Elements of Engineering Geology on the San Francisco Peninsula—Challenges When Dynamic Geology and Society's Transportation Web Intersect

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Introduction

The greater San Francisco Bay area currently provides living and working space for approximately 10 million residents, almost one-third of the population of California. These individuals build, live, and work in some of the most geologically dynamic terrain on the planet. Geologically, the San Francisco Bay area is bisected by the complex and active plate boundary between the North American and Pacific Plates prominently marked by the historically active San Andreas Fault. This fault, arguably the best known and most extensively studied fault in the world, was the locus of the famous 1906 San Francisco earthquake and the more recent 1989 Loma Prieta earthquake. There is the great potential for property damage and loss of life from recurring large-magnitude earthquakes in this densely populated urban setting, resulting from ground shaking, ground rupture, tsunamis, ground failures, and other induced seismic failures. Moreover, other natural hazards exist, including landslides, weak foundation materials (for example, bay muds), coastal erosion, flooding, and the potential loss of mineral resources because of inappropriate land-use planning. The risk to humans and their structures will inexorably increase as the expanding San Francisco Bay area urban population continues to encroach on the more geologically unstable lands of the surrounding hills and mountains.

One of the critical elements in the development of urban areas is the requirement that people and things have the ability to move or be moved from location to location. The list of "things" that have to be moved is extensive and diverse, ranging from people, food products, and building materials to water and energy resources in all forms (solid, liquid, and gas). In California, long known for its love affair with the automobile, many of these items are transported by road although railroads and pipelines play significant roles. These corridors of transport that spread like a web throughout the Bay area are essential to our present way of life. By their very nature, being long continuous features, they must cross a wide variety of terrain including some that is geologically unstable. While avoidance of a potentially threatening geological location is often the best approach, there are many areas in which this approach is not feasible. Further complicating the situation is the fact that many hazardous intersections of transportation lines and geologic hazards were established before the presence and level of geologic risk at a particular location were known or fully appreciated.

Today's brief trip will provide the opportunity to visit and discuss a number of these intersections between society's transportation web and California's dynamic geology. These intersections illustrate past and continuing problems of slope instability (Highway 92, Devil's Slide), coastal erosion (Half Moon Bay Harbor area), active faulting (San Andreas Fault), and the impact of these geological constraints on transportation lines including water supply conduits as well as railroads and roadways (fig. 5.2).

In addition to the geological complexities of these situations, one also must be aware of the complicated and often overlapping roles played by local, state, and Federal agencies and the public as they work together to regulate the planning, the construction, and the operation of these varied construction projects. One of the challenging problems often encountered is that of the situation when a project already exists and functions well, but it was designed and built using older standards that are not equal to those of today. The question that is often difficult to answer is whether it is appropriate to divert the available limited resources to upgrade these older projects away from new projects that may be desperately needed by the public.

The data contained in this field guide are the results of many years of thoughtful and careful work and writing by many geologists, engineers, and land-use planners from government and private practice. No one individual could possibly know all of the information contained in this guide or could have been personally responsible for its development. The author is grateful for the opportunity to draw generously upon the work of many others and to bring some of these data together to provide an overview of one of the many significant roles that geology plays in our society's activities. He is particularly appreciative for access to and use of the work and publications of the Association of Engineering Geologists, Caltrans, the San Francisco Public Utilities Commission, U.S. Geological Survey, California Division of Mines and Geology, Regional Water Quality Control Board, and other organizations and for the assistance of individuals too numerous to mention. It is hoped that this guide will be a starting point and a resource for others wishing to learn and teach about engineering geology.

Road Log

Mileage/Notes

0.0 Bus departure—Exit the U.S. Geological Survey, Menlo Park, by the main entrance, turning right (south) onto Middlefield Road.

0.5 Turn left onto Willow Road.

1.6 Travel northeast along Willow Road to Highway 101, exit Willow Road by north (San Francisco) exit to Highway 101.

11.8 Travel Highway 101 to Highway 92, exit Highway 101 by west (Half Moon Bay) exit.

14.5 Travel Highway 92 west to Interstate 280, (**Rolling Stop** to examine/discuss "Campus Cut" slope stability problem along Highway 92 and general plans for improving the highway from Highway 101 to Highway 1 in coastal community of Half Moon Bay—refer to attached discussion materials.

18.2 Exit Highway 92 south toward San José on Interstate 280; note the complex multi-level interchange between Highway 92 and Interstate 280 located within 1,000 feet of the San Andreas Fault.

21 Continue south on Interstate 280 to Edgewood Road exit. Take exit, turn east under Interstate 280 and use San Francisco entry ramp to reenter 280 going north.

22 Continue north on Interstate 280 to vista point overlook on east side of freeway.

22.2 **STOP 1—**Discussion of general geologic setting, San Andreas Fault, San Francisco water supply, Interstate 280, and engineering geology on the peninsula—refer to attached discussion materials.

25.5 Return to Interstate 280 northbound to Highway 92, take Half Moon Bay exit onto Highway 92.

26.8 Continue on Highway 92 to Half Moon Bay (**Rolling Stop** along Highway 92 to examine/discuss highway widening, slope instabilities and slope stabilization on western slope west of Highway 35—refer to attached discussion materials).

32.3 Ox Mountain /Corinda Los Trancos Landfill site—a landfill site originally permitted in 1976, owned and operated by Browning-Ferris Industries—refer to attached discussion materials.

34.9 Turn right, north, on Highway 1 in Half Moon Bay (at second traffic light). Travel north along the warped coastal terrace—refer to attached discussion materials.

38.1 Pillar Point Harbor—this is the area of Stop 3 to which we shall return later in the trip.

39.4 Half Moon Bay Airport—note the northwest-southeast trending, northeast-facing scarp west of the airport. This scarp, the Seal Cove Fault, is the northeastern segment of the active, right-lateral San Gregorio Fault Zone. Continued seismic activity and documentation of Holocene offset by trenching studies demonstrate its potential for future earthquakes and ground rupture.

40.5 Pass California Avenue and Fitzgerald Marine Reserve (an excellent stop for all, but particularly for geology and biology students, with fine examples of many aspects of geology including good exposures of folds at low tide) and continue to community of Montara.

45.3 Devil's Slide slope stability area—this will be the area of Stop 2 to which we will return after continuing north and turning around so that we may return to park on the west side of the highway.

47.0 Right turn at traffic light onto Linda Mar Boulevard; go east 2 blocks to "Park and Ride" area, and turn around.

Return on Linda Mar Boulevard to Highway 1; turn left at traffic light, south, and return to Devil's Slide area

48.7 **STOP 2**—Devil's Slide slope instability. Use **EXTREME CAUTION** at this site—narrow road with heavy and fast traffic—refer to attached discussion materials for Stop 2. After stop, continue south on Highway 1 toward Half Moon Bay.

56.8 **STOP 3**—Half Moon Bay Harbor, just south of Pillar Point Harbor southern breakwater (See Stop 3 discussion materials about the general geologic setting, coastal issues such as tsunami impact, coastal erosion, etc. with particular emphasis on human-induced coastal erosion—refer to attached discussion materials).

60 Continue south on Highway 1, to Highway 92 in Half Moon Bay; turn left (east) on Highway 92; continue to Highway 101; exit south toward San José onto Highway 101; continue to Willow Road; exit to west; continue to Middlefield Road; turn right; continue to entrance to U.S. Geological Survey; turn left. (This route basically retraces the route to the starting point of the trip.)

84.1 U.S. Geological Survey, Menlo Park, and conclusion of trip.

Introduction to Highway 92 Improvements

State Highway 92 is one of the major east-west traffic corridors in San Mateo County for an increasing number of commuter and commercial vehicles (truck traffic). It is the major link between San Francisco Bay and the Pacific Coast community of Half Moon Bay. Highway 92 links the San Mateo Bridge, north-south Highways 101, 84, 35 and 1, and I-280 (fig. 5.2). In the relatively short distance of 18 miles between San Francisco Bay and the Pacific Ocean, the highway climbs from sea level at the San Francisco Bay to an elevation of 880 feet at its intersection with Highway 35 near the crest of the Coast Range and returns to sea level at the Pacific Coast. Highway 92, often on grades as steep as 7 percent, crosses the complex geology of the California Coast Ranges. To construct the road, numerous road cuts were necessary. Along some of these cuts, slope instabilities have developed, which in turn have periodically resulted in serious disruptions of traffic flow, causing significant economic and emotional hardships on the motoring public.

At present, for much of its route west of Interstate 280, Highway 92 is a two-lane road. Between Interstate 280 and the San Mateo Bridge, it is a four-lane road. The increasing volume of traffic has prompted Caltrans to upgrade the highway. Four phases of improvement of Highway 92 are in progress. The section between Highway 101 and Interstate 280 is being studied to evaluate alternatives. An Environmental Impact Study (Negative Declaration) has been filed on the portion between Crystal Springs Reservoir and Highway 35 (Caltrans, 2000). The widening and slope stabilization have been completed between Highway 35 and Pilarcitos Creek, east of Half Moon Bay. The section of Highway 92 between Pilarcitos Creek and Half Moon Bay is being evaluated for improvement, including widening and adding additional safety features.

Rolling Stop—Mitigation of Highway 92, College of San Mateo, "Campus Cut" Slope Instabilities[1]

The site of interest is in a road cut on Highway 92, between Highway 101 and Interstate 280 in San Mateo County (figs. 5.2, 5.3). It is approximately 7,000 feet in length, topographically below the College of San Mateo, and known as the "Campus Cut." Before highway construction, the area was open farmland with moderately steep, rolling hills. To construct the highway, it was necessary to excavate portions of the hill creating cut slopes on each side of the highway. Construction of the four-lane highway was completed in 1963. The cut slope on the westbound lane (north side) was originally designed with a slope ratio of 1.5 to 1 as were the cut slopes on the eastbound lane (south side). Since the construction of Highway 92, numerous landslides have occurred on the cut slopes.

Brabb and Pampeyan (1972) mapped the bedrock on the site as Jurassic-Cretaceous age Franciscan Complex. Regionally, the Franciscan Complex is variable in composition, and the site is predominately greywacke, siltstone, and shale with substantial portions having been sheared. There are isolated blocks of other Franciscan rock types present.

The USDA Soil Conservation Service (1991) describes the erosion potential on the westbound side as "high to very high" and on the eastbound side as "medium to very high." Groundwater appears to be higher on the westbound side in contrast to the eastbound side, based upon analysis of aerial photographs showing patches of green grass during the dry summer months suggesting water nearer to the ground surface. Irrigation of the football field and other vegetated areas of the College of San Mateo campus probably has contributed to the elevated ground-water levels in the area.

Since construction, slopes of the Campus Cut have failed repeatedly. Slope failures have been a combination of shallow slumps and rotational slides. A hummocky topography has developed that gives the appearance of a single large failure. Depths to the failure planes are estimated to be approximately 10 to 15 feet.

A field review in 1994 was conducted to determine the reason for the concentration of slope failures near the north end of the westbound cut. An earlier study by the Federal Highway Administration concluded that groundwater was the most important factor contributing to the slope instability. The 1994 review supported this earlier conclusion and noted that the failures followed the trend of the gully that had existed on the hill slope before construction. A drainage system (involving pipeline and culvert) was installed to replace the natural drainage path during construction. A subsequent investigation of the drainage system, which was intended to "replace" the gully, showed that although the pipe was in good shape, the concrete culvert was not. Water was able to bypass the culvert and infiltrate the slope. This additional water contributed directly to the slope instabilities.

In 1994, the drainage system on the Campus Cut was repaired reducing the negative impacts of increased pore pressure on the slope stability. Nonetheless, the excessively wet winter in 1998 reactivated many of the landslides, and the Caltrans maintenance department was unable to keep pace with the frequent and severe slides. Following the winter of 1998, a field investigation revealed 14 slides in various stages of development. Three landslides, posing the greatest threat to the highway, were repaired.

Because of the extreme instability of the slope, the lack of funds, and the potential threat to the highway, emergency repairs were completed without the benefit of soil analysis. Caltrans selected-rock slope protection (the placement of large rocks on a partially excavated slope) as the most appropriate mitigation measure. The cost of this repair in 1999 was $120,000.

Stop 1—Vista Point, Interstate 280

From this Vista Point, north of Edgewood Road on the east side of Interstate 280, many important features can be seen, including:

- a portion of the topographically well expressed San Andreas Fault Zone (figs. 5.2, 5.3),
- the reservoirs that have been developed in the fault zone to serve as the terminus for water brought from the Hetch Hetchy Reservoir in the Sierra Nevada, north of Yosemite National Park, to supply San Francisco and many mid-peninsula cities,
- Interstate 280 that parallels the San Andreas Fault as both traverse San Mateo County, and
- the Filoli Estate—famous for its beauty and use in a popular television series—is the location of a number of fault-trenching studies to document the rate of slip along this portion of the San Andreas Fault.

General Geologic and Physiographic Setting of the San Andreas Fault Zone[2]

From the vantage point of the Vista Point north of Edgewood Road along Interstate 280, one can view topography that has been sculpted by dynamic geologic processes. This terrain is dominated by one of the world's most spectacular tectonic features—the San Andreas Fault. For hundreds of miles, the San Andreas Fault is the boundary between basement rocks of the Franciscan Complex and the Salinian Block (figs. 5.4, 5.5). The Franciscan Complex of Jurassic and Cretaceous age is northeast of the fault and consists of mafic and ultramafic basement rocks and sedimentary rocks that were deposited in a deep ocean environment and subsequently accreted to the western margin of the North American plate. Most Franciscan Complex rocks in this area are part of the central tectonic belt (Irwin, 1960; McLaughlin and others, 1988), which is a tectonic mélange of Late Jurassic to Early Cretaceous age. Many of the larger blocks within the central belt mélange are given separate terrane names. The terranes are primarily gently dipping thrust sheets that trend northwesterly and dip northeasterly (Sullivan and Galehouse, 1991).

On the southwest side of the fault zone, Cretaceous and Tertiary sedimentary and volcanic rocks were deposited on a continental block of the Late Cretaceous granitic basement rocks, referred to as the Salinian Block (Clark and Brabb, 1978). The Tertiary section consists predominantly of marine classic sedimentary rocks ranging in age from Paleocene to Pliocene (Clark and Brabb, 1978). These deposits include a thick, early Tertiary sequence that accumulated in deep marine basins and a thick, late Tertiary sequence of predominantly diatomaceous beds that accumulated in sediment-starved basins (Sullivan and Galehouse, 1991). The rocks of the Salinian Block originated south of their present location; however, there has been debate about the distance traveled by the Salinian Block along the transform (strike-slip) system (Page, 1989). Hill and Dibblee (1953) suggested that the Salinian Block was displaced several hundred miles from the southern part of the Sierra Nevada. Evidence for this model includes similarity of the Salinian rocks to granites along the crest of the Sierra Nevada in terms of age, mineralogy, and chemistry.

Approximately 28 million years ago, the Pacific Plate first came into direct contact with the North American Plate, creating a transform boundary. Since that time, there have been slight shifts in both the direction and the rate of movement of the Pacific Plate with respect to the North American plate. Geologists agree that one of the more notable of these changes, a shift to slightly oblique movement, caused convergence between the Pacific and the North American Plates, producing the northwest-oriented mountains of the Coast Ranges beginning approximately 3 to 4 million years ago. The Peninsula segment of the San Andreas Fault is estimated to have been initiated between 1 to 2 million years ago. Several paleoseismic studies of the Peninsula segment have been completed (fig. 5.6). The slip rate estimate determined from the studies at the Filoli Estate near Woodside is 17±3 mm/year (Clahan and others, 1995).

The San Andreas Fault is well defined by seismic activity and conspicuous geomorphic expression. However, contrary to the above discussion, the San Andreas Fault is not the fundamental boundary between the Franciscan Complex rocks and the Salinian Block in the San Mateo County region. The juxtaposition of basement rocks in this region is marked by the Pilarcitos Fault, a fault that extends from Black Mountain to the offshore environment at Rockaway Beach in Pacifica (fig. 5.5). Many geologists have assumed that the Pilarcitos Fault was the principal strike-slip boundary of the San Andreas Fault Zone on the San Francisco Peninsula, and that the San Andreas Fault is the product of a geologically recent (1 to 2 million years ago) eastward shift of tectonism. However, this model has been challenged recently by Wakabayashi (1999), who argues against significant Cenozoic slip on the Pilarcitos Fault, and suggests that the Peninsula Segment of the San Andreas Fault represents a shift from faults located east of the San Francisco Peninsula.

The San Gregorio Fault (mostly offshore) is a major, right-lateral strike slip fault that forms the principal active tectonic structure west of the San Andreas Fault in central coastal California (fig. 5.5). Recent investigation in the Moss Beach/Seal Cove area by Simpson and Lettis (1999) led to recognition of offset alluvial deposits associated with a paleovalley in the uplifted fault block. Simpson and Lettis (1999) estimate a late Pleistocene slip rate of between 3.5 to 4.5 mm/year for the eastern, on-land trace of the San Gregorio Fault, and suggest that an offshore (western) San Gregorio Fault trace may contribute a similar amount of slip. Thus, the total slip across the entire zone may be 6mm/year or greater.

Onshore, along the San Mateo coastline west of the Half Moon Bay Airport, the San Gregorio Fault extends for approximately 1.5 miles, from Pillar Point to Moss Beach. Along this segment, which is sometimes referred to as the Seal Cove Fault, the on-land portion of the fault zone forms the eastern margin of an uplifted fault block. The western margin of this block appears to be bounded by a second trace that has been seismically imaged offshore.

The Coast Range is being uplifted in the modern tectonic regime. The Peninsula portion of the San Andreas Fault was a segment of the fault that ruptured during the 1906 earthquake. This event, the first major seismic event to be so thoroughly studied, was brilliantly reported upon by Andrew Lawson and his colleagues (figs. 5.7, 5.8). Much of our basic understanding of seismic mechanisms was initiated by that study (Lawson and others, 1908). The Santa Cruz Mountains west of the San Andreas Fault were uplifted as much as 4 feet during the Bay area's most recent major earthquake, 1989 Loma Prieta event. The San Francisco Bay region has been and continues to be a dynamic portion of California. This is attested to in part by the data contained on regional maps prepared by the Association of Bay Area Governments showing the intensity of ground shaking during the 1906 and 1989 earthquakes on the San Andreas Fault (figs. 5.9, 5.10).

Filoli Estate[3]

The Filoli Estate, located 30 miles south of San Francisco, is a 654-acre property containing a historic house and 16 acres of formal garden (fig. 5.3). From 1917 until 1937, the house was occupied as the private residence of its original owners, William Bowers Bourn II and his wife. The property was sold in 1937 to the Roth family, owners of the Matson Navigation Company, who donated the house and 125 acres to the National Trust for Historic Preservation in 1975. Within the last decade, the estate has been the location of several important geologic studies involving trenching of the 1906 trace of the San Andreas Fault to determine earthquake recurrence intervals and rates of fault slip (fig. 5.6).

The Filoli house was built for the Bourn family, whose chief source of wealth was the Empire Mine, a hard-rock gold mine in Grass Valley, California. Bourn was the owner and president of the Spring Valley Water Company comprising Crystal Springs Lake and the surrounding watershed areas that are now part of the San Francisco Water Department (fig. 5.3). He selected the southern end of Crystal Springs Reservoir (then known as Crystal Springs Lake) as the site for his estate, in part, to escape the dangers experienced during the 1906 earthquake by the population of the City of San Francisco. (It is interesting to note that the site selected for the house is within a few hundred feet of the 1906 San Andreas Fault rupture trace.) He created the name "Filoli" by combining the first two letters of the words of his credo: Fight for a just cause; Love your fellow man; and Live a good life.

Bourn chose his longtime friend, the San Francisco architect Willis Polk, to design the house. In addition to the Filoli Mansion, Polk designed the Pulgas Water Temple, which is the western terminus of the Hetch Hetchy Water System for water flowing into Crystal Springs Reservoir, and a number of important structures in San Francisco, including Kezar Stadium. Polk had played a major role as the city architect in the rebuilding of San Francisco following the 1906 earthquake. Construction of the Filoli mansion began in 1915, and the Bourn family moved into the house in 1917.

History and Construction of the Hetch Hetchy Water Distribution Project[4]

In 1900, San Francisco Major James Phelan directed the City Engineer Carl Grunsky to study 14 possible water sources for San Francisco. Of these possible sites, Grunsky selected the Tuolumne River system for its high quality and large supply of water, good reservoir sites, and hydroelectric production potential.

Later renamed Hetch Hetchy, the Tuolumne System was believed to be the best answer to San Francisco's problem of providing safe, reliable drinking water to a growing number of residents. However, political conflicts within the San Francisco city government and with the managements of the Modesto and Turlock Irrigation Districts developed. The management of these districts feared that San Francisco would threaten their established rights to use Tuolumne River water. As a result of these conflicts, in early 1906, the city dropped the Tuolumne System proposal.

In the early morning of April 16, 1906, a devastating earthquake struck San Francisco. The earthquake was followed by fires that destroyed much of the downtown area. The city lacked an adequate quantity of water to fight the fires primarily because of earthquake damage to the water distribution system. The earthquake and resultant fires reinforced the city's need to construct a more reliable water system with a higher capacity. After several years of political bickering at local, state, and national levels, on September 3, 1913, the Raker Act was adopted by the U.S. House of Representatives.

As the Raker Act moved to the floor of the Senate, controversy ensued between environmentalists and the City of San Francisco. Many people, including the noted environmentalist John Muir, feared that the Hetch Hetchy system would destroy Yosemite Valley and other natural resources of the area. Eventually, after much debate, the Senate passed the bill on December 2, 1913.

Also known as the Hetch Hetchy Act, the Raker Act included provisions that met the objections of the Turlock and Modesto Irrigation Districts by allowing them to retain their already existing water rights. The act also granted San Francisco the use of public land to construct, operate, and maintain dams, tunnels, and other structures necessary to develop a water and power system. One important element of the act was the provision that no water or power generated by the system could be sold to private companies for resale.

Work on the Hetch Hetchy system began in 1914. The system was to bring water from 650 square miles of watershed in Yosemite National Park and the Stanislaus National Forest to San Francisco. Water moves from the source area to the terminal reservoirs exclusively by gravity flow. Ultimately the elements of the system included the following:

- major reservoirs: O'Shaughnessy (360 thousand acre feet), Eleanor (27 thousand acre feet), Cherry (270 thousand acre feet),
- five dams,
- four hydroelectric plants with a total capacity of 380,000 kw,
- a total storage capacity of 659,600 acre feet (The San Francisco Public Utilities Commission maintains an additional 238,700 acre feet of storage in the Bay area.)

The Hetch Hetchy System has the ability to meet a peak demand for water of 400 million gallons a day. Construction took place in separate, simultaneous, construction projects across a distance of 150 miles (fig. 5.11). The main dam (O'Shaughnessy) was completed in 1923 and was in full operation by 1934. Today the system provides San Franciscans with about 85 percent of their water. The remaining 15 percent of their supply comes from a watershed on the San Francisco Peninsula, which is mostly west of the Crystal Springs Reservoir and San Andreas Lake, and a watershed in portions of Alameda County surrounding, in part, the Calaveras Reservoir.

Interstate 280—"The World's Most Beautiful Highway"

Interstate 280 was approved for California's Interstate system on September 15, 1955, and was opened to traffic in the mid-1970's (figs. 5.2, 5.3). This Interstate, named the Junipero Serra Freeway, honors Father Junipero Serra, the Spanish missionary who established nine of the missions along the El Camino Real during the colonization of California by the Spanish in the 1700's and 1800's. Many individuals who travel this highway consider it one of the more beautiful roadways in the world, and the portion of the Interstate in San Mateo County has received a number of national awards for its design. Each direction is on a separate grade to minimize grading and excavation, and some bridges were designed to blend with the surrounding terrain.

The engineers and designers working on the highway faced many challenges including:
- the environmentally sensitive road alignment,
- the potential for generating a significant and unwanted visual impact,
- the proximity to the active San Andreas Fault with its history and potential for great earthquakes accompanied by intense ground shaking and the generation of secondary ground failures,
- the varied and often unstable bedrock materials of the Franciscan Complex underlying the highway's alignment, and
- hydrologic factors including concern for the potentially contaminated runoff from the paved surfaces.

Rolling Stop—Modification of Highway 92 Between Crystal Springs Reservoir and Highway 35

Caltrans has proposed to improve Route 92 between the Crystal Springs Reservoir and Highway 35 (fig. 5.2). These 2.1 miles of highway have been the location of an increasing number of accidents and significant traffic delays as the result of increasing vehicular traffic, including a significant increase in heavy trucks traveling between the Peninsula and Half Moon Bay. The annual average daily traffic flow was 24,400 vehicles in 1998, and is projected to increase to 39,300 vehicles daily by 2020. Truck traffic increased by 4.5 percent between 1995 and 1997 (Caltrans, 2000).

In 1993, an Initial Study/Environmental Assessment was approved for a proposed westbound, up-hill, slow-vehicle lane and safety improvement. Since the initial assessment, there have been a number of suggested changes, and a new and more comprehensive environmental document has been prepared (Caltrans, 2000). Currently, the project includes:
- an interchange at Highway 92 and Highway 35,
- a median barrier,
- realignment and curve correction,
- a bridge across a small canyon to allow wildlife to cross under the highway, and
- an undercrossing to allow San Francisco Water District personnel access to their corporation yard.

One of the more important environmental issues associated with the project is the potential for increased storm-water runoff because of the increase in paved surface area and the increased number of disturbed cut slopes. There is the need to restrict the flow of turbid water (particularly storm runoff) into the Crystal Springs Reservoir, the City of San Francisco's water supply. Currently, there is no turbid-water collection system, and any runoff from the highway moves into natural drainage ways and eventually into the reservoir.

The proposed turbid-water collection system consists of a series of interconnected ditches and pipes capable of handling a 50-year design flow (Caltrans, 2000). Beginning at the ridge crest, near Highway 35, the system will collect approximately two-thirds of the runoff from the paved road surface and the disturbed slopes. This flow will be transferred downhill where it will enter the proposed Highway 92 detention basin and pump-plant storage box. After appropriate dentition time, this flow will be released back to the turbid water collection system, where it will combine with the remaining one-third of road and slope runoff. This combined flow will be piped across the existing causeway to a pump plant, where it will be collected and pumped up to Basin no. 3 which is part of the Interstate 280 turbid water collection system. The Interstate 280 turbid water pipeline connects a series of seven basins that ultimately drain into San Mateo Creek and then into San Francisco Bay.

A separate, clean-water collection system is also proposed to collect and pass natural runoff from the undisturbed areas to the natural drainages that lead to the Crystal Springs Reservoir (Caltrans, 2000). Any abandoned segments of Highway 92 generated by realignment will be removed and the slopes restored to as near a natural state as possible.

Five major active faults are located within 50 miles of this section of Highway 92 between Crystal Springs Reservoir and its intersection with Highway 35. The closest is the San Andreas Fault at the eastern margin of the project (fig. 5.5). Caltrans has estimated that this fault has the potential for a maximum credible earthquake magnitude of 8.0 and a maximum peak bedrock acceleration of 0.73 g (Caltrans, 2000). During the 1906 earthquake, approximately 8 feet of right-lateral offset occurred in the causeway crossing Crystal Springs Reservoir (fig. 5.1). The causeway currently carries Highway 92 across the reservoirs.

Rolling Stop—Improvement of Highway 92 Between Highway 35 and Pilarcitos Creek (East of Half Moon Bay)

Key Elements and Background of the Project[5]

Highway 92 is the primary east-west route between the San Francisco Peninsula and Half Moon Bay serving an increasing volume of commuter and truck traffic (fig. 5.2). The two-lane road between Highway 35 and Pilarcitos Creek on the western-facing slope of one of the ridges of the Coast Ranges long has been a bottleneck to efficient traffic flow. Steep grades of as much as 7 percent and sharp curves contribute to significant traffic delays. The project provides for a continuous uphill lane for slow vehicles. Other safety improvements include standard lane and shoulder widths and a concrete median barrier. Construction began in March 1997, and was completed in October of 2000 at a cost of $21.5 million (Caltrans, 2000b). Of the total cost, approximately $4.5 million was for repairing storm-induced landslide damage (15 slides) during the El Niño events.

Topographically, the project area rises from the alluvium-filled valley of Pilarcitos Creek at 210 feet elevation to 880 feet at the intersection between Highway 92 and Highway 35, near the crest of the ridge. Structurally and lithologically, the project area is complex, in large part because of its location within the San Andreas Fault system (fig. 5.5). The main trace of the San Andreas Fault is approximately 1.5 miles east of the project area. The Pilarcitos Fault, a subsidiary branch of the San Andreas Fault, passes through the project area just west of the ridge crest along which Highway 35 runs.

This section of Highway 92 crosses five distinctly different bedrock formations—Jurassic-Cretaceous Franciscan Complex, Cretaceous Montara Granite (quartz diorite), and an Oligocene through lower Miocene sequence of rocks including the Vaqueros Sandstone, Mindego Basalt and Lambert Shale. Generally, these formations are overlain by surficial deposits consisting of varying thickness of alluvium, colluvium, and (or) residual soil derived from the underlying bedrock (Caltrans, 1996). Geological investigations for the project included:

- literature review,
- field investigations to include geologic mapping,
- 16 seismic refraction survey lines,
- vertical and horizontal borings, and
- laboratory tests on collected samples for shear strength and corrosion properties.

The subsurface exploration for the proposed retaining walls required for the widening of this section of Highway 92, consisted of seventeen 2-inch diameter vertical and twelve 2.5 to 3-inch subhorizontal, diamond rock core borings. Depths of the subhorizontal borings ranged from 17.5 to 66.5 feet. Depths of the vertical borings ranged from 40 to 45 feet (Caltrans, 1996).

A shallow seismic refraction investigation was conducted using a 12-channel exploration seismic unit. Because of the widely differing geologic conditions and rock materials, seismic velocities varied greatly. Overlying the weathered bedrock are several feet of unconsolidated rock and (or) soils characterized by seismic velocities ranging from 624 to 1,639 feet per second. In the underlying weathered bedrock, the velocities varied between 1,549 and 5,805 feet per second and, for less weathered bedrock, varied between 5,141 and 15,108 feet per second.

The original plans specify cut slopes to accomplish the needed road widening. Based in part upon results of subsurface exploration, the construction of soil-nailed retaining walls was recommended to minimize the right-of-way expansion, environmental impacts, and material disposal costs (Con-Tech Systems, Ltd. [CTS], 2001). (See “Elements of Soil Nailing,” below.) ”The major structures associated with the retaining wall component of this Highway 92 improvement project include nine land-sculpted soil-nailed retaining walls and 14 soldier-pile retaining walls (figs. 5.12, 5.13).

Elements of Soil Nailing

Soil nailing as a slope stabilizing technique has become increasingly popular in the past two decades. Until recently, it was more frequently used in Europe compared to its use in the United States. It is a technique by which untensioned rods are placed in a closely spaced grid pattern into material that needs to be reinforced to remain stable. The rods may be placed in predrilled holes or emplaced by direct push; commonly, the rods are grouted in place. Generally, the daylighting ends of the rods are embedded in a facing to help minimize interrod slope erosion. Figure 5.14 illustrates some of the fundamentals of the technique (CEN Technical Committee 288, 2000).

Ox Mountain (Corinda Los Trancos) Municipal Refuse Disposal Site[6]

Browning-Ferris Industries of California owns and operates a Class III municipal refuse disposal site in Corinda Los Trancos Canyon, San Mateo County, approximately 2 miles northeast of Half Moon Bay, immediately north of Highway 92 (fig. 5.2). The Ox Mountain landfill originated as a small, 33 acre, Class-III landfill in the upper portion of Corinda Los Trancos Canyon. The initial landfill received approximately 7.5 million cubic yards of waste from 1976 to 1993. In 1992, the discharger was issued waste discharge permits for a 140-acre landfill expansion that has led to the present landfill configuration. The 1992 permit design extended the landfill approximately 2,700 feet down canyon and required a composite liner with an underdrain, a leachate collection system, and 2 feet of soil with permeabilities less than $1x10^{-7}$ cm/sec. Construction began in 1992. Recently, the landfill operator received approval to expand the permitted area by approximately 9 acres. The landfill receives non-hazardous municipal solid waste including:

- household wastes,
- construction debris,
- sewage sludge,
- autoclaved medical waste,
- demolition wastes,
- green waste,
- treated auto shredder waste,
- clean-fill materials, and
- petroleum contaminated soils with concentrations below or at specified levels.

The landfill's current permitted capacity is 37.9 million cubic yards. With the recent expansion, the capacity will increase to 48.2 million cubic yards. The discharger estimates that the useful life of the landfill is 28 years starting January 1, 1999.

The surface and subsurface geology at the site was evaluated by geologic consultants based on field mapping, literature reviews, a seismic-refraction survey, and review of the geologic logs of over 80 borings totaling more than 4,000 linear feet of drilling. The disposal area is underlain by granitic rocks, alluvial and colluvial units, and landslide and debris-flow deposits. A number of shear zones were mapped in cut slopes and through borings, but as recent displacements were not noted, these zones are not considered active faults. Some of the alluvial deposits underlying the facility were considered susceptible to liquefaction and were stabilized through a ground improvement program in 1992. None of the observed landslides was considered active, but they could be reactivated as the result of heavy rains and (or) seismic activity.

Groundwater movement in the area occurs in two hydraulically connected hydrostratigraphic units. The upper unit includes the alluvial and colluvial deposits, the deeply weathered granite, and the moderately weathered granite. This unit can be considered an aquifer with hydraulic conductivities of $3.8x10^{-4}$ to $13.8x10^{-6}$ cm/sec based on pumping tests. The second unit is the slightly-weathered to fresh granite. The hydraulic conductivity of this unit is so low ($8.0x10^{-7}$ to $1.0x10^{-4}$, averaging ~10^{-6} cm/sec based on packer tests) that it is not considered an aquifer although it might serve as a recharge source area and contribute groundwater to regional aquifers.

Along Corinda Los Trancos Canyon, depth to groundwater during the wet season rises to within a few feet of the ground surface. Along the ridge tops, depth to groundwater is about 85 feet with as much as 20 feet of seasonal variation.

A Brief History and the Geologic Setting of the Half Moon Bay Area

Half Moon Bay, originally known as Spanishtown, is the oldest settlement in San Mateo County, dating back to the 1840's (fig. 5.2). The level, relatively narrow coastal terrace on which Half Moon Bay is built has had a colorful history. This history includes the exciting but failed attempt to build and operate a coast side railroad, the Ocean Shore Railroad, between San Francisco and Santa Cruz. Geologic problems played a large role in the failure of the railroad. Excitement generated by rum runners enlivened the prohibition era of the 1920's and 1930's. As a legacy of that period, one of the local restaurants is reported to have at least one ghost in residence.

Half Moon Bay, with a current population of 11,000, is the only incorporated city along this portion of the coast; being incorporated in 1959. All of the other coastal communities, such as El Granada, Miramar, Pescadero, and La Honda, are unincorporated areas governed by the San Mateo County Board of Supervisors. The region is a sought-after housing location for those working in San Francisco and in the Peninsula communities. Currently, the median-priced home in Half Moon Bay is in the $700,000 range, with those on golf courses costing between $900,000 and $1,500,000 (Half Moon Bay, 2001).

The largest industry in the area is agriculture, primarily floriculture (flowers), followed by tourism and commercial fishing. The beauty and climate of this scenic coastal area have stimulated tourism and the building of a number of hotels, motels, and restaurants.

Because of the recent rapid growth of the community, commuting and visitor traffic have become important economic and political issues. As an example of the impact of visitors, the Pumpkin Festival during the fall of each year has become a Bay area landmark event, attracting thousands of individuals (along with their cars) to this coastal community. At present, north-south Highway 1 along the coast and east-west Highway 92 provide the only significant routes for vehicular traffic into and out of the community. The competition for space on the these roadways has created hotly contested debates adding to the complexity of trying to resolve the Devil's Slide issue. Geologically, the area has a number of interesting features (figs. 5.15, 5.16) including:

- warped marine terrace,
- landslides on the western slopes of the Coast Ranges,
- landslides along the coastal bluffs and cliffs,
- topographic expressions of active faulting,
- well-exposed geologic structures, in particular, folded and faulted units,
- evidence of accelerated rates of coastal erosion, and
- varied geologic bedrock units.

Given what is known about the types and severity of geologic hazards along some portions of the coast, it is interesting that it was to this area that a number of residents of the City of San Francisco moved to seek a safer living environment following the 1906 earthquake and fire.

Stop 2—Devil's Slide—A Slope Instability in a Stranglehold Location[7]

Highway 1—The Present Road

After a major landslide in January 1995 closed Highway 1, Caltrans began a $1.5 million construction project to repair and stabilize the road (figs. 5.2, 5.17). Grouted and post-tensioned rock bolts were installed under the highway. A steel net was bolted to the slope above the road to catch detached rocks. Although the road was reopened after approximately 150 days and has remained intact through subsequent winters, Caltrans personnel maintain that the repairs are only temporary measures. Following extensive litigation and public debate, the construction of a tunnel east of Devil's Slide was determined to be the most feasible permanent solution to the problem of providing reliable north-south access along Highway 1 to the Half Moon Bay area.

Devil's Slide Tunnel Project—The Bypass

Projected Coast: $165 million

Environmental Report: Approval by the Federal Highway Administration of the environmental report is expected in 2001.

Schedule: If the environmental impact report is finalized in 2001 and no significant delays are caused by the lack of funding, Caltrans and its consultant can complete the design of the tunnel project by spring of 2003. Construction will start in the summer of 2003 and is expected to take 3 years.

Design: The tunnel plan specifies two 30-foot wide bores with one directional lane and standard 8-foot shoulders per bore. Each bore will be about 4,000 feet long. A bridge approximately 1,000 to 1,500 feet long will be constructed at the north portal. The primary purpose of the bridge will be to protect the red-legged frog habitat and other environmentally sensitive areas.

Bicycle Path: Upon completion of the tunnel, Caltrans expects to deed the original section of Highway 1 at Devils Slide to the County of San Mateo for bicyclists, hikers, and other nonmotorized traffic.

Alignment: Highway 1 will diverge from its present alignment near Gray Whale Cove north of Montara, pass through a tunnel, and exit at Shamrock Ranch in Pacifica.

Funding: This project will be primarily funded by Federal emergency funds. Less than 5 percent of the funds will come from the State Transportation Improvement Program.

Measure T: Measure T is the San Mateo County initiative that was approved by 76 percent of the voters in November 1996. It changed the local coastal plan to designate the tunnel as the chosen alternative to bypassing Devil's Slide. Before this initiative, an overland bypass to the east of Devil's Slide had been the preferred alternative.

Historical Perspective on the Devil's Slide[8]

Devil's Slide is a large bedrock landslide complex, extending from the ridge crest, at approximately 900 feet elevation down to at least sea level on the San Mateo County coastline located just south of Pacifica. The complex has a width of approximately 4,000 feet (fig. 5.17). Highway 1 crosses the landslide between elevations 450 and 300 feet. Local geologic conditions are complex, involving steeply dipping Paleocene and Cretaceous sedimentary rocks and underlying Jurassic-Cretaceous granitic rocks. The relationship between the two rock types is complex because of past faulting, folding, and landslide movement. The most active landslide failure surface is approximately 150 feet below the ground surface. A number of discrete failure zones have been identified within the landslide complex by the monitoring of slope change using inclinometers. It appears that the granitic rocks are not involved in the landsliding (figs. 5.18, 5.19). The exact details of this complex slide, particularly the exact depths of the critical failure surfaces, are still a matter of debate.

The landslide complex is readily recognized in an 1866 topographic map of the area. Since 1897, the landslide area has frustrated road builders, repair crews, and the traveling public, disrupting in turn a county road, a railroad, and a State highway. The first county road crossed Devil's Slide at approximately elevation 400 feet. Because of numerous failures, this road was abandoned in 1914, and replaced with a bypass road to the east over San Pedro Mountain (fig. 5.22).

The Ocean Shore Railroad Company was incorporated in the early 1900's with the intent of constructing a double-track, electric railroad from San Francisco to Santa Cruz. The railroad alignment began near 12th and Mission streets in San Francisco, and reached the Pacific coast near Thornton Beach in Daly City. Farther south near Devil's Slide, the railroad alignment penetrated San Pedro Point with a 400-foot-long tunnel at approximately an elevation of 50 feet, and then began a long 2 percent grade. From that point southward, the railroad grade climbed to its highest point at the "saddle cut" of present Highway 1. Severely damaged in the 1906 earthquake and by subsequent chronic landsliding, the railroad was abandoned in the 1920's. Remnants of the railroad grade are still visible near Devil's Slide.

In 1933, 1,600 miles of county roads were incorporated in the State highway system. The State Division of Highways acquired the Ocean Shore Railroad right-of-way by condemnation and constructed Highway 1 (then known as Route 56) in its present location. Construction and maintenance of the highway were difficult because of the continuing slope instabilities.

Since the opening of the roadway in 1936, landsliding and road closures have plagued the route. Major road closures occurred in every subsequent decade. In the late 1950's, the State Highway Department determined that the alignment across Devil's Slide should be abandoned, and that a new bypass should be constructed around the inland margin of landsliding. By 1970, a 6.8-mile bypass was ready for construction. The construction contract was halted by a lawsuit filed by the Sierra Club and others, invoking provisions of the recently passed legislation: California Environmental Quality Act and National Environmental Policy Act. The litigation was successful, and the State Highway Department was directed to conduct environmental studies for the bypass.

In the early 1980's, landsliding and $50 million in Federal funding prompted renewed design studies of the highway realignment. In 1986, the Martini Creek Alignment (a proposed road alignment east of the Devil's Slide area) was selected as the preferred alignment by the Federal Highway Department as a solution to road failures at Devil's Slide. The bypass was designed to be a 4.5-mile-long, two-lane roadway with slow up-hill lanes. This alignment would require extensive grading in environmentally sensitive areas. For the next decade, the question of whether the Martini Creek alignment would be built or not was the subject of legal argument and was not resolved until 1996.

The Marine Disposal Alternative was studied as an alternative to the inland bypass. This proposal consisted of unloading the driving force at the top of the landslide and buttressing at the bottom of the slide (fig. 5.20). The project would require the removal of an estimated 1 million cubic yards of material from the head of the landslide and placing the material offshore into a nonerodible buttress constructed behind a concrete, reinforced, tetrahedral breakwater (fig. 5.20). This technique has been used at a number of locations along the California coastline but never of the scale proposed for Devil's Slide. Although considered feasible, this proposal left many critical issues unanswered. Eventually, the creation of a national marine sanctuary by the Federal government immediately offshore eliminated this alternative.

In January 1995, heavy rains again caused the roadway to fail at Devil's Slide, closing the road for 150 days and created many traffic problems for the coastal communities to the south. For all practical purposes, all vehicular traffic from the Half Moon Bay area was forced to use the only remaining highway, Highway 92, to reach the urbanized portion of the Bay area, thus creating numerous traffic delays. Caltrans worked aggressively to repair the road (see figs. 5.21-5.26). In 1996, the voters of San Mateo County overwhelmingly passed Measure T. This measure identified the preferred alternative to be a tunnel bypass, and eliminated the Martini Creek alignment alternative (figs. 5.27, 5.28).

The final environmental document is expected to be approved in 2001, and tunnel design will then begin. The tunnel is planned to be a 4,000-foot long, double-bore facility with one lane in each direction. The north approach will leave the existing alignment of Highway 1 onto an approximately 1,000- to 1,500-foot-long bridge structure that crosses the valley at Shamrock Ranch, entering the tunnel facility beneath San Pedro Mountain. The south approach will exit on the south side of San Pedro Mountain onto a 1,000-foot approach fill that rejoins Highway 1 south of Devil's Slide.

In November 1997, Caltrans evaluated the feasibility of stabilizing the landslide complex using dewatering wells in conjunction with existing horizontal drains. The study concluded that the rock mass has a low hydraulic conductivity and transmissivity. There is no evidence of a pressurized aquifer that could be relieved, and the shallow and moderately deep failure surfaces are located above the average groundwater-table level. In addition, slow landslide movements appear to continue regardless of rainfall patterns and dewatering activities. Consequently, it was determined that dewatering would not be an effective, long-term mitigation measure. However, as part of an ongoing effort to maintain the Highway 1 roadway bench until the tunnel project is completed, continual near-surface and deep dewatering is performed though the use of horizontal drains and the existing drainage wells. The roadway and the slope face directly above the roadway bench are constantly monitored, and the roadway will be closed in the event of significant movement.

Geologic Setting of the Devil's Slide Bypass Tunnel[9]

The proposed tunnel will pass through Montara Mountain and San Pedro Mountain. The proposed tunnel alignment crosses at least two geologic formations—the Montara Granite and a series of folded and faulted Paleocene sedimentary rocks (turbidites) that overlie the granite (fig. 5.29). The granitic mass that makes up Montara Mountain covers about 30 square miles along the coast. The northernmost outcrop is in the cliff face at Devil's Slide. Franciscan Complex rocks crop out about 1 mile to the northeast, separated from the granitic complex by the Montara and Pilarcitos Faults. At the south end of the alignment, for approximately the first 1,500 to 1,600 feet, the tunnel alignment is in granitic rock. The remainder of the tunnel alignment is in the Paleocene sedimentary rocks. Because of the current uncertainty about the geologic structure at depth, it is unclear as to whether the tunnel will encounter Cretaceous sedimentary rocks. While not penetrated by the proposed tunnel alignment, alluvial deposits exist within the valley north of the north portal. These deposits will be crossed by the proposed roadway between the north portal and where the new roadway will join existing Highway 1. Small local slides have occurred near the north and south portals.

The Devil's Slide area is within a seismically active area. The San Andreas Fault is less than 4 miles east of the study area. The San Gregorio Fault and the associated Seal Cove Fault are about 1.5 miles offshore to the west. No known active faults, however, pass directly through the tunnel alignment.

The effects of earthquakes on underground structures such as tunnels can be broadly grouped into two general classes, displacement (rupture) or shaking. Sympathetic fault displacement in the rock mass along the tunnel alignment would result in relatively minor structural damage. The Devil's Slide bypass tunnel will be subject to shaking during its useful life. In general, worldwide experience shows that tunnels survive earthquakes significantly better than surface structures. Damage to tunnels is not likely if horizontal acceleration at the ground surface above the tunnel does not exceed 0.5g (Caltrans, 1999). The effect of an earthquake is to impose deformations on the underground structure that cannot be overcome by strengthening the structure. The object of an effective earthquake-resistant design is, therefore, to produce a structure of sufficient ductility to absorb the imposed deformation without losing the capacity to carry static loads.

Stop 3—Coastal Erosion Accelerated by Human Activity in the Half Moon Bay Area (Pillar Point Harbor)

Along the San Mateo County coastline, cliff erosion and retreat by wave erosion, landslides, block falls, and debris slides occur at different rates. Wave erosion is the primary erosive process. All waves, but particularly storm waves, erode the shore, oversteepening and destabilizing the slopes. Landslides, block falls, and surface erosion move the weakened and detached material to the beach where it is reworked by wave action. Along many parts of the San Mateo County coastline, augmenting the destabilizing action of the waves is the movement of groundwater out of the cliff and bluff faces, softening, and detaching materials in the cliffs and bluffs (Lajoie and Mathieson, 1998).

The U.S. Geological Survey has prepared a series of geologic and erosion maps for the coast of San Mateo County depicting the general geologic relationships and the relative amounts and types of erosion occurring (Lajoie and Mathieson, 1998) (figs. 5.30 to 5.33). For the region near Half Moon Bay, these maps record the influence of human intervention and construction in modifying the natural patterns of erosion. Human actions have contributed significantly to acceleration of the rate of coastal erosion in a localized area adjacent to the Pillar Point Harbor breakwater.

Aerial photographs of the area show the wave-refraction patterns around the resistant headland, Pillar Point, produced by the prevailing northwesterly winds (fig. 5.34). Before the construction of the breakwater-protected harbor, the energy of the waves refracted around Pillar Point was dissipated uniformly over a length of beach that was in equilibrium—neither eroding nor growing seaward.

Because of the marine-oriented economy of the Half Moon Bay area and the fact the Half Moon Bay area is the only good safe harbor along this section of the California coastline between Santa Cruz and San Francisco, the community has had a long history of interest in the quality of the harbor. During times when southwesterly storms strike the coast, boats in the Half Moon Bay anchorage had been at risk. A number of them sank, and others were damaged by being driven onto the coastal rocks (McLaughlin and Sarna-Wojcicki, 1997). To provide protection for the boats, the U.S. Army Corps of Engineers completed a breakwater in 1960. The impact of this breakwater was immediate and significant. It did provide protection for the boats, but at the same time it also altered the wave-refraction patterns. The refocused wave energy was concentrated on a small segment of the coastline south of the breakwater, El Granada Beach, and it dramatically accelerated the rate of erosion. For the period between 1861 and the completion of the breakwater in 1960, the rates of erosion were somewhat variable, but they averaged about 0.03 meters (approximately 1 inch) per year. These relatively stalemate conditions suggest that the shoreline essentially was in equilibrium. Following construction of the breakwater, the rate of coastal erosion increased sharply to 1.1 meters per year, slightly more than 3 feet per year (Mathieson and others, 1997) (fig. 5.35). This increase in erosion damaged and has caused the removal of coastal buildings, railroad tracks, and roads. Currently, Caltrans is constructing and repairing existing rip-rap to protect Highway 1 (Caltrans, 1999b).

Notes

[1]Data for this section of the field guide have been taken from two reports prepared by Anne Rosinski, 2000, 1994, currently a geologist at the California Division of Mines and Geology and a graduate student in engineering geology at San José State University. The text of her reports has been abstracted and slightly revised by the author.

[2]This brief overview of the general characteristics of the San Andreas Fault system is taken from the paper, *Living with Moving Ground – Landslides and Coastal Erosion in San Mateo Country*, by Cole and others (2000). Minor modifications and editorial changes have been made to the text by the author.

[3]Material for this section is based on information contained in the web site for the Filoli Center and has been abstracted and edited by the author.

[4]The material for this section is based on information contained in the web site of the San Francisco Public Utilities Commission.

[5]The data for this section are from reports prepared by Caltrans (2000, 1996), slightly abstracted and edited by the author.

[6]Data for this portion were taken from the California Regional Water Quality Control Board San Francisco Bay Region Order No. 99-067 (San Francisco Bay Area Regional Water Control District, 1999). The text has been abstracted and slightly modified by the author. The Regional Water Quality Control Board has the responsibility for permitting these facilities. As an element of that responsibility, both water-control boards require specific elements for the geologic investigations done in support of the permit requests. The Boards also review all materials submitted in support of the permit requests to determine their completeness.

[7]Data for this portion are from a Caltrans Summary Statement (Caltrans 2001).

[8]This historical perspective of Devil's Slide is a slightly modified version of a portion of a paper on Devil's Slide prepared by Cole and others (2000).

[9]This section is a portion of the Environmental Impact Study (1999) by Caltrans which has been slightly modified by the author.

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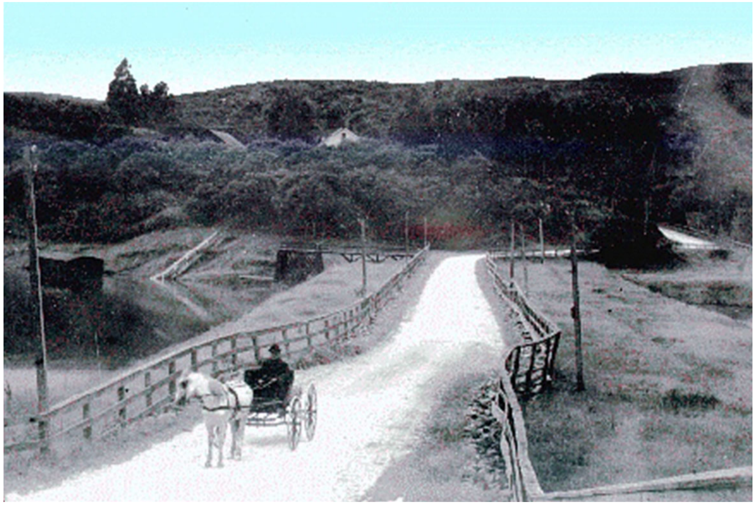


Figure 5.1. Offset of road across Crystal Springs Reservoir causeway following the 1906 San Francisco Earthquake (Bancroft Collection, University of California, Berkeley).

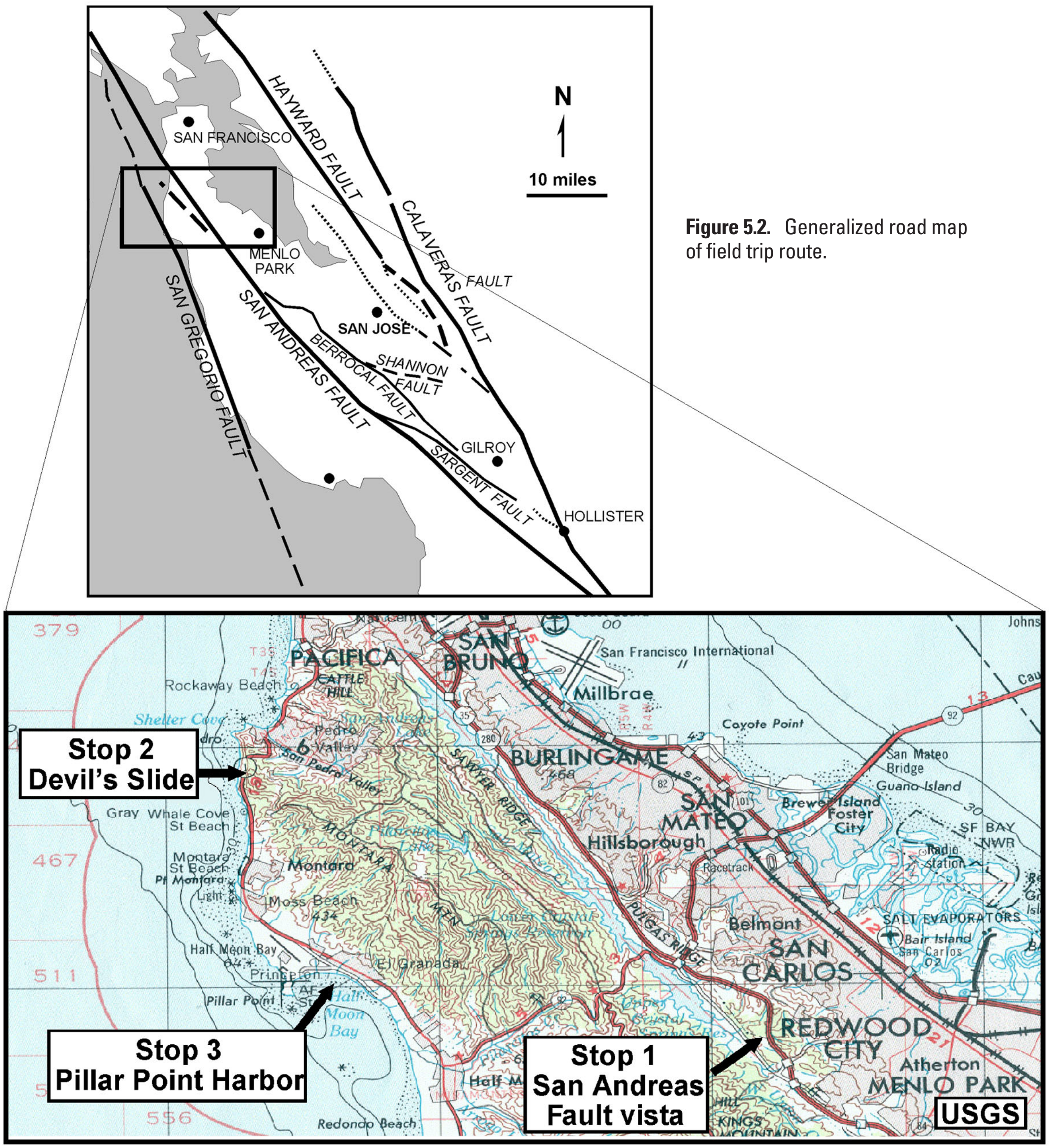


Figure 5.2. Generalized road map of field trip route.

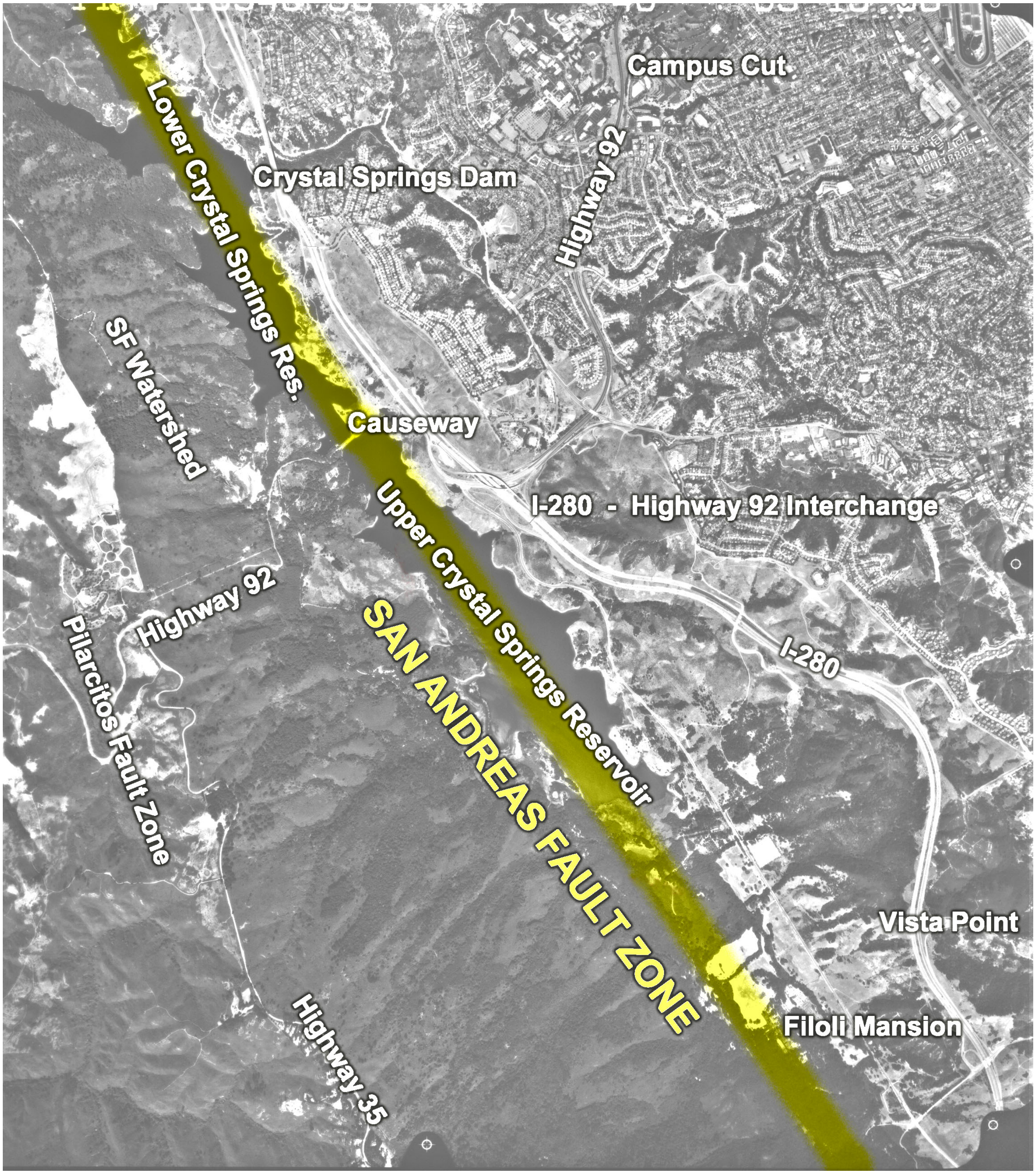


Figure 5.3. Aerial photograph taken in 1998 of Crystal Springs Reservoir, Interstate 280, Highway 92, and Vista Point (Stop 1).

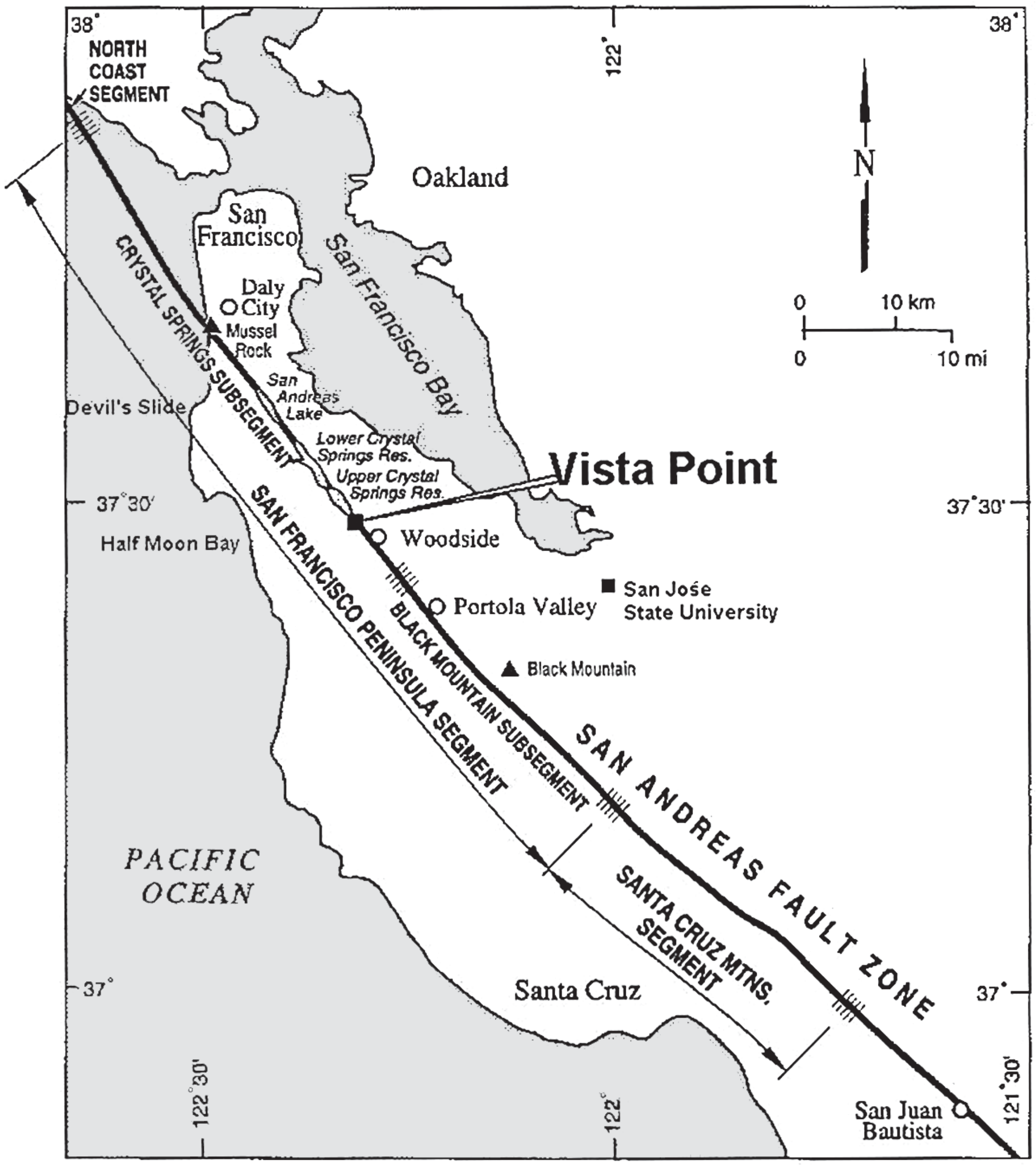


Figure 5.4. Map delineating segmentation of the San Francisco Bay area portion of the San Andreas Fault (after Wright and Hall, 2001).

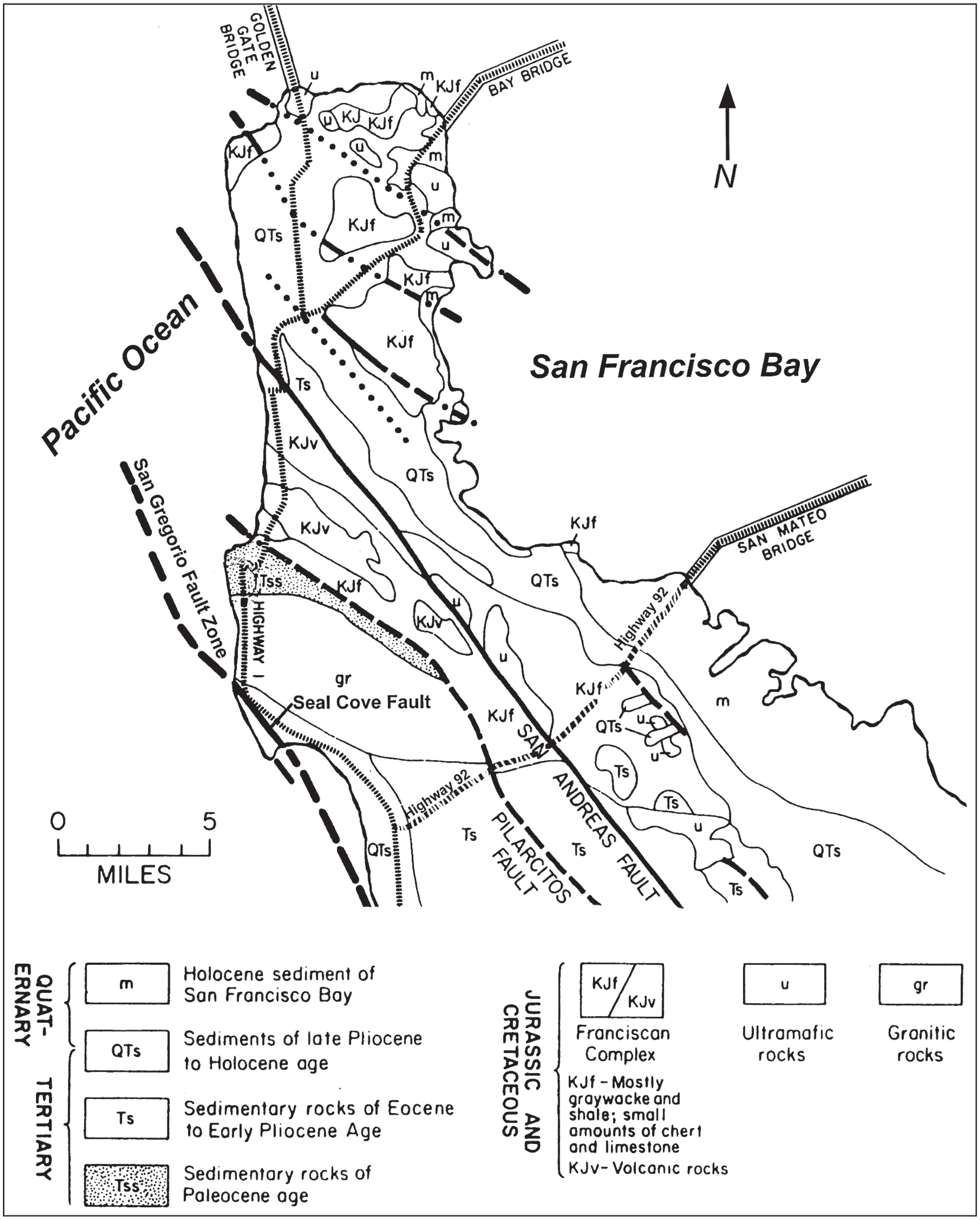


Figure 5.5. Simplified geologic map of the San Francisco Peninsula (modified from Heyes, 1984).

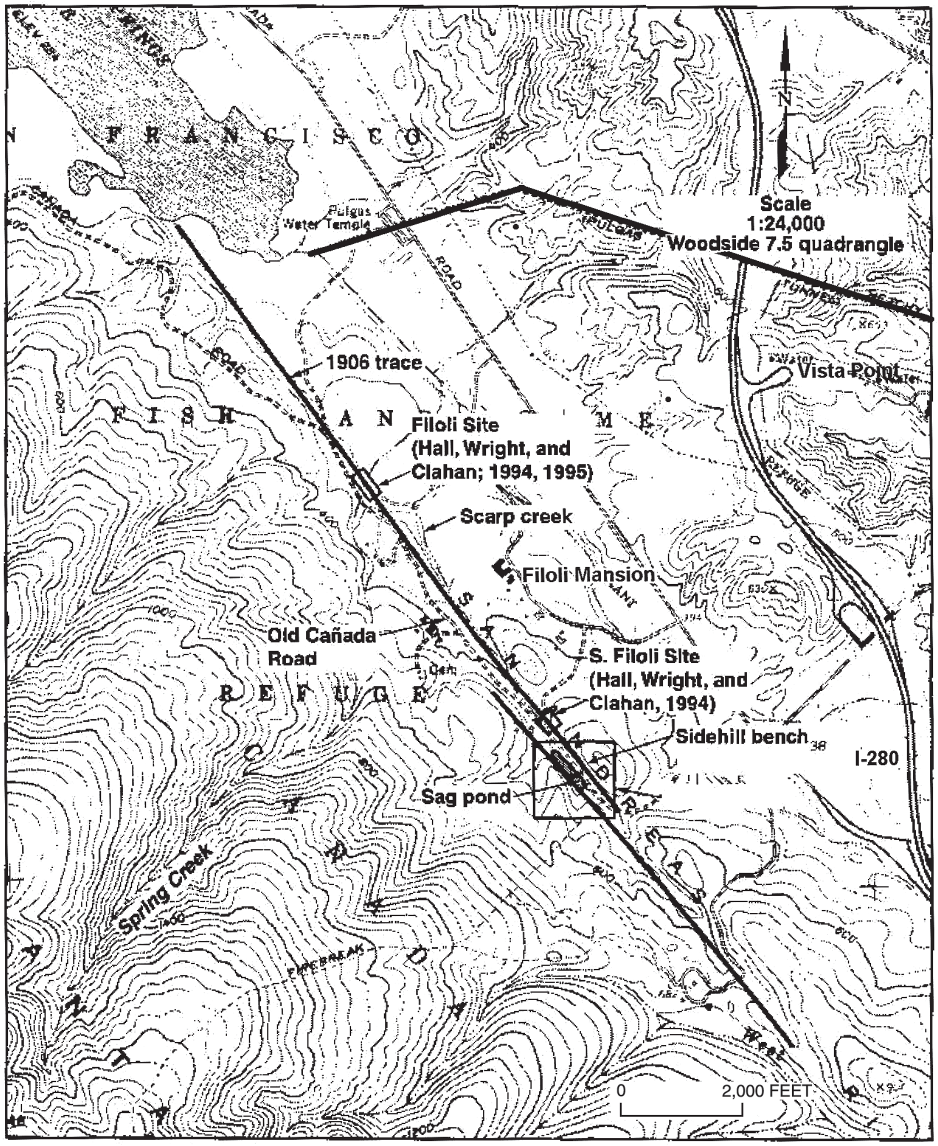


Figure 5.6. Map of the San Andreas Fault 1906 rupture trace with existing and proposed trenching sites in vicinity of the Filoli Mansion (after Wright and Hall, 2001).

Figure 5.7. Photograph of 1906 San Andreas Fault offset of fence on San Francisco Peninsula (Bancroft Collection, University of California, Berkeley).

Figure 5.8. Photograph of 1906 San Andreas Fault rupture trace on San Francisco Peninsula (Bancroft Collection, University of California, Berkeley).

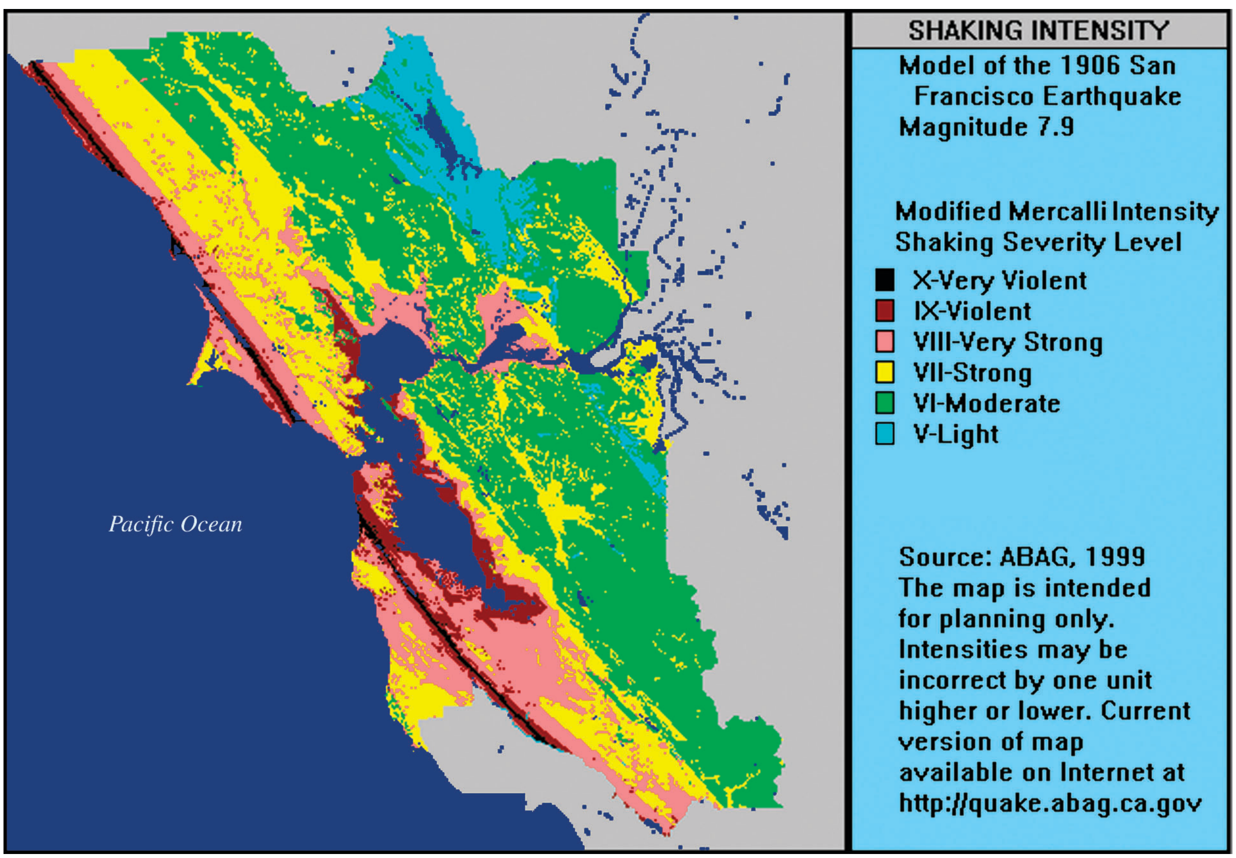


Figure 5.9. Map delineating ground shaking intensities for the San Franciso Bay area from the 1906 San Francisco Earthquake (Association of Bay Area Governments, 1999).

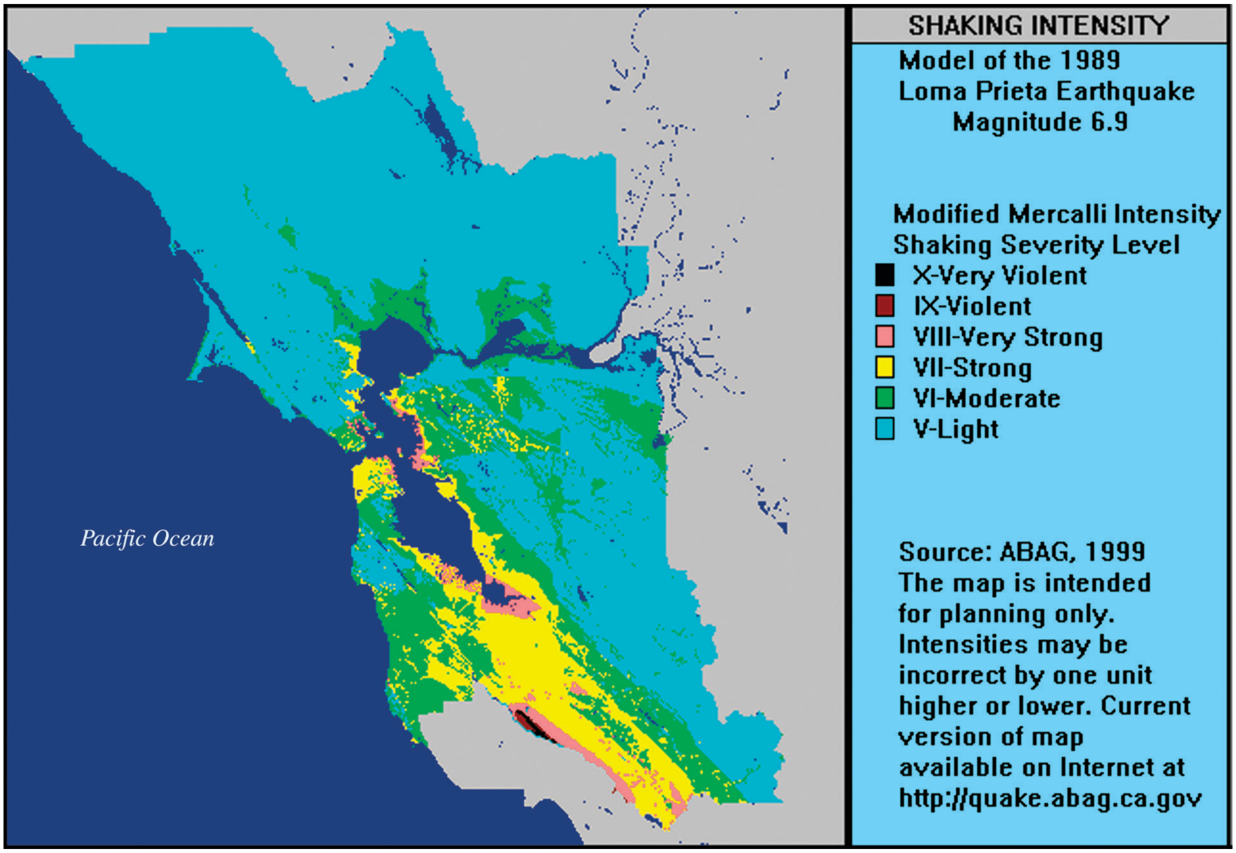


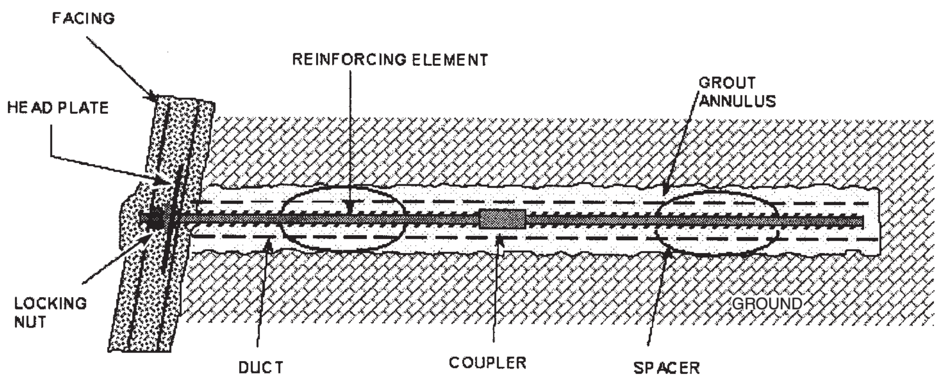
Figure 5.10. Map delineating ground shaking intensities for the San Francisco Bay area from the 1989 Loma Prieta Earthquake (Association of Bay Area Governments, 1999).

Figure 5.11. Map of Hetch Hetchy water distribution system (San Francisco Public Utilities Commission, 2001).

Figure 5.12. Photograph of soil-nailed retaining wall being constructed along Highway 92 east of Half Moon Bay. On right, slope has been nailed. On left, slope has been stabilized with shotcrete (Con-Tech Systems, Ltd. [CTS], 2001).

Figure 5.13. Photograph of completed soil-nailed retaining wall along Highway 92 east of Half Moon Bay (Con-Tech Systems, Ltd. [CTS], 2001).

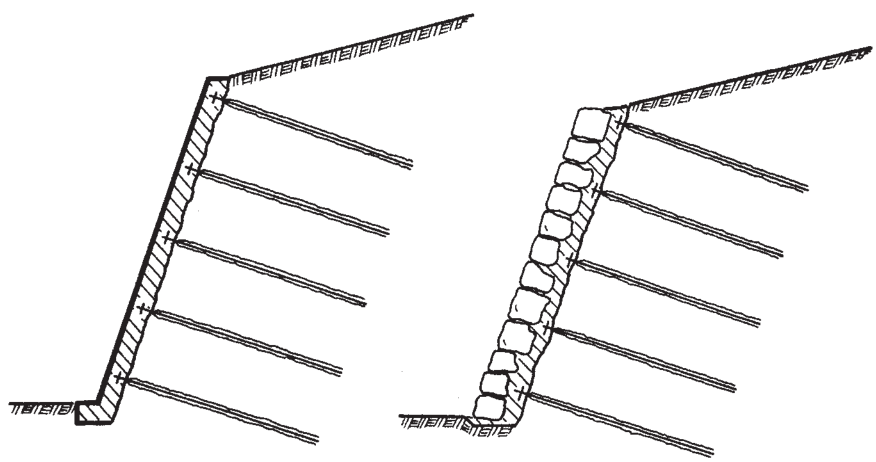
EXAMPLES OF SOIL NAIL SYSTEMS



Typical components of soil nail system, prebored and grouted shown with rigid facing (note: other systems may not use grout/duct/couplers/facing/spacers).

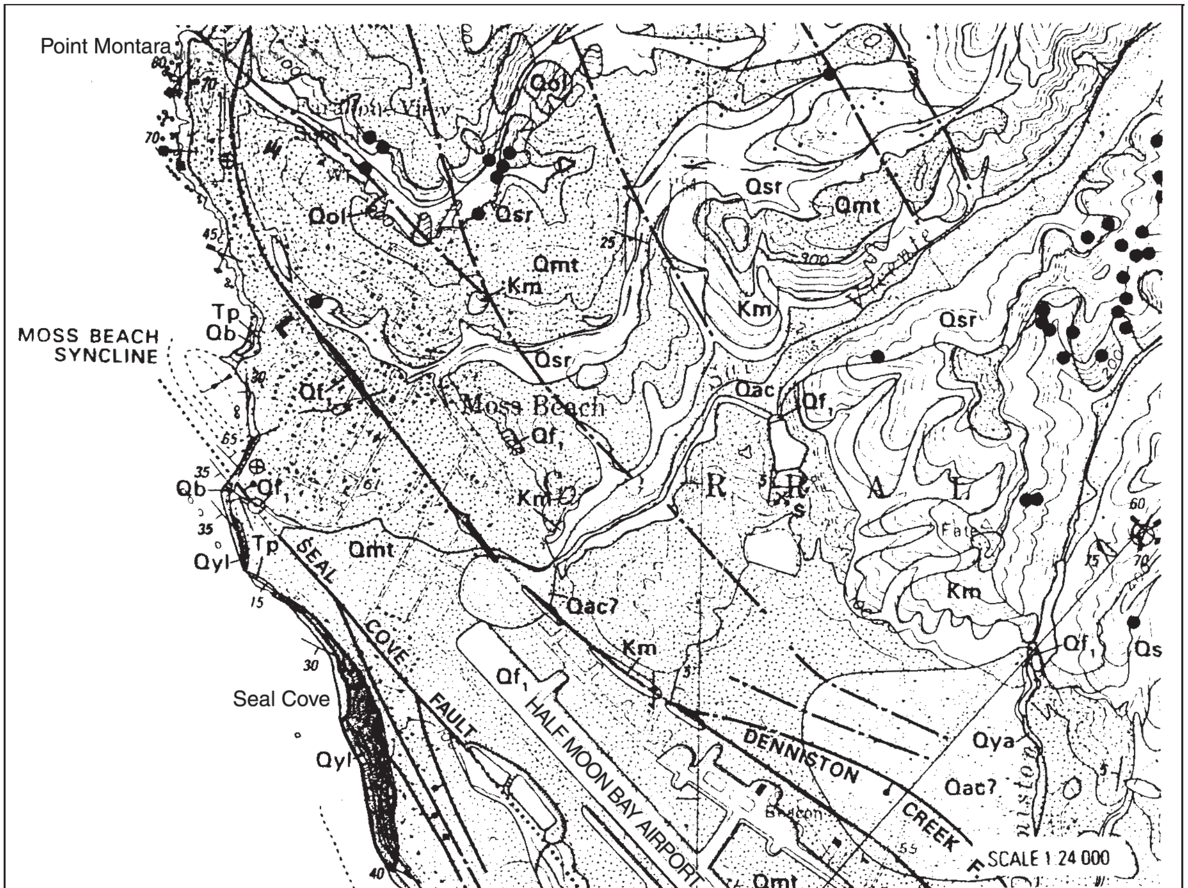
EXAMPLES OF FACING SYSTEMS USED IN A SOIL NAIL STRUCTURE

Hard facing (a structural part of the whole nail system) has to fulfill a static function to stabilize the slope between the nails and must therefore be dimensioned to the appropriate pressures.



Constructed hard facing with concrete (either sprayed or placed or precast).

Figure 5.14. Diagrams of the basics of soil-nailing slope stabilization technique (CEN Technical Committee 288, 2000).



Qf_1	Artificial Fill	Qol	Holocene and Pleistocene (?) older landslide deposits
Qsr	Holocene slope wash ravine fill, and colluvium	Qmt	Upper Pleistocene marine terrace deposits
Qb	Holocene beach deposits	Tp	Pliocene Purisima Formation
Qyl	Holocene younger landslide deposits	Km	Cretaceous granitic rock of the Montara Mountain Pluton

Geologic Map of Area of Half Moon Bay Airport

Figure 5.15. Geologic map Half Moon Bay Airport area (McLaughlin and Sarna-Wojcicki, 1997).

Figure 5.16. Photograph of Moss Beach Syncline, which involves the Miocene to Pliocene-age Purisima Formation (Barnes, 1995).

Figure 5.17. Regional perspective aerial photograph of Devil's Slide area (Montara Press, 2001).

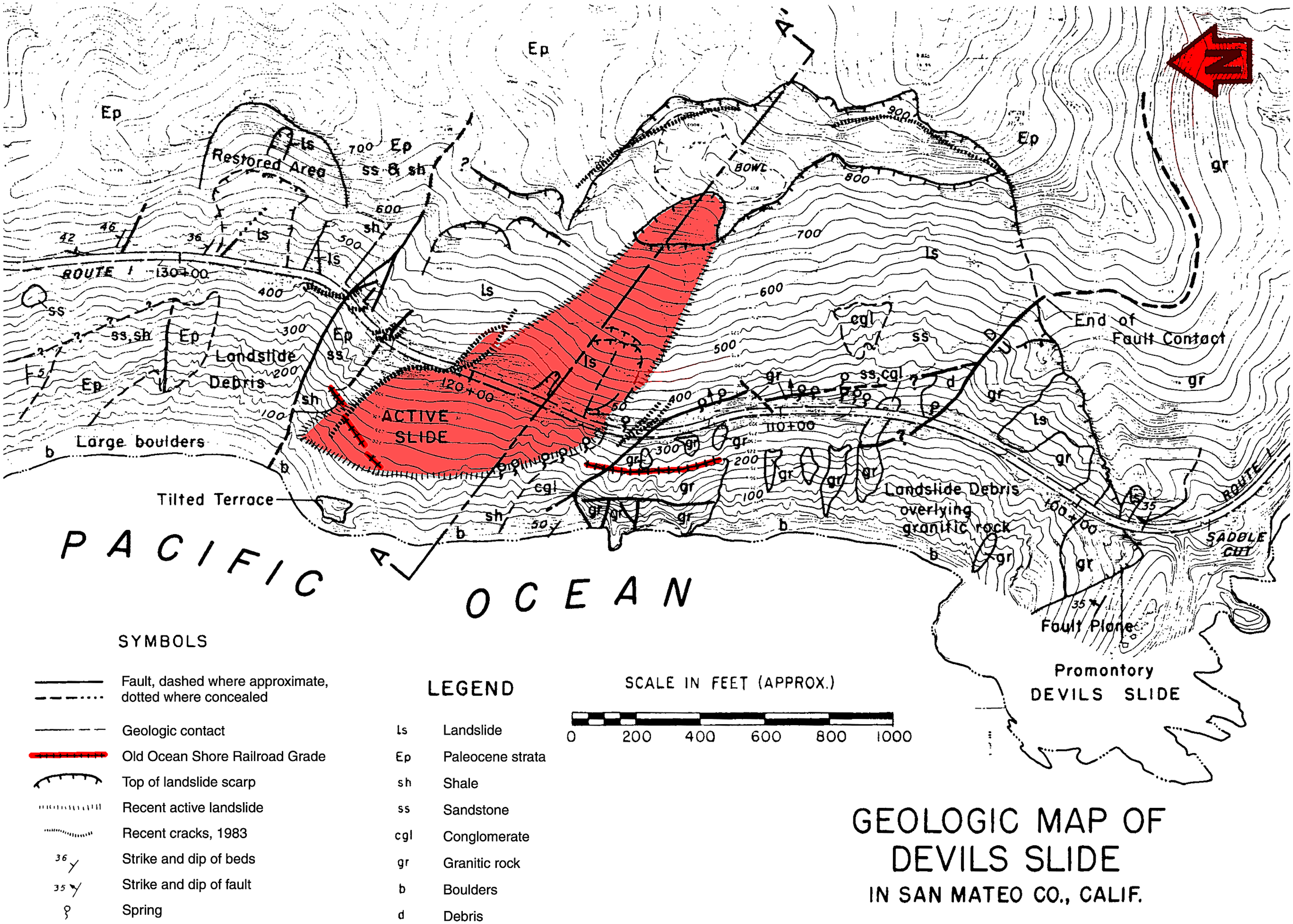


Figure 5.18. Geologic map of Devil's Slide area (Heyes, 1984).

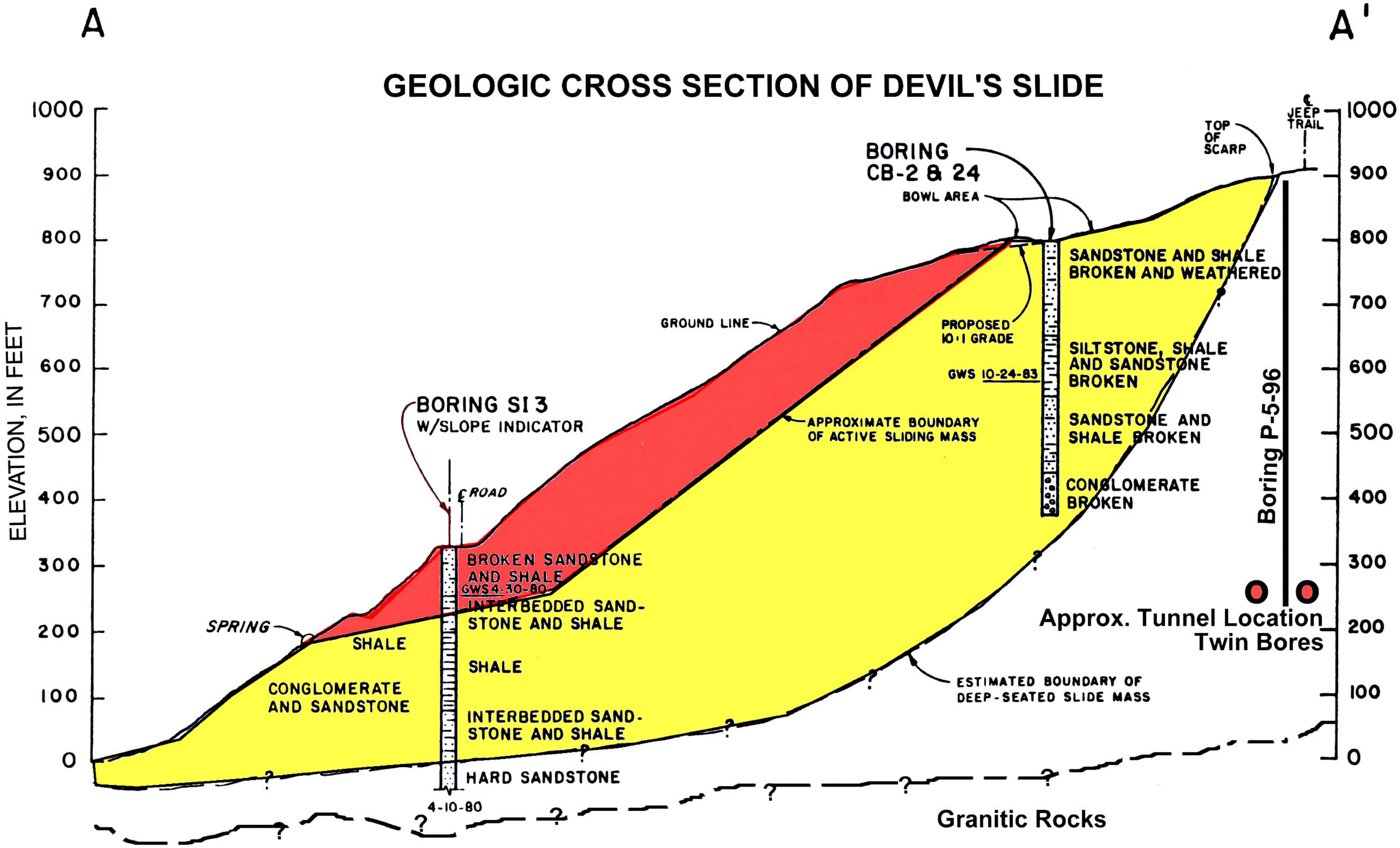


Figure 5.19. Schematic cross section of Devil's Slide (modified from Heyes, 1984).

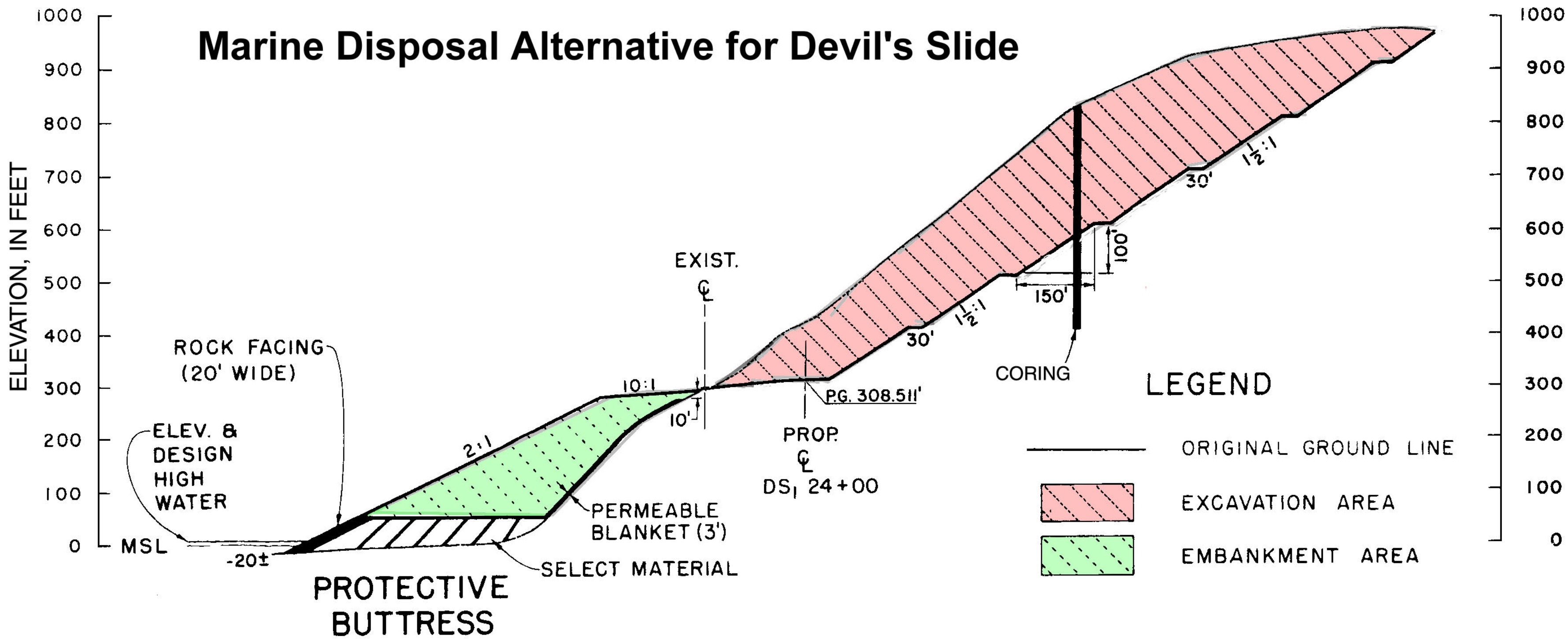


Figure 5.20. Diagrammatic cross section of marine disposal alternative for Devil's Slide. (after Heyes, 1984).

Figure 5.21. Photograph of initial 1995 failure of Highway 1 at Devil's Slide (Barnes, 1995).

Figure 5.22. Photograph of slope movement and rock falls at Devil's Slide (February 2, 1995) (Barnes, 1995).

Figure 5.23. Photograph of installation of wire mesh at Devil's Slide (Barnes, 1995).

Figure 5.24. Photograph of installation of anchors at Devil's Slide (Barnes, 1995).

Figure 5.25. Photograph of installation of grout blanket at Devil's Slide (Barnes, 1995).

Figure 5.26. Photograph of completed repairs at Devil's Slide, August 1995 (Barnes, 1995).

Figure 5.27. Artist's rendition of south portal of Devil's Slide tunnel bypass. This rendition shows a single bore, although current plans call for a dual bore (Montara Press, 2001).

Figure 5.28. Artist's rendition of north portal of Devil's Slide tunnel bypass. . This rendition shows a single bore, although current plans call for a dual bore (Montara Press, 2001).

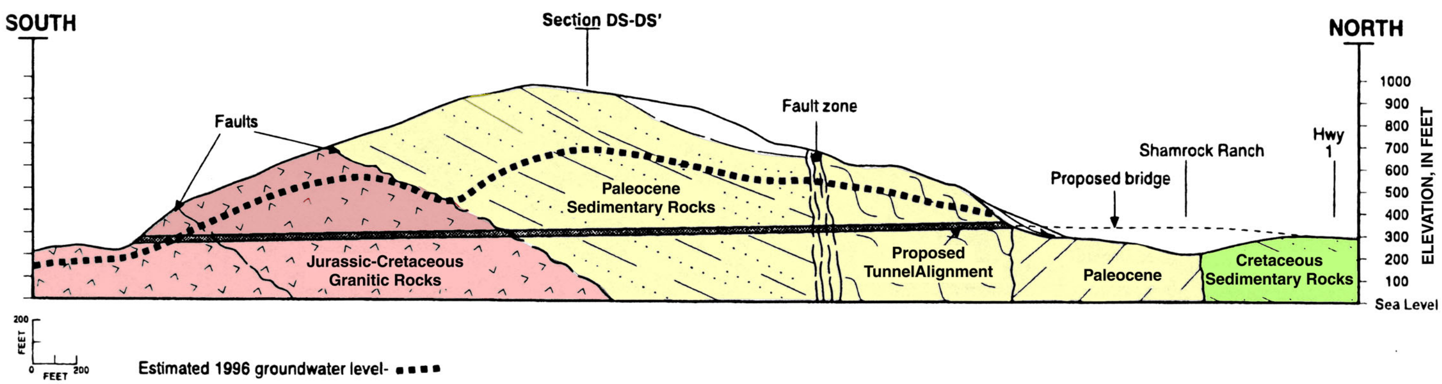


Figure 5.29. Geologic cross section along Devil's Slide bypass tunnel alignment (after Cole and others, 2000).

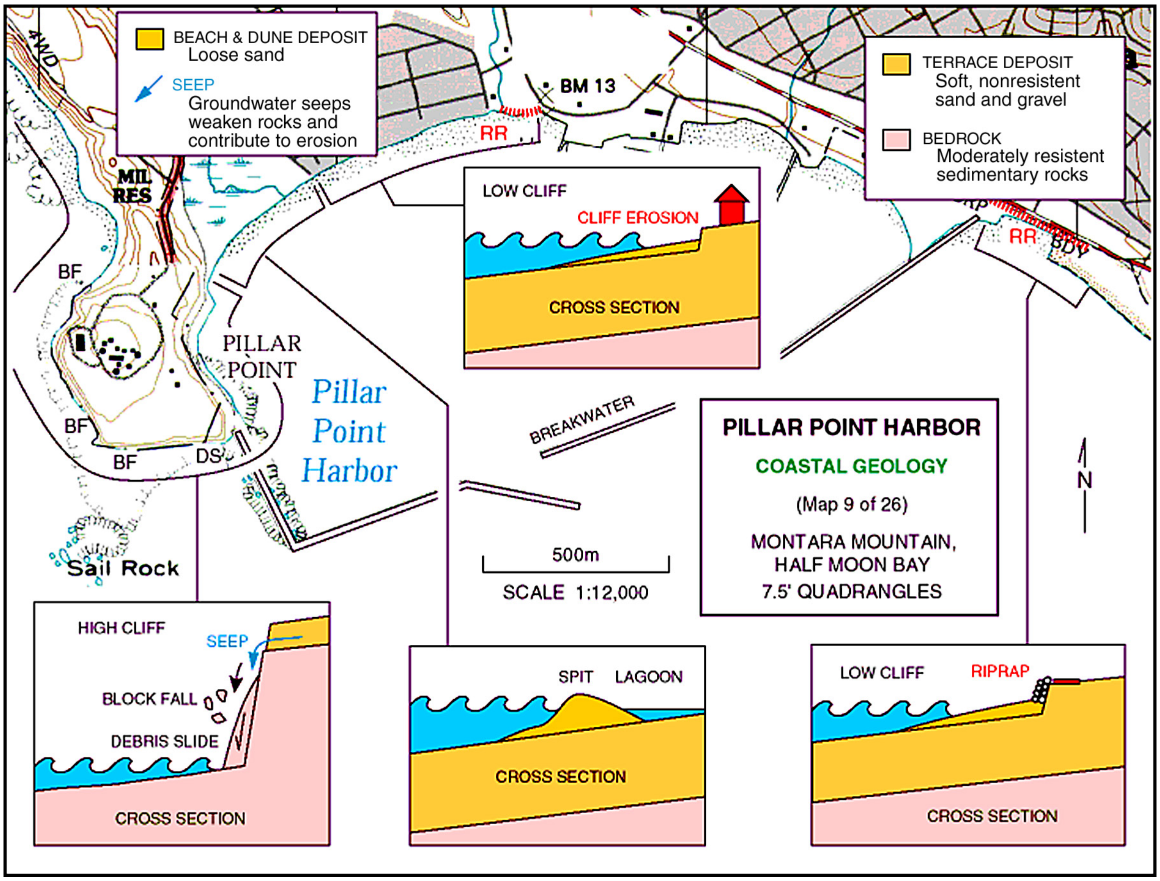


Figure 5.30. Pillar Point Harbor coastal geology map (Lajoie and Mathieson, 1998).

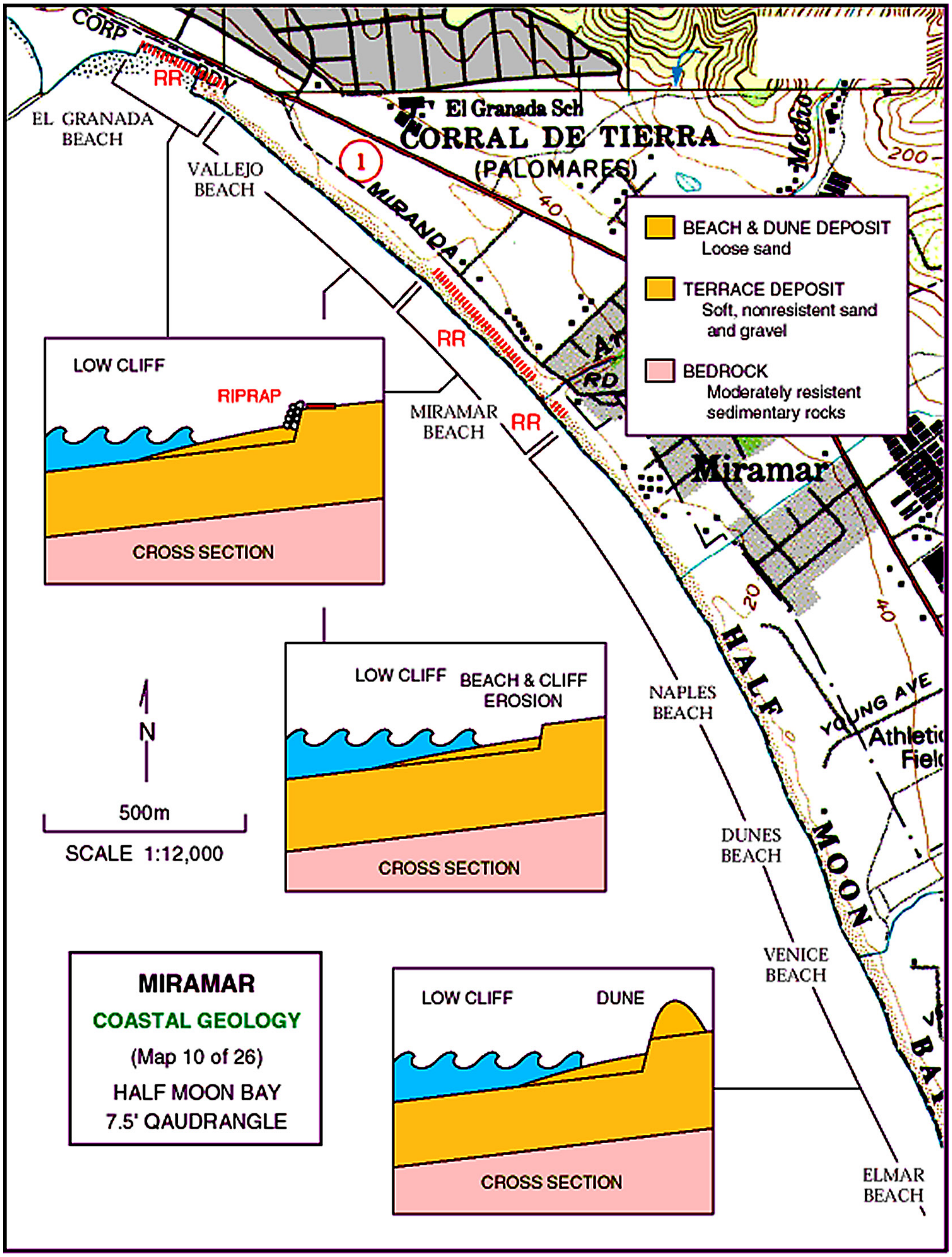


Figure 5.31. Miramar coastal geology map (Lajoie and Mathieson, 1998).

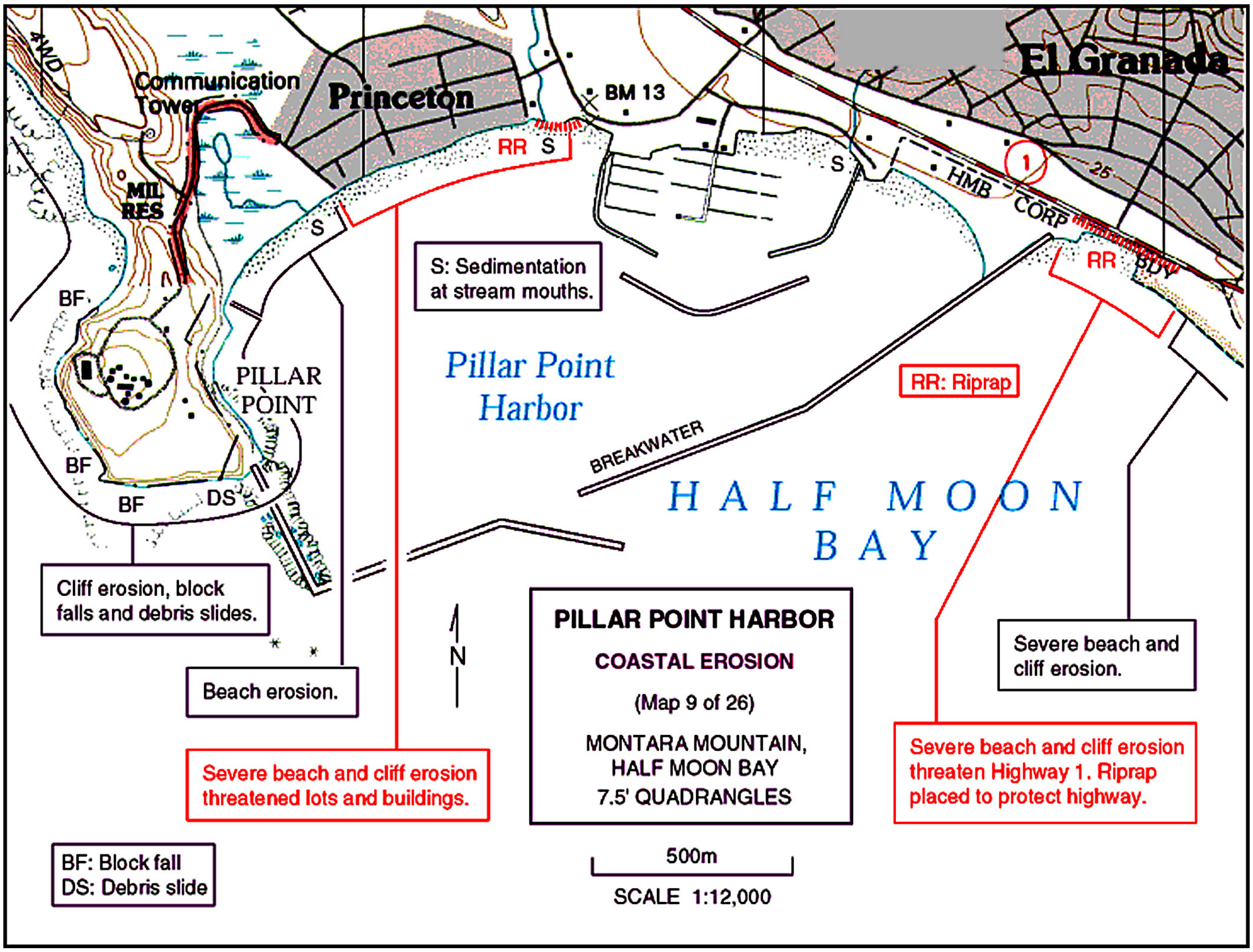


Figure 5.32. Pillar Point Harbor coastal erosion map (Lajoie and Mathieson, 1998).

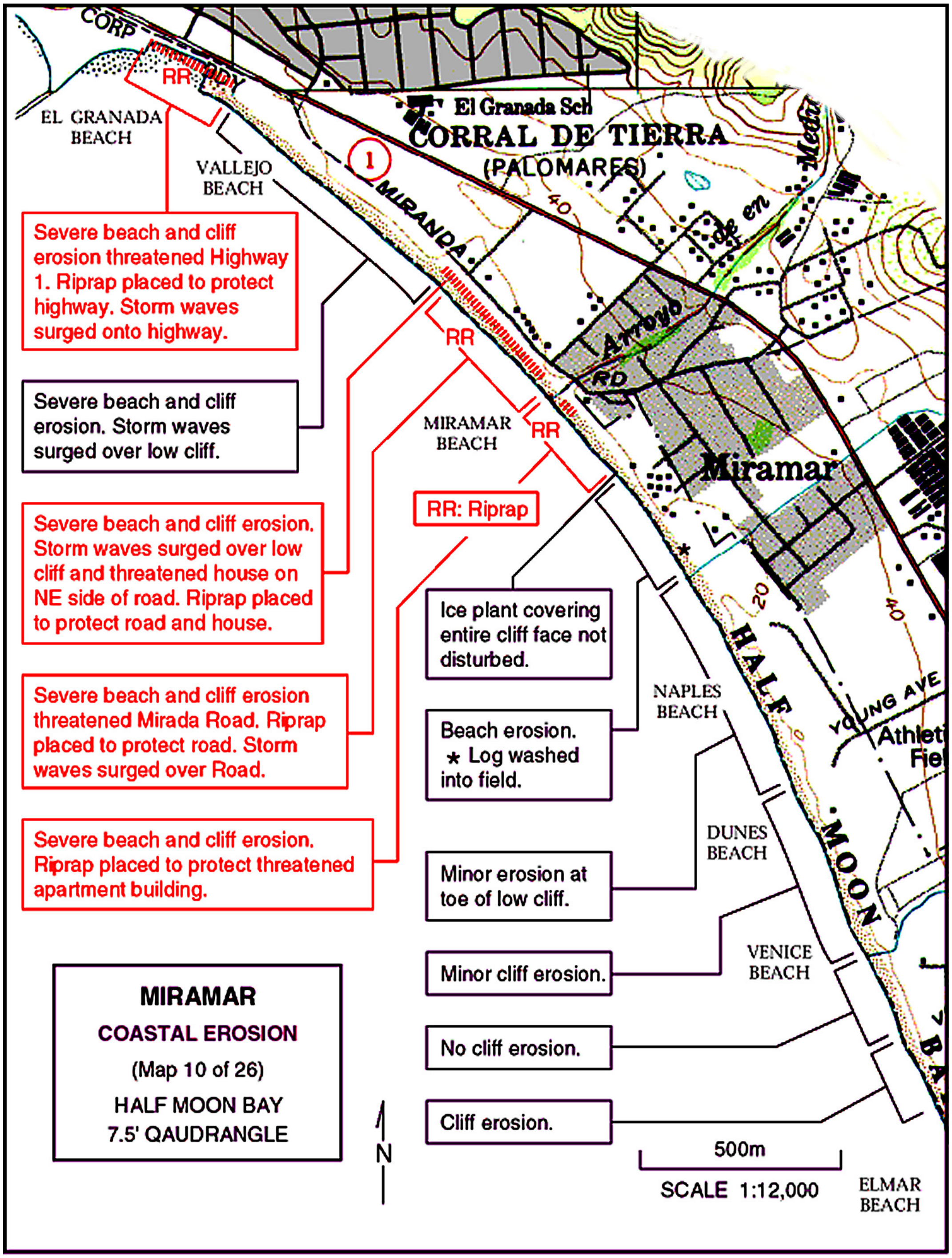


Figure 5.33. Miramar coastal erosion map (Lajoie and Mathieson, 1998).

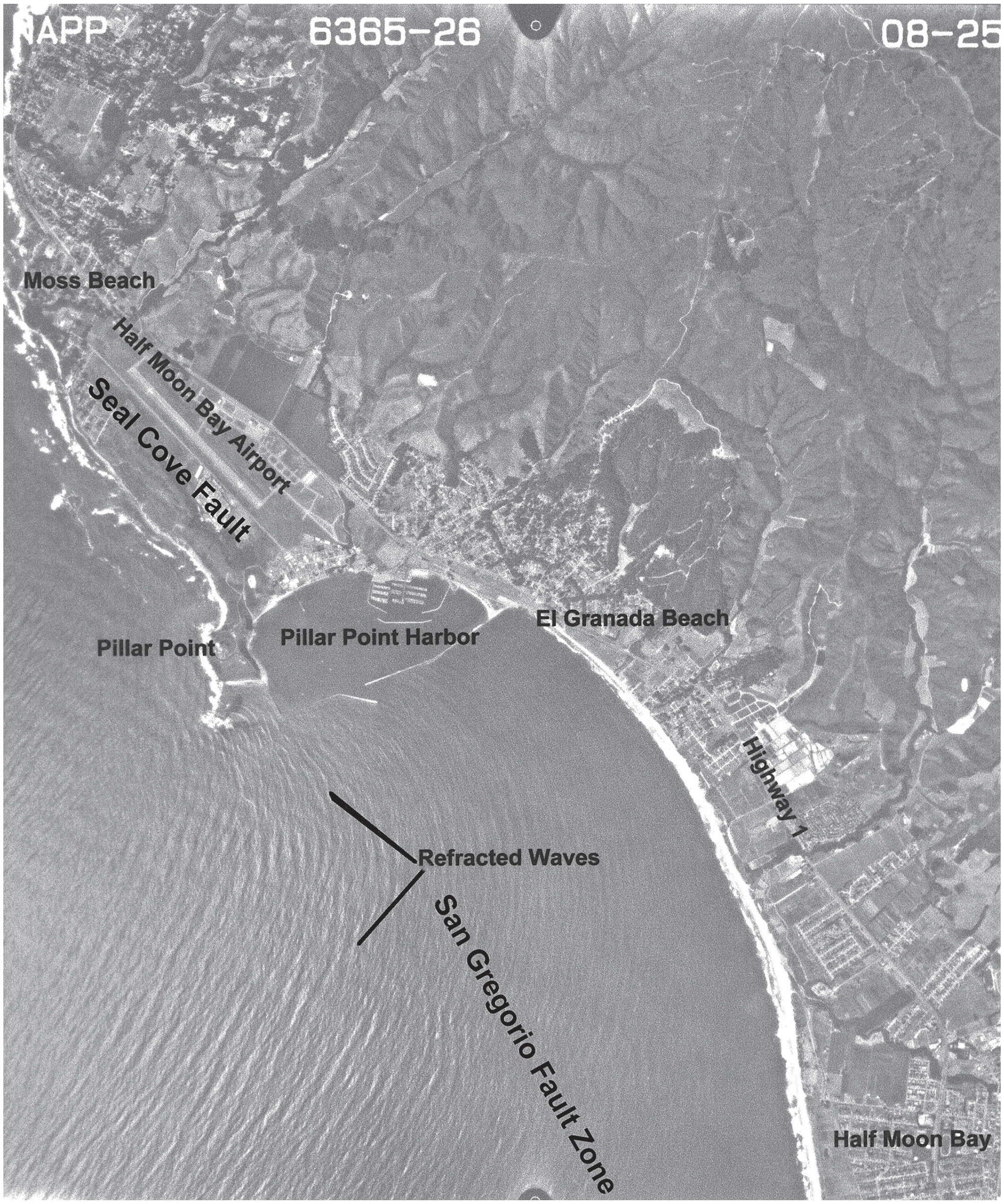


Figure 5.34. Aerial photograph taken in 1993 of wave refraction patterns at Half Moon Bay/Pillar Point Harbor.

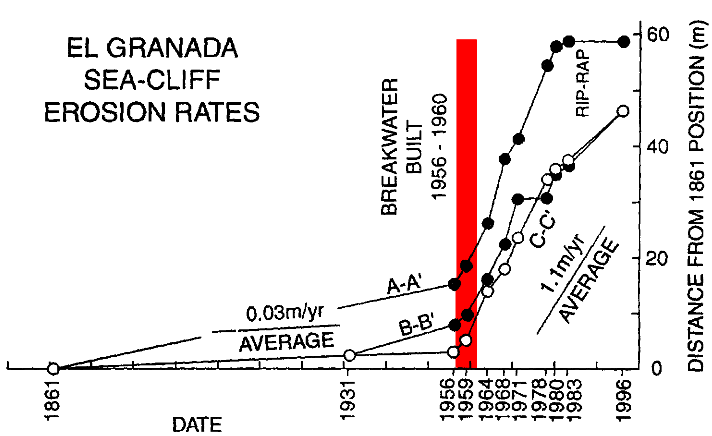


Figure 5.35. Graphical presentation of change in erosion rates at El Granada Beach before and after installation of Pillar Point Harbor breakwater (McLaughlin and Sarna-Wojcicki, 1997).