley consists mostly of sandstone and metasandstone of

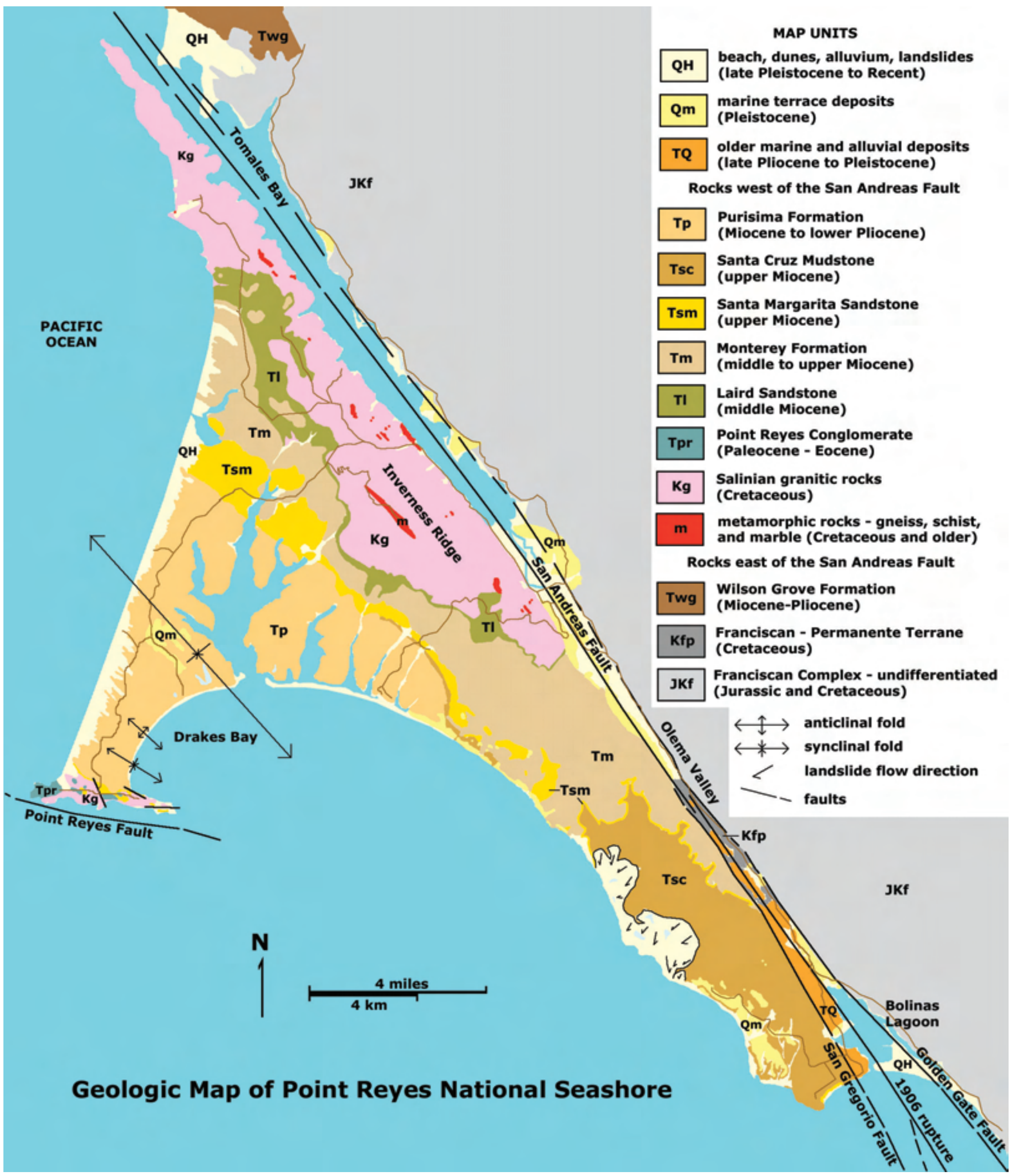


**Figure 9-2.** Generalized geologic map of Point Reyes National Seashore after Clark and Brabb (1997), Blake and others (2000), and Bruns and others (2002).

Cretaceous age. Pillow basalts are exposed along the highway near Nicasio Reservoir. The pillow basalts formed on submarine volcanoes associated with ancient spreading centers in the Pacific Ocean basin. Basalt that has been altered to greenstone crops out along Highway 1 south of Bolinas. Other rocks in the Franciscan Complex exposed along Highway 1 include chert, shale, and argillite; they represent rocks that formed from sediments that accumulated in mid-ocean to outer-continental-margin environments. Serpentinite occurs in scattered outcrops along the highway and throughout the Mount Tamalpais area. Serpentinite is a mineralogically complex rock of ultramafic composition (rich in magnesium and iron). Serpentinite is derived from rocks that originally crystallized deep in the ocean crust or mantle before undergoing physical and chemical alteration during migration to the surface. A sliver of Franciscan rocks that contain limestone (the Calera Limestone of the Permanente Terrane) occurs within the San Andreas Fault Zone in Olema Valley. The limestone accumulated as limey sediments on the crest of a submarine volcano or plateau.

Point Reyes Peninsula is an elevated block of ancient crystalline basement with a sedimentary cover of Tertiary sedimentary rocks and some Quaternary marine terrace, alluvial, and dune deposits (fig. 9-2). The crystalline basement consists of Cretaceous granitic rocks and some ancient metamorphic rocks (schist, gneiss, and marble). These rocks are called Salinian Complex, named for an extensive belt of granitic and crystalline metamorphic rocks exposed in the Salinas Valley region. However, the name Sur Series also applies because the basement rocks of Point Reyes are closely associated with equivalent crystalline basement rocks exposed along the Big Sur coast south of Monterey. Salinian crystalline rocks are exposed along the crest of Inverness Ridge and in the Point Reyes headlands. In the Point Reyes headlands, a thick sequence of conglomerate and sandstone of Paleocene age rests nonconformably on the Salinian granitic basement. The granitic basement and conglomerate are in turn are unconformably overlain by sedimentary formations of middle Miocene age. Along Inverness Ridge, middle Miocene marine sedimentary rocks (Laird Sandstone and Monterey Formation) rest directly on crystalline basement (the Point Reyes Conglomerate is not present). A sequence of late Miocene and Pliocene formations (Santa Margarita Sandstone, Santa Cruz Mudstone, and Purisima Formation) rests unconformable on top of the Monterey Formation. The Miocene and Pliocene sedimentary rock formations are folded into a broad syncline with a northwest-trending axis. The trough of the syncline is between Inverness Ridge and Point Reyes (see fig. 9-2).

Three separate faults merge near Bolinas Lagoon and in the southern Olema Valley to form the San Andreas Fault Zone at Point Reyes–the Golden Gate Fault, San Andreas Fault, and San Gregorio Fault (Bruns and others, 2002) (see fig. 9-2). These faults extend south through the Gulf of the Farralones. The Golden Gate Fault runs along the eastern shore of Bolinas Lagoon and crosses the Gulf west of the Golden Gate before running onshore in the vicinity of Lake Merced in San Francisco. The North Coast segment of the San Andreas Fault is the trace that ruptured in the 1906 earthquake. It comes onshore near the east end of Stinson Beach. The San Andreas extends southward beneath the Gulf and comes onshore in the vicinity of Mussel Rock in Daly City. The northern extension of the San Gregorio Fault extends onshore in between the town of Bolinas and Duxbury Point on the southern end of the Point Reyes Peninsula. To the south, the San Gregorio Fault runs along the San Mateo Coast and extends across Monterey Bay. These three faults merge into a narrow (less than a mile) fault zone that extends northward through Olema Valley and under Tomales Bay. A large thrust fault, the Point Reyes Fault, runs offshore near the Point Reyes Headlands and is probably responsible for ongoing uplift of the headlands region. All of these faults show signs of tectonic activity extending from late Miocene time to the present.

The composition and characteristics of the Salinian basement and Paleocene conglomerate suggests that the Point Reyes Peninsula actually migrated northward along the San Gregorio Fault system to its present location. Salinian granitic rocks and Paleocene conglomerate on the Monterey Peninsula at Point Lobos are nearly identical to the rocks on Point Reyes. In addition, the late Miocene- to Pliocene-age sedimentary sequence (Santa Margarita Sandstone, Santa Cruz Mudstone, and Purisima Formation) are essentially identical to the same stratigraphic sequence on the east side of the San Gregorio Fault in Santa Cruz County.

Elevated marine terraces along with ancient alluvial and coastal-dune deposits suggest that the Point Reyes Peninsula has been rising throughout the Quaternary Period. However, ongoing sea-level rise associated with the melting of extensive ice-age continental glaciers is responsible for the flooding and subsequent Holocene sediment filling of ancient valleys beneath Tomales Bay, Drakes Estero, and Bolinas Lagoon. Coastal processes associated with the gradual sea-level rise following the last ice age are responsible for the erosional development of the sea cliffs and headlands and the accumulation of sediments on ocean beaches and dunes, as well as the back filling of baylands and lagoons throughout the peninsula.

## Cultural History of the Point Reyes Region

[Summarized after Gilliam (1962), Caughman and Ginsberg (1987), and from National Park Service sources.]

We don't know when humans first arrived on the Point Reyes Peninsula. Archeological studies report human activity in California extending back to near the end of the Pleistocene Epoch, nearly 11,000 years ago. The record of early human history in the region has probably been lost to the nearly 400 foot (120 m) rise in sea level since the final maximum of the Wisconsin glaciation about 18,000 years ago. At that time, the shoreline was about 30 miles (50 km) west of its present location, and the Point Reyes Peninsula was part of a system of low inland hills. Archeological evidence indicates that for at least the past several thousand years people have utilized the peninsula. When Europeans arrived in the region, the Coast Miwok

Indians lived in villages along the bays; they hunted, fished, and gathered food and living supplies from the region's abundant wildlife and natural resources. The Miwok people were probably descendents of earlier cultures in the region.

Historians still debate whether Sir Francis Drake stopped at Point Reyes. Drake was an English pirate and explorer serving Queen Elizabeth I. Drake had a ship, the *Golden Hind*, loaded with stolen Spanish treasure taken from settlements in the New World on his voyage north from Cape Horn. Facing the prospects of revenge by Spanish galleons, he choose not to spend more time seeking a fabled Northwest Passage but rather to sail west across the Pacific Ocean to return to England. Before heading west, Drake returned south along the California coast seeking a location to repair and resupply his ship before the long journey home. Journals from Drake's adventurous voyage (1577 to 1580) described landing at a location with white cliffs, similar to the White Cliffs of Dover. In 1579, Drake's crew brought the ship onshore to remove barnacles and clean, caulk, repair damage, and gather supplies before the next stage of their voyage. This possibly took place somewhere on one of the sheltered shores of Drakes Estero, inland of Drakes Bay. However, no authenticated artifacts from Drake's voyage have been recovered in the Point Reyes area.

The earliest mention of Point Reyes is in historic records of the 1595 shipwreck of the Spanish galleon, the San Agustin. The ship, captained by Sebastián Rodrígues Cermeño was on her return journey from the Philippines. Despite a damaged ship and a mutinous tone from the crew, Cermeño chose to spend 3 weeks exploring the coast in the vicinity of Point Reyes. However, the ship was probably anchored near the mouth of Drakes Estero when, on a November day, an unexpected storm drove the ship into the coast. Several of the crew members were lost. The remains of the ship and cargo were abandoned. Still following Cermeño's command, the crew modified and crowded into the San Agustin's small launch vessel and heroically paddled nearly 1,500 miles south to Spanish outposts in Mexico. In his exploration, he named the coastal embayment between Point Reyes and Point San Pedro, "La Baya de San Francisco," but never actually sailed through the Golden Gate or visited the land that now bears the name. Chinese Ming pottery from the shipwrecked cargo of the *San Agustin* has been recovered from Miwok Indian village sites. The loss of the San Agustin was perhaps the first of many shipwrecks that have occurred in the treacherous waters around Point Reyes. Point Reyes extends nearly 9 miles (15 km) seaward, perpendicular to the coast. During major coastal storms, many ships driven by strong winds and currents were unable get far enough to the west to get around Point Reyes and ended up trapped and shipwrecked in Drakes Bay.

On a return journey to Spain from Cape Mendicino in 1603, Spanish explorer Sebastián Vizcaíno mistook what is now the entrance to Tomales Bay for the mouth of a great river. He named it "Rio Grande de San Sebastián." On the Roman Catholic holiday of the Three Kings (January 6, 1603), Vizcaíno sighted the headlands and gave the name "La Punta de Los Tres Reyes," and hence the name, Point Reyes. Not until 1793 when another Spaniard, Juan Matute, explored the area, did Vizcaíno's river prove to be a bay. Matute named his new bay "Puerto Nuevo."

The bay and peninsula were home to Miwok Indians who had a settlement along the shore. Both Drake and Vizcaíno reported friendly encounters with the Miwok people who provided supplies for the ships. Unfortunately, like most native California cultures, the Miwok population was decimated by disease, subjugation, and slavery during the era of Mexican colonization. A mission was built in 1817 in what is now San Rafael. During Spanish rule, the Point Reyes Peninsula was divided into land-grant ranchos. However, after the Mexican Revolution of 1821, the San Rafael Mission was secularized, and the few remaining Miwok that escaped or were released from subjugation had lost their land.

After California was ceded to the United States after the Mexican American War of 1848, the Point Reyes Peninsula became the possession of a San Francisco law firm. The peninsula was then subdivided into dozens of dairy and cattle farms. For nearly 75 years, dairy products and cargo from the ranches were loaded onto schooners that docked in Drakes Estero and Tamales Bay and shipped to San Francisco. The Gold Rush brought a wave of immigrant pioneers to the area. Bolinas was a thriving logging town by 1850. Lumber and firewood were loaded at Bolinas Lagoon for shipment to San Francisco. Over time, Bolinas and nearby Stinson Beach grew as a result of tourism and inhabitants who chose to live in the coastal communities and commute to the city. The town of Olema was established in 1859 and for a short period became a commercial center for the peninsula. In the early 1870s, the North Pacific Coast Railroad was built to link the port of Sausalito near the Golden Gate to parts of Marin and Sonoma Counties. From San Rafael, the rail line followed Lagunitas Creek Valley to the south end of Tomales Bay. By 1875, the rail line extended northward along the east side of the bay to the town of Tomales. By 1877, the railroad was extended to serve lumber mills in the Russian River area. In 1883, the town of Point Reyes Station was developed. The new train stop 2 miles north of Olema caused the older established town to fade in significance. While in operation, the railroad transported lumber, farm produce, commuters, and tourists, until the rail line ceased operation in 1933.

Point Reyes National Seashore was authorized for addition to the National Park Service on September 13, 1962. The park now encompasses about 71,000 acres (28,700 hectares), with additional extensive land holdings in the region managed in cooperation with Golden Gate National Recreation Area and California State Parks. The southeastern end of the peninsula is set aside as part of the Philip Burton Wilderness Area and Research Natural Area. The Tule Elk Reserve encompasses the north end of the peninsula including Tomales Point. Much of the western end of the peninsula consists of pastoral lands associated with dairy and cattle ranches that are maintained in cooperation with the National Park Service. The U.S. Coast Guard maintains small stations near Abbotts Lagoon and at Palomarin Beach, and private land holdings encircle the small communities of Bolinas, Olema, and Inverness Park.

# Road Log from Golden Bridge to Point Reyes National Seashore's Park Headquarters

| **Golden Gate Bridge to Bear Valley Visitor Center (Park Headquarters) by Lucas Valley Road** | |
|---|---|
| **Distance** | **Description** |
| **0 mi (0.0 km)** | Golden Gate Bridge Vista Area on Highway 101 (northbound lane at north end of bridge). Restrooms are available at the Vista Area. |
| **3.5 mi (5.6 km)** | Pass exit to Highway 1 to Stinson Beach (this is recommended as a return route; it is 31 miles to the Bear Valley Visitor Center/Park Headquarters along Highway 1). |
| **9.0 mi (14.5 km)** | Pass Sir Francis Drake Boulevard (this is an optional park access route, but has many more stop lights than Lucas Valley Road). |
| **15.5 mi (24.9 km)** | Take the Lucas Valley Road exit from Highway 101. Turn left (west) on Lucas Valley Road. |
| **21.5 mi (34.6 km)** | Large outcrops of Franciscan Complex rocks occur along road. |
| **25.2 mi (40.5 km)** | The route passes through groves of coast redwoods (*Sequoia sempervirens*). |
| **26.3 mi (42.3 km)** | Turn right (north) on Nicasio Valley Road. Nicasio Reservoir is on the left. |
| **26.5 mi (42.6 km)** | The road passes the small town of Nicasio. |
| **29.3 mi (47.1 km)** | Nicasio Reservoir is on the left. Many Franciscan Complex "knockers" outcrops are in this area. |
| **30.5 mi (49.0 km)** | Turn left on Point Reyes-Petaluma Road toward Point Reyes Station. |
| **33.4 mi (53.7 km)** | Pillow basalts are exposed in roadside outcrops on the left near a sign for Golden Gate National Recreation Area. These rocks are part of the Nicasio Terrane of the Franciscan Complex. |
| **33.7 mi (54.2 km)** | Bear right across a bridge to continue on Point Reyes-Petaluma Road to Point Reyes Station. |
| **36.9 mi (59.4 km)** | Turn left on Highway 1 (Shoreline) at Point Reyes Station. The town of Point Reyes Station offers restaurants, gas, and other travel services. Highway 1 (Shoreline) makes a few turns through town. See the discussion and historic photographs of the Point Reyes Station area below.<br><br>**NOTE:** Optional **Stop 2—Tomales Bay Trail** is located along Highway 1 at 1.7 miles north of Point Reyes Station on the east side of the bay. See the stop 2 discussion below. |
| **37.4 mi (60.2 km)** | The historic Point Reyes Station (a brick building) is on the right (see fig. 9-3 below). |
| **37.6 mi (60.5 km)** | Turn right on Sir Francis Drake Boulevard just past the bridge over Lagunas Creek. |
| **38.3 mi (61.6** | Turn left on Bear Valley Road. |
| **38.7 mi (62.3 km)** | Pass Limontour Road on right (see **Stop 10 – Limantour Road** description below). |
| **38.8 mi (62.4 km)** | A small dirt road to the left leads to a parking area along the San Andreas Fault. An undeveloped path that starts at the parking area leads to the top of a pressure ridge developed along the fault. The top of the grassy knoll is a good place to view the sag ponds, marshlands, and fault scarps at the south end of Tomales Bay (see fig. 9-7).<br><br>For the next mile, Bear Valley Road follows the trace of the San Andreas Fault that ruptured in the 1906 earthquake. The road follows and crosses a fault scarp; sag ponds and marsh along Olema Creek are on the right. |
| **40.0 mi (64.3 km)** | Turn right into the Bear Valley Visitor Center and Park Headquarters area near the red barn. |
| **40.2 mi (64.7 km)** | **Stop 1—Bear Valley Visitor Center and Earthquake Trail** (see description below). |

## Point Reyes Station and the 1906 Earthquake

Shortly after the 1906 earthquake and fire that destroyed much of San Francisco, reports started arriving about surface ruptures and damage in the Olema Valley and the Tomales Bay-side community of Point Reyes Station. Reporters and earthquake investigators made their way north to document the damage associated with rupture along a fault line that would eventually be known as the San Andreas Fault. Perhaps the most famous pictures from those early investigations include a picture of a toppled train at Point Reyes Station, taken with a borrowed camera by one of train's engineers, and pictures of the fault rupture taken by U.S. Geological Survey geologist Grove Karl Gilbert (1908) (figs. 9-3 to 9-6).

**Figure 9-3.** A famous historical photograph taken by an engineer of a derailed train that tipped over at the Point Reyes Station during the 1906 earthquake (image from Jordan, 1907). The narrow gauge train was stopped at the station on a section of track that ran roughly parallel to the fault less than a mile east of the rupture. Based on the engineer's description of the rocking motion that fell the locomotive, Anooshehpoor and others (1999) calculated the earthquake motion created ground acceleration that was in the range of 0.7 to 1.1*g* (*g* is the force of gravity).

## Stop 1—Bear Valley Visitor Center (Park Headquarters) and Earthquake Trail

**Stop highlights:** San Andreas Fault scarp, 1906 earthquake rupture, park geology and ecology exhibits

The Point Reyes National Seashore, Bear Valley Visitor Center (Park Headquarters) is located near the towns of Olema, Point Reyes Station, and Inverness, and is near the south end of Tomales Bay (see figs. 9-1 and 9-7). The Visitor Center is the best place to start a field trip in the park. The Visitor Center provides brochures, maps, book sales, and exhibits about the land, wildlife, and the Coast Miwok Indians that inhabited the peninsula before European settlement. It is

**Figure 9-4.** Photograph by Gilbert (1908) of surface rupture along the fault near Point Reyes Station. The view is looking northwest toward marshlands at the south end of Tomales Bay. The photograph illustrates a classic example of a sidehill bench. Note the extent of timber removal on Inverness Ridge in the distance (top left).

**Figure 9-5.** View looking southeast along the fault near Point Reyes Station. Note the woman for scale near the top of the hill to the left of the fault scarp.

**Figure 9-6.** This view of an offset road near Point Reyes Station shows 20 feet (6 m) of horizontal slip caused by the 1906 earthquake. Photograph by Gilbert (1908).

**Figure 9-7.** This view is looking north from the top of a shutter ridge located along Bear Valley Road about 1.5 miles (2.4 km) north of the Bear Valley Visitor Center. Inverness Ridge is on the left (west). The wetlands of southern Tomales Bay are near the center of the image, and Point Reyes Station is on an elevated terrace to the right (east). A scarp along the main trace of the San Andreas Fault is visible as a vegetation change along a break in slope located just above the parked vehicle on the left.

recommended that you check the Point Reyes National Seashore website and call the Visitor Center before planning a trip to the park.

The Visitor Center is located near the historic 1906 rupture of the San Andreas Fault. Fault rupture and ground failure features in the area around Point Reyes Station and Olema were described and photographed by Grove Karl Gilbert (1908), and by others. Although little physical evidence remains from the great earthquake, the National Park Service maintains a trail to the 1906 fault rupture zone (figs. 9-8 and 9-9). The Earthquake Trail starts in the Visitor Center parking lot. Earthquake Trail guides are available at the Visitor Center. Signs and displays along this 0.5 mile (0.8 km) walk provide basic information about plate tectonics and the geologic setting and history of the San Andreas Fault. A fault scarp is clearly visible along the trail. The fault scarp represents the cumulative effects of slip from many earthquakes over many thousands of years that have occurred along this active strand of the San Andreas Fault; only a small fraction of the vertical relief along the fault scarp is from the 1906 rupture. More features related to earthquake faults can be seen along the Rift Zone Trail. This trail roughly follows the trace of the 1906 rupture from the Visitor Center southward for 4 miles (7 km) to the trailhead at Five Brooks along Highway 1. Paleoseismic studies based on trench excavations by Neimi and Hall (1992) indicate that the slip rate of the 1906 trace (North Coast segment of the San Andreas Fault) averaged about 24(±3) mm per year for the past 2,000 years and that the recurrence interval for large earthquakes is in the range of 221(±40) years.

According to G.K. Gilbert, who recorded the 1906 earthquake's impacts, the only recorded casualty in the Point Reyes region was a cow that was supposedly crushed and killed upon falling into an open fissure during the earthquake. It was later revealed that the cow story was really a hoax perpetrated by a farmer who had dumped a dead cow into an open fissure. The sensational story was widely distributed before it was revealed to be a joke on reporters.

**Figure 9-8.** A reconstructed historical fence offset by the San Andreas Fault in 1906. This exhibit is along the Earthquake Trail near the Bear Valley Visitor Center. The original fence at this location was offset about 18 feet (5.5 m). As much as 26 feet (8 m) of horizontal surface slip was reported on the fault in the Olema area (Gilbert, 1908).

**Figure 9-9.** Blue posts mark the trace of the surface rupture of the 1906 earthquake. The Shaffer Ranch barn was built on the trace of the fault and was damaged by the earthquake. This view is looking north from the offset fence exhibit area along the Earthquake Trail.

## Stop 2—Tomales Bay Trail (Golden Gate National Recreation Area) (optional)

**Stop highlights:** San Andreas Rift Valley, Tomales Bay, Franciscan Complex, blueschist knockers, marshland and coastal-prairie habitats

The Tomales Bay Trail is a good optional destination to examine unusual outcrops of Franciscan Complex bedrock in a scenic setting on the east side of Tomales Bay. The Tomales Bay Trail is located 1.7 miles (2.7 km) north of Point Reyes Station along Highway 1 (Shoreline) and is 4.3 miles (7 km) north of the Bear Valley Visitor Center (Stop 1) near Olema.

The Tomales Bay Trail area is located at the north end of a marine terrace that extends southward through the Point Reyes Station area. From the parking area, the trail crosses a low incised plateau-like area (part of the old terrace) before dropping down to the salt marsh at the south end of Tomales Bay. Of geologic interest are outcrops of metamorphosed sandstone which rise above the coastal prairie near the parking area (fig. 9-10). The features are called "blueschist knockers"—blueschist being the grade of metamorphic change that the rock has experienced, imparted to the rock by crystallization of the mineral glaucophane under moderate crustal depth pressure and at relatively low temperature. The word "knocker" is a regional geologic term used to describe lone outcrops of bedrock that rise above the surrounding landscape in areas typically underlain by Franciscan Complex. Over time as erosion has worn down the landscape, resistant blocks of metamorphic sandstone and other rock are left behind as softer, more fractured and weathered material erodes away. Knockers typically occur in areas where bedrock has been heavily sheared and mixed through the ongoing tectonic development of the region, beginning with tectonic forces associated with plate-tectonic transport and subduction, as well as later uplift and shearing along fault zones. The French word *mélange* (meaning mix) is applied to areas of sheared rock in the Franciscan Complex where rock masses are often too small and discordant to be mapped as individual geologic units. Rocks of the Franciscan underlie the countryside east of Tomales Bay.

Also of interest are the elevated marine terraces along Highway 1 along the shores of Tomales Bay (fig. 9-11). These ancient surfaces correspond to periods of time when sea level was higher than at the present. Shoreline erosion and sediment deposition during high-standing sea level associated with interglacial periods of the Pleistocene Epoch resulted in the formation of wave-cut platform and beaches. Later, sea level fell and as the land in many coastal areas continued to rise and these ancient beaches and wave-cut platforms became isolated from shoreline and became elevated marine terraces that we see today. The town of Point Reyes Station is built on a prominent marine terrace that originally formed about 100,000 to 150,000 years ago and is currently about 30 to 50 feet (9 to 15 m) above sea level. These terraces are offset or tilted along the San Andreas Fault and provide useful information to determine the rates of tectonic uplift and erosion affecting the landscape.

**Figure 9-10.** Large blueschist "knockers" rise above the coastal prairie in low hills along the east shore of Tomales Bay along the Tomales Bay Trail. The blueschist is part of the extensive belt of Franciscan Complex along the east side of the San Andreas Fault in the Point Reyes National Seashore region. Along the eastern shore, salt marsh gives way to coastal prairie grasslands. The grasslands dominate the hillsides east of the bay extending to the top of Bolinas Ridge. To the south and east, grasslands give way to coastal sage scrublands. Farther inland, the hillsides are dominated by oak woodlands, chaparral, and mixed evergreen forest dominated by bay laurel and Douglas fir.

**Figure 9-11.** View of Tomales Bay and Inverness Ridge from a roadside pull off along Highway 1 about a mile north of the Tomales Bay Trail parking area. Note the contrast of the grassland prairie on the east side of the bay with the mixed evergreen and pine forest on the slopes along the west side of the bay. The vegetation contrast on opposite sides of the bay reflects the different characteristics of the bedrock and soils on opposite sides of the fault zone. The contrast also reflects the difference between the slope, aspect, precipitation, and other climatic factors influencing vegetation on opposite sides of the bay.

## Road Log–Bear Valley Visitor Center to the Lighthouse Museum at Point Reyes Headlands

**Route highlights:** Tomales Bay, Point Reyes Peninsula, Inverness Ridge, Drakes Estero, Drakes Beach, Point Reyes Headlands, Chimney Rock, Point Reyes Lighthouse, Purisima Formation, Monterey Formation, Point Reyes Conglomerate, Cretaceous granitic rocks, marine terrace deposits

The destination of most people visiting Point Reyes National Seashore is probably the Point Reyes Lighthouse area. The road log listed below provides mileages to selected destinations along Sir Francis Drake Boulevard that leads to the lighthouse. The road log begins at the Bear Valley Visitor Center (Park Headquarters) and ends at the parking area for the Point Reyes Lighthouse and Visitor Center (Stop 3). Be sure to check weather conditions at the lighthouse before proceeding (it may be closed due to inclement weather). See discussions below for stop information, other optional routes, or alternative destinations.

| Distance | Description |
|---|---|
| **0.0 mi (0.0 km)** | **Bear Valley Visitor Center—Park Headquarters (Stop 1)** |
| **1.4 mi (2.6 km)** | Pass intersection for Limantour Road; see discussion for **Limantour Road (Stop 10)**. |
| **1.7 mi (2.7 km)** | Turn left on Sir Francis Drake Boulevard.<br><br>The small communities of Inverness Park and Inverness are spread out for several miles along Sir Francis Drake Boulevard north of the intersection with Bear Valley Road. For several miles the road runs through the bayside residential community along the western shore of Tomales Bay. As many as 45 residences were destroyed in the Inverness Park area by the 1995 Vision Fire that burned much of the central Point Reyes Peninsula. |
| **3.7 mi (6.0 km)** | Town of Inverness. The parking area behind Inverness Store provides a good view of the bay and an uplifted and tilted marine terrace along the east shore (see figs. 9-12 and 9-13). |
| **6.5 mi (10.5 km)** | Intersection of Pierce Point Road on right. Pierce Point Road leads north towards Tomales Point; see discussions for **Tomales Bay State Park (Stop 6), Kehoe Beach (Stop 7),** and **Tomales Point Peninsula (Stop 8)**.<br><br>The road crosses the crest of Inverness Ridge near this intersection. Bedrock in this area consists of Salinian granitic rocks, but along the ridge they are deeply weathered. Only traces of the weathered granitic rock are exposed along the road. |
| **6.9 mi (11.1 km)** | The Laird Sandstone is exposed on the right side of the road near historic M Ranch. |
| **7.6 mi (12.2 km)** | Intersection of Mount Vision Road on left. See discussion for **Mount Vision (Stop 9)**. |
| **7.9 mi (12.7 km)** | Gently dipping beds of the Monterey Formation are exposed in an old quarry-like cut along the right side the road. |
| **9.5 mi (15.3 km)** | A view of Schooner Bay on Drakes Estero is on the left (east). The north end of Schooner Bay is used for oyster farming. Entrance to a U.S. Coast Guard Station is on the right. |
| **10.6 mi (17.1 km)** | A large radio transmission and receiving antenna facility on the right was used primarily for ship-to-shore communications in the Pacific region. The Marconi RCA, AT T, and MCI stations are still partly operational, but have more historic significance. Wireless communications began in the Point Reyes area in 1913, but the large Art Deco-design antenna field began operation in 1929 and was used through the WWII Era.<br><br>Large vegetation-stabilized dunes are visible along the shore west of the antenna field. |

**Continued.**

| | |
|---|---|
| **11.2 mi (18.0 km)** | The mouth of Drakes Estero is visible to the left near historic F Ranch. The road continues south and crosses a saddle area on the elevated marine terraces are visible. |
| **13.3 mi (21.4 km)** | Point Reyes Beach North access road is on the right (west). |
| **14.5 mi (23.3 km)** | Road to **Drakes Beach (Stop 5)** is on the left (east). |
| **15.0 mi (24.1 km)** | Pont Reyes Beach South access road is on the right (west). |
| **18.8 mi (30.2 km)** | Road to the **Chimney Rock** and the **historic Point Reyes Lifeboat Station (Stop 4)** is on the left (east). Outcrops in the vicinity consist of Point Reyes Conglomerate. |
| **19.8 mi (31.9 km)** | **Point Reyes Lighthouse and Visitor Center parking area (Stop 3)** |

## Stop 3—Point Reyes Lighthouse

**Stop highlights:** Salinian basement, porphyritic granite, Paleocene-Eocene conglomerate, Point Reyes Fault, San Gregorio Fault system

Point Reyes Lighthouse is the most popular destination in the park. Note that on weekends and holidays during whale watching season the road is closed to private vehicles and it is necessary to shuttle to the lighthouse museum area. Also note that the lighthouse is closed when winds exceed about 40 mph (18 m/sec). It is recommended to call the park in advance.

The weather at Point Reyes ranges from capricious to atrocious. Windy conditions can occur any time of year. The maximum wind speed recorded at the lighthouse was 133 mph (60 m/sec), and wind above 60 mph (27 m/sec) is not uncommon. The point is engulfed in fog an average of about 140 days a year, especially in the summer. However, the annual rainfall at the point averages less than 20 inches per year. Perhaps surprisingly, the average temperature is fairly constant at the lighthouse. The warmest temperatures are late summer (August to September) when the mean daily temperature is about 56° F, whereas the average daily temperature in January is about 50° F (Galloway, 1977).

The Point Reyes Lighthouse was constructed in 1870 on a headland point about 296 feet (90 m) above sea level. Traditional lighthouse operation ended when the Coast Guard installed an automated light and foghorn in 1975. The lighthouse was not built on top of the 600-foot (183 m) summit of Point Reyes because the high point is more often enshrouded in fog. However, on a clear day the view from the lighthouse

**Figure 9-12.** View of Tomales Bay from the parking area of Inverness Store (in the town of Inverness) along Sir Francis Drake Boulevard. A small sea cliff on the opposite side of the bay (to the left) is at the end of an uplifted marine terrace located near the trace of the San Andreas Fault in Tomales Bay. As a result of folding along the fault zone, the once probably flat marine terrace now dips gently to the east.

**Figure 9-13.** G.K. Gilbert (1908) took this photograph of a pushed up shoal in the marsh flats along the west shore of Tomales Bay. Gilbert reported stories of tsunamis more than 6 feet (2 m) high along the northeast shore of Tomales Bay caused by the earthquake. Note the large slumps along the east shore of the bay. Gilbert did not report whether these slumps were caused by the 1906 earthquake. However, he described significant landscape changes in the tidal flats as a result of mud shifted by the motion of the earthquake.

extends from the San Mateo coast to the south, to the Farollan Islands to the west, and Tomales Point and beyond to the north. The lighthouse was operated by a lighthouse keeper and usually three assistants. The light operated with a 120,000 candlepower flame lamp focused by a rotating Fresnel lens (later modified with a half-million candlepower electric lamp). The light was operated only from sunset to sunrise. At night, the lighthouse could project to the horizon—a distance of about 24 miles (39 km). At 5:12 am on April 18, 1906, the great earthquake struck and the Fresnel lens shifted off its track. However, the lighthouse keeper was able to make quick repairs so that the light was operational that evening.

The water depth quickly drops to about 150 feet (46 m) within a few hundred feet from shore. The lighthouse observation platform is an excellent location to observe gray whales in migration during January to April. Harbor seals, elephant seals, and sea lions are commonly seen swimming around the point, and occasionally great white sharks are sighted in search of their sea mammal prey. During high seas, crashing waves around the point provide an awesome display.

Uplift along the offshore Point Reyes Fault is likely responsible for the steep topography and bathymetry on the west- and south-facing headlands. Other faults can be observed onshore in the headlands (see fig. 9-2). Outcrops of Point Reyes Conglomerate can be examined along the path and around the Lighthouse Visitor Center (figs. 9-14 to 9-17). Granitic rocks are exposed in the sea cliffs near the parking area and in the Chimney Rock Point area (see Stop 4 below). Clark and Brabb (1997) mapped the granitic rocks as the "Porphyritic granodiorite of Pont Reyes" and published radiometric dating data, suggesting a middle Late Cretaceous age of

**Figure 9-15.** The Point Reyes Lighthouse was built on a headland promontory of Paleocene conglomerate. The historic lighthouse building is now a museum. The lighthouse observation deck is a good place to observe gray whales as they migrate in January to April. Reaching the lighthouse requires descending and ascending 300 steps. It is frequently foggy and windy at the lighthouse, and the lighthouse is closed during inclement weather.

about 82 million years (see discussions about the other granitic rocks on the Point Reyes Peninsula at stops 6, 7, and 8 below).

The Point Reyes Conglomerate is about 700-feet (213 m) thick, but is probably only a fraction of its original thickness. The age of the conglomerate is disputed. Galloway (1977) describes the unit as Paleocene in age, but Clark and Brabb (1997) assign the unit a younger age of Eocene (about 50

**Figure 9-14.** View of the beach strand north of Point Reyes. Cliffs of Paleocene conglomerate crop out in the headlands in the foreground. Note the extensive belt of coastal dunes in the back beach area. Older dune deposits stabilized by vegetation occur throughout the Point Reyes peninsula. This photograph was taken near the Lighthouse Visitor Center on Point Reyes. The beach extends in a north-northeast direction perpendicular to the prevailing north-northwest wind direction.

**Figure 9-16.** Outcrops of Paleocene conglomerate and sandstone are well exposed near the Lighthouse Visitor Center. The conglomerate and sandstone represent deep-sea canyon and upper submarine-fan deposits. Large, barren cement surfaces near the Lighthouse Visitor Center were used to trap rainwater for storage in cisterns to supplement the water needs of the lighthouse staff.

million years). Burnham (1998a, 1998b, 1999) demonstrates that the Point Reyes Conglomerate is essentially identical to the Carmelo Formation which crops out at and near Point Lobos south of Monterey. In both locations, the conglomerate is in direct contact with the underlying granitic basement (granodiorite). Distinctive clasts within the conglomerate include pebbles and cobbles of pink to purple porphyry tuff that contain pink crystals of feldspar and clusters of zircon and titanomagnetite grains (fig. 9-17). Burnham obtained radiometric (zircon U/Pb) ages of about 152 million years from conglomerates at Point Reyes and Point Lobos. In addition to these factors, the depositional sedimentary features preserved within the conglomerate suggest that the Point Reyes and Point Lobos deposits accumulated within the same submarine canyon system. Today, the deposits are separated by about 112 miles (180 km), offset by movement on the San Gregorio Fault system.

Clark and others (1984), Clark and Brabb (1997), and Stanley and Lillis (2000) describe the correlation of other units on the Point Reyes Peninsula to equivalent units in the Santa Cruz Mountains. Clark (1984) suggested that stratigraphic relationships within the Monterey Formation indicated that right-lateral slip along San Gregorio Fault was initiated about 10 million years ago. Clark also demonstrated that a glauconitic facies dated at about 8 million years within the Santa Margarita Sandstone crops out in both the Santa Cruz Mountains and the Point Reyes Peninsula. The Santa Margarita glauconitic unit indicates an offset of about 100 km. Although estimates vary, the timing and slip displacement of equivalent

**Figure 9-17.** The Point Reyes Conglomerate contains clasts that represent an assortment of different rock types; most are of volcanic origin. The person's finger points to a dark andesitic porphyry (tuff) that contains small, pink feldspar crystals. This striking lithology can be seen in conglomerate beds throughout coastal California extending from Ventura to Point Reyes. The conglomerate and granitic rock at Point Reyes correlates with the Carmelo Formation and Monterey Granodiorite at Point Lobos south of Monterey, California (Burnham, 1999).

units in Point Reyes and along the Santa Cruz Coast indicates that the rate of slip along the San Gregorio Fault was greatest in late Miocene time (about 25 to 30 mm/yr), but has gradually diminished to between about 4 to 10 mm/year (Clark, 1998; Bruns and others, 2002). The diminishing rate of offset along the San Gregorio Fault is likely related to increasing slip accommodation along the other faults on the San Francisco Peninsula and East Bay region.

Geophysical data demonstrate that fault systems in the San Francisco Peninsula and beneath the Gulf of the Farallones merge together to become the San Andreas Fault Zone in the Point Reyes Peninsula region. This means that the cumulative measurable slip for the San Gregorio, Pilarcitos/Montara, San Andreas, and Golden Gate Faults must also be accommodated by the San Andreas Fault Zone at Point Reyes. The Peninsula segment of the San Andreas Fault displays slip of about 14 miles (22 km) since about 1.8 million years ago; this displacement followed about 65 miles (105 km) of slip that occurred since late Miocene time on the Pilarcitos/Montara Fault system (Jachens and others, 1998). However, the Golden Gate Fault appears not to extend south of Lake Merced on the San Francisco Peninsula, so fault motion along the Golden Gate Fault near Point Reyes must be step over from the San Andreas and the other faults south of Bolinas. Using the combined offset of the San Gregorio, Pilarcitos, and San Andreas Faults on the San Francisco Peninsula, the total slip along the San Andreas Fault Zone on the Point Reyes Peninsula is estimated to be more than about 185 miles (300 km) since late Miocene time. As an independent line of evidence, the cumulative amount of post-early Miocene slip on the San Andreas Fault is about 196 miles (315 km) of right-lateral slip based on correlation of the Neenach Volcanic Formation in the western Mojave region with the Pinnacles Volcanic Area south of the Bay Area (Sims, 1993). However, studies of correlation of Cretaceous plutonic rocks, and Paleocene and Eocene sedimentary rock indicate that rocks on the Northern California Coast, including Point Reyes, have experienced additional northward displacement on fault systems that predate the San Andreas Fault system (Brabb and others, 1998; Wentworth and others, 1998). The granitic basement at Point Reyes originally formed as part of a long, north-south Cordilleran magmatic arc in a crustal block that was probably originally connected to southern California about 80 to 100 million years ago. Hill and Dibblee (1953) were the first to postulate a total displacement of about 348 miles (560 km) for Mesozoic basement along the fault systems in coastal California.

## Stop 4—Chimney Rock and the Historic Point Reyes Lifeboat Station Area

**Stop highlights:** Salinian granite, nonconformity, faults, marine wildlife viewing area

Before the railroad and modern highway system, shipping was the primary means of cargo and human transport.

Historically, the Point Reyes Peninsula was a primary hazard to coast navigation because of its close proximity to the port of San Francisco, because it juts out 10 miles (16 km) to sea, and because it is frequently enshrouded in fog. As a result of the untold loss of life and property from dozens of shipwrecks, a lifesaving station was built in the 1890s on the sheltered east side of Point Reyes. During its operation through the mid 20$^{th}$ century, observers walked the beaches on 4-hour shifts to watch for ships in trouble. With the development of modern maritime navigation systems and modern rescue craft, the Coast Guard ended the coastal watch in 1968. Still, several small fishing vessels and pleasure craft are lost practically every year in the treacherous waters around the point. Today, the historic Point Reyes Lifeboat Station is used for limited group overnight accommodations and other park activities.

The Chimney Rock Trail and the Sea Lion Overlook Trail both start at the parking area and both are worth investigating. **Be extremely cautious when approaching cliff areas. Active slumps are carving away at the ridgeline, undercutting the cliffs in some areas.**

The trail to Chimney Rock offers spectacular views of the Point Reyes headlands and of Drakes Bay. The trail to the Chimney Rock Overlook is about one mile. The overlook provides a view of a sea arch in addition to Chimney Rock, a large sea stack just offshore of the point. Both are formed in the Salinian granitic rocks (Porphyritic Granodiorite of Point Reyes of Clark and Brabb, 1997). Take the extra time to walk the loop trail along the south facing cliff top near the Chimney Rock Point. Another sea arch and many sea stacks are visible near the point and along the south facing shore of Point Reyes (figs. 9-18 and 9-19).

The nonconformable boundary between the granitic rocks and sedimentary rocks of late Miocene age are exposed in the sea cliffs along the Chimney Rock Trail and the trail that loops around the south side of the point (fig. 9-20). Green sandstone, rich in the mineral glauconite, is exposed locally along this unconformable surface. The sandstone unit is mapped as Santa Margarita Sandstone (Clark and Brabb, 1997), but the unit is probably younger than sandstone with the same name on the opposite side of Drakes Bay where the Santa Margarita Sandstone is overlain by a thick sequence of Santa Cruz Mudstone.

**Figure 9-19.** This view is looking west along the south face of the granite headlands of Point Reyes. The image was taken from the loop trail on Chimney Rock Point. Drakes Bay is to the right.

**Figure 9-18.** The cliffs and sea stacks at the east end of the Point Reyes headlands consist of granitic rocks. Chimney Rock (upper right) is a prominent sea stack. Note the sea arch formed in the fractured granitic rocks in the foreground.

**Figure 9-20.** Late Miocene sedimentary rocks rest nonconformably on granitic rocks and Point Reyes Conglomerate at Chimney Rock Point. The nonconformity is visible near the center of the image. The late Miocene rocks consist of a thin, intermittent basal bed of greenish glauconitic sandstone overlain by fine-grained siltstone and shale of the Purisima Formation. This view is looking toward the northwest from Chimney Rock. Drakes Bay in the distant right is on the opposite side of the point.

In the Point Reyes headlands area, this basal sandstone is directly overlain by sandstone, shale, and mudstone of the Purisima Formation of latest Miocene and Pliocene age (Clark and Brabb, 1997). Round sandy limestone concretions are weathering out of the Purisima Formation. **Please note that these outcrops are far too dangerous to investigate in the sea cliffs!**

The mesa-like top of Chimney Rock Point is capped by a marine terrace. Granitic cobbles from the Point Reyes Conglomerate are reworked into the marine terrace deposits. The terrace gravel is locally overlain by sand with a thin organic-rich soil horizon on top (fig. 9-21). The Point Reyes Conglomerate is well exposed and is accessible in the western end of the headlands near the Point Reyes Lighthouse area (see Stop 3). The conglomerate in the nearby headlands was probably the source of the conglomeratic material in the marine terrace deposits at Chimney Rock.

During low tide, the granitic rocks are well exposed along the beach near the lifeboat station, providing the dual opportunity to examine the rock and the marine wildlife that utilize the hard rock substrate. A short trail to Elephant Seal Overlook starts at the Chimney Rock parking area. Elephant seals, harbor seals, and other marine mammals frequently cover the cobble beach located at the intersection of Drakes Beach and the Chimney Rock (fig. 9-22). Although the beach is closed to public access, the overlook provides a relatively good view of the unconformable boundary between the Cretaceous granite and steeply eastward dipping strata of late Miocene age (Santa Margarita Sandstone and Purisima Formation). The Paleocene conglomerate exposed at the Point Reyes Lighthouse is not present along the Drakes Bay side of the promontory. The strata exposed in the sea cliffs in the east end of Drakes Bay reveal a syncline and an adjacent anticline; these folds are shown on the geologic map (see fig. 9-2).

**Figure 9-21.** Quaternary marine terrace deposits rest unconformably on late Miocene Purisima Formation. Rounded cobbles of granite and porphyry derived from the Point Reyes Conglomerate make up the base of the marine terrace deposit. The upper part of the terrace deposit consists of sand and a thin organic-rich soil horizon.

## Stop 5—Drakes Beach (Kenneth C. Patrick Visitor Center)

**Stop highlights:** Purisima Formation, faults, fractures, porecellanite, synclines and anticlines

Drakes Beach is accessible from a 1.5-mile (2.4 km) drive along an access road that intersects Sir Francis Drake Boulevard at 16.2 miles (26 km) from Highway 1, and 5.8 miles (9 km) north of the end of the boulevard at Point Reyes Lighthouse. The Kenneth C. Patrick Visitor Center is located at the beach parking area. Drakes Beach is a popular destination on warm weekends in the late summer.

Notes from the journals of the Sir Francis Drake voyage (1577 to 1580) suggested the white cliffs of what may now be Drakes Bay were very similar in appearance to England's White Cliffs of Dover. The cliffs of Drakes Bay are also reminiscent of those on the Channel Islands. The rocks exposed in the cliffs consist of porcellanite and glauconitic mudstone, siltstone, and sandstone and bear fossils of late Miocene to Pliocene age (Clark and Brabb, 1997; fig. 9-23). The porcellaneous character of the rock comes from original sediment that was rich in siliceous skeletal material of marine plankton. Glauconite is a greenish hydrous-potassium-iron silicate mineral common in marine sedimentary rocks that often is associated with fossilized invertebrate fecal material. The sedimentary rocks formed from sediments that were deposited under the sea while the landmass (that is now the Point Reyes Peninsula) was submerged offshore

**Figure 9-22.** This beach gravel bar is commonly covered with resting sea lions. The view is to the north from the end of the trail at Elephant Seal Overlook near the historic Point Reyes Lifeboat Station. The beach cobbles consist of granitic rock eroded from exposures along the shore near the lifeboat station and extending to the eastern point at Chimney Rock. In the distance, the steeply dipping sedimentary layers consist of late Miocene marine sedimentary rocks (Santa Margarita Sandstone and lower Purisima Formation). The dipping strata are along the western flank of a syncline exposed in the sea cliffs at the west end of Drakes Beach.

during its plate-tectonic voyage northward along the California coast. Galloway (1977) originally named the geologic units exposed in the sea cliffs the Drakes Bay Formation. However, Clark and others (1984) renamed the units the Purisima Formation to match the equivalent units that occur along the coast in Santa Cruz and along the San Francisco Peninsula.

A walk along the beach provides an opportunity to examine the marine beds, their orientation, as well as small faults, fractures, and joints in the rock exposed in the sea cliffs and on the remnants of a low, wave-cut bench located a short walk east of the Visitor Center (fig. 9-23). Viewed on a larger scale, the overall geologic structure of the Point Reyes Peninsula is revealed by the orientation of the layered sedimentary rocks exposed in the sea cliffs along the shore of Drakes Bay. The rock layers near the mouth of Drakes Estero at the east end of Drakes Beach form the center point of a broad, gentle syncline between the structural highs of Inverness Ridge and the Point Reyes headlands. The structural axis of the Drakes Bay syncline runs to the northwest along the west shore of Drakes Estero and roughly parallels the structural trend of Inverness Ridge and the San Andreas Fault Zone.

While standing on the beach you can see why the National Park Service encourages you to stay away from the base of the cliffs. Parts of the cliff are constantly giving way, showering the area below with falling rock and debris. The cones of debris that build up along the base of the sea cliffs between storms and high tides show how quickly the landscape is changing along the coast.

## Stop 6—Tomales Bay State Park

**Stop highlights:** Salinian granitic rocks, Tomales Bay, mixed evergreen forest, Bishop pines

Tomales Bay State Park is a good destination to study the geology and ecology of the west shore of the bay. The park entrance is located along Pierce Point Road about 1.2 miles (2 km) north of the intersection with Sir Francis Drake Boulevard. Although the park requires a day-use fee per vehicle, it is worth a visit, especially to take advantage of the park's picnic area or a walk or even a swim at one of the several sheltered sandy beaches along the shore of Tomales Bay. The park is perhaps best known for its Bishop pine forest. Bishop pine (*Pinus muricata*) occurs only as discontinuous relict stands along the California coast, occupying north-facing slopes where it can maximize fog exposure and precipitation. Bishop pines inhabit areas with shallow, acidic and poorly drained soils associated with the weathering of granitic- and shale-parent material.

Cliffs of granitic composition crop out along the shore of Tomales Bay (fig. 9-28). The plutonic rocks of Inverness Ridge and Tomales Point are best described as granitic in composition. They range in composition from granodiorite, quartz diorite, to granite in composition, and contain some pegmatite and aplite intrusions (see more discussion about granitic rocks in Stop 7 and 8).

## Stop 7—Kehoe Beach

**Stop highlights:** Salinian granitic rocks, aplite dikes, Laird Sandstone, Monterey Formation, nonconformity, faults, avalanche and debris chutes, sea cliffs

Kehoe Beach provides access to a variety of geologic features in a scenic setting. A half-mile trail starts at a parking area on Pierce Point Road and follows a freshwater marsh to the beach. Cliffs of steeply dipping layers of Monterey Forma-

**Figure 9-23.** These sea cliffs and wave-cut bench are along Drakes Beach near the Kenneth C. Patrick Visitor Center. Light gray siliceous mudstone in the sea cliffs is of the Drakes Bay Formation (Galloway, 1977) or equivalent Purisima Formation (Clark and Brabb, 1997). Fossils indicate the sedimentary rocks are of late Miocene age.

**Figure 9-24.** This view looking south from along Pierce Point Road shows the high ridgeline of Inverness Ridge at Mount Vision. The low hilly escarpment on the right consists of Monterey Formation. The Laird Sandstone underlies the grassy pastures in the foreground. This view is about a mile south of the entrance to Tomales Bay State Park.

## Road Log for Pierce Point Road (Optional Route)

**Route highlights:** Abbots Lagoon, Kehoe Beach, McClures Beach, Tomales Point, granitic rocks, schist, Laird Sandstone, Monterey Formation, ancient dune deposits, headlands, coastal prairie, Tule elk

A trip to the north end of the Point Reyes Peninsula along Pierce Point Road provides opportunities to see many unique geologic and ecological features. Pierce Point winds northward for 7.5 miles (12 km) across the coastal prairie. Along the way, the road passes Tomales Bay State Park, several active dairy farms, Abbotts Lagoon, and Kehoe Beach before entering the Tule Elk Reserve. The road ends at historic Pierce Point Ranch near McClures Beach. Outcrops of Laird Sandstone can be seen along the Pierce Point Road (between Tomales Bay State Park and Kehoe Beach). Elk herds grazing across the coastal prairie are a scene not to be missed! Early visitors to the Point Reyes Peninsula described great herds of elk. However, the original elk population on the peninsula was wiped out by over hunting and competition with cattle ranching by the 1870s. The elk were reintroduced to the area in 1978.

With extra time, it is worth considering a hike to one of the beaches (Kehoe Beach or McClures Beach), or the long hike to Tomales Point itself. **Please note that riptides and pounding surf can be extremely dangerous along the Pacific beaches; do not attempt to walk along the sea cliffs during high tide or during inclement weather. Poison oak is common along trails and in the back beach areas.**

| Distance | Description |
|---|---|
| **0.0 mi (0.0 km)** | Intersection of Pierce Point Road with Sir Francis Drake Boulevard. The intersection is located on a pass through Inverness Ridge. Bishop pine and Douglas fir forest dominate the landscape in the area. |
| **1.2 mi (1.9 km)** | Entrance to Tomales Bay State Park on right (see description for **Stop 6—Tomales Bay State Park**).<br><br>Continuing north along Pierce Point Road for the next 2 miles, the road crosses cattle and dairy ranch lands. Laird Sandstone and some Monterey Formation underlie this section of the route; changes in lithology are reflected by vegetation contrasts. An escarpment of low hills to the left (south) of the road consists of more resistant beds of the upper Monterey Formation capped unconformably by the softer Santa Margarita Sandstone (fig. 9-24). |
| **3.5 mi (5.6 km)** | Abbotts Lagoon is on the left (west). Coastal dunes and beach form the barrier across the entrance of this submerged valley (fig. 9-25). A hilly escarpment of Monterey Formation capped by Santa Margarita Sandstone runs along the left (south) side of the lagoon and valley. |
| **5.6 mi (9.0 km)** | Kehoe Beach parking is on both sides of the road (see description for **Stop 7—Kehoe Beach**).<br><br>Laird Sandstone is exposed in the hillside south of the trailhead to Kehoe Beach. A mile to the north, the road passes Kehoe Ranch and ascends to the top of a ridge underlain by granitic rocks. Much of the Point Reyes Peninsula is visible to the north from the top of the ridge about 2 miles south of Kehoe Beach. |
| **7.9 mi (12.7 km)** | Boundary of the Tule Elk Reserve (fig. 9-26). |
| **9.2 mi (14.8 km)** | Upper Pierce Point Ranch at end of Pierce Point Road. McClures Beach access is to the left (west).<br><br>A trail to Tomales Point starts at historic Pierce Point Ranch (fig. 9-27). The hike to Tomales Point is about 8 miles (out and back). Exceptional views of the granite headlands on the Pacific side can be seen along the trail. Some sections of the trail cross loose dune sand, particularly near the point. The hike is not recommended in cold and |

**Continued.**

| | |
|---|---|
| | windy weather. However, on a warm early spring day, hikers will enjoy the wildflowers and may be treated with glimpses of pods of whales migrating around the point between the Pacific shore and Tomales Bay. |
| **9.6 mi (15.4 km)** | McClures Beach parking area (see description for **Stop 8—McClures Beach**). |

**Figure 9-25.** Abbotts Lagoon as seen from the parking area on Pierce Point Road. The hill to the left of the lagoon consists of Monterey Formation capped by Santa Margarita Sandstone. Coastal dunes make up the hills to the right of the lagoon.

**Figure 9-27.** View looking north toward Tomales Point. Tomales Bay is to the right; the Pacific Ocean is to the left. Historic Pierce Point Ranch is in the center of the image. This image was taken from a ridgeline near the south end of the Tule Elk Reserve along Pierce Point Road.

tion are exposed where the trail intersects the beach (fig. 9-29). Monterey Formation underlies the pasture lands and coastal dunes extending southward to Abbotts Lagoon.

Farther north along the beach, cliffs of Laird Sandstone give way to Salinian granitic rocks (figs. 9-30 to 9-32). The nonconformity between the massive Laird Sandstone (middle Miocene) and the underlying Salinian granitic basement is well exposed in sea cliffs at the north end of the beach (fig. 9-31). The sea stacks of granite covered with mussels stand

**Figure 9-26.** Tule elk along Pierce Point Road.

**Figure 9-28.** Cliffs of Salinian granitic rocks (tonalite) crop out along the shore in Tomales Bay State Park. The cliffs and slopes along the west side of Inverness Ridge are covered with a unique mixed evergreen forest. Red alder dominates the forest community near the shore, whereas Douglas fir and Bishop pines dominate higher on the ridge.

**Figure 9-29.** Steeply northward dipping beds of Monterey Formation are exposed in the sea cliff next to where the Kehoe Beach access trail reaches the beach. The rock consists of thinly laminated siliceous mudstone and siltstone (porcellanite).

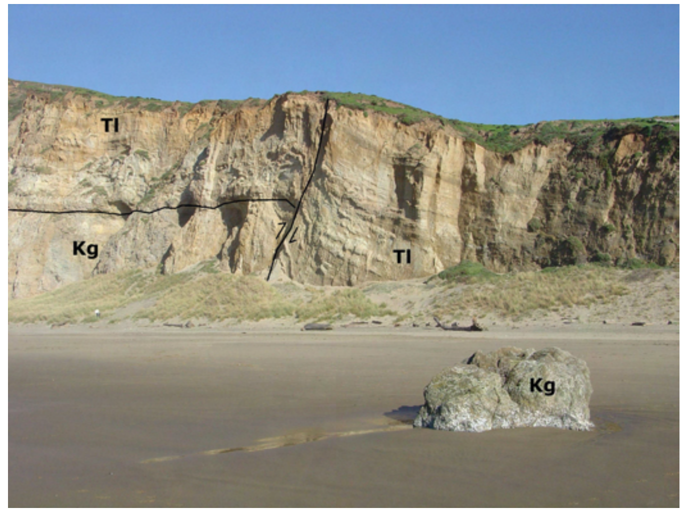


**Figure 9-31.** At Kehoe Beach, the Laird Sandstone (Tl) rests nonconformably on Cretaceous granitic rocks (Kg). The sandstone is offset by a high angle reverse fault.

out along the beach. A well exposed high-angle reverse fault is exposed in the cliff. The massive beds of the Laird Sandstone are offset by about 130 feet (40 m) along the main fracture of the exposed fault (fig. 9-31). The fault trace creates an escarpment in the pastures above the sea cliff (see fig. 9-30).

Fossil marine mollusks and echinoids found at the base of the Laird Sandstone on Kehoe Beach indicate that deposition occurred in shallow during middle Miocene time (Clark and Brabb, 1997). These sandy facies grade into finer grained rocks (sandstone, siltstone, and shale) of the lower Monterey Formation. The Monterey Formation grades upward into siliceous shales, porcellanite, and chert. The upper Monterey Formation yields fossil benthic foraminifera that suggest the sediments were deposited in bathyal depths of about 600 to 13,000 feet (200 to 4,000 m) during middle to late Miocene time (Clark and others, 1984).

The granitic rocks exposed at Kehoe Beach are a complex mix of lithologies (fig. 9-32). Intrusive igneous rocks consist of granite, granodiorite, quartz diorite, and tonalite, and include dikes of aplite and alaskite—a classification of

**Figure 9-30.** This view is looking north along the sea cliffs at Kehoe Beach. Gently dipping layers of Laird Sandstone are exposed in the lower sea cliffs in the foreground, whereas the higher cliffs in the distance are granitic rocks.

**Figure 9-32.** The granitic basement rocks at Kehoe Beach consist of a mix of granodiorite with inclusions of older metamorphic rock that are cut by dikes of aplite and alaskite. Aplite is a light-colored, fine-grained rock with granitic texture, consisting essentially of quartz and orthoclase. Alaskite is also a light-colored granitic rock that has orthoclase, microcline, and subordinate quartz (see fig. 9-33). Both rock types lack mafic constituents.

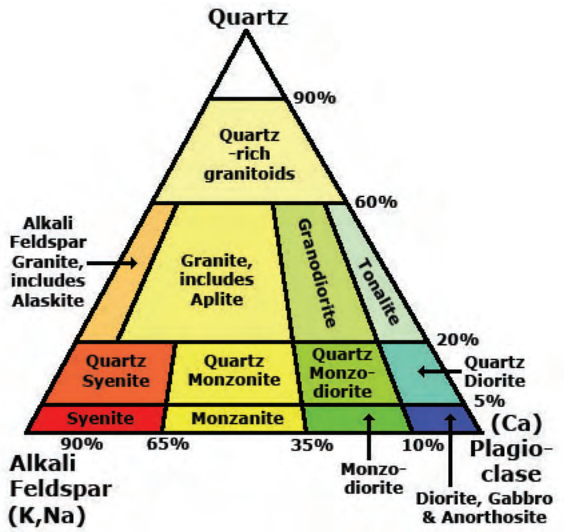


**Figure 9-33.** Classification of granitic rocks based on composition of feldspars (K-, Na-, and Ca-rich varieties) and quartz. Mafic components (igneous minerals rich in iron and magnesium) are not included in this classification. This classification of granitic rocks is modified from an igneous petrology chart prepared by the International Union of Geological Sciences and presented by Best (1982).

these rocks is illustrated in fig. 9-33. Some bodies of darker schist and gneiss included in the granite probably represent fragments of more ancient metamorphic rock (xenoliths) that predate the intrusive igneous rocks. These granitic rocks are probably mid-Cretaceous in age (roughly 80 to 100 million years old) and the metamorphic rocks are much older, with

**Figure 9-34.** View looking toward the south end of McClures Beach. The beach is located in a cove along the Pacific side of Tomales Point. The Salinian granitic basement exposed at the south end of the beach is lithologically different than the rock exposed at the north end of the beach. Clark and Brabb (1997) include the lithologies exposed at the south end of the beach within a map unit they named "Granodiorite and Granite of Inverness Ridge."

**Figure 9-35.** View looking toward the north end of McClures Beach where the granitic basement has a different appearance than at the opposite end of the beach. Clark and Brabb (1997) assigned the name "Tonalite of Tomales Point" to rocks exposed on the peninsula north of McClures Beach.

zircon-based radiometric ages ranging from Paleozoic to Precambrian age (Ross, 1983). Clark and Brabb (1997) include the granitic rocks exposed at Kehoe Beach within a mapped unit called "Granite and Granodiorite of Inverness Ridge."

The granitic rock exposed along Kehoe Beach is heavily fractured and displays evidence of faulting, both ancient and more recent. The highly fractured character of the rocks makes them dangerous to climb. Debris chutes formed in the granitic rocks channel falling material onto talus cones along the shore; these are eroded away during high wave activity. Some of the chutes start from cave-like overhangs beneath the base of the Laird Sandstone (fig. 9-31).

## Stop 8—McClures Beach

**Stop highlights:** Salinian granitic basement rocks, granodiorite, tonalite, eolianite

The Salinian granitic basement rocks are well exposed at McClures Beach (figs. 9-34 and 9-35). A half-mile trail leads from a parking area downhill to the beach located in a cove between massive headlands on the Pacific side of the Tomales Point peninsula. The headlands at the south end of McClures Beach mark a lithologic boundary in the Salinian basement. The exposures of the "Granite and Granodiorite of Inverness Ridge" exposed at Kehoe Beach give way to the "Tonalite of Tomales Point" (Clark and Brabb, 1997). The Granodiorite and Granite of Inverness Ridge is of middle Cretaceous age and contains inclusions (xenoliths) of older metamorphic rock that have cross cutting dikes of aplite and alaskite (see figs. 9-32 and 9-33). The Tonalite of Tomales Point on northern McClures Beach to Tomales Point has a more uniform texture and appearance (fig. 9-35). Tonalite is a rock rich in plagioclase, quartz, and hornblende or biotite, but has slightly less orthoclase than granodiorite. Clark and Brabb (1997) note the similarity to the rock at Tomales Point with similar rock exposed on Bodega Head (located about 10 miles (16 km) north of Tomales Point) and present a recalculated radiometric age of 94.3 million years (early Late Cretaceous) for the tonalite.

A nonconformity between the granite and overlying ancient dune deposits (eolianite) of Quaternary age can be seen near where the trail intersects the beach (fig. 9-36). The ancient dune sands probably accumulated in an earlier valley in the Quaternary Period before or during the last ice age (Wisconsin) and before the modern rise in sea-level that is responsible for the ongoing coastal erosion. The sandstone is fairly tightly cemented, but preserves bedding structures consistent with features of wind-blown sand deposits. The sandstone fills an ancient stream valley that is being exhumed by modern McClures Creek.

## Stop 9—Mount Vision on Inverness Ridge (Optional Route)

**Stop highlights:** Granitic rocks, area of the 1995 Vision Fire, views of Tomales Bay and Drakes Estero (drowned river valleys)

Mount Vision Road winds uphill for about 4 miles (7 km) along the crest of Inverness Ridge. Inverness Ridge is a long and narrow mountain with a core of Salinian crystalline basement rocks. These rocks consist of Cretaceous granitic intrusive rock with some older metamorphic rocks. The older rocks are commonly referred to as "roof pendants"—they are pieces of the original rock that did not melt when large igneous bodies formed the southern Sierra Batholith in Cretaceous time. The Salinian crystalline basement rocks are bounded by the San Andreas Fault Zone to the east and are blanketed by gently dipping sedimentary rocks of late Tertiary age on the south and west. Unfortunately, no significant bedrock exposures are accessible along the Mount Vision Road except occasional granitic boulders placed around parking areas. More accessible exposures of Salinian granitic rocks are available at Stops 6 and 7.

On a clear day, the drive along Mount Vision Road provides sweeping views of the Point Reyes Peninsula, Tomales Bay, and upland regions in Marin and Sonoma Counties to the east (fig. 9-37). Parking areas near the top of Mount Vision also provide a view of Drakes Estero (fig. 9-38). "Estero" means estuary or marsh in Spanish. Tomales Bay and Drakes Estero are both stream valleys that were flooded by the roughly 400 foot (120 m) rise in sea level since the end of the last glacial maximum of the Quaternary Period, about 18,000 years ago. The bays are flushed by marine currents and tides. Compared with Tomales Bay, Drakes Estero receives only a small quantity of freshwater input from streams and springs.

Much of the Mount Vision area, about 5,000 hectare (12,354 acres) of maritime scrublands, Bishop pine forest, and grasslands, burned in a 1995 fire (called the Vision Fire) that extended from Limantour Beach to much of the crest of Inverness Ridge. At least 50 years of past fire suppression activities prior to the fire contributed to the buildup of combustible material, leading to the uncontrollable firestorm that engulfed much of the central Point Reyes Peninsula region.

**Figure 9-36.** Quaternary dune deposits exposed by coastal erosion crop out near the McClures Beach access trail. These old dune deposits are well cemented and appear to be filling an old valley that existed in close proximity to the modern stream valley along the beach access trail.

**Figure 9-37.** This view from the summit of Mount Vision on Inverness Ridge is looking northeast toward Tomales Bay. Bolinas Ridge (in the distance) runs along the east side of the San Andreas Rift Valley on the far side of the bay. Note the vegetation contrast of the mixed evergreen forest on the Point Reyes side of the bay compared to the grasslands that dominant the landscape on the east side of the bay.

Although most of the fire was on park land, at least 45 homes were destroyed in nearby Inverness Park. The fire had devastating effects on some plant and animal species, whereas other species, both native and exotic, benefited from the new space available after the fire. For example, the Point Reyes mountain beaver population was partially devastated by the fire and loss of habitat. On the other hand, Bishop Pines release their seeds from resinous cones during a fire, a natural way of propagation for the species. The long-term regrowth of plant and animal communities are being monitored by the National Park Service (National Park Service, 1996; Brown and Holzman, 1998).

## Stop 10—Limantour Road (Optional Route)

**Stop highlights:** Estuary, lagoon, sand spit, marine terraces

Limantour Road intersects Bear Valley Road about 1.4 miles (2.2 km) west of the Park Headquarters. Driving west, Limantour Road crosses Inverness Ridge before descending to Limantour Beach. The highest point on Point Reyes Peninsula is Mount Wittenberg, elevation 1,407 feet (429 m). The summit is located about a mile south of the Sky Trail parking area near the high point along Limantour Road about 3 miles (5 km) west of Bear Valley Road. Older metamorphic rocks (marble, schist, gneiss, quartzite, and aplite dikes) are present in the upland region along Inverness Ridge between Mount Wittenberg and Mount Vision. These rocks predate the Cretaceous granitic rocks and are roof pendants in the greater intrusive complex of the Salinian basement (see description of the granitic crystalline basement for Stop 9). Unfortunately, because of intense weathering in the upland area, none of these rocks are exposed along the road. The upland area receives about 40 inches (102 cm) of precipitation per year, mostly as plant initiated condensation associated with fog.

The Point Reyes Hostel and Clem Miller Environmental Education Center are located 5 miles (8 km) west of the intersection with Bear Valley Road. Both are an optional destination for overnight group housing, but planning is needed well in advance. Parking access to Limantour Beach and Lagoon (Estero de Limantour) is located another 1.5 west (2.4 km) of the Environmental Education Center.

Sedimentary formations of middle to late Miocene age crop out in the hillsides west of granitic rocks that make up Inverness Ridge. The sedimentary rocks dip steeply to the west (about 30 degrees). Laird Sandstone and Monterey Formation are poorly exposed in the upland region east of the Environmental Education Center. The Santa Margarita Sandstone of Clark and Brabb (1997) crops out along a faint northwest-trending escarpment in the vicinity of the Environmental Education Center. The Coast Trail starts at the Point Reyes Hostel and follows a canyon west for about 1.5 miles (2.4 km) to the beach. The canyon cuts downhill through increasingly younger beds of the Purisima Formation.

Limantour Beach is on a spit built by longshore currents that flow northward along the beach (fig. 9-39). The current is generated by the refraction of prevailing wave swells as they arrive from the northern Pacific region. As the prevailing waves are refracted around the point, they come onshore along the beaches in Drakes Bay and Limontour beach from a more southerly direction. Over time, this refraction of wave energy helped erode the crescent-shaped coast, and is responsible creating the northward-flowing longshore current that helped build up the barrier island (or spit) at Limontour Beach. Similar processes helped create the barrier island spit at the Bolinas and Stinson Beach area (Stop 13). The lagoon behind the bar-

**Figure 9-38.** This view from the summit of Mount Vision is looking southwest toward Drakes Estero. The headlands of Point Reyes are in the distance.

**Figure 9-39.** Estero de Limantour is a small bay and lagoon on the south end of Drakes Bay. The high headland area of Point Reyes is in the distance. Note the crescent shape of Drakes Bay. The barrier island associated with Limontour Beach is actually a spit that built up from sediment that migrated northward along the coast, transported by prevailing longshore currents.

rier (Limantour Estero) is a popular destination for bird watching, particularly during migration periods.

Blackened, charred stumps along the road are a reminder of the extensive 1995 Vision Fire that burned throughout the central Point Reyes Peninsula region, extending from Limantour Beach eastward across Inverness Ridge. In most areas, shrub and underbrush have returned to near pre-fire conditions, but it will take perhaps another century to restore the Douglas fir and Bishop pine groves that thrived along the upland areas before the fire.

## Stop 11—Olema Valley (rolling stop)

**Stop highlights:** San Andreas Fault Zone, linear rift valley, shutter ridges, deflected streams, Calera Limestone

Most of Olema Valley is now part of National Park Service holdings and is protected from future development, and for good reason. Three major fault systems converge in Olema Valley (see fig. 9-2). The most catastrophic surface rupture during the 1906 earthquake happened in the Olema Valley region (fig. 9-40). Fortunately, the area was sparsely populated at the time of the great earthquake.

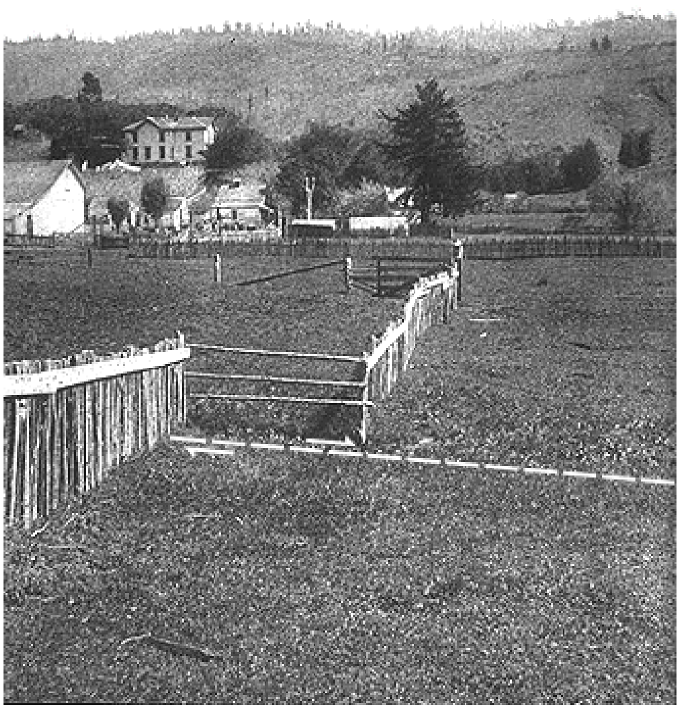

**Figure 9-40.** This historical photograph of an offset fence near Bolinas, California was taken by G.K. Gilbert shortly after the 1906 earthquake (Gilbert, 1908). The offset fence shows a right-lateral slip of about 8.5 feet (2.6 m). Also note the high degree of deforestation shown on the distant hillsides in this photograph.

The thick second growth forest of oak, mixed evergreens, and redwood in Olema Valley masks many of the geologic features of the rift valley. None of the surface rupture features described by Gilbert (1907) after the great 1906 earthquake remain visible today. However, along Highway 1 between Olema and Bolinas Lagoon, it is possible to see low, linear ridges (fault scarps) and depressions that flood during wet periods (sag ponds) and reveal the presence of great faults that run through the valley.

Olema Valley can be seen in two ways–by vehicle or by foot. Unfortunately, by vehicle there are few pull off where it is possible to stop to look at the San Andreas Fault Zone and associated landscape features. Shutter ridges and escarpments can be glimpsed while driving along the road. If hiking is an option, the Rift Zone Trail extends southward from the Bear Valley Visitor Center parking area to another parking area at Five Brooks–a distance of about 5 miles (8 km). Combined with the Earthquake Trail at the visitor center, the trail crosses or parallels the San Andreas Fault in many places or climbs or crosses shutter ridges and escarpments associated with the fault zone. South of Five Brooks, the Olema Valley Trail continues southward about 4 miles (7 km) along the rift valley to intersect with Highway 1 near Bolinas. Be sure to get trail conditions before attempting this hike especially after wet weather (see the park trail map on http://www.nps.gov/pore/).

An unusual stream drainage pattern in Olema Valley reveals the past motion of the faults in the valley. Many of the small streams draining from the uplands on both sides of the valley display right-lateral offset where they cross faults in the valley. For about a 2 mile (3 km) section of the valley midway between Five Brooks and Bolinas Lagoon two streams flowing in opposite directions drain from the valley. Pine Gulch Creek on the west side of the valley drains into Bolinas Lagoon, whereas Olema Creek on the east side of the valley drains northward into Tomales Bay. A low shutter ridge along the 1906 trace of the San Andreas Fault divides the two drainages where they run parallel to each other. On a larger scale, as the Point Reyes Peninsula gradually migrated northward, Inverness Ridge, itself a great shutter ridge, deflected all the stream drainages northward into the linear rift valley drained by Olema Creek and its submerged extension beneath Tomales Bay. In map view, Lagunitas and Nicasio creeks are deflected streams that were diverted northward into Olema Valley.

Part of the geologic story of Olema Valley is a small outcrop area of Calera Limestone located about a mile south of Five Brooks in central Olema Valley. An unsuccessful venture to utilize the limestone began with the construction of the Olema Lime Kilns in 1850. However, the low quality of the limestone, limited supply, and a poor economy forced the abandonment of the kilns by 1855; only ruins remain today. The presence of Calera Limestone reveals an important clue about the geologic development of the San Andreas Fault Zone in Olema Valley. Calera Limestone also occurs in the Permanente Terrane of the Franciscan Complex in the Santa Cruz Mountains and on the San Mateo Coast near Pacifica. Rocks of the Permanente Terrane occur only in a narrow belt of rock within the rift zone between the "eastern" and "western" boundary faults of Galloway, (1977). The mid Cretaceous-age limestone-bearing terrane between the boundary faults does not correlate with the Franciscan sandstone, basalt, and greenstone on the east side of the fault zone on Bolinas Ridge, nor does it correlate with the granitic basement and Tertiary-age marine rocks of Inverness Ridge to the west. The enigmatic limestone is part of a thin sliver of Franciscan basement rock that is bounded by faults within the rift associated with the fault system.

## Stop 12—Palomarin Beach

**Stop highlights:** Duxbury Reef, Palomarin slump, offset marine terrace deposits, syncline, Santa Cruz Mudstone

The Palomarin Beach area is a good place to observe a variety of geologic processes and to observe seashore wildlife. The parking area for Palomarin Beach is located at the end of Mesa Road two miles west of the intersection of Olema-Bolinas Road in the town of Bolinas. The Point Reyes Bird Observatory (field station) is also situated along Mesa Road about a half mile from the end of the road. **It is important to plan to arrive at low tide, otherwise access to the beach and tide-pool area is potentially dangerous if not impossible. Hikers along the coast have been trapped along the sea cliffs by the rising tide. In addition, be aware that loose material is constantly sloughing off the sea cliffs.**

The Santa Cruz Mudstone is the surficial bedrock throughout the southern Point Reyes Peninsula and is largely responsible for many of the topographic characteristics of the area. The Santa Cruz Mudstone is exposed in the sea cliffs along the coast at Palomarin Beach and southward to the end of the peninsula at Duxbury Point. Clark and Brabb (1997) reported that the Santa Cruz Mudstone is about 6,600 feet (2000 m) thick at the southern end of the peninsula at Bolinas Mesa but pinches out to the east of Drakes Bay. The Santa Cruz Mudstone contains fossil microplankton (diatoms and benthic foraminifera) that indicate the sedimentary rocks are of late Miocene age. This thick section of siliceous mudrock is complexly folded and faulted, but mostly dips quite steeply to the west of the structural high at the south end of Inverness Ridge. The layers of Santa Cruz Mudstone dip westward in the range of 20 to 60 degrees. The eastern extent of the Santa Cruz Mudstone borders the San Gregorio Fault (or "west boundary fault" of the San Andreas Fault Zone of Galloway (1977). It is bounded on the east by offset older Quaternary marine sediments of the Merced Formation and younger marine terrace deposits that are preserved in the rift valley area near Bolinas. From viewpoints along the coast, a well developed marine terrace is visible along the southern peninsula, with marine terrace deposits resting on an angular unconformity above the dipping layers of mudstone.

The steep shoreward dip is responsible for a large landslide complex along the shore north of Palomarin Beach. The landslide offsets bedrock of Santa Cruz Mudstone and marine terrace deposits (figs. 9-41 and 9-42, and see the landslide area shown on fig. 9-2). Beach erosion is constantly undercutting the toe of the slide area which initiates farther slide motion. The highly brittle character of the siliceous mudstone makes it prone to fracturing and subsequent erosion. The pounding action of waves has cut an extensive wave-cut platform that locally extends seaward for nearly a half mile. At low tide, a syncline is well exposed in the Santa Cruz Mudstone at the toe of the Palomarin slide (fig. 9-41). The wave-cut platform extends both northward and southward along the coast.

## Stop 13—Duxbury Reef

**Stop highlights:** Santa Cruz Mudstone, steeply dipping strata, views of the Gulf of the Farallones

The southern tip of Point Reyes Peninsula is called Duxbury Reef and is considered the largest shale reef in North America. Like the Point Reyes Headlands and Drakes Bay to the north, Duxbury Reef has been the site of many shipwrecks; materials reportedly lost on the reef include food, merchandize, animals, hides, wood, coal, petroleum products, mail, an organ, whiskey, and gold (National Oceanic and Atmospheric Administration, 2005). The reef was named after the shipwreck of the Duxbury that occurred there in 1849. In 1878, a freighter named the Western Shore bearing a heavy load of Alaskan coal was driven by ashore by a combination of strong northerly currents and possibly pilot error. It was reported that coal from the shipwreck washed up on Point Reyes beaches for decades after the ship-

**Figure 9-41.** A large slump is an impressive landscape feature at Palomarin Beach. At low tide a plunging anticline is exposed in a wave-cut platform below the toe of the great slump. Dipping marine-terrace deposits unconformably overlie marine mudrocks of the late Miocene-age Santa Cruz Mudstone. These marine terrace deposits are offset by rotation of the large slump block. The terrace deposits are best observed from the beach (see fig. 9-42). The Point Reyes headlands are in the distance.

wreck (Hobson, 1994). Extensive tide pools lined with seaweed, beds of mussels, and teaming with a variety of invertebrates are exposed at low tide. A trail to the tide pools at Duxbury Reef starts at Agate Beach County Park. From Bolinas, take Mesa Road about 0.7 miles (1.1 km) west, take Overlook Drive 0.5 miles (0.8 km) south, and then Elm Road 0.7 miles (1.1 km) west to the Agate Beach parking lot at the end of the road.

The Santa Cruz Mudstone is well exposed in the sea cliffs and in the exposed reef at low tide. More resistant layers within the steeply dipping strata produce ridges that extend seaward, whereas softer layers and fractures which eroded more quickly form parallel tidal channels (fig. 9-43). The broad shale reef created by coastal erosion of the Santa Cruz Mudstone extends seaward for nearly a half mile into outer Bolinas Bay. The reef is part of the Gulf of the Farallones Marine Sanctuary (for more information about the Gulf of the Farallones, see Karl and others, 2000).

**Figure 9-43.** Duxbury Reef extends southward about a half-mile from the southern end of the Point Reyes Peninsula, just west of Bolinas Lagoon. The reef and sea cliffs consist of steeply westward dipping beds of Santa Cruz Mudstone. This view is looking south toward the Gulf of the Farallones.

## Stop 14—Bolinas and Stinson Beach Area

**Stop highlights:** Drowned river valley, Franciscan Complex, San Andreas Fault Zone

The Gold Rush of 1849 initiated one of the greatest migrations in human history. Wood for building and firewood was needed to satisfy the growing population in San Francisco. Bolinas Lagoon served as a port for small flat bottom boats to ferry wood and lumber derived from the redwood forests in Olema Valley. A historic photograph taken by G.K. Gilbert after the 1906 earthquake shows that the hillsides were largely stripped of their redwood and Douglas fir forests by that time (see fig. 9-40). Discovery of a copper vein near the head of Bolinas Lagoon initiated marginally economic mining efforts that started in 1863 and continued intermittently until 1918. The development of the North Coast Railroad in the mid 1870s diverted much of the commercial activity associated with logging and ranching away from the Bolinas area, but fishing, tourism, and residential development continued. The Mount Tamalpais 15 minute quadrangle map of 1897 shows several dozen established buildings on the north side of the harbor entrance to Bolinas Lagoon, but the barrier island was uninhabited. An overland route that would eventually become the Shoreline Highway (U.S. Highway 1) was already established in 1897. The beach community started in about 1900 with a tent colony in the beach dunes adjacent to the lagoon, and a subdivision along the shore was planned and developed by Nathan H. Stinston starting shortly after the 1906 earthquake (figs. 9-44).

**Figure 9-42.** View of the slump block at Palomarin Beach (also shown in fig. 9-41). This view shows the angular unconformity between northwest dipping Santa Cruz Mudstone and the overlying marine terrace deposits. The slump block has rotated the marine terrace deposits so that they dip toward the shore. A small stream cascades from a ravine carved at the base of the headwall escarpment of the slump.

Three major earthquake faults of the San Andreas Fault Zone merge together from the south in the Bolinas area–the Golden Gate, San Andreas, and San Gregorio Faults, from east to west, respectively (figs. 9-45 and 9-46, and also see fig. 9-2). To the south, these faults are submerged or covered by sediments beneath the beach and lagoon. The three faults converge northward in the Olema Valley to the narrowest point of the fault zone near Five Brooks (where it is still about a half kilometer wide). The detailed geometry of how these faults merge or might behave during earthquakes is unclear.

The Golden Gate Fault (called the "east boundary fault trace" by Galloway, 1977) runs along the eastern shore of Bolinas Lagoon. Its location can be inferred from exposures in road cuts along Highway 1. Near the northern end of the lagoon poorly unsorted and poorly consolidated alluvial terrace gravels of Quaternary age (the Olema Formation) can be

Figure 9-44. These cracks along the shore of Bolinas Lagoon formed during the 1906 earthquake. Photograph by G. K. Gilbert (1908). This view is looking southeast along the western shore of the lagoon toward what was then the undeveloped barrier spit that is now home to Stinson Beach.

Figure 9-46. View looking north from Highway 1 toward Stinson Beach and Bolinas Lagoon. The crest of Inverness Ridge is in the center of the image. Olema Valley, the rift valley of the San Andreas Fault Zone, is to the right (east) of the ridge. Bolinas Ridge is to the far right (east) of Olema Valley.

seen in the road cut. Clark and Brabb (1997) show that deposits of terrace gravels occur scattered throughout Olema Valley. Franciscan rocks occur along the eastern side of the Golden Gate Fault and are exposed extensively along Highway 1 and the coast southward toward the Marin Headlands (figs. 9-47 and 9-48).

The geologic maps of both Galloway (1977) and Clark and Brabb (1997) show that the main trace of the San Andreas

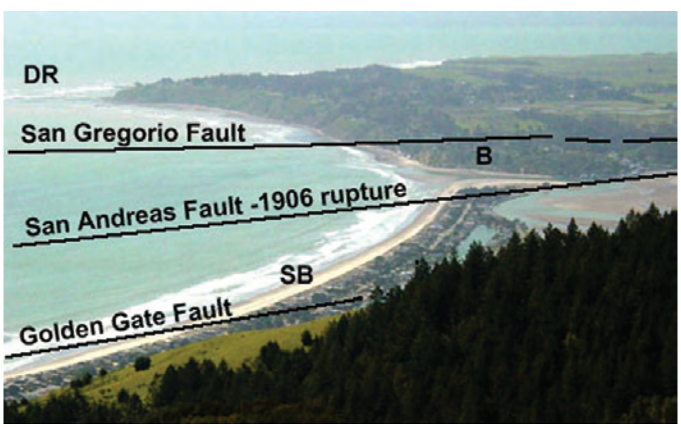


Figure 9-45. View is looking down toward Stinson Beach (SB) and Bolinas Bay from an overlook area on Bolinas Ridge along Bolinas-Fairfax Road. The town of Bolinas (B) is on the west side of the mouth of Bolinas Lagoon. Duxbury Reef (DR) is at the south end of the Point Reyes Peninsula. Lines show the approximate location of the three great faults—the San Gregorio Fault, San Andreas Fault (1906 rupture trace), and the Golden Gate Fault—that merge to form a single (or combined) fault zone in Olema Valley. How the faults interconnect, both near the surface and at depth, is uncertain. Onshore they collectively become part of the San Andreas Fault Zone and Olema Valley is a San Andreas Rift Valley.

Figure 9-47. Older Quaternary alluvial gravels of the Olema Formation overlie weathered Franciscan bedrock along Highway 1 south of the intersection of Bolinas-Olema Road along Bolinas Lagoon. The age of the gravels is about 55,000 years based on correlation of volcanic ash found in this unit (analysis by Andrei Sarna-Wojcicki, USGS).

Fault that ruptured in 1906 roughly parallels the western shore of Bolinas Lagoon. Their geologic maps show that the unsorted and poorly consolidated terrace gravels are offset along this strand of the San Andreas Fault. In addition, Pliocene- to Pleistocene-age marine and marine-terrace deposits (Merced Formation of Clark and Brabb, 1997) occur on the hillsides on the west side of the 1906 fault rupture.

The San Gregorio Fault (called the "west boundary fault trace" by Galloway, 1977) comes onshore on the east side of "downtown" Bolinas. The fault follows the linear trough of Paradise Valley before crossing into Olema Valley. Paradise Valley lies just to the west of Horseshoe Hill Road, which connects between Highway 1 and Bolinas. The fault scarp is expressed as a steep slope just east of the intersection of Olema-Bolinas Road and Mesa Road in Bolinas. Rocks on the east side of the fault are mapped as the Merced Formation, whereas rocks on the west side of the fault are mapped as Santa Cruz Mudstone.

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**Figure 9-48.** Headlands and sea cliffs along Highway 1 (Shoreline Highway) south of Stinson Beach consist of mostly greenstone of the Franciscan Complex. Outcrops of chert, sandstone, and serpentinite can be seen in road cuts along the highway between Bolinas and San Francisco. This view is looking north along Highway 1 in a section of road prone to landslides. Headlands near Duxbury Reef at the west end of Bolinas Bay are in the upper left.

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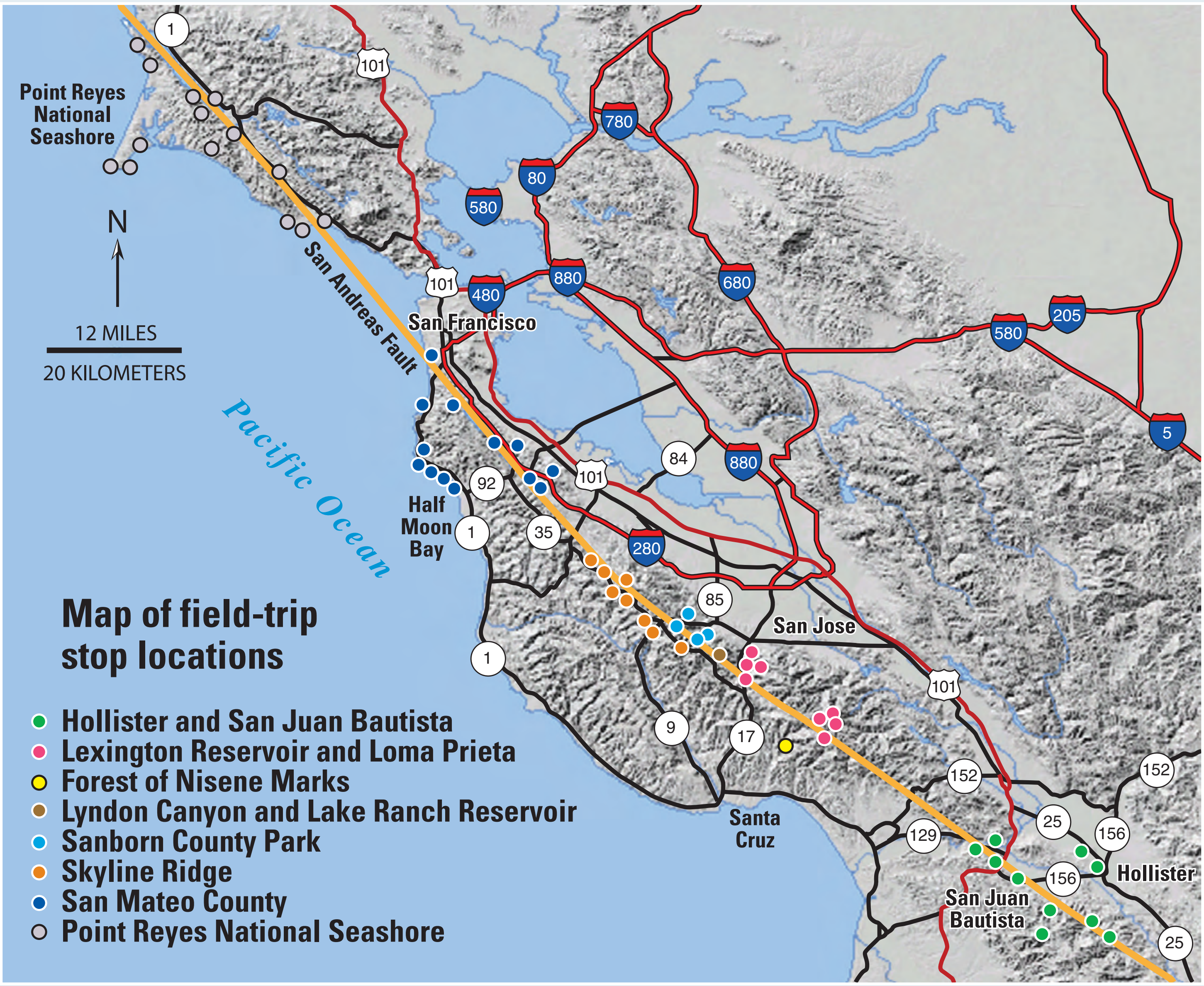


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