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Where's the Hayward Fault?
A Green Guide to the Fault

By Philip W. Stoffer

This report describes self-guided field trips to one of North America's most dangerous earthquake faults—the Hayward Fault. Locations were chosen because of their easy access using mass transit and/or their significance relating to the natural and cultural history of the East Bay landscape.

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Where's the Hayward Fault? A Green Guide to the Fault

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Introduction to this guide

This field-trip guidebook was compiled to help commemorate the 140th anniversary of an estimated M 7.0 earthquake that occurred on the Hayward Fault at approximately 7:50a.m., October 21st, 1868. Although many reports and on-line resources have been compiled about the science and engineering associated with earthquakes on the Hayward Fault, this report has been prepared to serve as an outdoor guide to the fault for the interested public and for educators. The first chapter is a general overview of the geologic setting of the fault. This is followed by ten chapters of field trips to selected areas along the fault, or in the vicinity, where landscape, geologic, and man-made features that have relevance to understanding the nature of the fault and its earthquake history can be found. See figure 1 for a location map of field trip destinations. A glossary is provided to define and illustrate scientific term used throughout this guide.

Why a "Green Guide" to the Hayward Fault? A "green" theme helps conserve resources and promotes use of public transportation, where possible. Although access to all locations described in this guide is possible by car, alternative suggestions are provided. To help conserve paper, this guidebook is only available on-line only; however, select pages or chapters (field trips) within this guide can be printed separately to take along on an excursion.

Transportation alternatives

The discussions below highlight transportation alternatives to visit selected field trip locations. In some cases, combinations, such as a ride on BART and a bus, can be used instead of automobile transportation.. For other locales, bicycles can be an alternative means of transportation. Transportation descriptions on selected pages are intended to help guide fieldtrip planners or participants choose trip destinations based on transportation options, interests, or special needs (see below).

San Francisco Bay Area Rapid Transit District
BART provides rail access to San Francisco and throughout the East Bay region, with links to other metropolitan air, rail, and bus services. Most field trip locations described in this guide are easily accessible by BART, or a combination of BART and an AC Transit metro bus. Figure 4 shows the proximity of the Hayward Fault to the Bart rail system to field trip sites. Visit **www.bart.gov** for more information about BART stations, schedules, and fares. With station stops fairly evenly distributed throughout the East Bay's piedmont urban corridor, BART

provides close access to many locations along the Hayward Fault. Each field trip destination map describes where the most convenient BART service is provided. *BART Transit Connection Maps* are available both online and as brochures in most stations. The field trips closest to BART stations are in downtown Hayward and downtown Fremont.

Alameda-Contra Costa Transit District

AC Transit provides bus service throughout the Alameda and Contra Costa Counties metropolitan region with links to other regional transportation hubs (air, rail, and bus). Visit **www.actransit.org** for information about routes, connections, schedules, and fares. AC Transit provides convenient connection to BART stations. Bus service is described with each destination map where convenient service is located; walking distances greater than about a mile to the closest BART station are noted.

Bicycle Access

Bicycle access to locations along the Hayward Fault can be an alternative to driving. San Francisco Bay Area bicycle routes and information can be found online at http://511.org. Bikes are allowed on most BART trains (see the BART website for exceptions and rules). All AC Transit buses have bike racks that can accommodate two bicycles. Some of the locations described in the field trip destination map pages are either not easily accessible by BART or AC Transit buses alone, but access is possible by bicycle (or car). Note also that some locations described herein may be strenuous and require long uphill and downhill rides (such as along the Skyline Drive in the East Bay Hills—a very popular biking destination). Safety is always a concern when riding bicycles in unfamiliar places. Bike route information is provided if locations along the fault are on or near established bike routes.

Hiking Access

Some walking is required to all destinations along the Hayward Fault, but some destinations require more significant distances to walk to see all the sites recommended. The Hayward Fault passes through a variety of landscape terrains (hilly, forested areas to flat urban landscapes). A hiking symbol is included if recommended field trip destinations require more than a mile walk, or if trailheads to parkland are accessible along the route.

Wheelchair Access

Wheelchair access to locations along the Hayward Fault is possible in some locations near BART and AC Transit stops. Wheelchair access to the fault may be best at Contra Costa College campus, Monclair Village, downtown Hayward, some locations in downtown Fremont, and Mission San Jose.

Automobile Access

All field trip locations along the Hayward Fault are accessible by automobile. Some locations described in this report are not accessible with public transportation and bicycle access may be too strenuous or time consuming. However, these sites are included because they may be of interest when planning a field trip or they are important to help understand the significance of the Hayward Fault. **To go green, take someone with you, and plan your route in advance.** Field trip planners for school or special interest groups may save time and resources by contracting a charter van or bus service. For instance, AC Transit will provide access to groups of 20 or more to Chabot Space & Science Center with advanced reservations. The Oakland Zoo also has discount rates for large groups.

Take a virtual tour of the Hayward Fault

All the photographs in this guidebook can be viewed online on a companion website at http://3dparks.wr.usgs.gov/haywardfault. The website contains larger format versions of the images with interpretive information presented in this guide, the same images without interpretive information, and 3D photographs—images that require red-and-cyan 3D viewing glasses to get the stereographic effect. All images on the website are ideal for online viewing, printing, or projecting, such as in a classroom Powerpoint presentation. A WWW search on "3D glasses" will yield many distributors of red-and-cyan viewing glasses, ranging from simple, inexpensive paper-frame glasses to high-end frame glasses with glass lenses.

Which trip would be best to go on?

The answer varies depending on your interests, time limits, and abilities. Suggestions are as follows.

If you have children: The best place, without a question, would be to go to the Oakland Zoo. There is a Hayward Fault exhibit in the Children's playground area within the zoo. Other good options with children would be to visit Monclair Village where there is a children's playground in the recreation center (park) just north of downtown. You could also have lunch downtown. In Fremont, next to the BART station is the Tule Pond Preserve that has children-oriented programs. A picnic in Memorial Park in Hayward or Central Park in Fremont would also be good options for children.

If you want to see fault-related impacts on infrastructure: The best place to see impacts on infrastructure is in downtown Hayward where many features can be observed in a relatively small area. It is easy to get to downtown Hayward from BART and a walk along the fault between Memorial Park to the corner of Rose Street and Prospect Street, and return, is a little more than two miles. On foot, this might take several hours if you include visits to the Hayward Historical Society Museum and include a lunch stop at a restaurant along the route. To the north, another good choice would be the Contra Costa College trip, but go there only on a weekend or when classes are not in session. Both Monclair Village and Fremont Central Park trips offer good views of offset curbs and walls.

The easiest trips using mass transit: The Hayward and Fremont trips are closest to BART stations. Most of the others would require taking a bus or riding a bike. The trip to the Oakland Hills is really not an option with mass transit. Also, the trip to Buena Vista Island and Treasure Island is really only suited for automobile travel with crossing the Bay Bridge as part of a scheduled trip.

If you want to ride a bike: The Berkeley area would be a good choice, especially if you are willing to tackle the ride up to the ridgeline of the Berkeley Hills. In the South Bay, a bike tour through the neighborhoods between Mission San Jose and Arroyo Caliente Park would be a moderately easy and scenic ride.

If you want a scenic hike: All the trip destinations could be turned into hikes, but most would be in urban residential settings. Point Pinole Regional Park has many miles of scenic trails, as do Tilden, Claremont Canyon, Sibley Volcanic, and other parks and preserves in the Berkeley Hills. An easy, scenic walk would be around Lake Temescal. A very popular, long (strenuous) hike in the South Bay is to the top of Mission Peak (near Mission San Jose).

Best places to see "geology": Rocks and landscape features are best seen at Point Pinole along the shoreline and in outcrop locations throughout the Berkeley Hills.

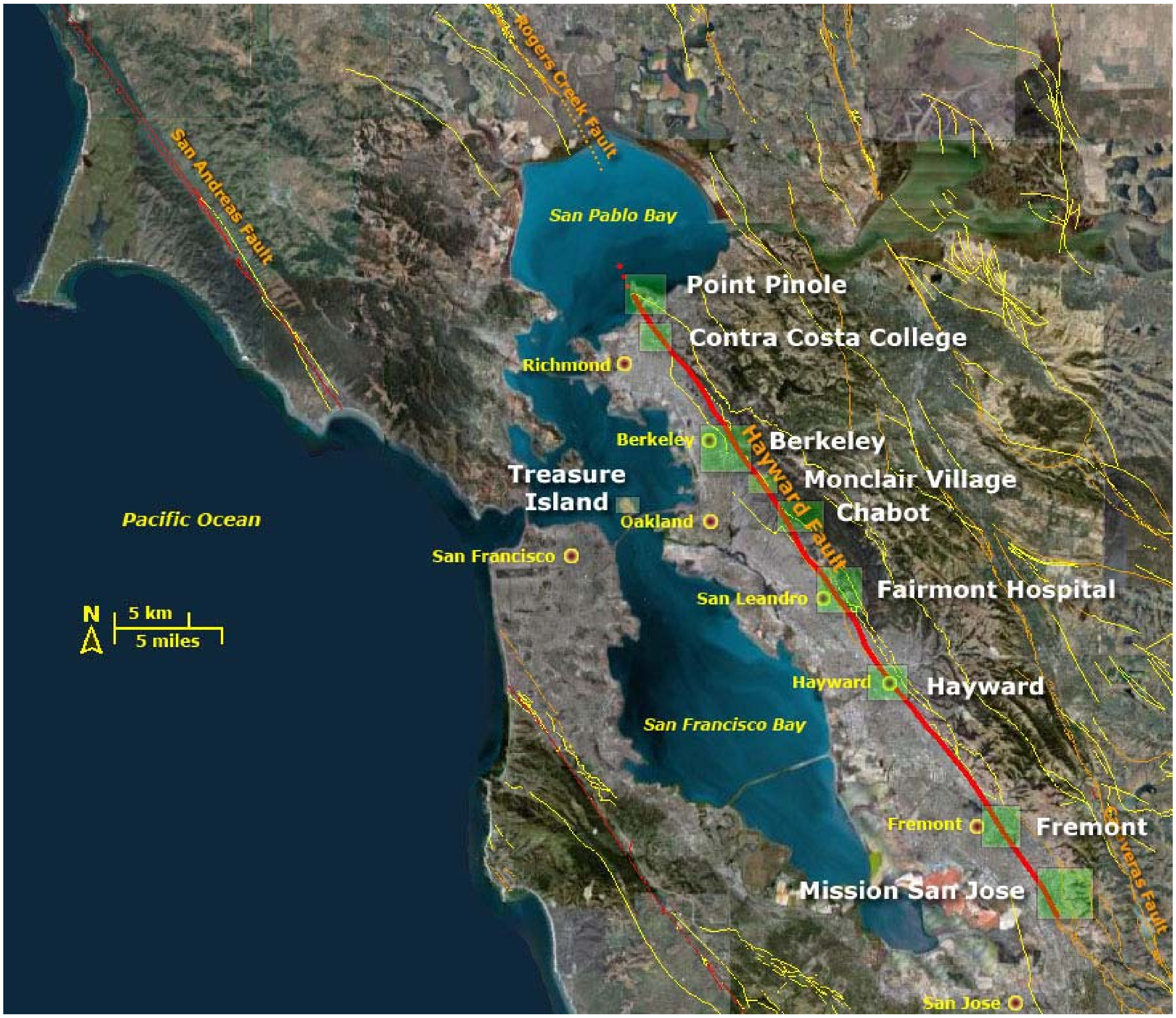


Figure 1. Locations of selected field trip destinations to observe features associated with the Hayward Fault. Locations were chosen based on public access, and some locations discussed highlight regional geologic features, historic buildings, or infrastructure. General locations of field trip destinations, shown as green boxes, are projected on a satellite image (modified from USGS Quaternary earthquake fault data and imagery retrieved from Google Earth).

Chapter 2—Introduction to the Hayward Fault

Although over time regional inhabitants had known about or experienced many earthquakes, the Hayward Fault “introduced itself” to the modern world in the form of the 1868 Hayward earthquake. The 1868 earthquake was originally called the *Great San Francisco earthquake* prior to the 1906 earthquake on the San Andreas Fault. The name, Hayward Fault, wasn’t applied until A.C. Lawson used the term in his 1908 report to the new California Earthquake Commission after the 1906 San Francisco earthquake.

Figure 2. Location of the Hayward Fault. Fault systems in the San Francisco Bay region are shown on a satellite composite image modified from Google Earth. Faults that have had major earthquakes in historic times (since 1776) are shown in red. Fault that display movement or earthquake history in roughly the last 10,000 years (Holocene Epoch) are shown in orange. Older faults that display evidence of having activity in the last 2 million years (Quaternary Period) are shown in yellow. Fault data from Graymer and others (2006).

The Hayward Fault is a major earthquake fault that runs for nearly 50 miles (70 km) through the East Bay of the San Francisco Bay region (fig. 2). The fault and the associated greater system of Bay Area faults, have been known to generate great earthquakes in the past and will continue doing so in the future. For its length, the Hayward Fault has probably been studied more than any fault in the world. And for good reason—the Hayward Fault is a known killer. The fault runs through, or near to, some of the most densely urbanized areas in North America. These areas also support a large portion of California's economy—the region encompassing the fault is host to a maze of transportation, energy, water, telecommunications, waste disposal, and emergency infrastructure that supports millions of people (figs. 3 and 4).

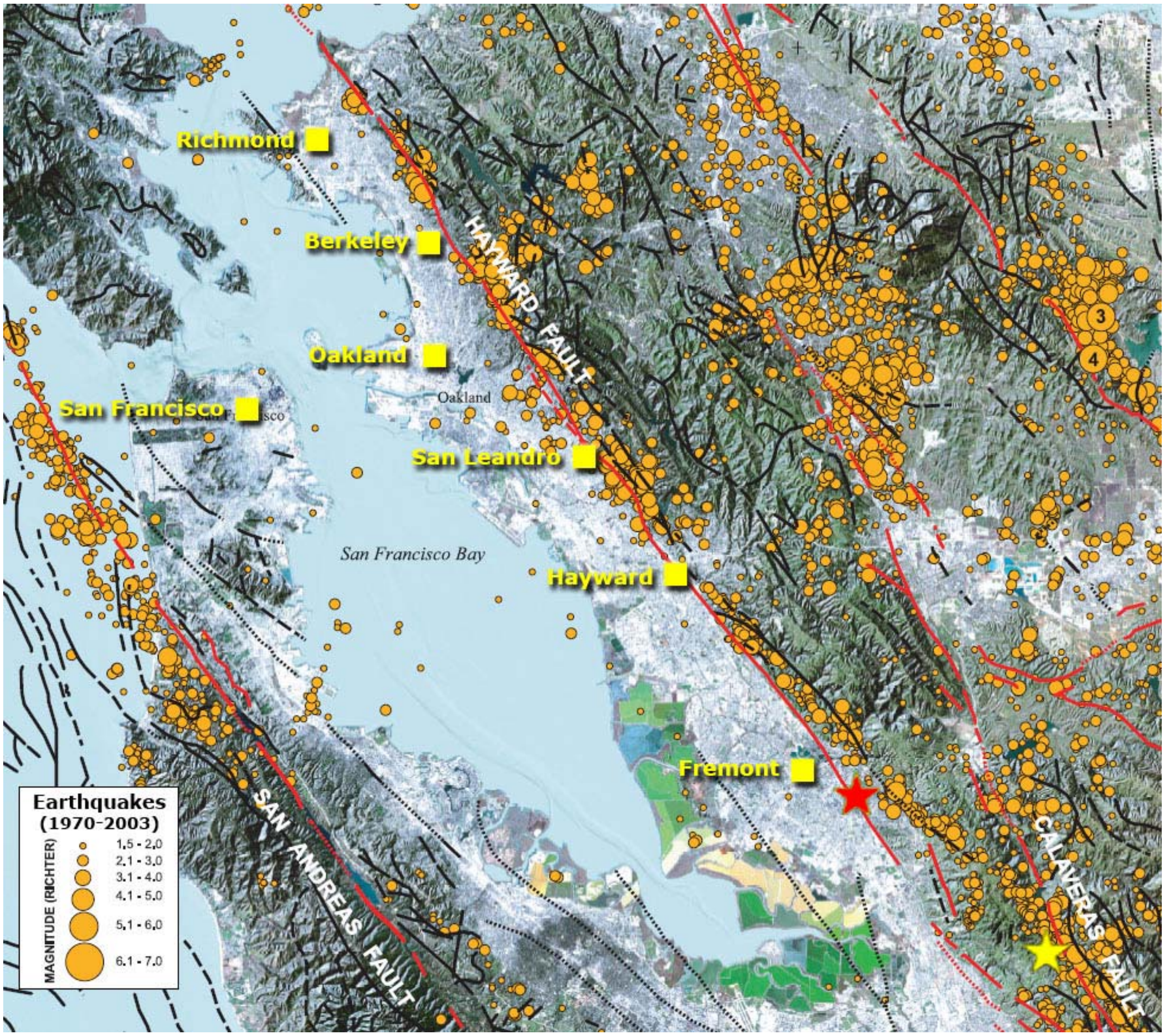


Figure 3. Earthquake map of the Hayward Fault and surrounding region. (Map modified from Sleeter and others, 2004). The map shows the epicenter and magnitude for earthquakes between 1970 and 2003. The epicenter of the estimated magnitude 7.0 earthquake in 1868 was probably in the Hayward or Fremont area, but the surface rupture extended from Fremont to Berkeley (see USGS Earthquake Hazards Program, 2007). The red star shows an educated guess about the epicenter for the 1868 earthquake (no reliable record of the earthquake exists from that period). The yellow star shows the location of the recent M 5.4 Alum Rock earthquake of October 30, 2007 on the Calaveras Fault (near where it merges with the southern end of the Hayward Fault system).

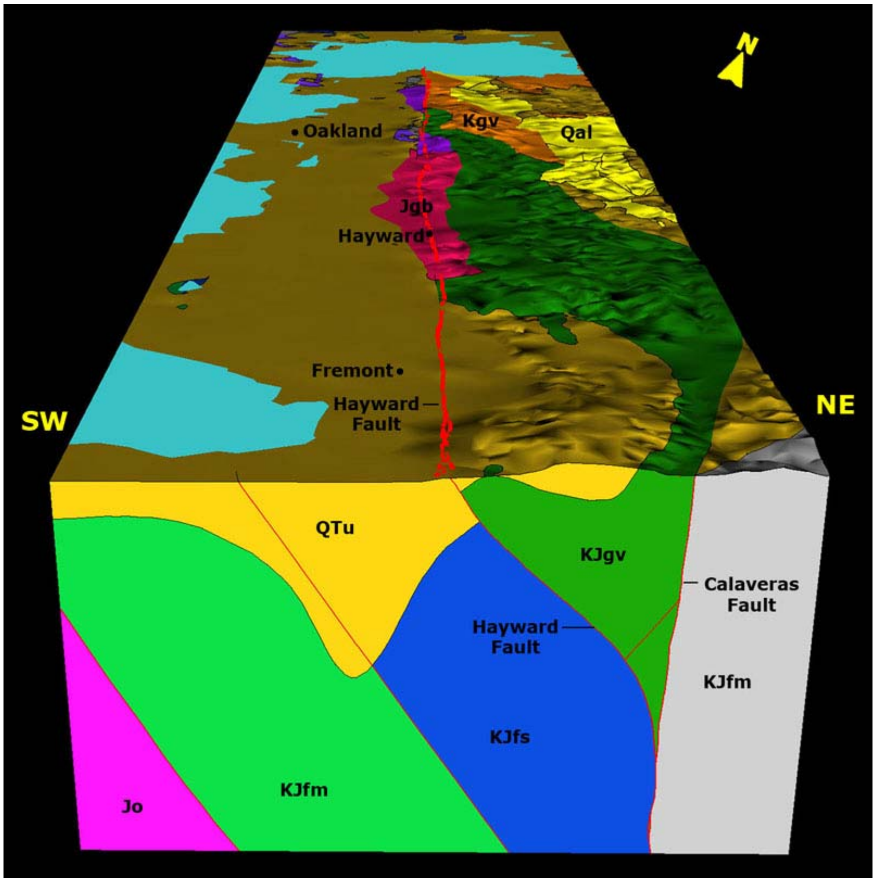
Figure 4. 1868 Hayward Earthquake Shaking Intensity Map with the BART System. The map of the of the San Francisco Bay Region shows the location of the BART rail system, the location of the Hayward Fault, and the earthquake shaking intensity from the USGS 1868 Hayward earthquake shakemap. The BART system is a useful indicator of the intensely urbanized corridor of the East Bay region relative to the location of the fault. For more information about the 1868 Hayward earthquake and its shakemap, see USGS Earthquake Hazards Program, 2007.

The Hayward Fault has a long and complex geologic history, and the character and history of the fault is continuously debated. Like almost all major earthquake faults in the San Francisco Bay region, the Hayward Fault is a *right-lateral strike-slip fault*, with the western side of the fault moving northward relative to the eastern side. The modern "Hayward Fault" is perhaps tens of millions of years old, but also is imprinted on older fault systems that formed millions of years earlier. Rocks of many ages and compositions are found along the fault—some of them are "far traveled" by the cumulative movements associated with the plate-tectonic evolution of western North America. The East Bay fault system (which includes the Hayward Fault) has accumulated as much at 107 miles (175 km) of right-lateral offset in the last 12 million years. Of this total, the Hayward Fault is responsible for about 60 miles (100 km) of the offset, with 36 miles (60 km) having occurred in the past 6 million years (Graymer and others, 2002).

The southern end of the Hayward Fault is complex. At depth in the region south of Fremont, the Hayward Fault merges with the central Calaveras Fault. In this region, the fault plane of the Hayward Fault dips gently at the surface but grows increasingly steeper with depth (determined on the basis of seismic and other geophysical data—see the geologic block diagram and cross section at Mission Peak near Fremont, figs. 5 and 6). Farther north, the plane of the Hayward Fault is steeper, approaching nearly vertical in profile (see the cross sections near San Leandro, Berkeley, and Richmond, fig. 6). At Point Pinole Regional Shoreline, the Hayward Fault runs offshore beneath San Pablo Bay. Beneath San Pablo Bay, the Hayward Fault probably merges with other fault systems in the North Bay, possibly the Rodgers Creek Fault.

A Creepy Fault: In earthquake terminology, ***creep*** is the slow, more or less continuous movement occurring on faults due to ongoing tectonic deformation that does not happen during major earthquakes. The Hayward Fault is actively moving, year-by-year. This is unlike other earthquake faults in the region that are locked between major earthquakes (like the San Andreas Fault in the Santa Cruz Mountains, San Francisco Peninsula, and north of the Golden Gate), or faults that are inactive or typically ancient faults that are no longer active. Detailed U.S. Geological Survey (USGS) investigations into movements along the Hayward Fault show the fault creep averages about 0.2 in (5 mm) per year. However, this creep occurs at different rates and in different locations and can also vary significantly from one year to the next. Just as creep is an observable surficial phenomenon, fault motion is also taking place at different levels in the earth extending downward to the base of the brittle crust—roughly 8 miles (12 km) in the San Francisco Bay region.

Just as surface creep varies, motion rates at depth vary as well. Some areas-at-depth along the fault zone may be temporarily locked whereas other locations are gradually moving. When stresses build up in the locked portions the fault will eventually rupture, or break, releasing energy in the form of an earthquake. Small, almost imperceptible earthquakes happen daily along the Hayward and other Bay Area faults. Larger (and fortunately, less frequent) earthquakes typically occur deeper in the crust or when larger locked sections of the fault yield to rupture. For more information about earthquakes and current earthquake activity in the region, check out the USGS ***Maps of Recent Earthquake Activity in California-Nevada*** (http://quake.usgs.gov/recenteqs/latestfault.htm).



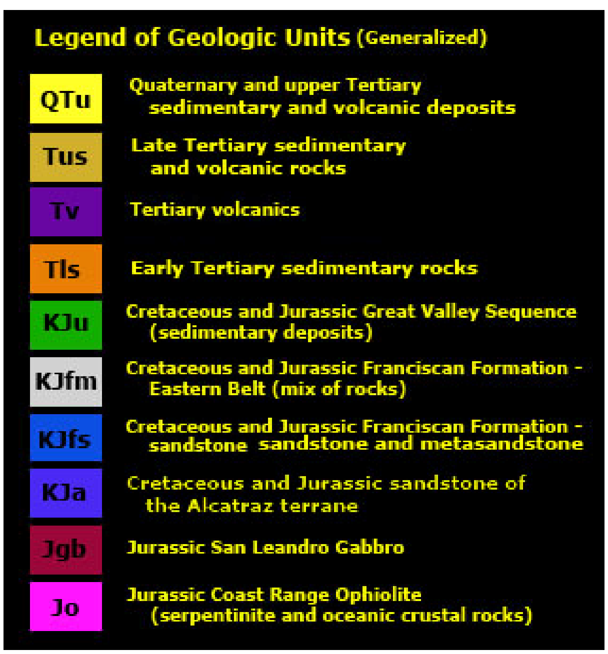


Figure 5. Geologic block diagram. This diagram shows generalized surficial geology with a cross section that shows the geologic interpretation at depth perpendicular (northwest to southeast) to the Hayward Fault (viewed toward the northwest). The cross section cuts through Mission Peak near Fremont (on the right) and crosses the south end of San Francisco Bay near San Jose and Mountain View (on the left). This cross section shows that at its south end the Hayward Fault dips moderately to the northeast, steepening as it merges with the central Calaveras Fault at depth (in the foothills of the Diablo Range east of San Jose in the vicinity between Alum Rock Park and Mount Hamilton). The "creeping" portion of the Hayward Fault system is shown in red. Note that the vertical scale is exaggerated about 2 times the horizontal scale. The cross section on the face of the block diagram is about 10 miles wide (15 km). The image was generated from a USGS 3D geologic map of the Hayward Fault zone.

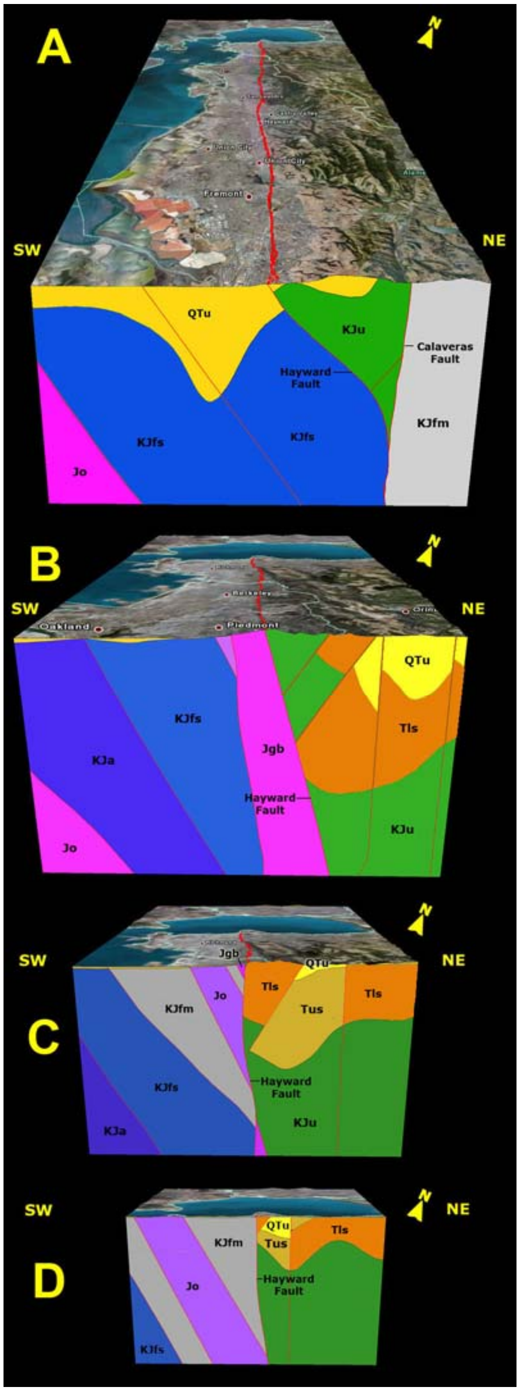


Figure 6. Cross sections along the Hayward Fault (see legend information on Fig. 5)**.** These four block diagrams show geologic cross sections perpendicular to the Hayward Fault with a draped image of the land surface (modified from *Google Earth*). The view for all figures is towards the northwest. The character of the fault and subsurface rocks are interpreted from USGS geologic and geophysical data. The "creeping" portion of the Hayward Fault is shown in red. Note that the vertical scale is exaggerated about 2 times the horizontal scale. The cross sections on the face of the block diagrams are about 10 miles (15 km) across.

A. Mission Peak area (cross section south of Fremont). The cross section cuts through Mission Peak near Fremont (on the right) and crosses the south end of San Francisco Bay near San Jose and Mountain View (on the left). It shows that at the south end of the Hayward Fault, the dip angle flattens out near the surface (along the mountain front). To the south, the fault becomes a series of interconnecting low angle faults that merge eventually with the central Calaveras Fault (in the foothills of the Diablo Range east of San Jose in the vicinity between Alum Rock Park and Mount Hamilton).

B. San Leandro area (cross section between Hayward and Oakland). The cross section cuts through the East Bay Hills (on the right) and the East Bay alluvial plain next to San Francisco Bay south of Oakland (on the left). By comparison to the Mission Peak area, the Hayward Fault in the San Leandro area has a nearly vertical profile. East of the Hayward Fault, a structural basin preserves a thick accumulation of Great Valley Sequence. West of the fault, the San Leandro Gabbro (Jgb) is a large intrusive igneous body that has unique physical properties compared to the Franciscan rocks (mostly volcanic and sedimentary rocks) or the Great Valley Sequence (sedimentary rocks). Gabbro is physical properties more like granitic rocks—being both harder and more brittle than sedimentary rocks. Geologists suggest that that where the Hayward Fault is in contact with the gabbro, it may be more prone to producing higher magnitude earthquakes than in surrounding areas.

C. Berkeley area cross section. The cross section cuts through the Berkeley Hills (on the right) and the East Bay alluvial plain in the vicinity of the Bay Bridge (on the left). By comparison to the San Leandro area to the south, the body of San Leandro Gabbro pinches out to the north, and the Great Valley Sequence (east of the Hayward Fault) comes in contact with Jurassic ophiolite (mostly serpentinite) and Franciscan Formation rocks (mostly metabasalt, chert, and sandstone).

D. Richmond area cross section. The cross section cuts through the north end of Berkeley Hills (on the right) and the East Bay alluvial plain just south of Point Pinole (to the left).

Observing the Hayward Fault

The selected field trip destinations described in this report include access to the fault in public places in regional parks, college campuses, public institutions, or in urban areas where features can be accessed from streets, sidewalks, or parking areas. Some of the selected destinations described in this report are not on the Hayward Fault. However, they are included because they provide information about the regional geology and geologic history, landscape features, or important infrastructure or historical sites that share a heritage with the earthquakes and creep history associated with the Hayward Fault. Fault research requires studying landforms from predevelopment photographs and research of historical maps and records—which may be difficult to acquire even if they exist—and then digging of trenches to verify that faults exist in the subsurface (if the ground hasn't already been disturbed by previous excavation). Maps of the [known] traces of the Hayward Fault system have been published by the California Geological Survey in a map series called the *Alquist-Priolo*

Fault and landscape features	**Places where best to see them**
Offset curbs, sidewalks, and walls	Contra Costa College, Berkeley Memorial Stadium, Monclair Village, downtown Hayward, and Fremont Central Park area
En echelon cracks	Contra Costa College, downtown Hayward, Arroyo Agua Caliente Park (South Fremont)
Fault scarps	Point Pinole, Hayward
Sag Ponds	Lake Temescal (Berkeley), Tule Lake and Lake Elisabeth (Fremont)
Linear valleys, shutterridges	Lake Temescal, Hayward, views from Oakland Hills
Landslides	Point Pinole, Mission San Jose (Mission Peak landslide)
Cultural or historic features	
Historic buildings from 1868 era	Downtown San Leandro, Mission San Jose
Museums and exhibits	Mission San Jose, Tule Pond, Hayward Area Historical Society Downtown Museum, Oakland Zoo

Field trips to examine the Hayward Fault show the relationships of the fault to the landscape that it has created. Large geomorphic features associated with fault systems, such as rift valleys and linear mountain fronts, may be easy to observe from a distance. However, many of the features that can be observed up close along the fault trace are subtle and may not be recognizable without guidance. Features such as cracks in pavement or sidewalks occur practically everywhere, and most form from ground settling after construction. In some cases, offsets in sidewalks and curbs are generated by rapid tree growth or the natural down-slope movement of soil and rock rather than by the slow movements associated with creep along a fault. Also, the idea that a fault can be drawn as a simple narrow line on a map is often different from what can be observed on the ground. Fault traces can be complex—on a map scale they may appear as a line, but up close they may appear complex because of the variable physical properties of surficial materials (such as asphalt, concrete, buildings, soil, bedrock, etc.). Note that the term *creep* is also used to describe the movement of soil and landslide deposits. Faults and landslides produce many similar landscape features and may occur together. However, fault movement is caused by stresses from tectonic forces in the crust, whereas landslides are surficial processes that move materials down slope under the force of gravity.

A fault trace can change over time—measured in periods of thousands to millions of years. The trace of a fault may evolve, split, move to a more "convenient" (easier to rupture) location, or even be absent due to local bedrock conditions. Meanwhile, erosion is competing with the tectonic forces that are moving one side of the fault versus the other, or uplifting in one area while sinking (subsiding) in another. Over long periods of time, the impact of movement along the East Bay fault system has also resulted in the uplift of mountains (the Berkeley, Oakland, or East Bay Hills). Meanwhile, both surficial erosion and sediment deposition, and sea level changes (associated with the formation and melting of continental ice sheets), have impacted the surface of the land between what is now the hills (to the east) and the bay (to the west). For most of its length the Hayward Fault crosses (and offsets) old alluvial fans descending from the hills onto a gentle sloping surface (locally called the Piedmont) before merging with the bays. Year-by-year, and millennium-by-millennium, streams have carved channels down the slope and across the trace of the fault. Likewise, the fault has continued to move, either by slow-moving surface creep or the sudden jump during a major earthquake every century or two (1-2 meters offsets are typical during great earthquakes). These competing forces, tectonics versus erosion, have gone on in the past and will continue into the future and have created many of the landscape features along the trace of the fault.

The critical factors are when, where, what, and how a major earthquake on the Hayward Fault will impact the San Francisco Bay Area. Worst-case scenarios are dire, and negative impacts will affect the entire nation's economy and social fabric as well as those of the Bay Area. The most likely scenario is a repeat of an earthquake like the 1868 earthquake that ruptured a significant portion of the Hayward Fault (from Fremont to Berkeley). Scientists suggest that the Hayward Fault and the Rodgers Creek Fault in Sonoma County (north of San Pablo Bay) are probably interrelated, although their trends are offset by several miles in map view. When asked, many scientists who have studied the Bay Area fault systems agree that one of the worst-case scenarios for an earthquake in the Bay Area would be if the Hayward and Rodgers Creek faults were to rupture at the same time.

The recent Alum Rock earthquake of October 30, 2007 (8:05 p.m.) occurred near the junction of the Hayward and Calaveras Faults. The earthquake struck about seven miles east of the city of Milpitas. The moderate earthquake had a magnitude of 5.4 and ruptured at a depth of five miles. This moderate earthquake resulted in minor damage throughout the San Jose and southern East Bay region and briefly received much media attention. However, the Alum Rock earthquake was miniscule compared to the potential for a great earthquake on the Hayward Fault or other major faults in the San Francisco Bay Area.

The most recent great earthquake on the Hayward Fault occurred in 1868, and the estimated frequency of the past five major earthquakes is, on average, about every 140 years (USGS Earthquake Hazard Program, 2007). Simple math illustrates that we are due, almost overdue, for another major earthquake on the Hayward Fault. While the date, duration, magnitude, and regional impact of such an earthquake are speculative, its occurrence is exceedingly probable (USGS Earthquake Hazard Program, 2003). We cannot prevent it from happening so **earthquake preparedness** is essential. See the USGS Earthquake Preparedness website: <http://quake.usgs.gov/prepare/prepare.html>.)

Chapter 3 - Point Pinole Regional Shoreline

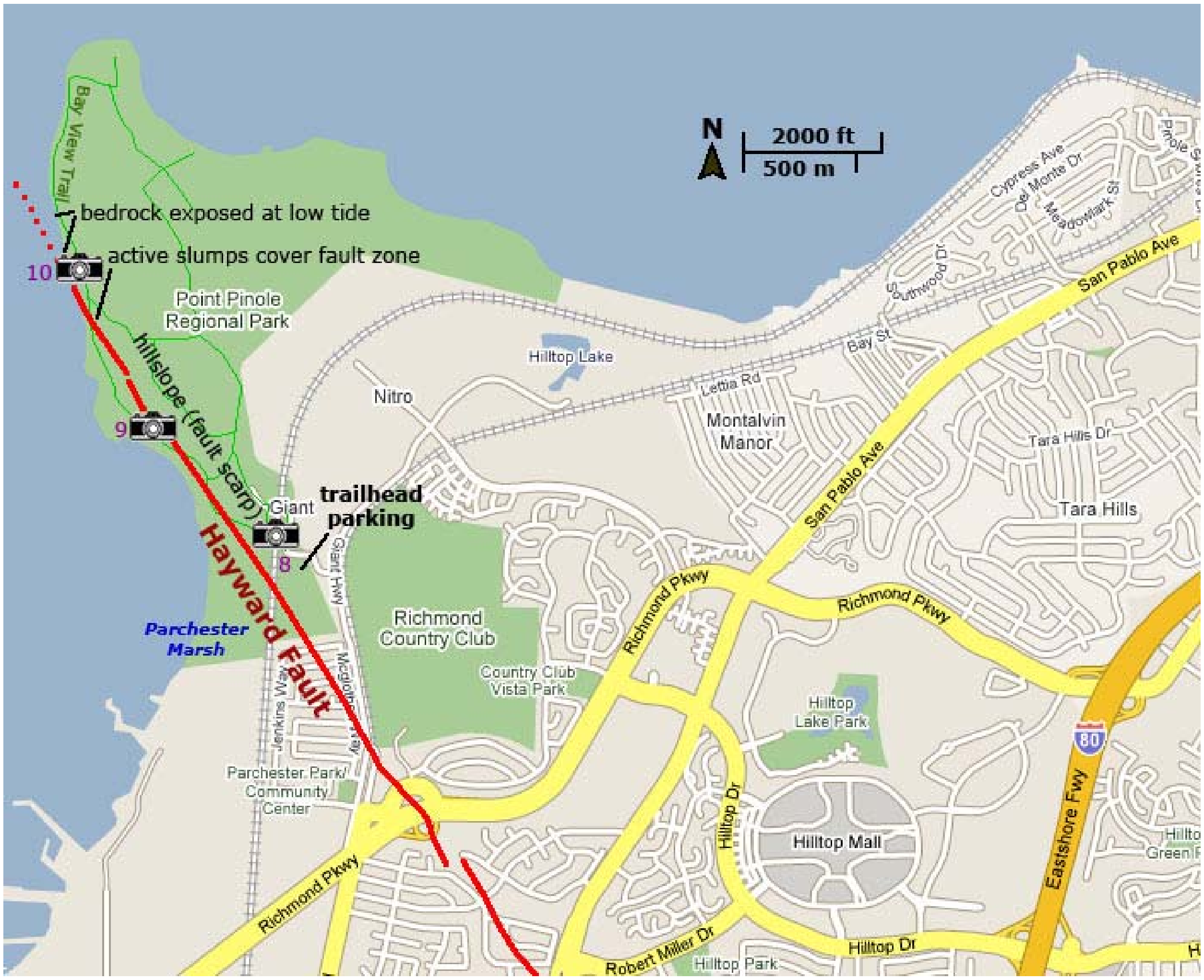


Figure 7. Trace of the Hayward Fault at Point Pinole Regional Shoreline, Bay Area, California. Cameras designate photograph locations; purple numbers indicate figure references.

What to look for: Point Pinole is an excellent location to observe how global climate change and earthquakes have impacted the San Francisco Bay Area landscape. The effect of the 1868 Hayward Fault earthquake on the Pinole area is unknown because this area was largely unsettled in 1868 when the land was still divided into large ranchos (ranches). The Point Pinole area has a rich history, best noted for an eighty-year period (1880-1960) when it was home to four explosives manufacturing companies (nitroglycerin and dynamite). During this period, the area was kept isolated from the public.

At Point Pinole, USGS investigations suggest that the fault continues northward under the San Pablo Bay. The fault runs along the base of a northwest-trending linear slope that at the downhill end intersects Parchester Marsh. The fault extends offshore near the northern end of low bluffs created by coastal erosion. Although the fault is covered by soil and landslide debris from the hill slope (scarp), complex fault-related structures in patches of bedrock can be seen along the shoreline during low tide. Within the Pinole Point Regional Shoreline, the Bay View Trail along the western shore of the park provides the best views of the landscape features associated with the Hayward Fault.

The fault is responsible for uplift of the landscape, while coastal erosion is wearing it away. As little as 10-15 thousand years ago the San Pablo and San Francisco Bays did not exist when sea level was about 350 feet (100 meters) lower during the peak of the last Ice Age. At that time, Point Pinole would have been a forested ridge above a gradual sloping plain that descended to the Sacramento River, which flowed in its channel about a mile north of the current shoreline. The river flowed through the Golden Gate and perhaps another 30 miles (50 km) to the west before it entered the Pacific Ocean. Since that time, close to 100 large earthquakes have occurred on the Hayward Fault, and the earth on the west side of the fault has moved northward perhaps hundreds of feet relative to the east side of the fault.

Access Options

BART: The closest BART station (about 3 miles) is the Richmond terminal at West Barnet Avenue.

AC Transit: The AC Transit line #71 serves Point Pinole daily and connects with both the Richmond and El Cerrito Del Norte BART stations (see www.511.org for details for bus schedules). The AC Transit line #71 also serves the Contra Costa College field trip area (Chapter 3).

Bike: The Park is about 3 miles from the Richmond BART station. Bicyclists should examine possible routes on a street map and should be extra cautious when riding during peak traffic hours on busy street routes.

Hike: Point Pinole Regional Shoreline has more than 12 miles of hiking trails. Park brochures with trail maps (showing the fault trace) and park-access shuttle information are available in the parking area. The Bay View Trail along the western shore of the park provides the best views of the landscape features associated with the Hayward Fault. The hike to the location where the fault runs offshore is a little more than a mile from the trailhead. The trails are dirt and gravel and are not accessible to typical wheelchairs.

Car: From I-80 in Richmond, take the Richmond Parkway exit and go west toward San Francisco Bay. Cross San Pablo Avenue and take the Point Pinole/Giant Highway exit. Turn right (north) at Giant Highway. Continue north and cross the railroad tracks. The park entrance is on the left past the railroad tracks. There is currently a $6 daily state park parking fee.

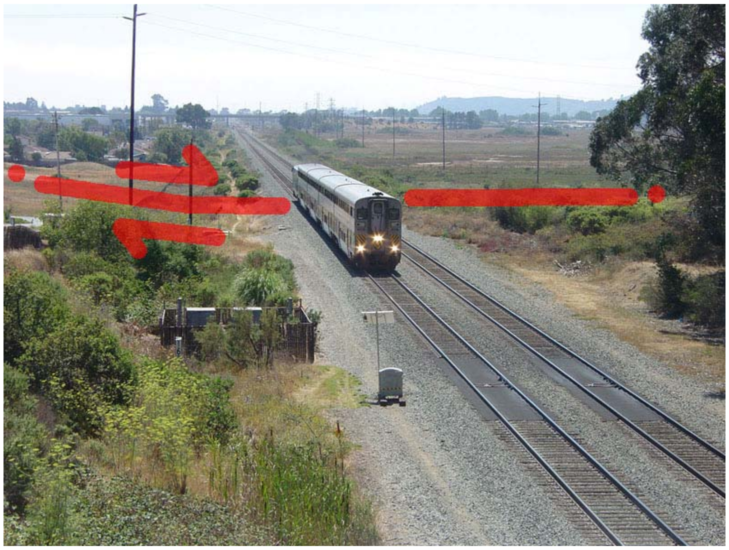


Figure 8. Commuter train in the vicinity of the Hayward Fault in Point Pinole Regional Shoreline. This view looks south toward Richmond from a park trail overpass near the Point Pinole Regional Shoreline trailhead parking area (and AC Transit metro bus stop for the park). The bridge is on a hillslope (fault scarp) of the Hayward Fault (trace shown by red line). Parchester Marsh adjacent to the Bay is on the right (west) side of the rail line.

Figure 9. View south from the Pinole Point Trail toward the hillslope escarpment (left) of the Hayward Fault. The fault runs across the break in slope where it meets Parchester Marsh (on the right).

Figure 10. View looking north along the shoreline near where the Hayward Fault trace vanishes beneath the waters of San Pablo Bay. Complex small-scale fold- and fault-related structures can be observed in the bedrock between gravel and sand deposits. Wave erosion along the shoreline undercuts the hillslope, causing landsliding along the scarp of the Hayward Fault.

Chapter 4 - Contra Costa College

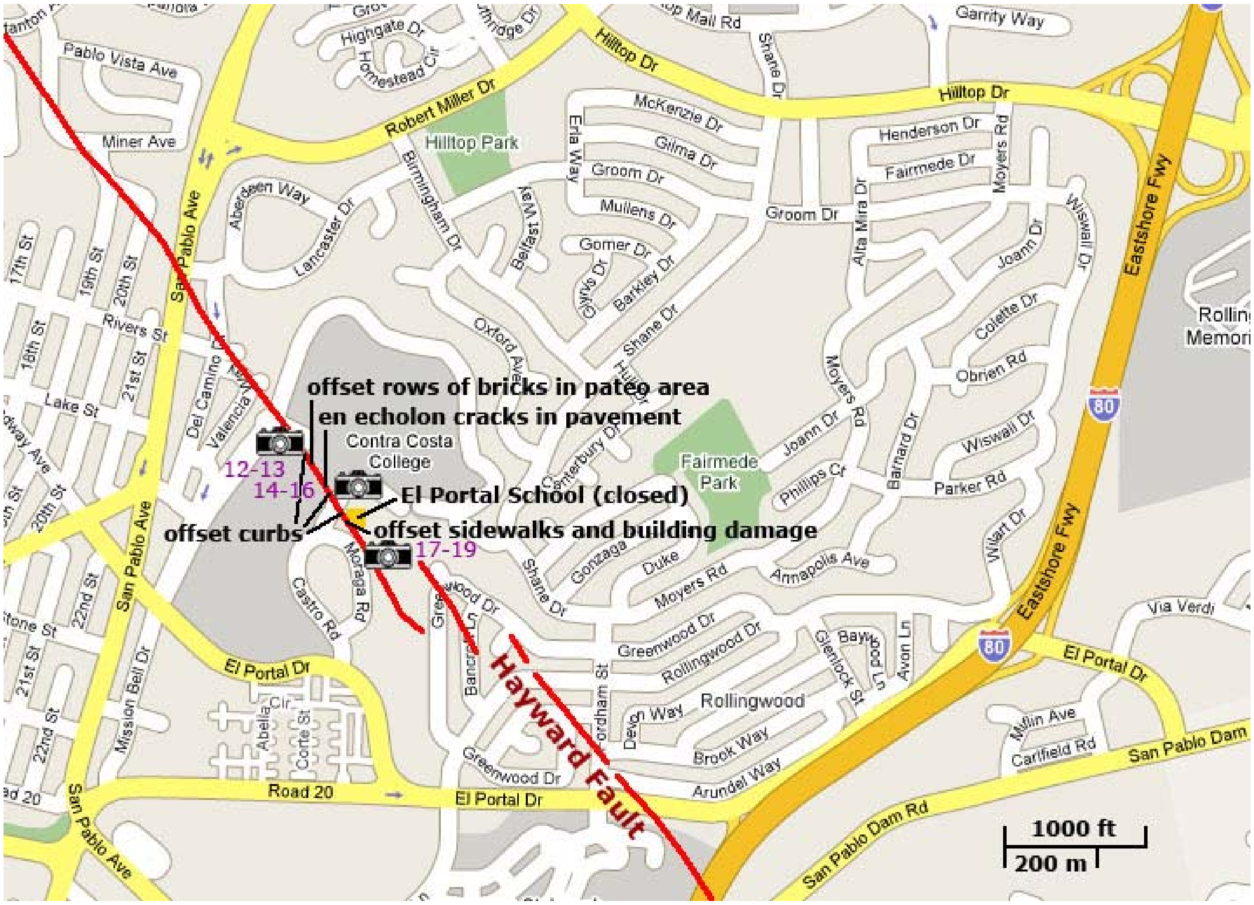


Figure 11. Trace of the Hayward Fault in the Contra Costa College area in Richmond, California. Cameras designate photograph locations; purple numbers indicate corresponding figures.

What to look for: Contra Costa College campus straddles the Hayward Fault and displays abundant evidence of active creep along the fault zone (offset curbs and cracks in pavement). El Portal School (now abandoned) is adjacent to the campus and displays creep damage to the building and sidewalks. This area was little developed at the time of the 1868 Hayward earthquake.

Access Options

BART: The Richmond BART Station is the closest to the community college campus, about 2 miles away.

AC Transit: The AC Transit line #71 runs between the Richmond BART Station and the community college campus. AC Transit: The AC Transit line #71 also serves Point Pinole and connects with El Cerrito Del Norte BART Station farther south (see www.511.org for details of bus schedules).

Bike: The City of Richmond is actively developing bike routes throughout the area. Contra Costa College is about two miles from the Richmond BART Station.

Hike and wheelchair access: Once on the community college campus it is a short and easy walk to see features associated with the creeping fault. Both the El Portal School and the community college provide easy access for wheelchairs.

Car: Parking can be an issue when the college is in session, but it is relatively easy to find parking on the weekends.

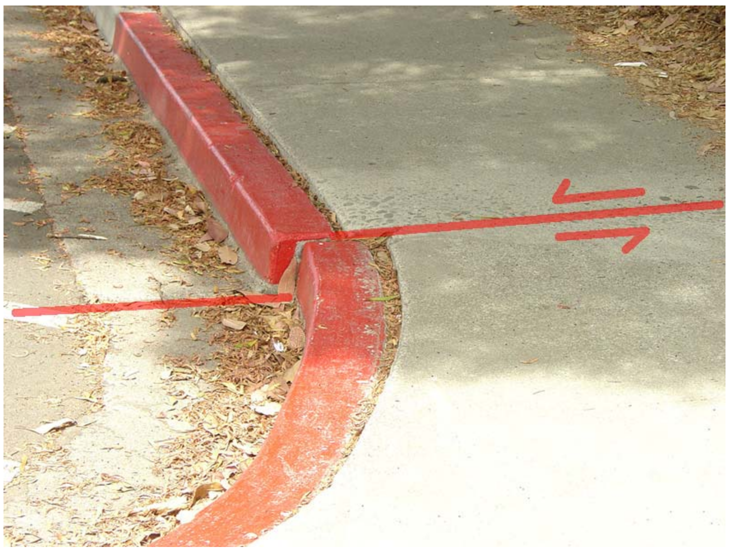


Figure 12. Offset curb along the Campus Circle parking area on the north side of the campus of Contra Costa College. Note that this offset curb shows displacement that is *left lateral* (not *right lateral*—see *strike-slip fault* defined in the Glossary). Displacements that are atypical of the fault motion may reflect complex ground motion, rotation of surface blocks, or may not even be fault related (for example, such a displacement can be caused by a tree growing nearby).

Figure 13. Rows of bricks offset by fault creep on a patio area next to the Campus Circle on the north side of the campus of Contra Costa College.

Figure 14. Strain and shear from creep on the Hayward Fault result in fractures in the asphalt of Parking Lot 10 on the campus of Contra Costa College. Car keys and a standard four- inch wide parking stripe are scale.

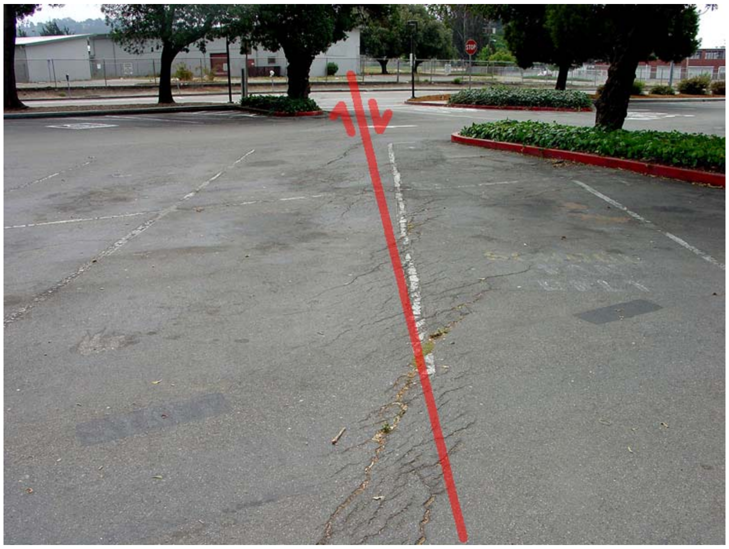


Figure 15. Strain and shear from creep on the Hayward Fault result in fractures in the asphalt of Parking Lot 10 on the campus of Contra Costa College. This shows how creep produced a series of right-stepping en-echelon fractures. This view looks south toward the abandoned El Portal School. This parking area is usually full when classes are in session.

Figure 16. Free parking is available on the Contra Costa College campus in the vicinity where the Hayward Fault offsets a curb on Castro Street next to the abandoned El Portal School.

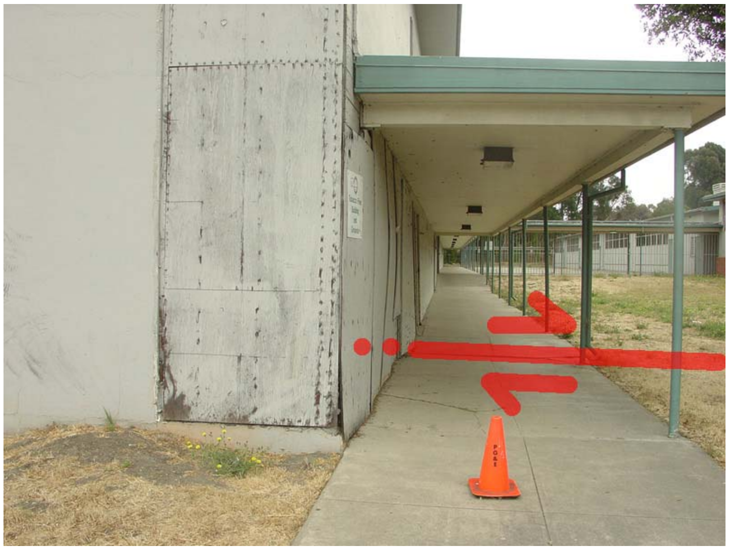


Figure 17. Creep along the Hayward Fault has caused structural damage to the now-abandoned El Portal School located next to the Contra Costa College campus. This view looks east along the side of the building.

Figure 18. Creep along the Hayward Fault has caused structural damage to the now-abandoned El Portal School located next to the Contra Costa College campus. This view is perpendicular, facing north, compared to the view in Fig. 17.

Figure 19. Creep along the Hayward Fault has offset sidewalks near the entrance to the now-abandoned El Portal School located next to the Contra Costa College Campus.

Chapter 5 -Treasure Island and Yerba Buena Island

Figure 20. Map of the Yerba Buena and Treasure Island area mid span on the Bay Bridge between San Francisco and Oakland, California. Purple numbers designate photograph locations.

What to look for: Yerba Buena Island consists mostly of natural bedrock, whereas Treasure Island was constructed of landfill; the two islands are connected by a causeway. Treasure Island was created in 1939 for the Golden Gate International Exposition from fill dredged from the Bay. A brief stop on the islands is recommended for field trips starting on the San Francisco Peninsula. From the islands it is easy to observe earthquake retrofit and replacement operations on the eastern span of the Bay Bridge. Views of the Bay Bridge (east and west spans), San Francisco, and the Bay are spectacular from the islands.

Because Treasure Island is built from fill, it experienced extensive liquefaction during the M 6.9 Loma Prieta earthquake of 1989—and it is expected to again in an anticipated Hayward Fault earthquake. Liquefaction occurs during earthquakes where shaking causes loosely consolidated sediments that are saturated with water to loose cohesion and become fluid. Once a zone of liquefaction occurs, it can cause the surrounding consolidated materials to shift or rupture. Sand, mud, and fluids can erupt on the surface along fissures. Areas of intense liquefaction can result in extreme damage to the landscape and any building and infrastructure built on those areas.

Access Options

Most of Yerba Buena and Treasure Islands belong to the U.S. Coast Guard and are inaccessible without permission. However, the exits on Interstate 80, about mid span on the Bay Bridge, are accessible to the public. Pull offs on the causeway to Treasure Island provide scenic vistas of the San Francisco Bay area (including views of the east and west extensions of the Bay Bridge). At the time of this writing, the eastern span of the Bay Bridge is under major earthquake retrofit construction.

BART and Muni Bus: The islands are served by a single Muni bus route—the 108 Treasure Island. The bus route connects to the Trans Bay Terminal at Mission between 1st Street and Fremont in San Francisco (between the Embarcadero and Montgomery Street BART Stations).

The islands are not accessible directly by bicycle from either San Francisco or the East Bay. Because most of the two islands are owned and managed by the U.S. Coast Guard, there is very limited access to places to bike, hike, or have wheelchair access.

Car: There are exits to Treasure Island on both directions on Interstate 80 about mid way across the Bay Bridge. Use caution when exiting and entering the highway.

Figure 21. View east toward the eastern section of the Bay Bridge from Treasure Island. This photo taken in late summer of 2007 shows the construction of the more earthquake resistant design for the new section of the bridge.

Figure 22. View east toward the eastern section of the Bay Bridge from Treasure Island. This photo taken in late summer of 2007 shows the construction of the more earthquake resistant design for the new section of the bridge. The Hayward Fault runs along the western flank of the Berkeley (East Bay) Hills near Berkeley and Oakland in the distance.

Figure 23. View looking west toward San Francisco at the suspension section of the Bay Bridge west of Treasure Island. This photo was taken in late summer of 2007.

Chapter 6 - U.C. Berkeley and Berkeley Hills

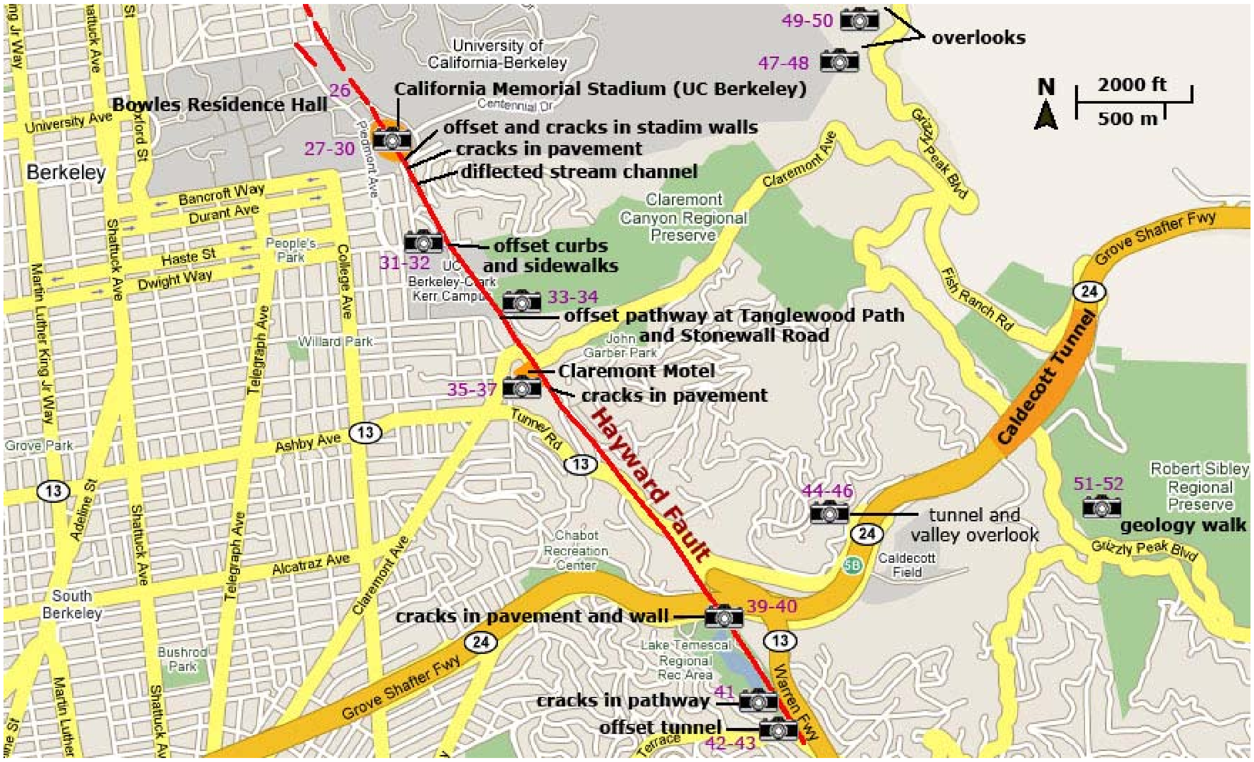


Figure 24. Location of the Hayward Fault in the Berkeley area, California. Purple numbers designate photograph locations.

What to look for: The University of California Berkeley is the largest employer in the East Bay, with 20,000 employees and 30,000 students. The Hayward Fault runs through part of the campus. As a result of the 1868 earthquake, starting in the 1870s new buildings constructed on the Berkeley campus were designed to be earthquake resistant. Creep along the Hayward Fault is responsible for damage to sidewalks, buildings, and infrastructure throughout the Berkeley area. The fault is also responsible for a variety of landscape features including scarps, deflected drainages, Lake Temescal is in a linear rift valley through which Highway 13 also runs. A trip into the Berkeley Hills provides scenic vistas of the urbanized alluvial plain in the Berkeley area bisected by the Hayward Fault, a shutterridge adjacent to Lake Temescal, and features of an ancient volcanic complex exposed at Sibley Volcanic Preserve and along roadways on Grizzly Peak ridge.

Access Options

BART: The Downtown Berkeley and Rockridge BART Stations provide access to AC Transit services in the Berkeley area.

AC Transit: The AC Transit line #7 provides access to many locations on or near the fault including California Memorial Stadium and Claremont Hotel. The bus route connects to both the Berkeley and Rockridge BART Stations (see www.511.org for details of bus schedules). AC

Transit line #59 and 59A provide access from the Rockridge BART Station to both Lake Temescal Regional Recreation Area and the Monclair Village field trip area (Chapter 6).

Bike: All locations along the fault between U.C. Berkeley and Lake Temescal are an easy bike ride. Destinations in the Berkeley Hills, while popular for bicyclists, would be strenuous to the casual rider.

Hike: The walk between U.C. Berkeley and the Claremont Hotel is about 1.5 miles (2 km) in one direction. Shorter round-trip walks (under 2 miles) include the hikes around Lake Temescal Regional Recreation Area or Sibley Volcanic Regional Preserve. Longer, more strenuous hikes would include treks in Claremont Canyon Regional Preserve or in Tilden Regional Park.

Wheelchair access: Wheelchair access is difficult at any of the locations in the Berkeley area because of the steep grades of the hillslopes. Once in the parking area at the south end of Temescal Park, there is wheelchair access to both the cracks in the pavement from fault creep, the offset tunnel, and to the shore of the lake (the lake was modified from a natural sag pond along the deflected Temescal Creek.

Car: It is best to leave your car at home if you go to Berkeley, especially when school is in session, a ball game is taking place, during rush hour, or when other activities are going on in the area (which is usually all the time). A car is necessary to access the parks in the Berkeley Hills (Tilden and Sibley Volcanic Regional Parks).

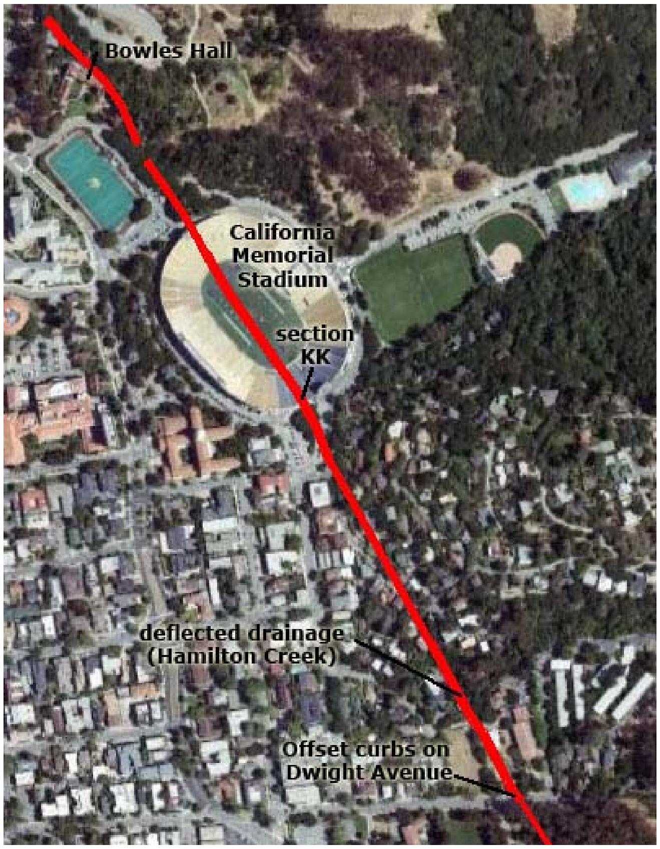


Figure 25. A Google satellite image showing the location of the Hayward Fault relative to Bowles Hall, California Memorial Stadium, a deflected stream (Hamilton Creek) and offset curbs on Dwight Avenue. California Memorial Stadium was built over another deflected stream (Strawberry Creek draining from Strawberry Canyon—to the right [east] of the stadium).

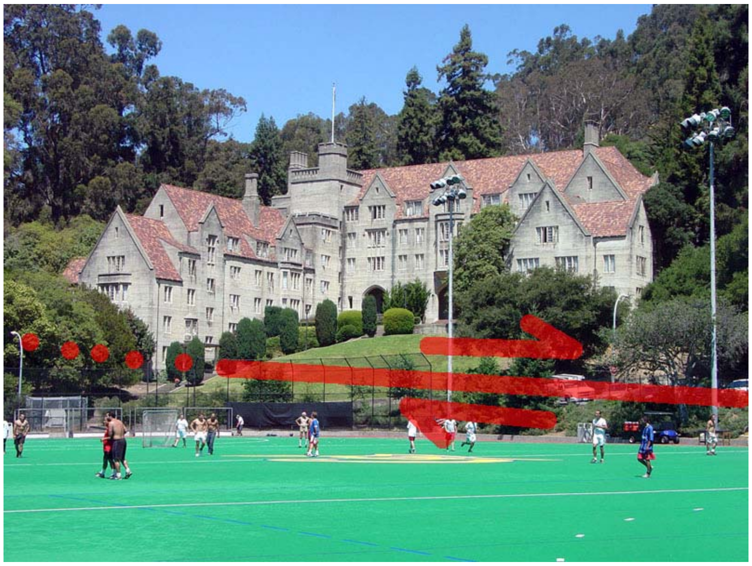


Figure 26.The Hayward Fault crosses the University of California, Berkeley campus. However, with so much construction history there is little visible evidence on the campus itself. In this view, the Hayward Fault is thought to run along the slope just behind Bowles Residence Hall on the southeast side of campus. It grazes the back corner of the building (the library), The California Memorial Stadium is out of view just to the right (south) of this playing field.

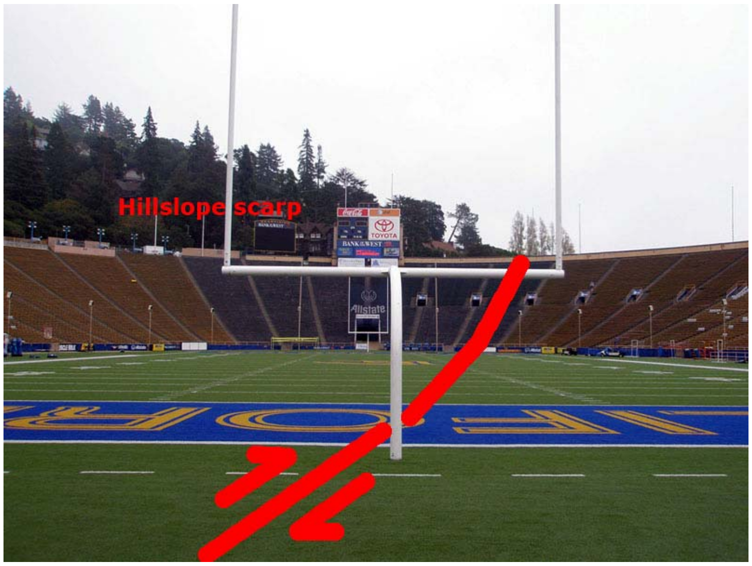


Figure 27. View looking south past the goal post near the north end of California Memorial Stadium. Beyond the stadium, the Hayward Fault continues south along the base of a slope into residential neighborhoods of Berkeley. In the stadium, the fault runs through the playing field and through the section of seats (section KK) in the distance to the right of the goal post.

Figure 28. California Memorial Stadium straddles the Hayward Fault and its walls display visible structural damage as a result of slow creep along the fault trace. This crack in the wall is near the north entrance to the stadium, close to the photograph of the goal post shown in the previous image. Similar cracks in walls can be seen in many locations within the stadium.

Figure 29. Offset of the rim wall of California Memorial Stadium produced by creep along the Hayward Fault. This photo is of an offset cement wall in section KK, row 64; the offset of about 7 inches (18 cm) is between seats 22 and 23.

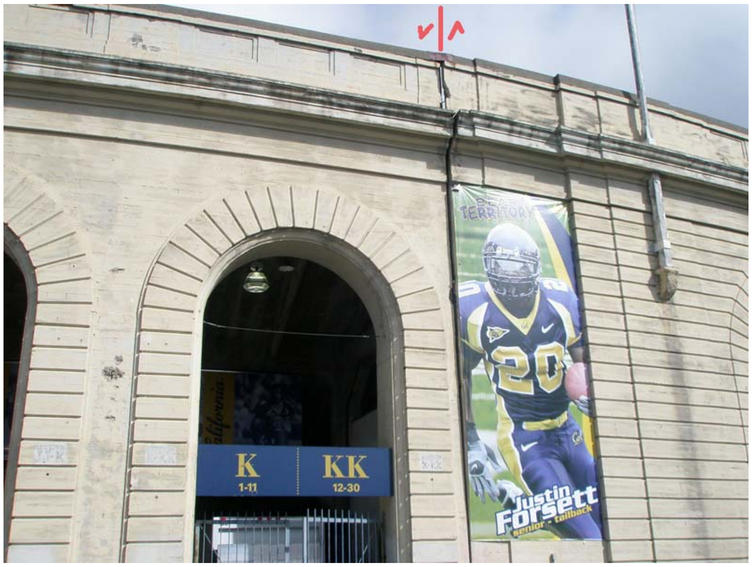


Figure 30. View of the offset outer wall on the south side of Berkeley Memorial Stadium in section KK where damage to the stadium by the creeping Hayward Fault is most obvious.

Figure 31. View looking west along a broken-up sidewalk on Dwight Way near Hillside Avenue in Berkeley. The surface trace of the Hayward Fault is complex at this location.

Figure 32. One of the offset curbs where Dwight Way in Berkeley crosses the Hayward Fault.

Figure 33. View looking east up Tanglewood Path just downhill of the intersection of Stonewall Road (near the Claremont Hotel in Berkeley). The pathway has been heavily damaged by both mass wasting on the hillslope and by creep along the Hayward Fault.

Figure 34. Trailhead to Claremont Canyon Regional Preserve near the intersection of Tanglewood Path and Stonewall Road (near the Claremont Hotel in Berkeley). The trace of the Hayward Fault is just downslope of the trailhead. The steep slope is part of the scarp of the Hayward Fault.

Figure 35. The Claremont Hotel. The Hayward Fault passes near the southeast corner of the building and runs along the base of the slope near the tall eucalyptus trees on the far side of the building in this view.

Figure 36. The Hayward Fault runs through the parking lot and beneath the corner of the building (on the right side of the photograph) near the south entrance to the Claremont Hotel.

Figure 37. Fractures in the asphalt of the Claremont Hotel parking lot are probable evidence of surface movement associated with the Hayward fault. This fracture between cars in valet parking displays evidence of pull-apart (tension) offset. The mapped trace of the fault is in the parking lot behind and above these cars (also visible to the right in fig. 36).

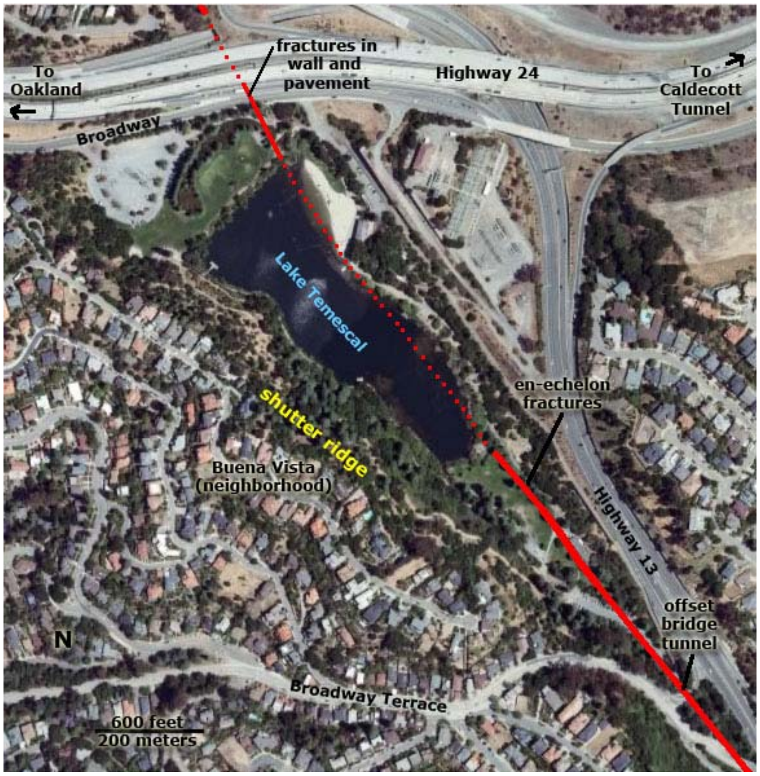


Figure 38. A *Google Earth* image map showing the location of the Hayward Fault and associated features in the Lake Temescal area. The Buena Vista neighborhood is on the shutterridge on the west side of the fault at Lake Tamescal. Highway 13 runs south from the intersection of Highway 24 down the rift valley of the Hayward Fault for much of its route. Temescal Lake was built during 1866 and1869 by damming Temescal Creek, which happens to be offset more than 1.5 miles (2 km) right-laterally by the fault. The ridge to the west blocks the outflow of the creek, but the blockage is caused by the large displacement and the slowing of the stream by the reduced gradient along the fault, and probably not by "sagging".

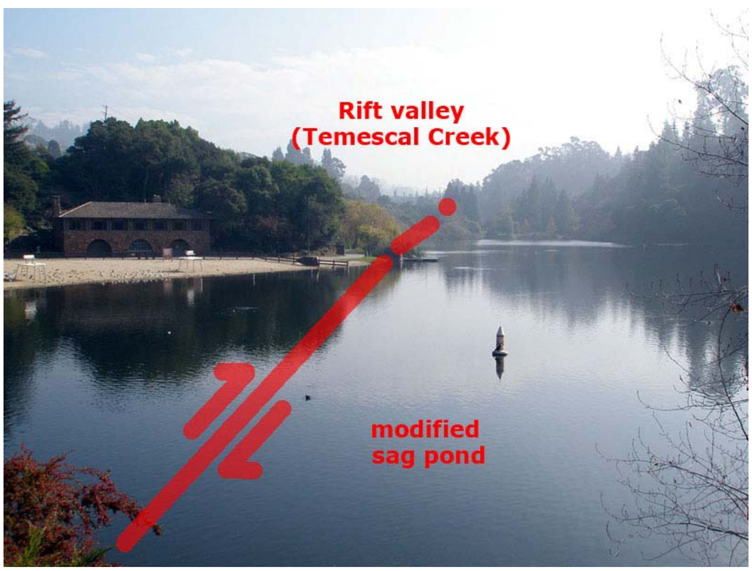


Figure 39. View of Lake Temescal from the north. The active trace of Hayward Fault runs along the eastern shore of the lake. The lake is a modified sag pond along the straight valley of Temescal Creek.

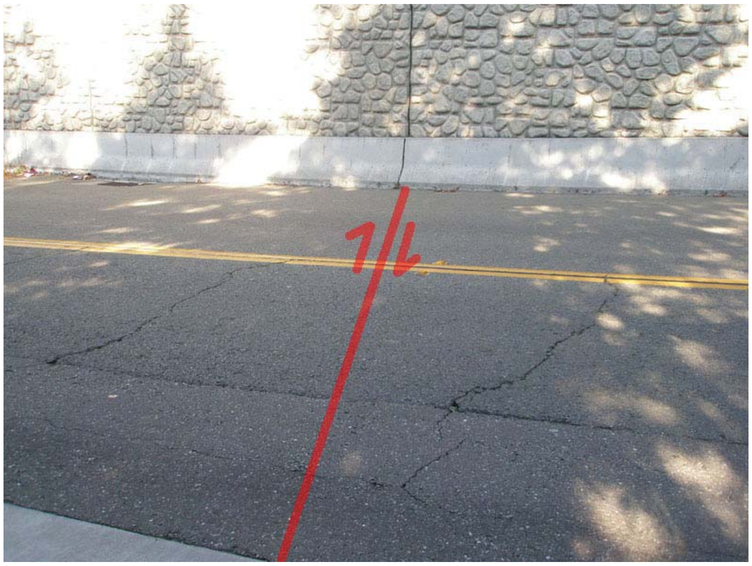


Figure 40. Cracks in the pavement reveal the trace of the creeping Hayward Fault at Lake Temescal Regional Recreation Area. This view shows the location of the cracks in the pavement on Broadway adjacent to the north end of the park. Cracks also can be seen in the retaining wall of Highway 24 where it crosses the fault.

Figure 41. En echelon fractures from creep along the Hayward Fault in the pavement in front of the Park Office in Lake Temescal Regional Recreation Area. The Park Office is located near the south end of the lake.

Figure 42. View looking north at the entrance to an old railroad bridge tunnel in Temescal Regional Recreation Area. The tunnel displays evidence of creep from movement along the Hayward Fault. The tunnel is at the south entrance to the park on Broadway Terrace near the intersection with Highway 13. The tunnel was probably constructed around 1918 for the Sacramento Northern Railway, a subsidiary of the Western Pacific Railroad, and was an electric train system that linked the state capitol in Sacramento with Oakland until train service ceased in 1983.

Figure 43. View of an offset curb and crack in the side of the old railroad bridge tunnel near the south end of Lake Temescal Regional Recreation Area (the tunnel is also shown in fig 42).

Figure 44. View southwest from an overlook on Tunnel Road near Highway 24 near where it crosses the Hayward Fault. Homes occupy the top of the forested shutterridge on the west side of the Hayward Fault rift valley. The Bay Bridge and San Francisco are visible in the distance. The overlook has exhibits commemorating the Oakland Hills Firestorm of 1991. The fire killed 25 people and injured 150 others. The fire consumed or damaged 2,843 single-family dwellings and 437 apartment and condominium units and burned an estimated 1,520 acres (6.2 km²).

Figure 45. View southwest across Highway 24 toward the PG&E Claremont Substation near Lake Temescal. The tree-covered slope beyond the electrical power station is on the west side of the Hayward Fault rift valley incised by Temescal Creek. Downtown Oakland is in the distance. The tree-covered ridge is a shutterridge ("shutting in" and diverting Temescal Creek). Lake Temescal is to the right of this view taken from Tunnel Road, north of Highway 24. The neighborhood of Buena Vista is built on the shutterridge west of the Hayward Fault rift valley.

Figure 46. View of the western portal of the Caldecott Tunnel on Highway 24. The Caldecott Tunnel cuts through the Berkeley Hills. Construction of the tunnel began in 1929, and the first two tunnel bores were completed in 1937; a third bore was completed in 1964. An additional bore has been approved for construction. The western portal of the Caldecott Tunnel is located in Claremont Canyon, about one mile upstream from Lake Temescal. The forested ridge above the tunnel is mostly within the Robert Sibley Regional Preserve.

Figure 47. View looking down (southwest) into Claremont Canyon from near a water storage tank in the Berkeley Hills (near the intersection of Grizzley Peak Boulevard and Marlborough Terrace—the water tank is just to the right of this photo).The rift valley of the Hayward Fault and the shutterridge near Lake Temescal run diagonally through the upper part of the image. This area was burned during the Oakland Hills Firestorm of 1991. The western portal of the Caldecott Tunnel on Highway 24 is just to the left of this view.

Figure 48. Folded sedimentary rocks (ribbon chert of Franciscan Formation of Jurassic age) located near the water tank and the view in fig. 47. The chert is exposed in a cut in the Berkeley Hills (near the intersection of Grizzley Peak Boulevard and Marlborough Terrace). The chert formed from radiolarian ooze originally deposited in a deep, marine setting far from any source of continental sediments. Today these rocks help form the ridgeline of Grizzley Peak—reflecting the long, complex geologic evolution of the San Francisco Bay Area landscape.

Figure 49. View looking southwest from an overlook area on Grizzley Peak in the Berkeley Hills in Charles Lee Tilden Regional Park. The view looks down the valley of Strawberry Creek (Strawberry Canyon). California Memorial Stadium is in the lower right. The densely urbanized alluvial plain of Berkeley and northern Oakland, and the Bay Bridge and hills of San Francisco are in the distance. The Hayward Fault cuts through the stadium and runs along the base of the forested hillside on the left. Strawberry Creek also has a right-lateral offset caused by displacement of the stream channel along the Hayward Fault.

Figure 50. View looking west toward the Golden Gate from an overlook on Grizzley Peak in the Charles Lee Tilden Regional Preserve. The City of Berkeley is on the alluvial plain at the western base of the Berkeley Hills. Alcatraz, the Golden Gate Bridge, and the highlands of southern Marin County are in the distance. The Hayward Fault runs along the base of the forested slope in the foreground.

Sibley Volcanic Regional Park

Sibley Volcanic Regional Park preserves the remnant of an old volcano that formed about 10 million years ago as the San Andreas Fault System (including the Hayward Fault) formed across the region. The fault ruptured through the Earth's crust, allowing magma to migrate to the surface and erupt as volcanoes. Volcanic rocks crop out in many places along the Hayward, San Andreas, and other faults in the region. Studies of volcanic rocks throughout the region demonstrate that the oldest volcanoes (about 10-18 million years old) lie to the south of the Bay Area and younger ones exist to the north of San Pablo Bay (including the relatively young and active Clear Lake-Sonoma Volcanic Field—less than 5 million years old). The study of the volcanic rocks has helped reveal much information about the age of the fault system and the rates that the faults have moved through time.

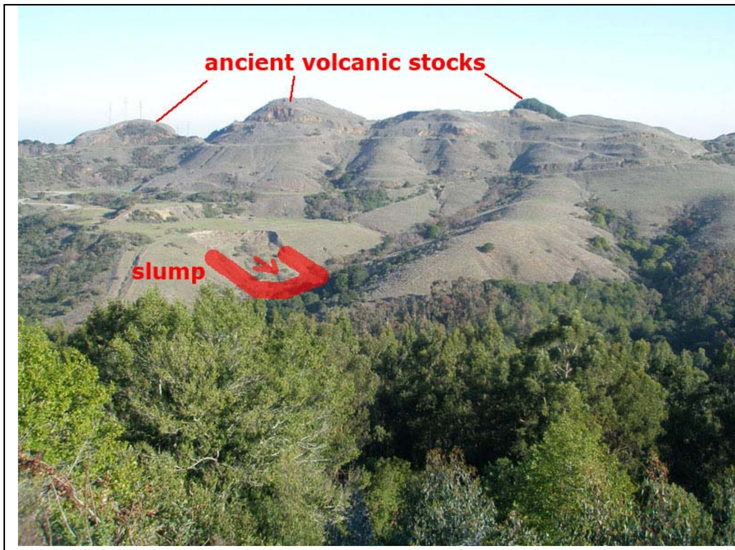


Figure 51. View looking east from Skyline Boulevard in the East Bay Hills (east of Berkeley) toward Round Top Hill in Sibley Volcanic Regional Preserve. The peaks on Round Top Hill are the remains of ancient volcanic stocks—the underground passages or vents that magma flowed along to erupt at the surface. Some of the magma that cooled to stone in the passages (becoming the stocks). These rocks are more resistant to erosion than the rock formed from ash, cinders, and lava flows that accumulated on the flanks of the ancient volcanic area. Also note the landslide (slump) near the left of center in the image.

Figure 52. This display of labeled rocks is in front of the kiosk and restrooms at Sibley Volcanic Regional Preserve. The preserve is host to the remnants of a volcano and associated rocks that accumulated about 10 million years ago and are now exposed by tectonic folding and uplift, and erosion. The park features about a mile of easy walking trails that lead to the stocks of the old volcano. Sedimentary rocks (mudstone, sandstone and conglomerate) and volcanic rocks (basaltic lava and tuff) are exposed along the trails. The parking area for the park is located a short distance east of the intersection of Grizzly Peak Boulevard on Skyline Boulevard. The park is not accessible via public transportation. However, the park is along the Oakland #59 bike route that follows Skyline Boulevard.

Chapter 7 – Monclair Village

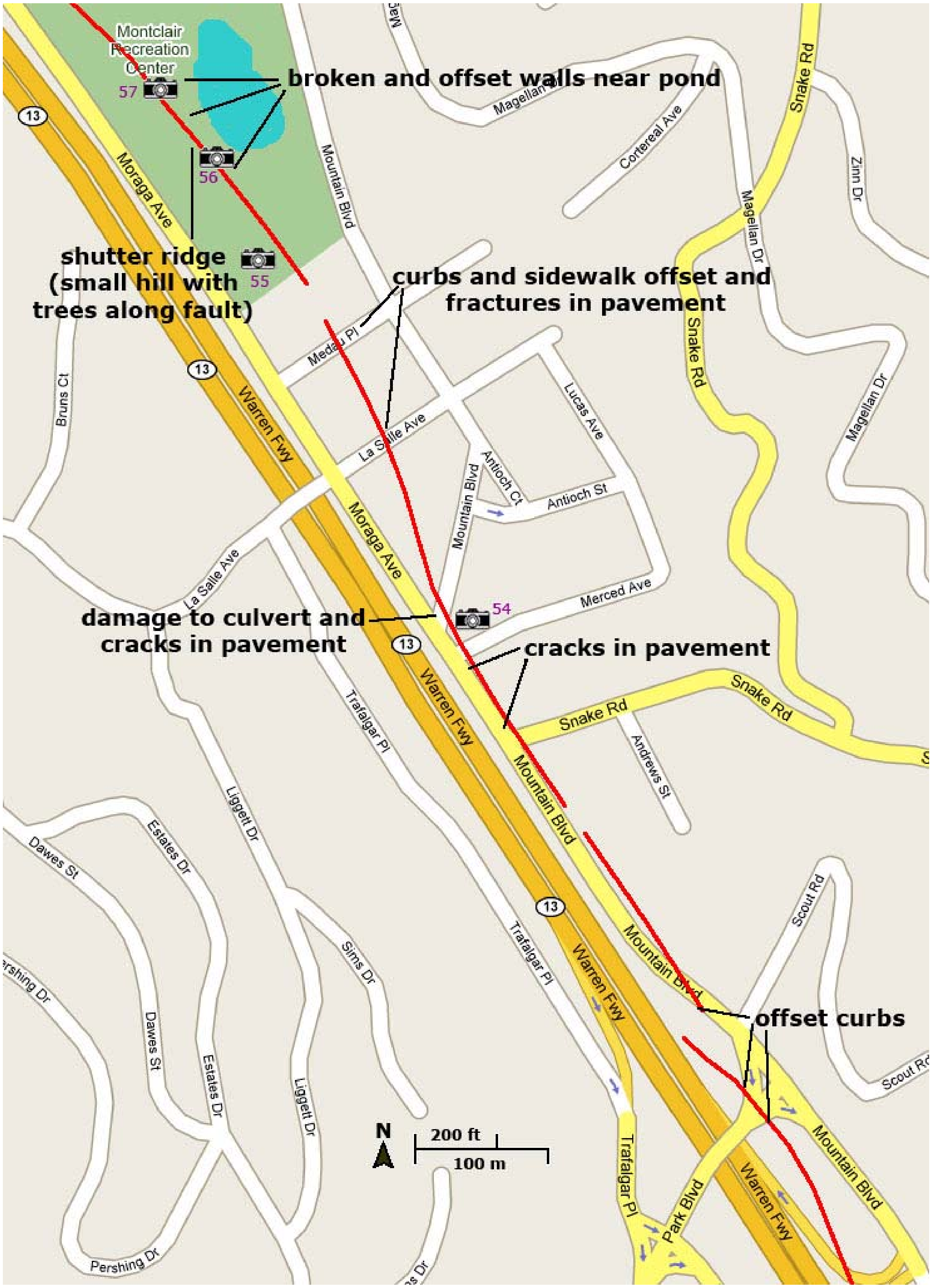


Figure 53. Location of the Hayward Fault in the Monclair Village area. Purple numbers designate photograph locations.

What to look for: Monclair Village straddles the Hayward Fault along the (appropriately numbered) California Highway 13, which runs down the Hayward Fault rift valley north of Berkeley. Both the streets and sidewalks display evidence of subtle creep along the fault. The Monclair Recreation Center, a small park on the north side of downtown, has offset stonewalls next to a modified sag pond formed by the fault. The village has a small-town feel and is a pleasant destination for a field trip (you can dine in restaurants right on the fault!). The Monclair Village area was unsettled at the time of the 1868 earthquake so damage in the area at that time is unknown.

Access Options

BART: Monclair Village is accessible by bus service from the Rockridge BART Station. Slightly more distant bus service to Monclair Village is provided from the Oakland City Center/12th Street BART Station.

AC Transit: The AC Transit line #59 and 59A begins at the Rockridge BART station and provides service to both Lake Temescal (Berkeley field trip area) and Monclair Village. AC Transit line #15 provides service to Monclair Village from the Oakland City Center/12th Street BART Station (see www.511.org for details of bus schedules).

Bike: Monclair Village is about a three-mile bicycle ride (one way) from the Rockridge BART Station but the field trip could include a visit to the Lake Temescal area (see Chapter 5).

Hike and wheelchair access: From Monclair Village it is a short and easy walk to examine evidence of the fault between the intersection of Moraga Avenue and Mountain Boulevard and the pond area in Monclair Recreation Center.

Car: Monclair Village is accessible from Highway 13 at the Moraga Exit about two miles south of the interchange with Highway 24.

Figure 54. This view looks north along Moraga Avenue at the intersection with Mountain Boulevard in Monclair Village, where the Hayward Fault crosses the intersection. The fault passes beneath the gas station sign and just to the left of the gas station building. North of the gas station the fault crosses through several walls, streets, and buildings in the downtown area.

Figure 55. This view looks north along the trace of the Hayward Fault where it crosses through Monclair Recreation Center, a small park just north of Monclair Village. The trees are on a low shutterridge on the left (west) side of the fault (located about where the people are standing).

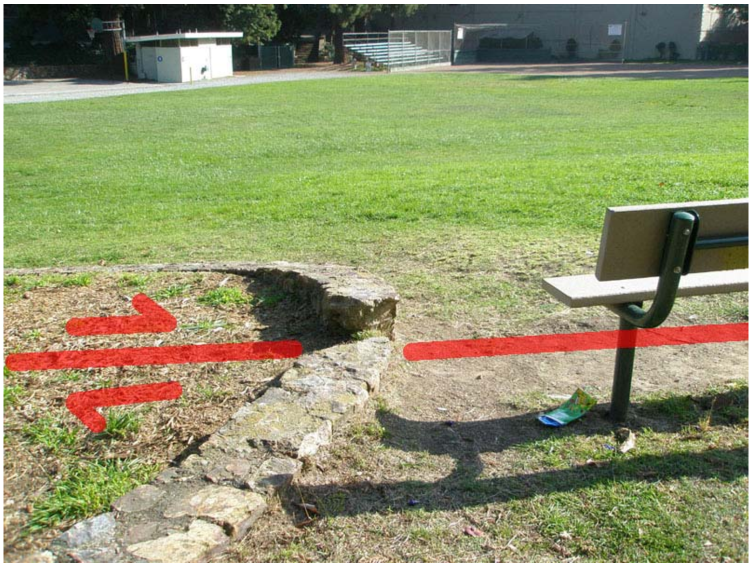


Figure 56. This broken stonewall is along the trace of the Hayward Fault in Monclair Recreation Center. The park is located just north of downtown Monclair Village.

Figure 57. View along an old damaged and repaired wall in the Hayward Fault zone in Monclair Recreation Center (park). Montclair Park's pond is not a sag pond. It was formed artificially around 1910 by the construction of a railroad fill of the Oakland-Antioch line. Passenger service on the rail ended in 1941, and freight service ceased in 1957.

Chapter 8 – Oakland Hills

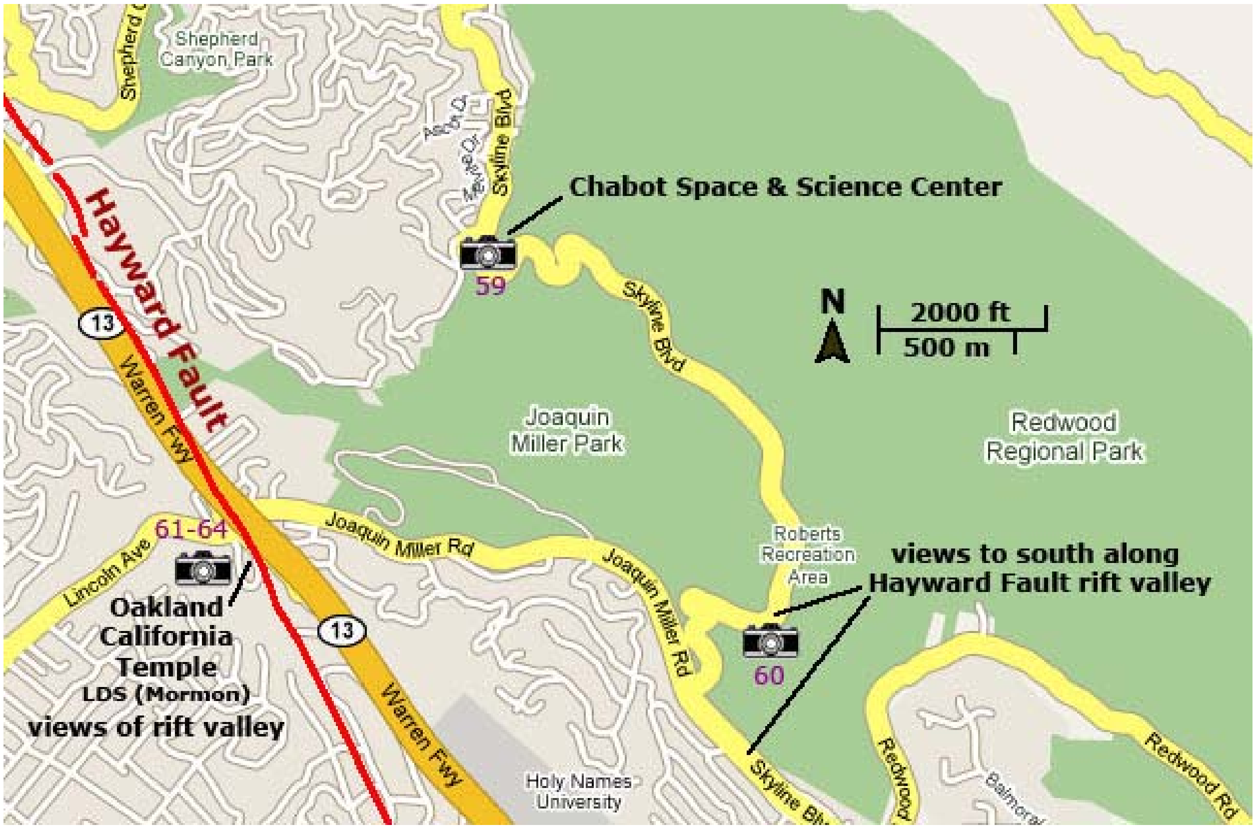


Figure 58. Location of the Hayward Fault in the Oakland (East Bay) Hills area. Purple numbers designate photograph locations.

What to look for: This trip highlights landscape features formed by the Hayward Fault in the Oakland (East Bay) Hills. The rift valley of the Hayward Fault reflects the long geologic history required to uplift the mountains and erode the valleys and canyons draining the upland. Imprinted on the landscape is the effect of countless numbers of earthquakes and the steady displacement by creep along the Hayward Fault. The rift valley is a result of an increased rate of erosion of the fractured bedrock in the fault zone.

The Oakland Mormon Temple (Church of Jesus Christ of Later-day Saints) is located on Lincoln Avenue near the intersection with Highway 13 (Warren Freeway). The temple is perhaps the most visible manmade feature along the Hayward Fault. Its location perched on a hilltop (shutterridge) along the fault makes it visible from practically anywhere in the San Francisco Bay Area on a clear day. Fractures along the fault can be traced on nearby streets and on the temple grounds, and the fault crosses through the Interstakes Building next to the main temple. This area was unsettled at the time of the 1868 earthquake.

Access Options

BART: This trip is not easily accessible from the nearest BART station at Lake Merritt.

AC Transit: The AC Transit provides limited charter bus service to groups of 20 people or more to the Chabot Space & Science Center. Charter bus service can be arranged from starting locations, such at the Lake Merritt, McArthur, or Fruitvale BART Stations. (Contact AC Transit, or see www.511.org for details about access to the Chabot Space & Science Center).

Bike: Skyline Boulevard along the Oakland (East Bay) Hills ridgeline is a very popular destination for long and strenuous bike rides (not recommended, however, for the casual rider).

Hike and wheelchair access: Joaquin Miller Park, Roberts Recreation Area, and Redwood Regional Park are all popular hiking destinations in the forested ridgeline near the Chabot Space & Science Center. Wheelchair access would be easy to the California Mormon Temple from the parking area near the Visitor Center.

Car: The Oakland Mormon Temple is not accessible from public transportation. The temple, parks in the Oakland Hills, and Chabot Space & Science Center are accessible from the Lincoln Avenue exit on California Highway 13.

Figure 59. The Chabot Space & Science Center is located along the crest of the East Bay Hills on Skyline Boulevard, east of Oakland. Skyline Boulevard runs along much of the ridgeline from the southern Berkeley Hills and the East Bay Hills, providing exceptional views of redwood and mixed evergreen forests and views of the San Francisco Bay region.

Figure 60. South-facing view from an overlook along Skyline Boulevard located about 1 mile south of the Chabot Space & Science Center in Joaquin Miller Park. The view shows the rolling upland of the East Bay Hills east of Oakland near Merritt College. The Hayward Fault crosses the western flank of the East Bay Hills in the valley beyond the grass-covered hill. The highly urbanized alluvial plain of the East Bay is in the upper right.

Figure 61. The Oakland Mormon Temple (Church of Jesus Christ of Later-day Saints) is located near the intersection of Lincoln Avenue and Highway 13. The pinnacle-like towers and massive white granite facade of the temple and associated buildings are perhaps the most visible landmark on the Hayward Fault in the East Bay region. The hilltop location of the temple provides fantastic views of the San Francisco Bay region, as well as the rift zone and shutterridges formed by the Hayward Fault on which the temple buildings and ground were constructed.

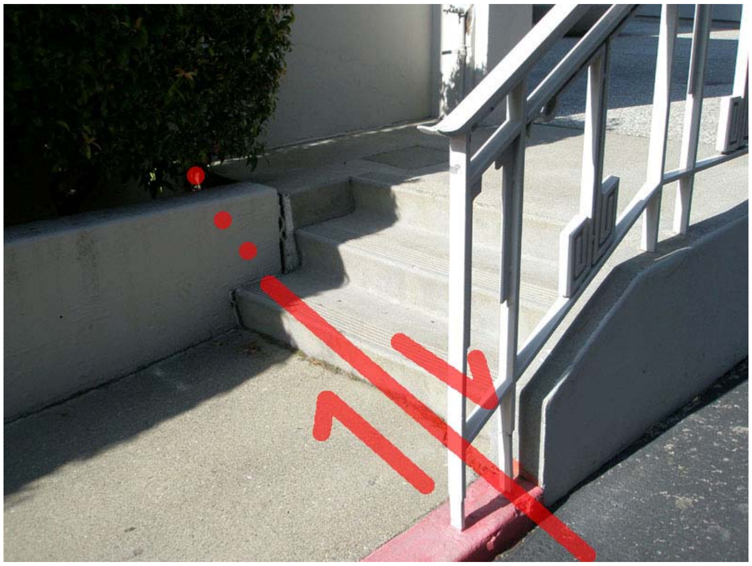


Figure 62. Fault creep along the Hayward Fault may be responsible for this offset stairway and wall on the northeast corner of the Interstakes Building on the temple grounds.

Figure 63. View looking west from the Oakland Mormon Temple toward downtown Oakland with the Bay Bridge and San Francisco in the distance.

Figure 64. View is looking south from the grounds of the Oakland Mormon Temple. The Hayward Fault extends south across this rolling upland region east of downtown Oakland, crossing through older established neighborhoods before extending through the sedimentary cover of the alluvial plain west of the East Bay Hills in the vicinity of the towns of Hayward and Fremont (far in the distant right side of this image).

Chapter 9 – Oakland Zoo-San Leandro-Fairmont Hospital

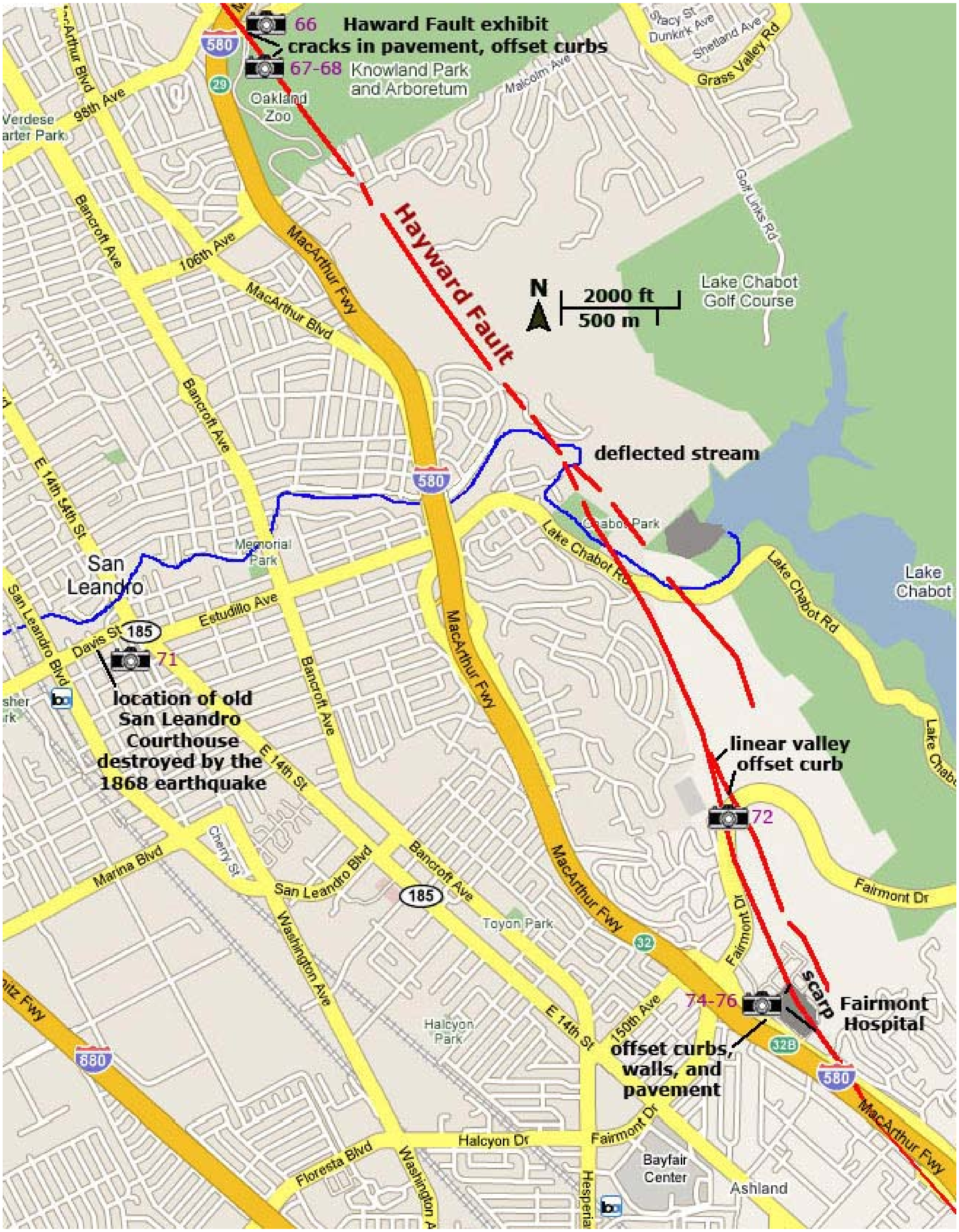


Figure 65. Map of the Hayward Fault in the San Leandro-Oakland Zoo-Fairmont Hospital area. Purple numbers designate photograph locations.

What to look for: San Leandro was one of the most heavily damaged communities in the 1868 Hayward earthquake. The fault crosses the grounds of the Oakland Zoo and the San Leandro Hospital complex. Cracks in the pavement caused by fault creep can be seen in the pavement on the road near the entrance to the Oakland Zoo. Recently, part of the San Leandro Hospital complex had to be abandoned and dismantled because it was built directly on the Hayward Fault. Evidence of the creep can be seen throughout the parking areas on the east and south sides of the hospital in the form of offset curbs, fractures in pavement, broken walls, and a scarp. South of the hospital, the trace of the fault rises into the western flank of the Oakland Hills east of Interstate 580. On Fairmont Drive, the fault offsets a curb and follows a linear valley. The historic Alameda County Courthouse and Estudillo House were destroyed and heavily damaged (respectively) in the 1868 Hayward earthquake. In the hills, the fault zone has changed the course of a stream valley below Lake Chabot Dam. While most of these features can be seen without charge, the Oakland Zoo has an entrance fee; the zoo offers group rates and educational services. (See figures 67 through 78.)

Access Options

BART: The San Leandro and Coliseum/Oakland Airport BART Station are a bus or bike ride away from the Oakland Zoo and Knowland Arboretum Park. The San Leandro and Bay Fair BART Stations are roughly the same distance from Fairmont Hospital.

AC Transit: AC Transit line #98 provides service to the Oakland Zoo and Knowland Arboretum Park from the Coliseum/Oakland Airport BART Station. The AC Transit line #82 and #82 L provide service to Fairmont Hospital from both the San Leandro and Bay Fair BART Stations. (See www.511.org for details of bus schedules.)

Bike: The bicycle ride to the Oakland Zoo and Knowland Arboretum Park from the San Leandro Bart station is about 3 miles and could include a visit to the site of the Alameda County Courthouse and Estudillo House. The bicycle ride to Fairmont Hospital is about three miles for either the San Leandro or Bay Fair BART Stations. The ride up Fairmont Boulevard to the trace of the fault would add an additional two miles to the trip.

Hike and wheelchair access: All locations at either the Oakland Zoo or the Fairmont Hospital are an easy walk and would also be accessible by wheelchair. A hike through the Oakland Zoo and Knowland Arboretum Park would be easy and enjoyable.

Car: Both the Oakland Zoo and Knowland Arboretum Park and Fairmont Hospital are close to exits on I-580 and have ample parking.

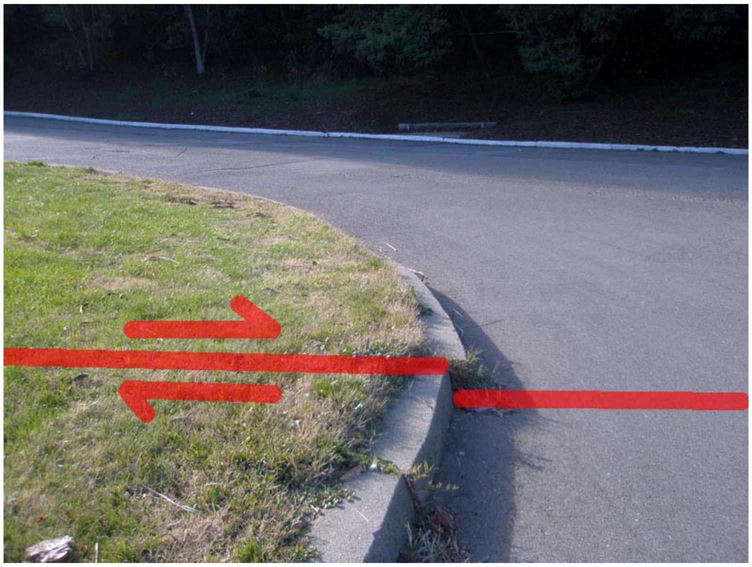


Figure 66. Offset curb in the lower parking lot access road near the Oakland Zoo Education Center entrance close to the park entrance station.

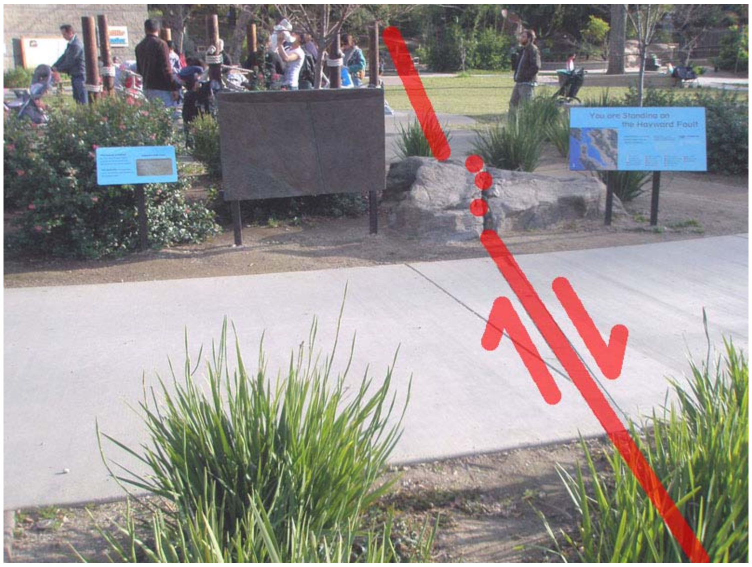


Figure 67. Display about the Hayward Fault in the Children's Playground in the Oakland Zoo. The fault runs past the otter tank and through a bear pen (in the distance beyond what is visible in this image).

Figure 68. Garden of plants that had living relatives during the Cretaceous Period (before about 65 million years ago during the Age of Dinosaurs) on display at the Oakland Zoo near the trace of the Hayward Fault. Besides having animals, the Oakland Zoo also has some fossil exhibits.

Figure 69. Historic photograph of the damage to the Estudillo House in San Leandro. This was the home of the family of José Joaquín Estudillo, grantee of Rancho San Leandro and founder of what became the city of San Leandro. The landmark is located at 550 West Estudillo Avenue (image courtesy of the Bancroft Library).

Figure 70. Historic photograph by Carleton Watkins showing the condition of the Alameda County Courthouse after the 1868 Hayward earthquake. One person was killed when the courthouse collapsed. Note that the building on the far left appeared to escape damage and still had its chimney. The old courthouse was located at the intersection of Davis and Clarke Streets.

Figure 71. View looking south at the intersection of Davis and Clarke Streets at the location where the Alameda County Courthouse used to stand before being destroyed by the 1868 Hayward earthquake. Commemorative plaques are on display at the corner outside of the modern school building that was built on the old courthouse grounds.

Figure 72. The Hayward Fault crosses a low divide where stream erosion has produced a linear stream valley. This view is looking north from a bend in the road along Fairmont Drive in the vicinity of the Alameda County Juvenile Hall in the foothills east of San Leandro.

Figure 73. *Google Earth* view of the San Leandro Hospital grounds showing locations of features associated with the Hayward Fault. The fault crosses the hospital grounds at the rear (east side) of the buildings. The building with the red roof in the lower right was modified to remove part of the wing built on the fault.

Figure 74. Fairmont Hospital is an Alameda County facility in San Leandro. Some of the original hospital buildings were constructed on the Hayward Fault but were later abandoned or modified. Evidence of the active creep of the fault can be seen on the hospital grounds in the form of cracks in the pavement and older walls and offset curbs, particularly on the east and south sides of the main hospital building.

Figure 75. View of the Fairmont Hospital campus drive on the south side of the main building. Fractures in the older pavement and offset curbs are visible along the drive and surrounding parking areas. This view looks north along a steep slope that probably represents a modified scarp of the Hayward Fault.

Figure 76. Fractured and broken wall revealing the location of the creeping Hayward Fault in the rear (east side) of Fairmont Hospital.

Chapter 10 – Downtown Hayward

Figure 77. Map showing the Hayward Fault in the downtown Hayward area. Purple numbers designate photograph locations.

What to look for: Seldom has a city paid so great a price to have an earthquake and fault named after it. The 1868 Hayward earthquake damaged nearly every building in the then town of 500 residents. Downtown Hayward is perhaps the most famous destination of the Hayward Fault. The old City Hall (abandoned) is a classic landmark of a building slowly being torn apart by the steady creep along the Hayward Fault. The trace of the fault can be followed from block to block where the creep offsets building walls, sidewalks, curbs, and other infrastructure. En echelon cracks appear in pavement. Many of the buildings downtown have been retrofitted for earthquakes (bolts are visible holding old brick buildings together). Sites just outside the immediate downtown area display fault scarps, offset walls, and offset street curbs. Gravels exposed on the hillside in the fault scarp near Jackson Street indicate the movement of the fault has offset old alluvial fan deposits. The Hayward Area Historical Society Museum, with interesting 1868 earthquake memorabilia, is located on the corner of Main and C Streets. (See figures 80 through 91 for views of damage in Hayward.)

Access Options

BART: The Hayward BART Station is three blocks from old City Hall. All the locations are within easy walking distance of the BART station.

AC Transit: The AC Transit line #82 bus runs south on Mission Boulevard from Avenue C to both the Bay Fair and San Leandro BART Stations (including past the Fairmont Hospital fault locality in Chapter 8). The # 99 bus runs north Avenue C on Avenue C to both the South Hayward and Union City BART stations. (See www.511.org for details of bus schedules).

Bike: All locations are on city or residential streets. Caution should be used when riding bicycles.

Hike: All locations on the map can be visited with an easy walk of just over two miles. Several restaurants are on or near the walking route along Mission Boulevard.

Wheelchair access: Downtown Hayward between the old City Hall and Hotel Avenue is easily accessible by wheelchair. Both Memorial Park and the Hayward Area Historical Society Museum are also wheelchair accessible.

Car: All areas are easily accessible by car.

Figure 78. View of an offset curb at the southwest corner of Prospect Street and Rose Street north of downtown Hayward. The displacement of the curb is consistent with the relative right-lateral displacement of the Hayward Fault. A right-lateral displacement refers to the relative motion of the two sides of a *strike-slip fault*. Offset features along the Hayward Fault show that the west side is moving northward relative to the east side of the fault.

Figure 79. The roots of this old tree have split the curb and sidewalk on Prospect Street just north of the intersection with Rose Street. The tree is growing in the active trace of the Hayward Fault, which closely follows Prospect Street in this area.

Figure 80. View west along Simon Street from the intersection of Prospect Street in Hayward (Mission Boulevard is in the distance). The slope in the foreground is a scarp of the Hayward Fault. The active trace of the fault crosses the street where the street curb (on the left side of the street) shows displacement from creep.

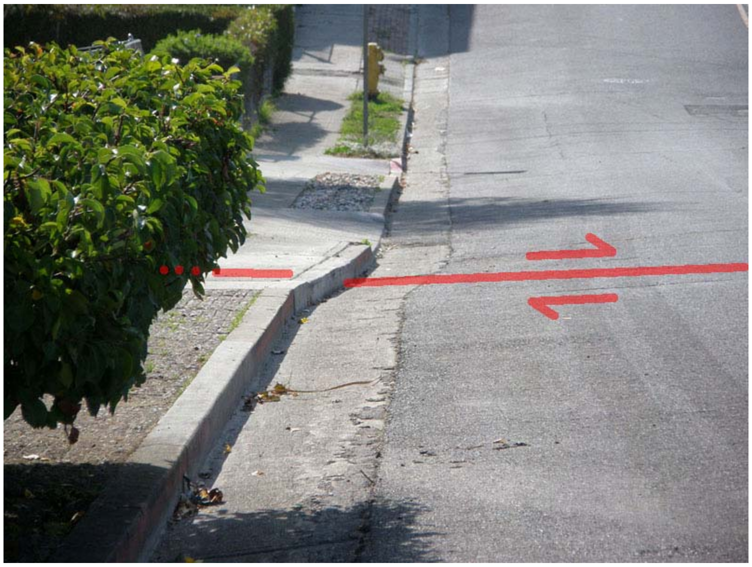


Figure 81.This view is a close up of the displacement of the curb shown in fig. 81. The view looks west along Simon Street from the intersection of Prospect Street in Hayward. The view highlights the right-lateral displacement of the curb caused by the creeping Hayward Fault.

Figure 82. Offset curbs and fractures in the pavement are visible along the creeping trace of the Hayward Fault in the municipal parking area between Avenue A and Hotel Avenue on the east side of Mission Boulevard. Many of the buildings in the area show various stages of retrofit and structural repairs, but the slow fault creep never ceases.

Figure 83. This view looks east along an alley between Avenues B and C in downtown Hayward where the creeping Hayward Fault has offset sidewalks, buildings, and just about everything along its trace.

Figure 84. Hayward's old City Hall was built in 1930 directly on the Hayward Fault. This view is looking northeast across Mission Boulevard. Over the years, fault creep has severely damaged the building. Two strands of the fault occur here—one passes beneath the front of the building (shown here) and the other crosses behind the building. Damage to the building can be viewed by looking through the front side windows, and offset and cracks can be seen in the sidewalks around the building. Downtown residents are used to seeing frequent fault tours where it is easy to trace the fault where it crosses streets and alleys, and cuts through buildings, for three blocks between old City Hall northward to Hotel Avenue.

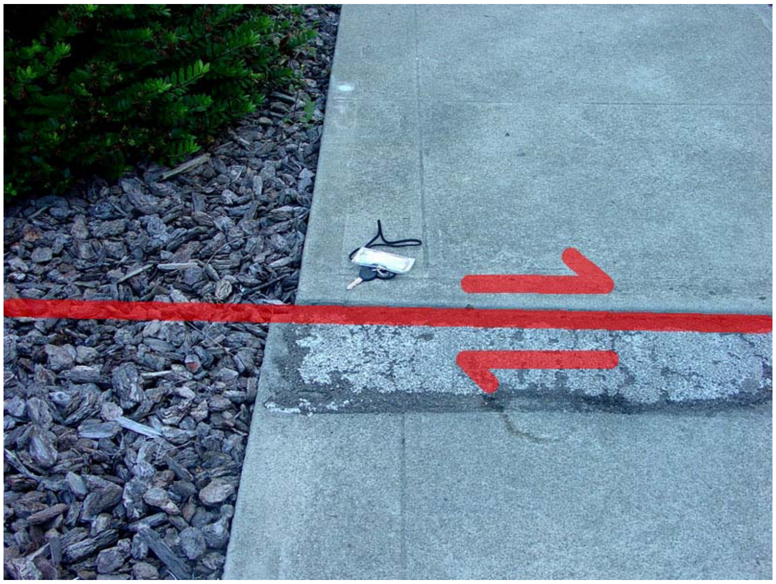


Figure 85. This sidewalk displays right-lateral offset that is typical for the older structures built across the creeping Hayward Fault. Car keys are shown for scale. This sidewalk is on the north side of old City Hall in downtown Hayward. While walking around downtown Hayward, it is interesting to see evidence of past and present attempts to fix or prevent damage to buildings and infrastructure caused by the creeping fault. Some buildings that had originally been constructed on the fault have been torn down and replaced with small open space parks.

Figure 86. View from the side of a small hill east of the intersection of Jackson Street and Mission Boulevard. The view is looking northwest along Mission Boulevard and the downtown area in the vicinity of old City Hall. Ongoing road maintenance has mostly masked the creeping trace (or traces) of the Hayward Fault here, but the hill represents an eroded scarp along the trace of the Hayward Fault. Gravel in the soil on the slope reveals that the bedrock in the Hayward area consists of relatively poorly consolidated alluvial fan (see glossary) and stream channel deposits. These kinds of deposits underlie the urbanized alluvial plain between San Francisco Bay and the East Bay Hills. However, the sediments closer to the bay become mud, and many areas in the urbanized region around the bay have been filled in over the years.

Figure 87. A twisted (displaced) cement wall of an old sandbox play area in Memorial Park near downtown Hayward. The slow creep of the Hayward Fault caused the warping of the cement. This cement wall is about 30 feet south of an old stonewall that also shows right-lateral displacement along the trace of the Hayward Fault.

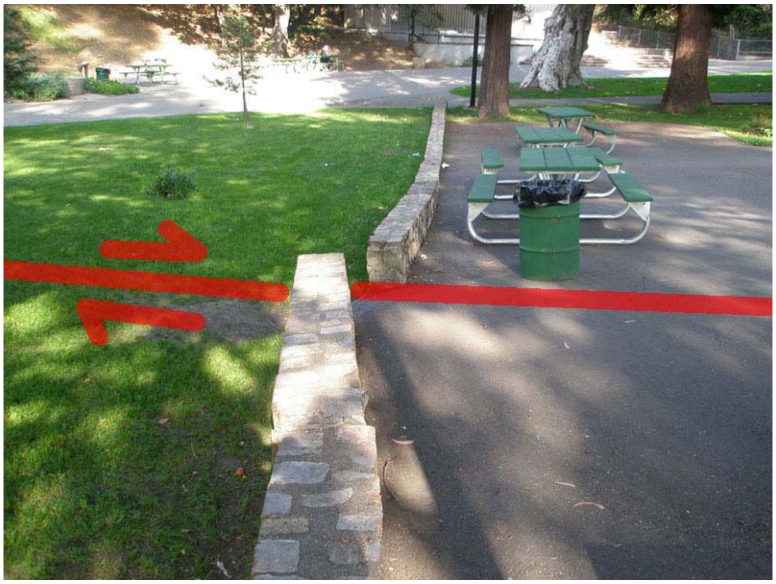


Figure 88. This old, low stonewall in Memorial Park near downtown Hayward has been displaced by creep along the Hayward Fault. This view is looking east.

Figure 89. View north past a low stonewall that has been offset by creep along the Hayward Fault (shown in fig. 88). The fault trace is in the path area between the two segments of the wall and continues toward the base of the stairs. The steep slope in the distance beyond the stairway is a fault scarp.

Historic Pictures of the 1868 Hayward Earthquake Damage

Not many photographs or accounts survive from the 1868 Hayward earthquake, partly because the East Bay region was sparsely populated at the time. Below are three famous photographs taken after the earthquake that illustrates the kind of damage caused by the earthquake.

Figure 90. The Pierce's house in Hayward—knocked off its foundation by the 1868 earthquake. Image courtesy of the Bancroft Library, University of California, Berkeley.

Figure 91. Edminton Grain Warehouse and flour mill—collapsed during the 1868 earthquake. The hills in the distance are the fault scarp/shutterridge of the Hayward Fault along Prospect Street between Hotel Avenue and Rose Street on the south side of downtown Hayward. Image courtesy of the Bancroft Library, University of California, Berkeley.

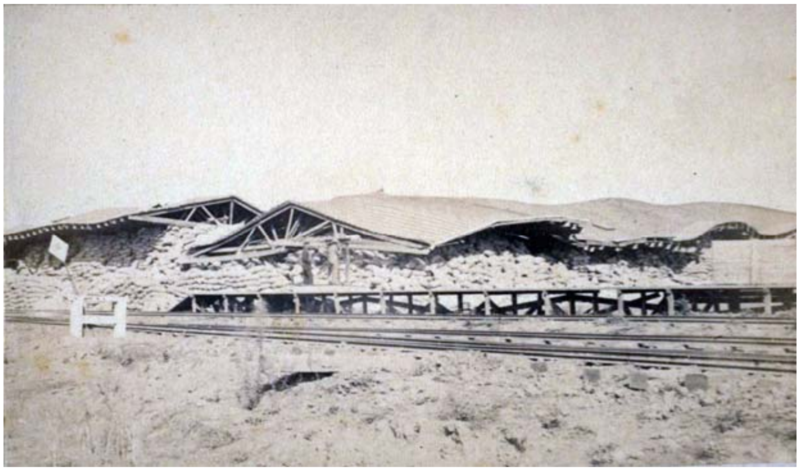


Figure 92. Edminton Grain Warehouse—collapsed during the 1868 earthquake. This view shows the rail lines that are now the location of the rails at the modern Hayward BART Station (on B Street). Image courtesy of the Bancroft Library, University of California, Berkeley.

Chapter 11 – Downtown Fremont

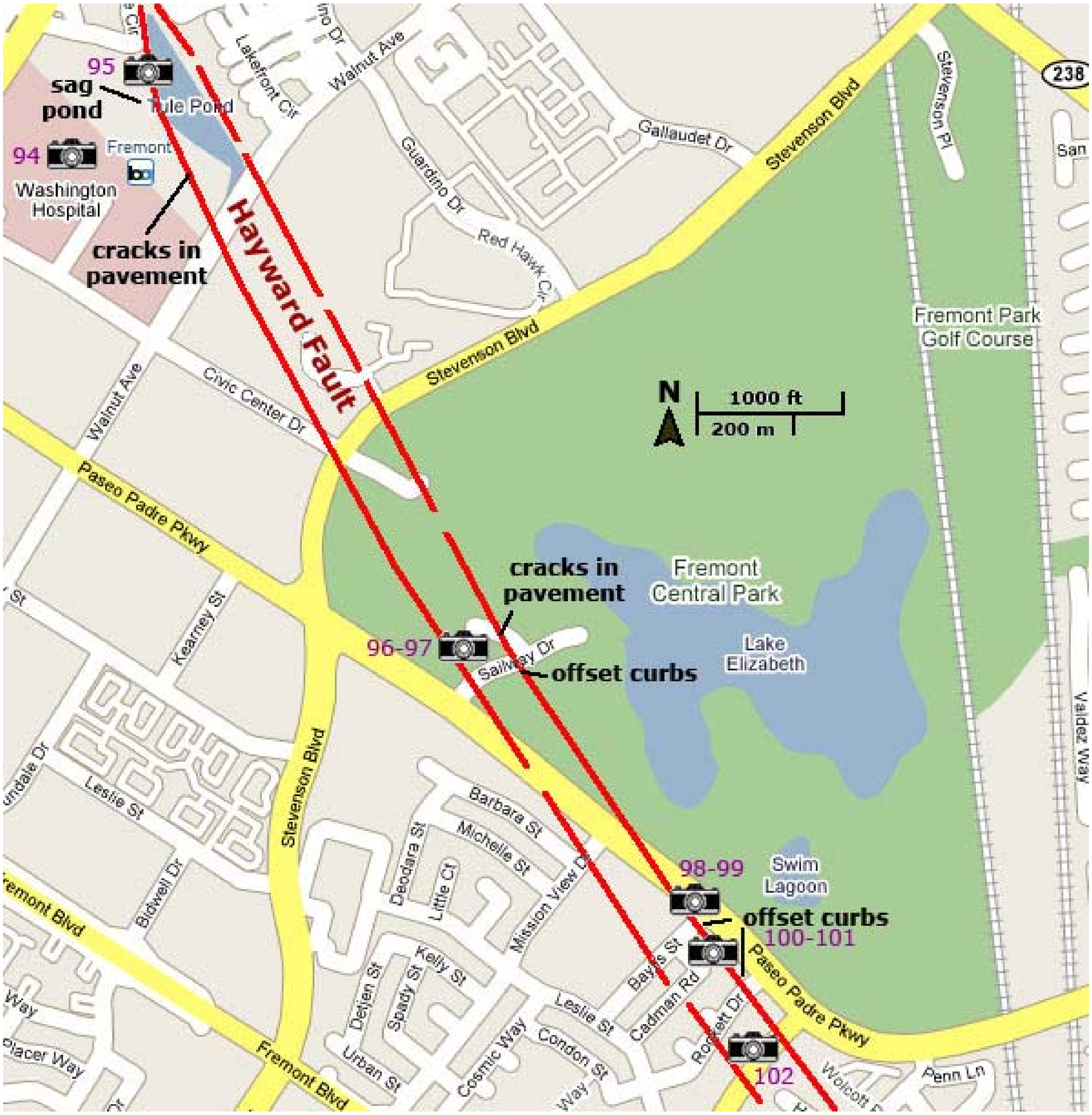


Figure 93. Location of the Hayward Fault in the Fremont Central Park area. Purple numbers designate photograph locations.

What to look for: Fremont experienced very strong shaking in the 1868 earthquake. The Fremont Central Park area offers a good view of a variety of offset street curbs, fractures in pavement, scarps, and sag ponds that have formed along the trace of the Hayward Fault.

Access Options

BART: Cracks in the pavement of the parking area at the Fremont BART station are a result of creep along the Hayward Fault. All locations along this route are within walking distance from the Bart Station.

AC Transit: The AC Transit line #218 connects to the Fremont BART station and runs past Fremont Central Park. (See www.511.org for details of bus schedules).

Bike: All sites are easily accessible by bicycle.

Hike: Total walking distance from the Fremont BART Station to all locations on this field trip would be about 2 miles.

Wheelchair access: The fault locations in Fremont Central Park on Sailway Drive and at the intersections of Rockett Drive and Baylis Street are easily accessible by wheelchair. The latter two locations are accessible from a parking area on the opposite side of Paseo Padre Parkway.

Car: All locations are easily accessible by car.

Figure 94. The Fremont BART station is the current terminus of the rail line. The track ends a very short distance from the Hayward Fault. Cracks in the pavement caused by slow creep of the fault can be seen in the train parking area on the southeast side of the train station. This view is looking southeast at the BART station with Mission Peak in the distance.

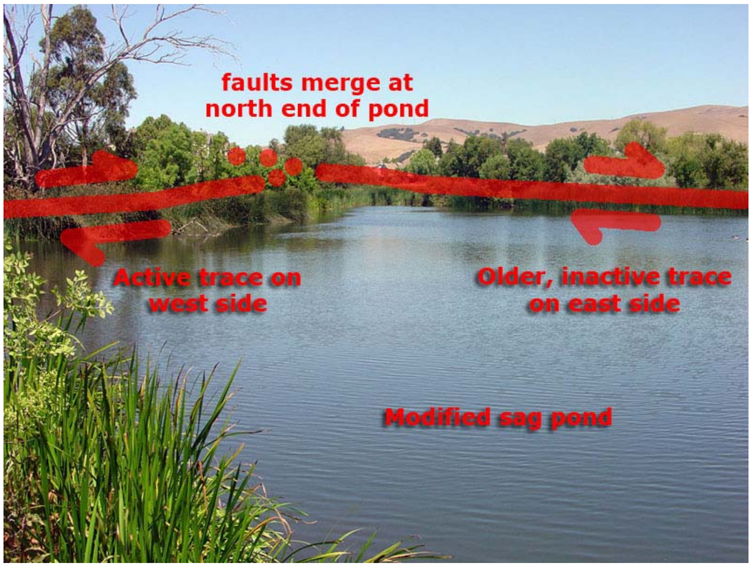


Figure 95. Tule Pond is a sag pond that fills a natural depression formed by two strands of the Hayward Fault (the active trace is on the west, or left side of this image; another inactive trace is on the right side of the pond). The pond has been modified at different times in the modern history of the region, but it still provides an example how fault movements modify the landscape, in this case as a small pull-apart structural basin. The Fremont BART station is just to the west (left) of this north-facing view of Tule Pond. The pond is now a small nature preserve in the center of the urban landscape.

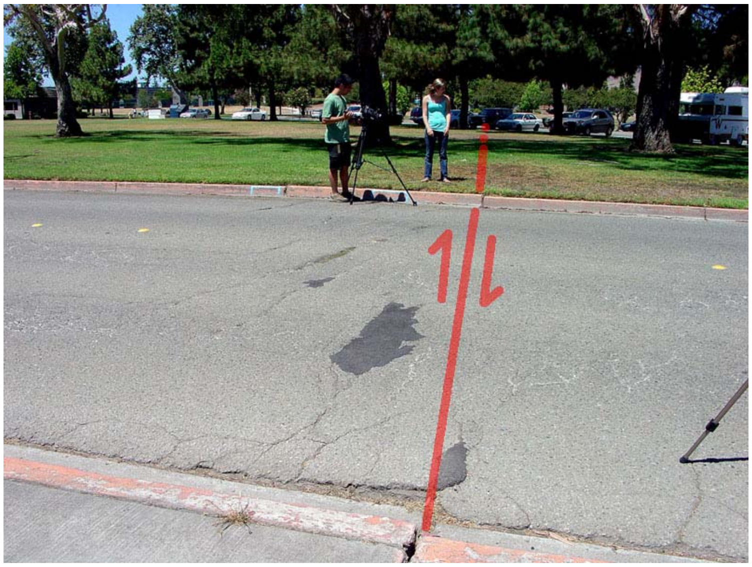


Figure 96. The Hayward Fault crosses through Fremont's Central Park. This view shows two USGS interns photographing offset curbs and fractures where the fault crosses Sailway Drive on the west shore of Lake Elisabeth. Look for the offset curbs and fractures in the pavement about 200 feet east of the intersection of Sailway Drive and Paseo Padre Parkway.

Figure 97. Close-up view of an offset curb on Sailway Drive in Fremont Central Park (in the same location as fig. 98).

Figure 98. View looking southwest across Paseo Padre Parkway toward a low hill on Baylis Street. The hill is an escarpment along the Hayward Fault. Fractures in the pavement and offset curbs near the intersection reveal evidence of creep on the fault.

Figure 99. View north across Paseo Padre Parkway toward Lake Elisabeth from the corner of Baylis Street. Fractures in the pavement are from creep along the Hayward Fault. The 1906 Niles 15 minute quadrangle topographic map shows that what is now Lake Elisabeth was called *The Lagoon* and was a natural lake (a large sag pond) on the relatively undeveloped alluvial plain that is now Fremont.

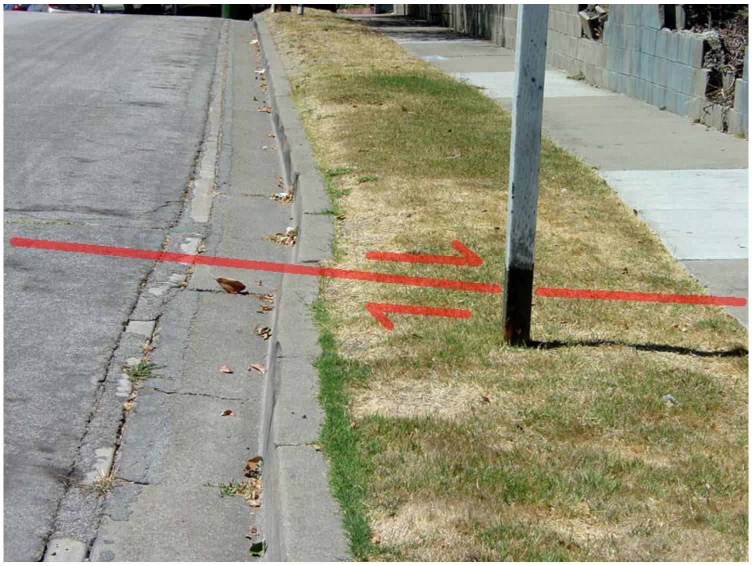


Figure 100. View of an offset curb on the north side of Rockett Drive near the intersection of Paseo Padre Parkway near Fremont Central Park.

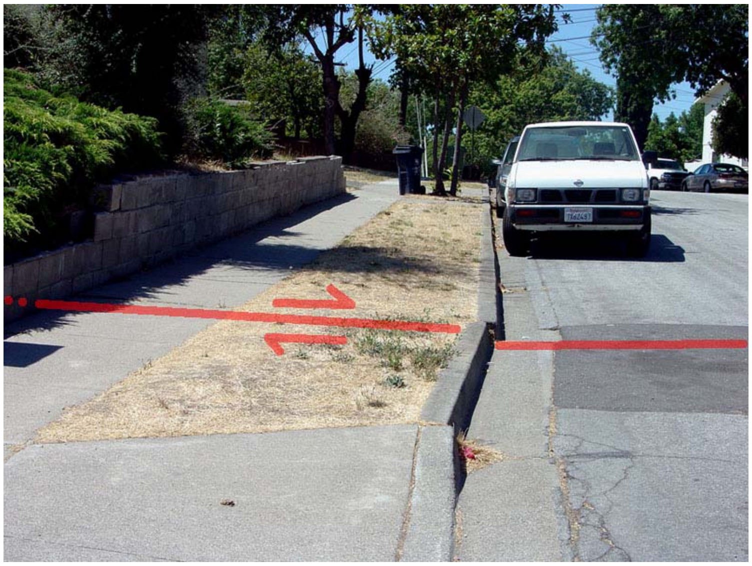


Figure 101. View of an offset curb and an attempt to repair fractures in the pavement on the south side of Rockett Drive near the intersection of Paseo Padre Parkway near Fremont Central Park. This photo is on the opposite side of the street from fig. 102.

Figure 102. This view shows water mains of the Hetch Hetchy water system (water mains #1 and #2) exposed in the vicinity where they cross the Hayward Fault along Grimmer Boulevard near the intersection of Paseo Padre Parkway (near Fremont Central Park). The water mains have been retrofitted and buried in the vicinity of the Hayward Fault nearby. Two other more recently constructed water mains associated with the Hetch Hetchy system cross the Hayward Fault in south Fremont.

Chapter 12 – Mission San Jose-South Fremont

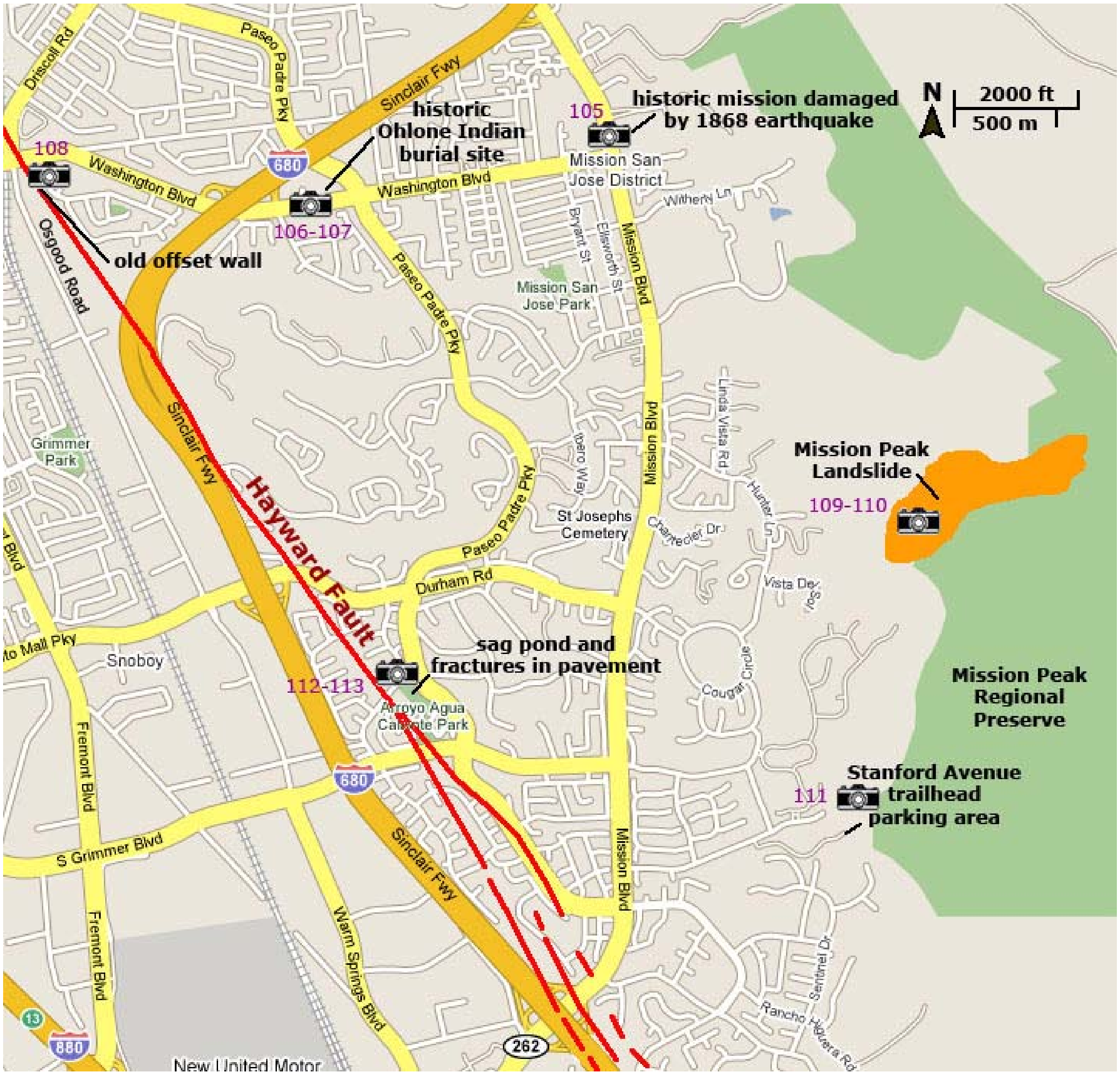


Figure 103. Location of the Hayward Fault in the Mission San Jose area in southern Fremont, California. Purple numbers designate photograph locations.

What to look for: Mission San Jose is both an active Catholic church and a museum with collections of archeological and historical artifacts. The original mission was destroyed in the 1868 Hayward earthquake but was later rebuilt in the fashion of the original building. The mission was built near a number of Ohlone villages.

The southernmost accessible location to easily see the creeping Hayward Fault is in the vicinity of Arroyo Agua Caliente Park. The park is host to a sag pond (filled with cattails). Cracks in the pavement can be seen at the intersection of Gardenia Way and Ivy Way. The historic Gallegos (Palmdale) Winery ruins near the intersection of Osgood Road and Washington Blvd is off limits to the public on land owned by BART.

The Mission Peak landslide is visible from throughout the area and provides an ominous presence on the mountain front above the Mission San Jose area. The landslide is not accessible to the public because of safety concerns. Details of damage and vistas are shown in figures 106 through 115.

Access Options

BART: The closest BART station is the end of the line in Fremont about 3 miles to the north. Plans are underway to extend BART service southward to the Irvington area (west of Mission San Jose and adjacent to the Hayward Fault) in the not-to-distant future.

AC Transit: The AC Transit line #217 and #218 extend to Mission San Jose and Ohlone College; #218 continues to Arroyo Aqua Caliente Park. (See www.511.org for details of bus schedules.)

Bike: All locations shown on the map are easily accessible by bicycle. Most area roads are wide and some are designated bike routes. Caution should be used in the vicinity of interstate interchanges and construction sites. Bicycles are allowed on select trails in the Mission Peak Regional Preserve.

Hike: Mission Peak Regional Preserve is a popular hiking destination with many miles of trails available. A trailhead is located near Ohlone College and another is on Stanford Avenue off of Mission Boulevard. Hiking in the preserve ranges from moderate to extremely strenuous and is not recommended in hot weather.

Wheelchair access: Mission San Jose and Arroyo Agua Caliente Park are accessible to wheelchairs; other locations are not recommended.

Car: Because of the distances involved between stops, driving is a logical option to this field trip area. Parking in the Mission San Jose area can be difficult while classes are in session at Ohlone College, and the parking areas for the Mission Peak Regional Preserve can fill up on weekends.

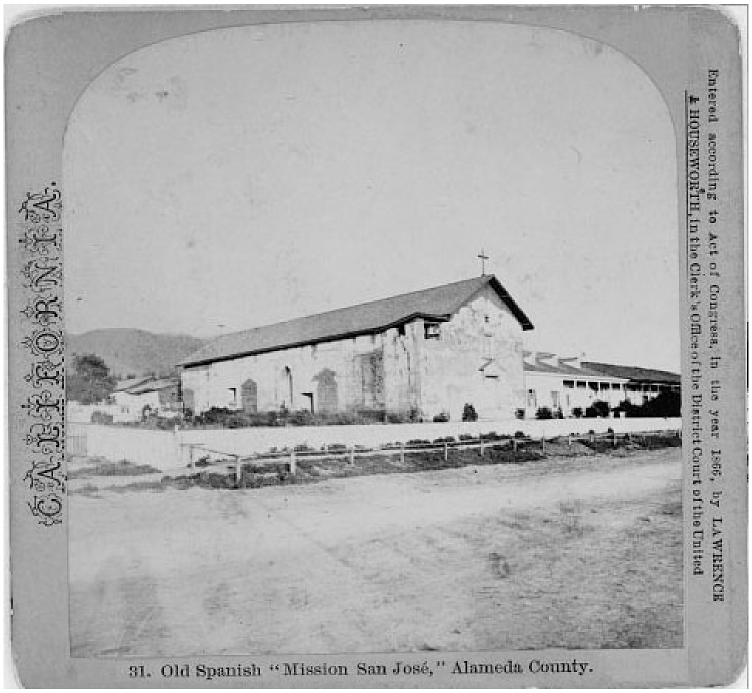


Figure 104. Mission San Jose was founded in 1797. The original church building was constructed of adobe and completed in 1809. The church was nearly completely destroyed by the 1868 earthquake. This historic stereograph of Mission San Jose was taken before the 1868 Hayward earthquake. Photograph by Thomas Houseworth.

Figure 105. A new church constructed of wood was built on the rock foundation of the old church. However, the wooden building was moved and the San Jose Mission church was rebuilt (restored) to look like the original; construction was completed in 1985. The mission is still used for religious services and has a unique historical collection of artifacts in a museum in one of the remaining original adobe buildings next door that survived the 1868 earthquake.

Figure 106. This small memorial park on Washington Boulevard is an Ohlone Indian burial ground where, according to a local marker on the site, as many as 4,000 Ohlone people were buried. The location of Mission San Jose was chosen because of its proximity to a large native population in the South Bay region that subsisted off the abundant food supply of the South Bay and oak woodlands of the Diablo Range nearby. This burial ground is about 0.5 mile west of Mission San Jose and 0.5 mile from the Hayward Fault.

Figure 107. View looking east along Washington Boulevard shows an offset curb and sidewalk near the entrance to the Ohlone Village Shopping Center in Fremont. The sidewalk was probably buckled by growth of the tree. No known fault creep has been mapped in the area (the Hayward Fault is about a mile to the west of this location). Features like this illustrate how difficult and time consuming fault finding can be.

Figure 108.This view is looking east at the property owned by BART near Osgood and Washington in Fremont. The photo shows the ruins of the Gallegos (Palmdale) Winery, which was built into a hillside that is a fault scarp of the Hayward Fault. In the brush-covered field is a stone perimeter wall built in 1884. By 1985, this stone wall had been offset by 2.5 feet of accumulated right-lateral creep on the main trace of the Hayward Fault (Lienkaemper, 2006).

Figure 109. The Mission Peak landslide occurred on March 22, 1998 and was a partial reactivation of a large bedrock landslide complex that has developed over many thousands of years on the western face of Mission Ridge. Although the landslide displaced a great volume of rock and debris, fortunately no structures were damaged in the neighborhoods at the base of the slope.

Figure 110. Detail of the headwall escarpment area of the Mission Peak landslide. See landslide features described in the Glossary.

Figure 111. View looking east toward Mission Peak from near the trailhead for Mission Peak Regional Park on Stanford Avenue in Fremont. The upland part of the eastern flank of Mission Peak is a steep hogback ridge of Briones Sandstone, a soft Miocene-age marine sandstone that is partly responsible for the formation of landslides on the mountainsides above Fremont. The Mission Fault, part of the regional system of faults that include the Hayward and Calaveras Faults, crosses through the valley at the base of the steep cliff below the peak.

Figure 112. Arroyo Agua Caliente Park is located in southern Fremont at the intersection of Paseo Padre Parkway and Parkmeadow Drive. The "hot water stream" no longer flows in the park, but it does have a natural sag pond area filled with cattails (visible behind the trees and to the right). The sag pond was formed by the active trace of the Hayward Fault. Nearby, the Spanish called the warm springs Agua Caliente (hot water). Americans developed a health spa and resort that utilized the hot water until the springs stopped flowing after the 1868 earthquake, causing the resort and surrounding businesses to close down.

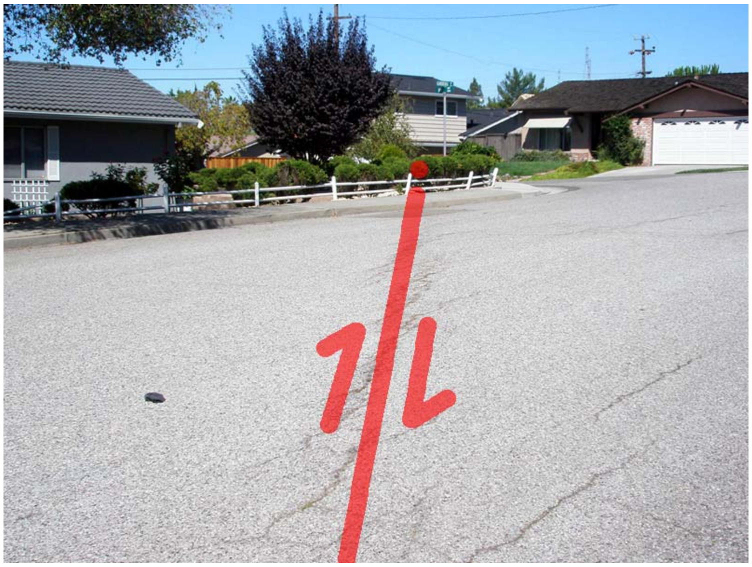


Figure 113. En echelon fractures in the pavement near the intersection of Gardenia Way and Ivy Way on the southwest side of Arroyo Agua Caliente Park in Fremont. The creeping section of the Hayward Fault continues for a couple of miles south of the park but is not accessible to the public. South of this area, the fault splays into strands that cross into the foothills of the Diablo Range east of San Jose. It is in the southern extension, south of Mission Boulevard, where the Hayward Fault is now thought to converge with the Central Calaveras Fault.

Chapter 13 – Now and Then: Comparison of Selected Historic USGS Topo Maps with Modern Satellite Views Along the Hayward Fault

This chapter compares historic U.S. Geological Survey topographic maps (1:62,500 scale; 15 minute quadrangles) with equivalent satellite images captured from *Google Earth* in February 2008. The topo maps were made 30 to 50 years after the 1868 Hayward earthquake but illustrate how sparsely the East Bay region was populated at the beginning of the 20th century. The recent satellite images help illustrate how many people and how much property and infrastructure will be impacted by another major earthquake on the Hayward Fault.

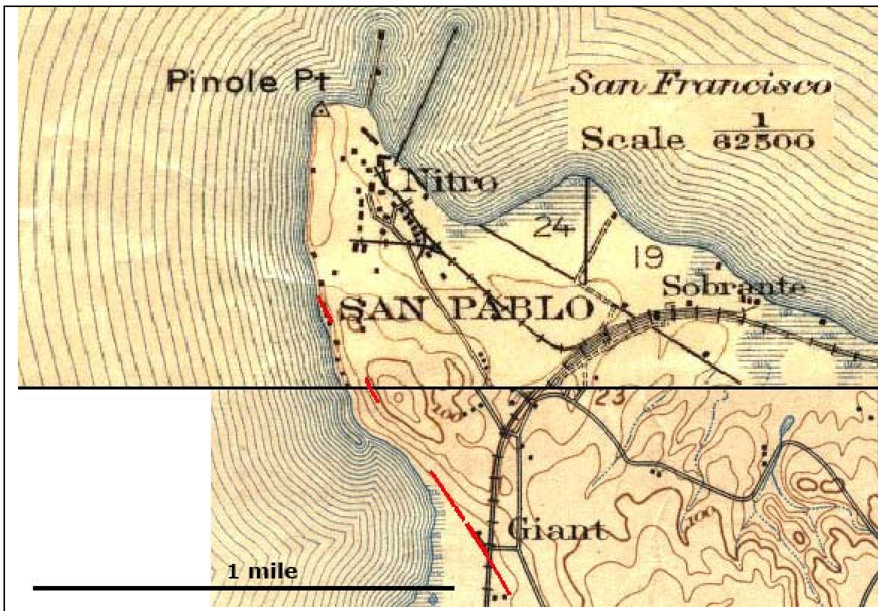


Figure 114. Point Pinole from portions of two maps: 1916 Mare Island 15' quadrangle (north half) and 1895 San Francisco 15' quadrangle (south half). In the late 19th Century the Point Pinole area was a site where explosives were manufactured. The small black dots show the locations of buildings that existed when the area was mapped—none of which exist in the park today.

Figure 115. Point Pinole as captured from current Google Earth satellite imagery. The red line indicates known locations of the Hayward Fault. The land north and west of the rail lines is unoccupied parkland of Point Pinole Regional Shoreline. The land on the opposite side of the tracks that is intensely developed was sparsely populated ranch land at the time of the 1868 Hayward earthquake.

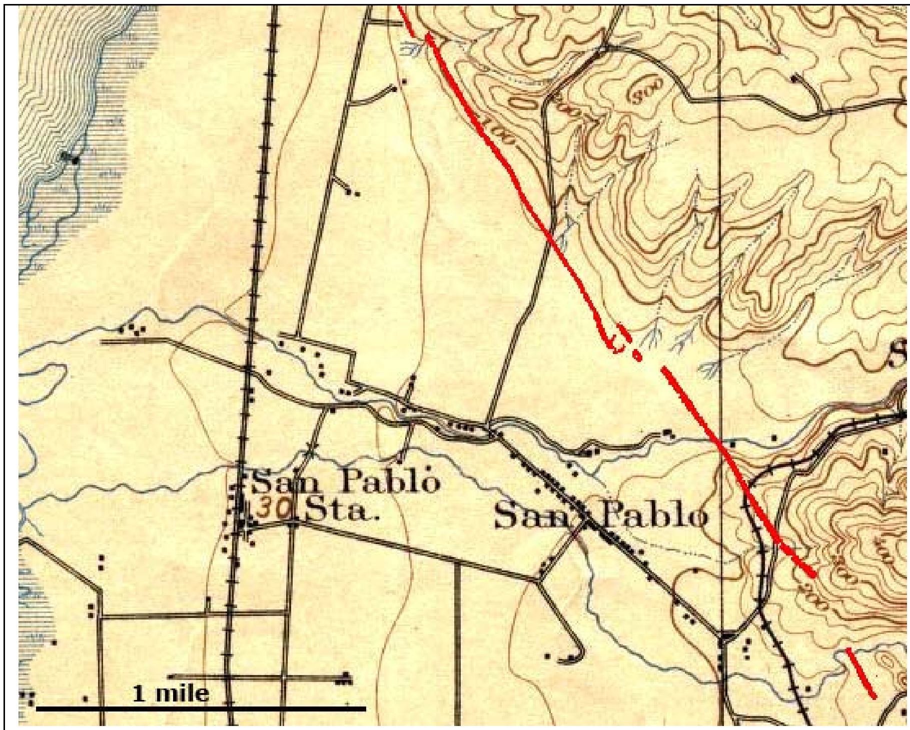


Figure 116. San Pablo (Richmond) area from the 1895 San Francisco 15' quadrangle. The only significant settlement shown on the map was along what is now McDonald Avenue in Richmond and near the San Pablo Railroad Station. The rail lines are still maintained for freight and commuter traffic. The modern BART station is a short distance north of the historic station shown on the map.

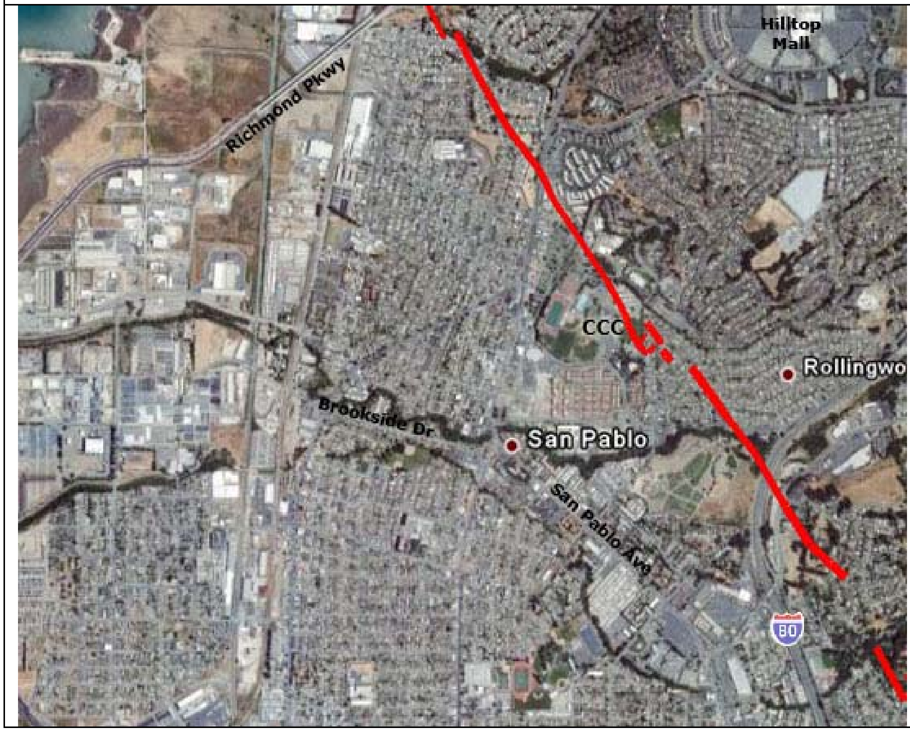


Figure 117. The satellite image of the Richmond area from February 2008 shows nearly complete urban development across the alluvial plain and upland hills east of the Hayward Fault. Contra Costa College (CCC) straddles the fault along the break in slope just to the northeast of the symbol location for San Pablo. The gray in the image represents pavement, rooftops, or other manmade features.

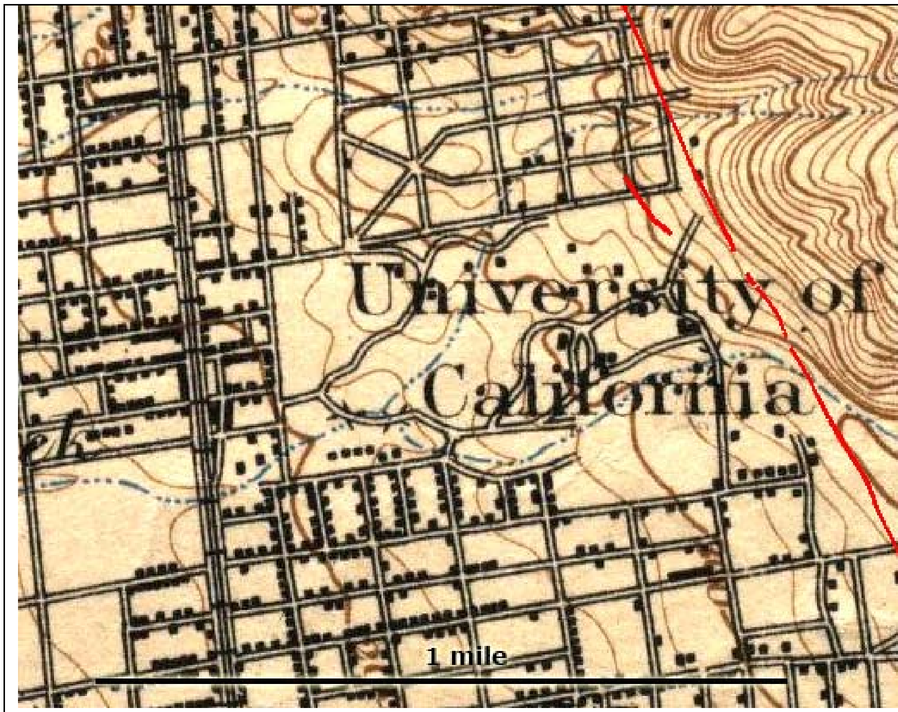


Figure 118. Berkeley from the 1895 San Francisco 15' quadrangle. The University of California, Berkeley was established on March 5, 1868 from the merger of two earlier academic institutions: the College of California (a private institution) and the Agricultural, Mining, and Mechanical Arts College (a land grant institution). The board of trustees of the College of California established the name Berkeley in 1866.

Figure 119. The Berkeley area is one of the most urbanized landscapes in the East Bay. This satellite view shows that the California Memorial Stadium next to the University of California, Berkeley, bisected by the Hayward Fault in the northeast corner of the image.

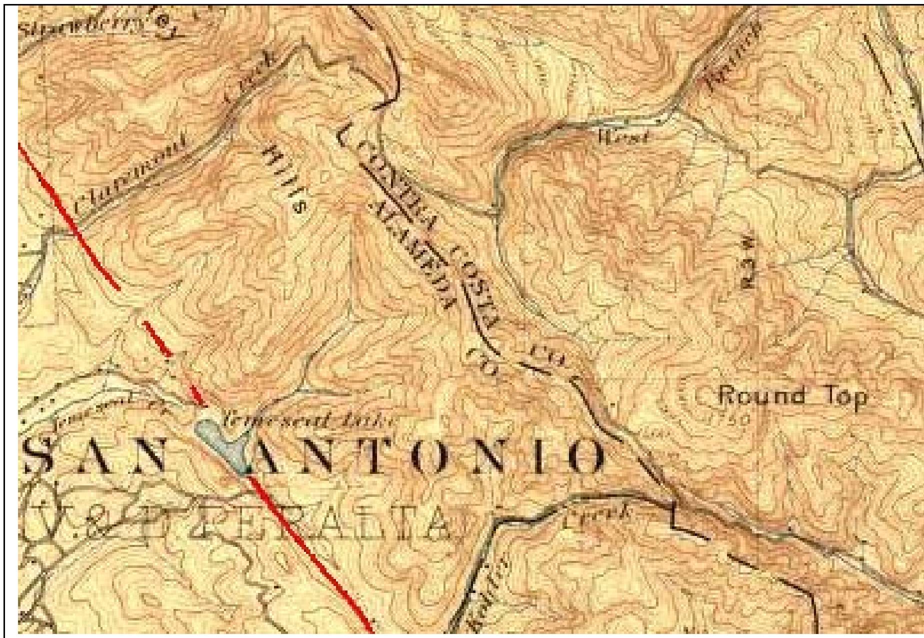


Figure 120. The Lake Temescal and Berkeley Hills area from the 1897 Concord 15' quadrangle map. The lake was a natural sag pond on the Hayward Fault. Temescal Creek is offset where it intersects the active fault zone. Very few people lived in the area at the time of the 1868 Hayward earthquake.

Figure 121. The modern satellite image shows the route of Highway 24 through the Caldecott Tunnel. Urban development has expanded across the alluvial plain into the Berkeley Hills.

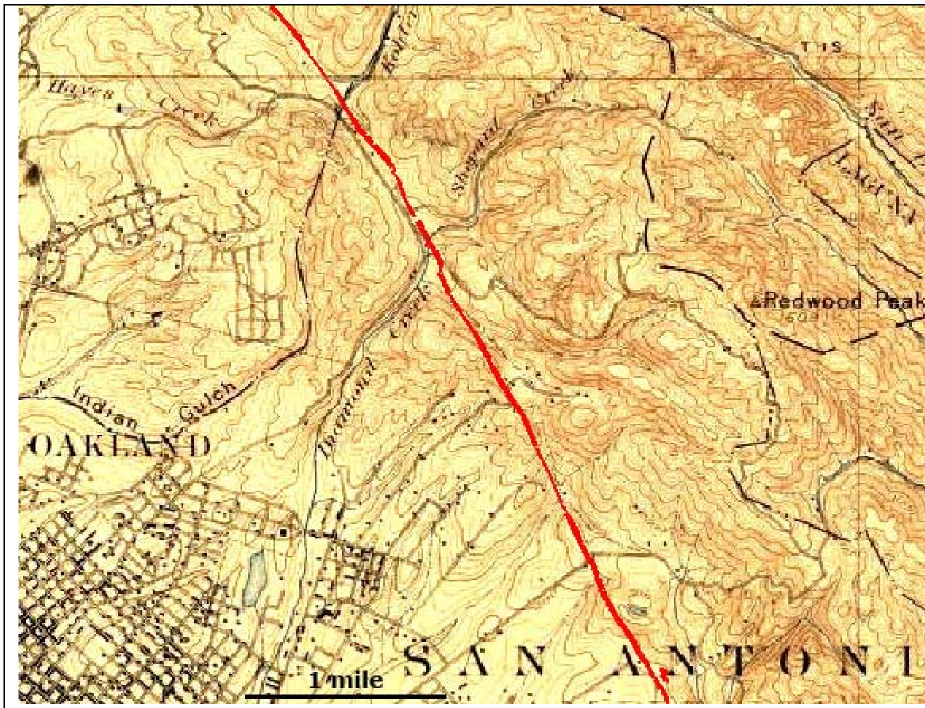


Figure 122. The Oakland Hills area from the 1897 Concord 15' quadrangle. This area was sparsely populated at the time of the 1868 Hayward earthquake. By the turn of the century, however, Oakland was already encroaching into the hills east of the city.

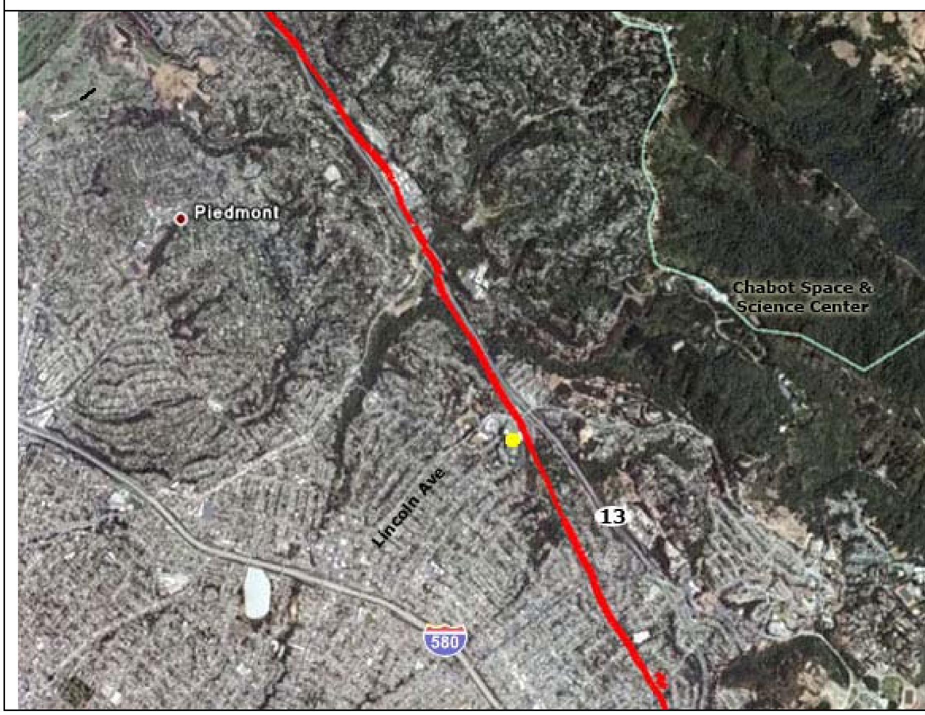


Figure 123. The modern satellite image shows that urban development has expanded nearly to the ridgeline of the Oakland Hills. The yellow dot shows the location of the Oakland Mormon Temple (Church of Jesus Christ of Later-day Saints). The temple is one of the most visible manmade features along the Hayward Fault and can be seen from throughout the Oakland area.

Figure 124. The San Leandro area from the 1899 Hayward 15' quadrangle map. San Leandro was a small village at the time of the 1868 Hayward earthquake and remained that way until the turn of the 20th Century. The Alameda County Courthouse there was destroyed by the earthquake.

Figure 125. Modern satellite view shows that the San Leandro area is now densely urbanized, as is most of the alluvial plain of the East Bay region.

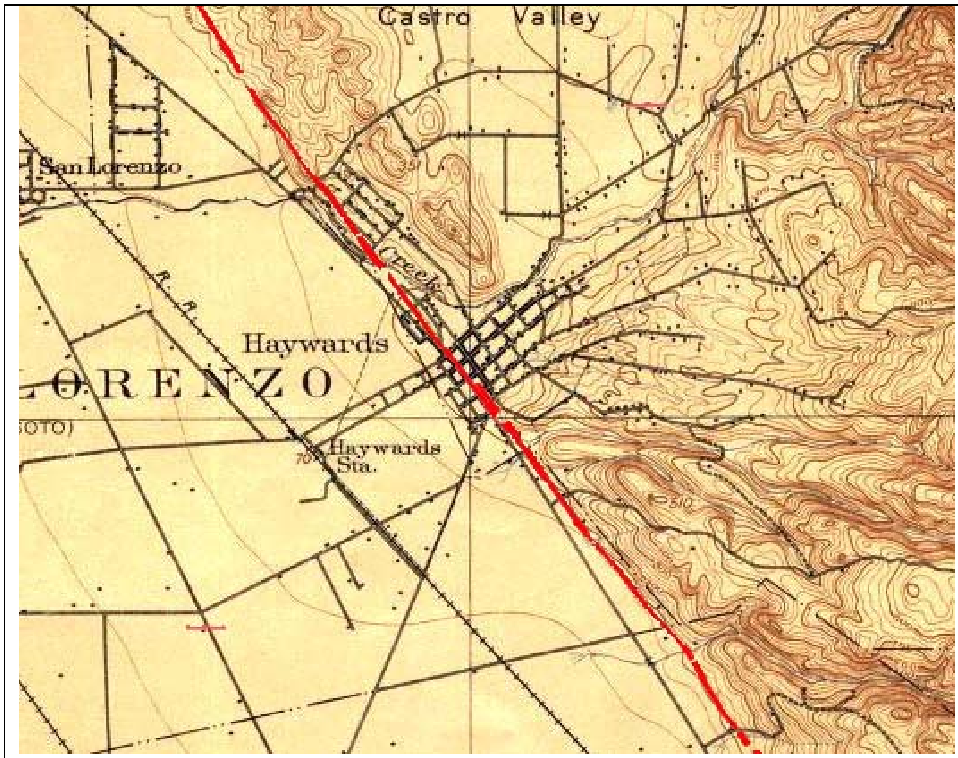


Figure 126. 1899 Hayward 15' quadrangle map showing that the Hayward area remained relatively undeveloped until the beginning of the 20th Century. The town was originally named "Haywards." Much of the development of the East Bay region happened when people fled across the Bay to settle after the 1906 San Francisco earthquake.

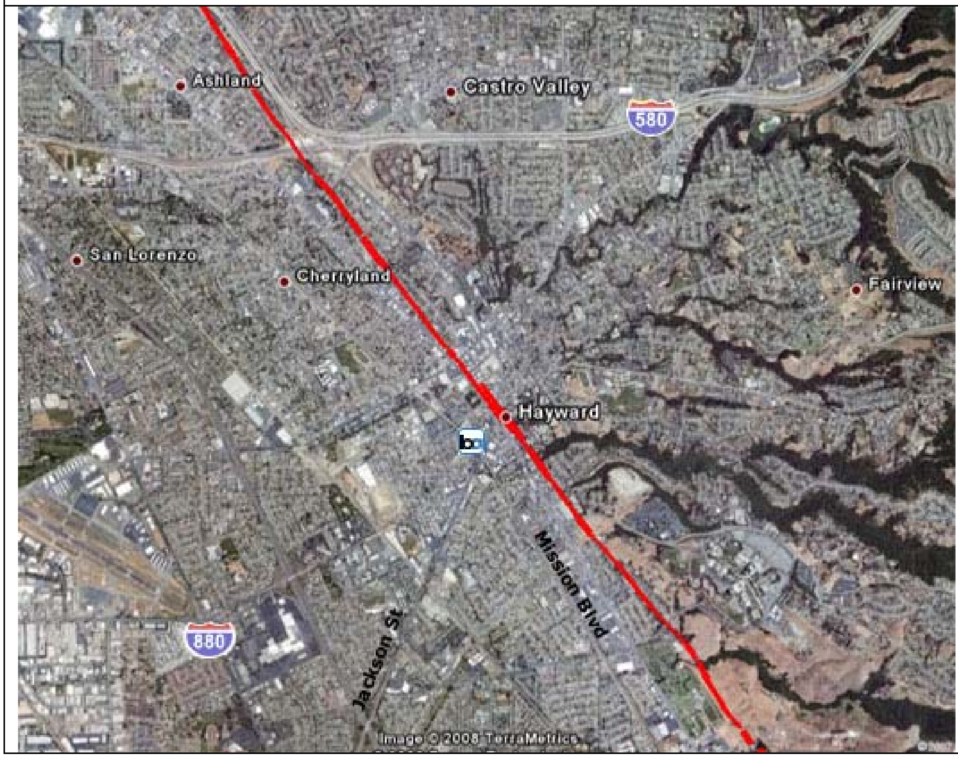


Figure 127. Modern satellite image showing that both the alluvial plain west of the Hayward Fault and the hill country east of the fault are now intensely urbanized.

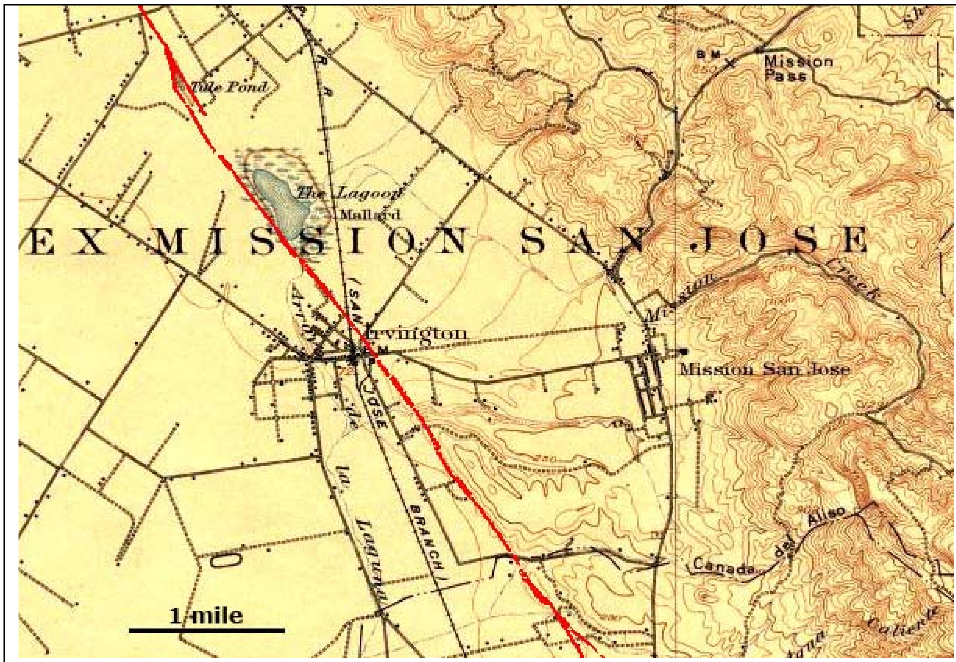


Figure 128. The villages of Irvington and Mission San Jose are the only significant settlements visible on this portion of the 1906 Livermore 15' quadrangle. "The Lagoon" and "Tule Pond" were natural sag ponds and wetlands formed by movement on the Hayward Fault.

Figure 129. The City of Fremont now encompasses the alluvial plain west of the Diablo Range. "The Lagoon" (now Lake Elisabeth) is part of Fremont Central Park, and Tule Pond is adjacent to the Fremont BART Station. Interstate 680 crosses the Hayward Fault in the old Irvington neighborhood.

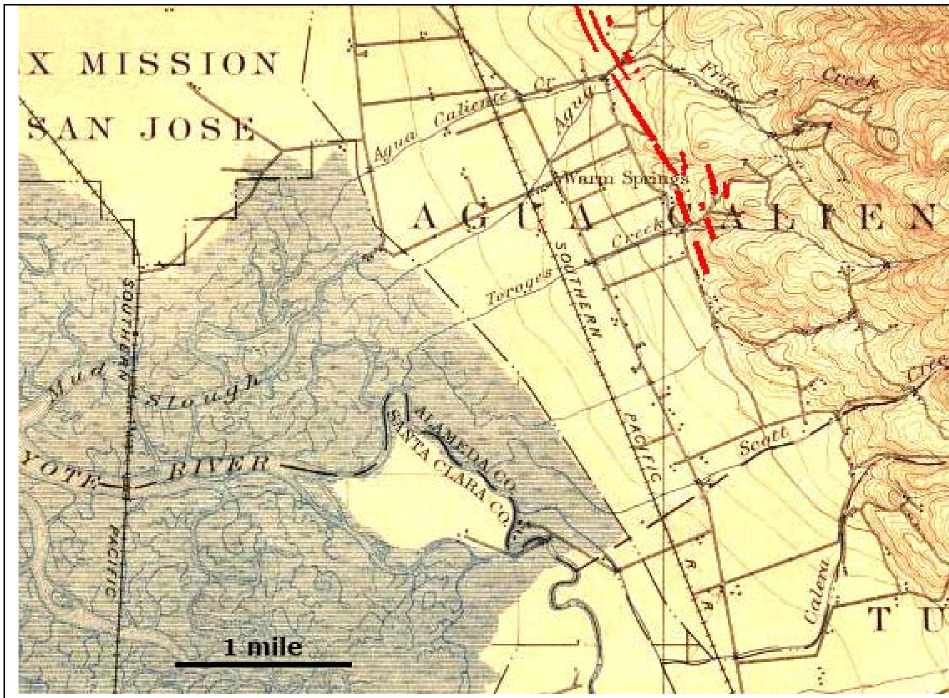


Figure 130. Agua Caliente area from the 1899 San Jose 15' quadrangle shows that the natural South Bay wetlands had not yet been disturbed. The narrow alluvial plain between the Bay and the western flank of the Diablo Range was already an important transportation corridor. Warm Springs was a resort and spa until the 1868 earthquake.

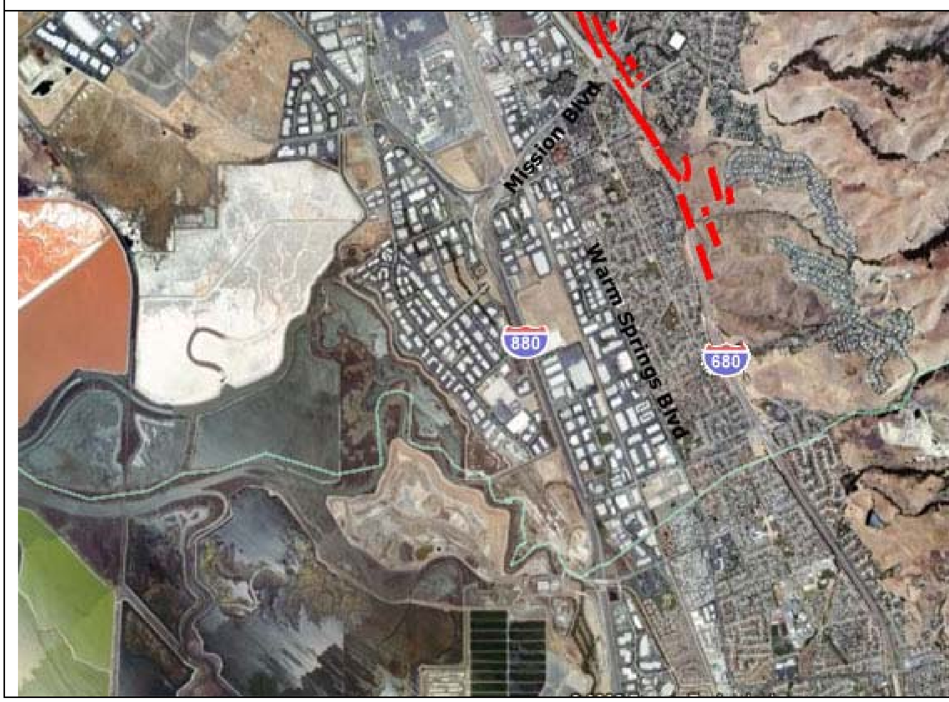


Figure 131. Modern satellite image showing the southern end of the creeping section of the Hayward Fault. The development of the narrow alluvial plain has expanded westward into the marshlands of the South Bay, where salt evaporator ponds have replaced most of the natural wetlands.

Glossary

Note that words in italics are defined elsewhere in this glossary.

Alluvial fan. An outspread, gently sloping mass of sediment deposited by a stream where it issues out of the mouth of a narrow canyon draining from and upland area. Viewed from above, an alluvial fan typically has the shape of an open fan with the apex being at the mouth of the canyon. Alluvial fans are common in arid to semi-arid regions but can be covered with forests in the California Coast Ranges. Alluvial fans may merge together to form an apron-like slope along the base of a mountain front.

Alluvium. A general term for unconsolidated sediments deposited by flowing water on stream channel beds, flood plains, and *alluvial fans*. The term applies to stream deposits of recent times and it does not include subaqueous deposits, such as in lakes or undersea.

Anaglyphic image. A type of photographic image or drawing that can create a three-dimensional view when viewed through colored filter glasses—red-and-cyan colored lenses are most common (standard). Anaglyphic images are created using two standard photographs taken in parallel position a short distance apart, then colors are subtracted from the two images (blue and green from the left image, and red from the right image) before the two images are merged into a reconstructed image (called an *anaglyph*). The red colored lens filters out green and blue from the anaglyphic image whereas the cyan colored lens filters out the red. With red-and-cyan 3D viewing glasses on, the brain reconstructs a 3D view from the original stereo pair of images used to make the anaglyphic image. Standard anaglyphic 3D glasses are worn with the red lens over the left eye.

Basalt. A dark-colored *igneous* rock, commonly *extrusive* (from volcanic eruptions) and composed primarily of the minerals of calcic plagioclase and pyroxene, and sometimes olivine. Basalt is the fine-grained equivalent of *gabbro*.

Beheaded stream. Streams draining across an active *strike-slip fault* trace may be captured by an adjacent stream. With loss of its water supply or a source of sediments, the older channel will remain as a beheaded stream channel as fault motion continues.

Cenozoic. The era of time spanning about 65 million years ago to the present. The term applies to rocks that formed or accumulated in that time period. The Cenozoic Era is subdivided into the *Tertiary* and *Quaternary* periods.

Chert. A hard, dense sedimentary rock, consisting chiefly of interlocking microscopic crystals of quartz and may contain opal. It has a conchoidal fracture and may occur in a variety of colors.

Coast Range *Ophiolite*. An assemblage of *mafic* and *ultramafic igneous* rocks of *Jurassic* to possibly *Cretaceous* age and whose origin is associated with the upper mantle and the lower oceanic crust of the ancient Farallon Plate. The Farallon Plate predates the development of the San Andreas Fault system, and rocks of the Farallon Plate were either subducted or partially accreted (merged) into the crust that now makes up the Coast Ranges. The Coast Range Ophiolite is associated with *serpentinite terranes* throughout much of coastal central and northern California. The modern Juan de Fuca Plate offshore of the Cascades volcanic range in Oregon and Washington is a remnant of what was once the greater Farallon Plate.

Colluvium. A general term applied to loose and incoherent surficial deposits, usually at the base of a slope and brought there chiefly by gravity.

Conglomerate. A coarse-grained *sedimentary* rock composed of rounded to subangular fragments (larger than 2 mm in diameter) set in a fine-grained matrix of sand or silt, and commonly cemented by calcium carbonate, iron oxide, silica, or hardened clay; the consolidated equivalent to gravel.

Creep. In *earthquake* terminology, creep is the slow, continuous movement occurring without large earthquakes on faults due to ongoing tectonic deformation. In *landslide* terminology, creep is slow, more or less continuous down slope movement of surface materials (mineral, rock, and soil particles) under gravitational stresses.

Cretaceous. The final period of the Mesozoic Era (after the *Jurassic* Period and before the *Tertiary* Period of the Cenozoic Era). The Cretaceous Period began about 144 million years ago and ended about 65 million years ago.

Debris flow. A moving mass of rock fragments, soil, and mud in which more than half of the particles are larger than sand size (otherwise it would be a mudflow) and with 70 to 90 percent of the material consisting of sediment (the rest is water and trapped gases). Slow debris flows may only move a few feet per year, whereas rapid ones can reach speeds greater than 100 miles per hour. Debris flows can display either turbulent or laminar flow characteristics.

Debris flood. A typically disastrous flood, intermediate between the turbid flood of a mountain stream and a *debris flow*, ranging in sediment load between 40 to 70 percent (the rest is water and trapped gases).

Deflected drainage. A stream that displays offset by relatively recent movement along a *strike-slip fault*. Fault motion and characteristics of the bedrock adjacent to and within a fault zone can influence erosion patterns and diversion of stream drainages over time.

Dip. The angle that a rock layer or any planar feature makes with the horizontal, measured perpendicular to the *strike* and in a vertical plane**.**

Dip-slip faults. Inclined fractures where the blocks have mostly shifted vertically. If the rock mass above an inclined fault moves down, the fault is termed *normal*, whereas if the rock above the *fault* moves up, the fault is termed *reverse.* A reverse fault in which the fault plane is inclined at an angle equal to or less than 45° is called a *thrust fault***.**

Earthquake. Ground shaking caused by a sudden movement on a *fault* or by volcanic disturbance.

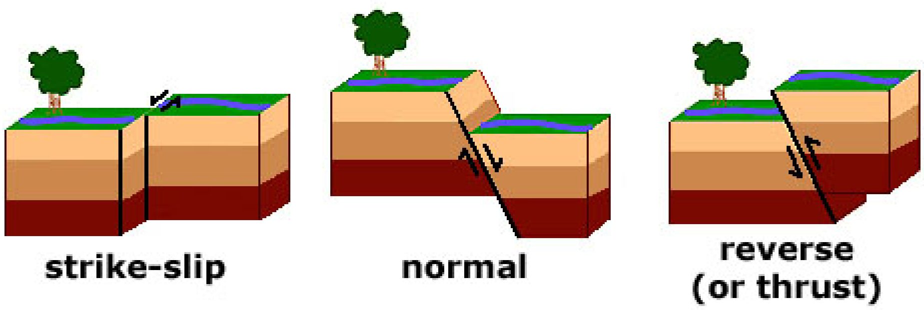
Earthquake fault. An active *fault* that has a history of producing *earthquakes* or is considered to have a potential of producing damaging earthquakes on the basis of observable evidence. Not all faults are active or are considered earthquake faults.

Epicenter. The point on the Earth's surface above the point at depth in the Earth's crust where an earthquake begins.

Escarpment. A long, more or less continuous cliff or relatively steep slope facing in one general direction, separating two level or gently sloping surfaces, and produced by earthquake faulting or erosion.

Extrusive rock. *Igneous* rock that forms from the eruption of molten material at the surface. Extrusive rocks include lava flows and pyroclastic material such as volcanic ash or cinders.

Fault. A fracture or crack along which two blocks of rock slide past one another. This movement may occur rapidly, in the form of an *earthquake*, or slowly, in the form of *creep*. Types of faults include *strike-slip fault*, *normal fault*, *reverse fault*, and *thrust fault*.



Fault line (or fault trace). The trace of a fault plane on the ground surface or other surface, such as on a sea cliff, road cut, or in a mine shaft or tunnel. A fault line is the same as fault trace. Faults lines can often be difficult to resolve from general surface observation due to cover by younger sediments, vegetation, and human-induced landscape modifications.

Fault zone. A *fault* or set of related faults that is expressed as a zone of numerous small fractures or of "*breccia*" or "fault gouge." A fault zone may be hundreds of feet wide and may locally have a complex structure.

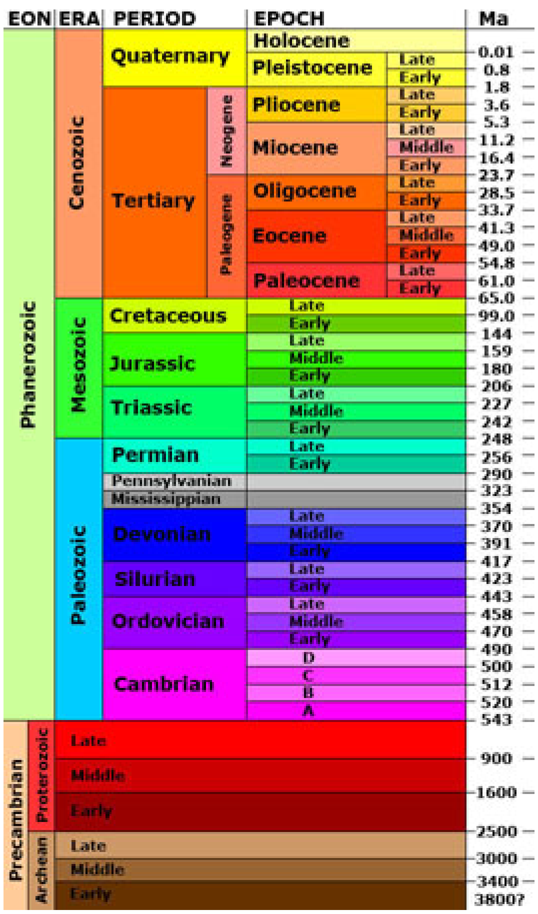
Fault system. A collection of parallel or interconnected *faults* that display a related pattern of relative offset and activity across an entire region (for example, the San Andreas Fault system).

Fault scarp. An *escarpment* or cliff formed by a fault that reaches the Earth's surface. Most fault scarps have been modified by erosion since the faulting occurred.

Franciscan Formation. An assemblage of rocks exposed throughout the Coast Ranges of California that consists of a mix of volcanic rocks, *chert*, shale, *greywacke* sandstone, limestone, *basalt*, and other oceanic crustal rocks that have been partially metamorphosed during their migration from place of origin in a deep ocean basin to being accreted by *plate tectonic* forces onto the west coast of North America. The name Franciscan was first applied to bedrock of *Jurassic* and *Cretaceous* age in the San Francisco region, but the name is commonly used throughout much of coastal central and northern California.

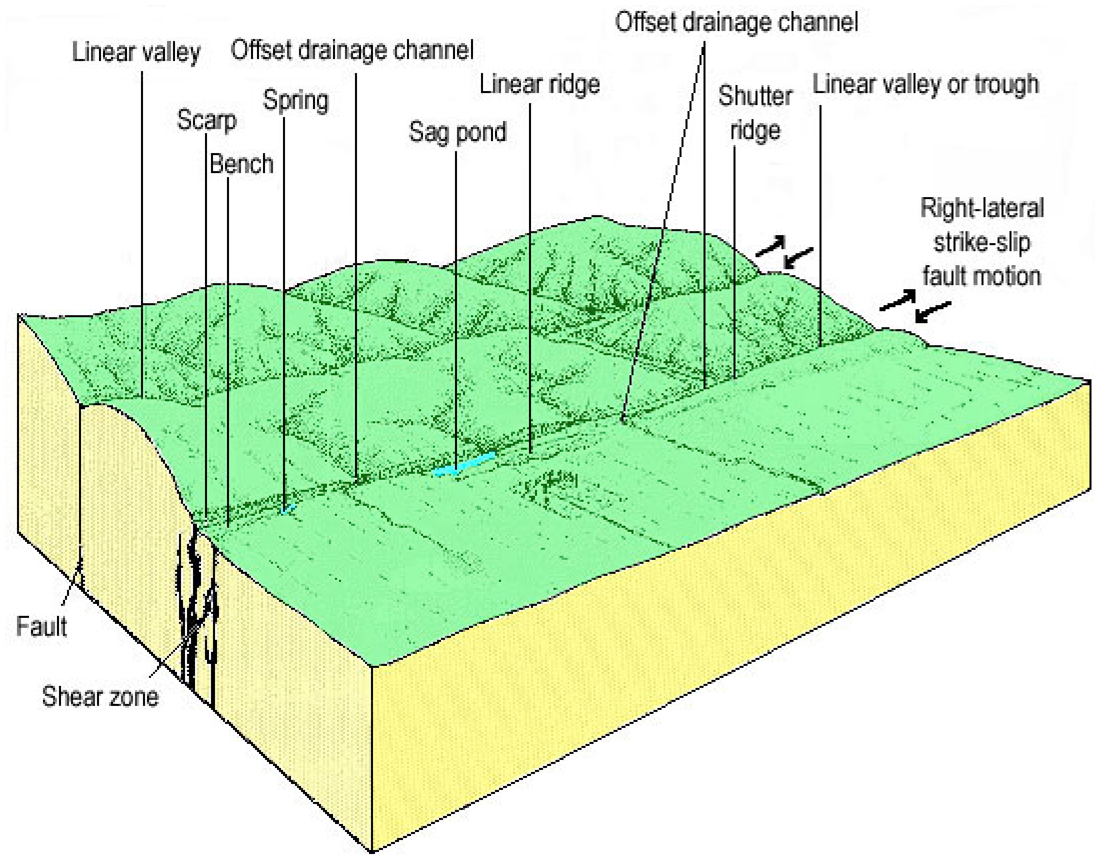
Gabbro. A group of dark-colored, basic *intrusive igneous* rocks composed principally of calcic-plagioclase minerals (labrodorite or bytonite) and augite, and with or without olivine and orthopyroxene. It is the approximate intrusive equivalent of *basalt*.

Geologic time scale. Geologists have subdivided periods in Earth's history is measured periods spanning millions of years (Ma). Segments of time periods have been named to help define the chronology of events (such as mountain range formation), the formation of rock units (such as the age of a lava flow), the age of fossils, organizing geologic map units, and other purposes. Below is a standard geologic time scale listing names of major time periods with time span information.



Click on image for larger view.

Geomorphology - the study of the earth's surface including classification, description, nature, origin, and development of landforms and their relationships to underlying structures and the history of geologic changes as recorded by these surface features. Examples of geomorphic features associated with faults are illustrated below.



Graben. An elongate, structurally depressed crustal area or block of crust that is bounded by *faults* on its long sides. A graben may be geomorphically expressed as a *rift valley* or *pull-apart basin*.

Great Valley Sequence. A thick sequence of late Mesozoic age *sedimentary* rocks (150 to 65 million years old). These rocks consist mostly of shale, sandstone, and conglomerate and are exposed throughout parts of California's Coast Ranges and underlie much of the Great Valley west of the Sierra Nevada Range. The Great Valley Sequence represents sedimentary material deposited in shallow shelf to deep-sea environments along the western continental margin mostly before the development of the modern San Andreas Fault System.

Holocene. The name applied to the time span that corresponds with the post-glacial warming period in which we now live. The Holocene Epoch began about 11,000 years ago (at the end of the *Pleistocene* Epoch of the *Quaternary* Period), about the time that human population growth and distribution expanded worldwide.

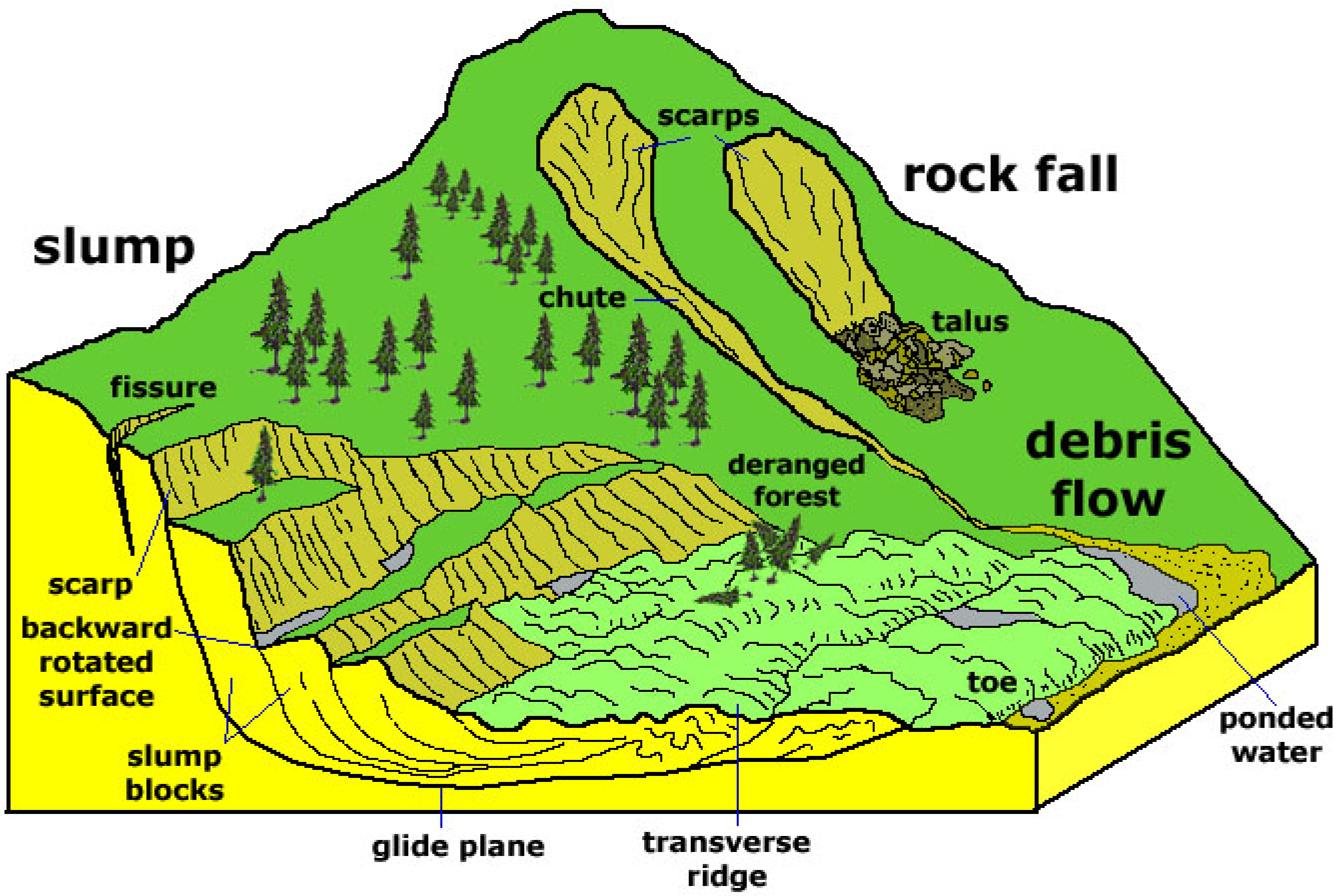
Igneous rock. A rock that solidified from molten or partly molten material (referring to magma underground or lava on the surface). The word igneous also applies to the processes related to the formation of such rocks. Examples of igneous rocks include granite, *gabbro*, and *basalt*.

Intensity. A measure of ground shaking describing the local severity of an earthquake in terms of its effects on the Earth's surface and on humans and their structures. The Modified Mercalli Intensity (MMI) scale, which uses Roman numerals, is one way scientists measure intensity.

Intrusive rocks. *Igneous* rocks that form from the process of emplacement of magma in pre-existing rock. Intrusive igneous rocks typically cool slowly compared to extrusive igneous rocks formed on the Earth's surface and therefore commonly have a coarse crystalline texture (like granite or *gabbro*). The word intrusive applies to both the intrusion process and the rock so formed.

Jurassic. The second period of the *Mesozoic* Era (after *Triassic* Period and before *Cretaceous* Period); the Jurassic spans the period of time between about 206 and 144 million years ago.

Landslide. A general term covering a wide variety of mass-movement landforms and processes involving the down slope transport of soil and rock under the influence of gravity. Usually the displaced material moves over a relatively confined zone or surface of shear. Landslides have a great range of shapes, rates, patterns of movement, and scale. Their occurrence reflects bedrock and soil characteristics and material properties affecting resistance to shear. Landslides are usually preceded, accompanied, and followed by perceptible *creep* along the surface of sliding and/or within the slide mass. *Slumps*, *debris flows*, rockfalls, avalanches, and mudflows are all forms of landslides.



Linear trough. A straight valley that may be bounded by linear fault scarps. A linear trough may be a *graben* or a *rift valley* and may be modified by erosion.

Linear drainage. A stream drainage that follows the trace of a fault. Stream alignment may be a result of *strike-slip fault* motion or the erosion of sheared and pulverized rock along a *fault zone*.

Linear ridge. A long hill or crest of land that stretches in a straight line. It may indicate the presence of a *fault* or a fold (such as an *anticline* or *syncline)*. If it is found along a *strike-slip fault* it may be a *shutterridge* or a *pressure ridge*.

Linear scarp. A straight *escarpment* where there is a vertical component of offset along a

fault (either *normal* or *reverse*). Linear scarps may also form when preferential erosion removes softer bedrock or soil along one side of a fault.

Mafic. A mnemonic term combining and “Ma” (for magnesium) and “Fe” (for ferric iron). The term is used to describe dark-colored igneous minerals rich in iron and magnesium, as well as the rocks that bear those minerals. See also ultramafic.

Magnitude (M). A numeric measure that represents the size or strength of an earthquake, as determined from seismographic observations.

Mesozoic. The era of geologic time spanning about 248 to 65 million years ago. The Mesozoic Era follows the *Paleozoic* Era and precedes the Cenozoic Era. The *Mesozoic* Era is subdivided into the *Triassic*, *Jurassic*, and *Cretaceous* Periods. The term also applies to rocks that formed and accumulated in that time period.

Metamorphic. Pertaining to the process of metamorphism or to its results. Metamorphism is the mineralogical, chemical, and structural adjustment of solid rocks to physical and chemical conditions imposed at depth below the surface and below surficial zones where processes of sedimentation, compaction, and cementation take place. Examples of metamorphic rocks include slate, marble, quartzite, greenstone, gneiss, and schist.

Miocene. An epoch of the late *Tertiary* Period, after the Oligocene Epoch and before the *Pliocene* Epoch, representing the time span between about 23.8 and 5.3 million years ago.

Normal fault. A *fault* in which the hanging wall appears to have moved downward relative to the foot wall. The dip angle of the slip surface is between 45 and 90 degrees. Many normal faults in mountainous regions form from gravitational pull along mountainsides and may be associated with the headwall escarpment of slumps.

Oblique-slip faults. Faults that display significant components of both horizontal (*strike-slip*) and vertical (*dip-slip*) motion.

Offset drainage. A stream that displays offset by relatively recent movement along a *strike-slip fault*. A better term is *deflected drainage.*

Ophiolite. An assemblage of *mafic* and *ultramafic* igneous rocks ranging from *basalt* to *gabbro* and *peridotite*, including rocks derived from them by later *metamorphism* (such as *serpentinite*), and whose origin is associated with the upper mantle and the formation of oceanic crust at *spreading centers* in deep ocean basin settings.

Paleozoic. The era of geologic time spanning about 543 to 248 million years ago. The Paleozoic Era follows the Precambrian Era and precedes the *Mesozoic* Era. The term also applies to rocks that formed and accumulated in that time period.

Plate tectonics. The scientific theory that the Earth's outer shell is composed of several large, thin, relatively strong "plates" that move relative to one another. Movements on the faults that define plate boundaries produce most earthquakes.

Pleistocene. The *Quaternary* Period is subdivided into the Pleistocene Epoch and the *Holocene* Epoch. The Pleistocene Epoch represents the time span of about 1.8 million to about 11,000 years ago. Many episodes of continental glaciation and intervening ice-free periods occurred within the Pleistocene Epoch. The Holocene Epoch began about 11,000 years ago, about the time that human population growth and distribution expanded worldwide.

Pliocene. An epoch of the late *Tertiary* Period following the *Miocene* Epoch and proceeding the *Quaternary* Period (or *Pleistocene* Epoch) and representing the time span from about 5.3 to 1.8 million years ago. The cycles of ice-age glaciations and intervening warming periods began in Pliocene time.

Plutonic rock. A rock formed at considerable depth by crystallization of magma and/or by chemical alteration. It is usually medium- to coarse-grained with a granitic texture.

Pressure ridge. A pressure ridge is a topographic ridge produced by compressional forces along a *strike-slip fault* zone. Pressure ridges typically are located where there are bends along a fault or where faults intersect or *stepover*. Pressure ridges can be *shutterridges* and can occur on one or both sides of a *fault* or within a *fault zone*.

Pull-apart basin. A surface depression will form along a fault where down warping of the surface occurs, such as from a developing fold or a fault-bounded *graben*. Closed depressions can form where extensional bends or *stepovers* occur along a *strike-slip fault* zone.

Quaternary Period. The period of time spanning about 1.8 million years ago to the present. The Quaternary Period is subdivide into two unequal epochs–the *Pleistocene* Epoch extends from about 1.8 million years ago to about 11,000 years ago, and the *Holocene* Epoch that extends from about 11,000 years ago to the present. The *Quaternary* Period encompassed many cycles of ice-age continental glaciations and intervening warming periods. The *Holocene* Epoch corresponds with the last warming period in which we now live.

Reverse fault. A *fault* in which the hanging wall has moved up relative to the foot wall.

Rift valley. A valley that has formed along a tectonic rift. Rift valleys may be *grabens* or *pull-apart basins*, may be structurally complex, and are typically modified by erosion.

Rockfall. The relatively free falling or precipitous movement of a newly detached segment of bedrock of any size from a cliff or very steep slope; it is most frequent in mountainous areas during spring when there is repeated freezing and thawing of water in cracks in rock. Movement may be straight down or in a series of leaps and bounds down the slope; it is not guided by an underlying slip surface (like a *slump*).

Rupture zone. The area of the Earth through which fault movement occurred during an earthquake. For large earthquakes, the section of the fault that ruptured may be several hundred miles in length. Ruptures start at several miles depth and may or may not extend up to the ground surface.

Sag pond. If a natural depression associated with a fault or associated with a *pull-apart basin* along a *fault system* can hold water, even temporarily, it is called a sag pond.

Scarp. A line of cliffs produced by faulting, slumping, or erosion. Scarp is an abbreviation for the word escarpment—the meaning is the same.

Sedimentary rocks. Materials consisting of sediments or formed by deposition. The word sedimentary applies to both the processes and the products of deposition. Examples of sedimentary rocks include shale, sandstone, *conglomerate*, limestone, and *chert*.

Seismic hazard. The potential for damaging effects caused by earthquakes. The level of hazard depends on the magnitude of likely quakes, the distance from the fault that could cause quakes, and the type of ground materials at a site.

Seismicity. Seismicity means earthquake activity, or the likelihood of an area being subject to *earthquakes*, or the phenomenon of earth movements.

Serpentinite. An *ultramafic* rock consisting almost wholly of serpentine-group minerals (such as antigorite and chrysotile) derived from the alteration of *peridotite*. Accessory chlorite, magnetite, and talc may be present.

Shutterridges. A shutterridge is a ridge formed by vertical, lateral, or oblique displacement on a *fault* that crosses an area having ridge and valley topography, with the displaced part of the ridge "shutting in" the valley. Shutterridges typically are found in association with *offset drainages*.

Sidehill benches. A step-like surface on the side of a hill or mountain. Both recent fault activity or erosional differences of bedrock lithology across a fault may produce sidehill benches and associated *linear scarps*. Sidehill benches may also form from *slumping* that may or may not be associated with faulting.

Slickensides. A polished and striated rock surface produced by friction along a *fault*.

Slip. The relative displacement of formerly adjacent points on opposite sides of a *fault*, measured along the fault surface.

Slump. A type of *landslide* where the downward slipping mass of unconsolidated material or rock moves as a unit. A slump block usually displays backward rotation and on a more or less horizontal axis parallel to the slope or cliff from which it descends. Slumps typically form a fault-like escarpment and may occur at the head of a *landslide*.

Spreading center. A linear area where new crust forms where two crustal plates are moving apart, such as along a mid-oceanic ridge. Spreading centers are typically seismically active regions in ocean basins and may be regions of active or frequent volcanism.

Stepover. Closely spaced *strike-slip faults* within a greater *fault zone* over which the total displacement is distributed.

Strike. The direction taken by a structural surface, such as a layer of rock or a fault plane, as it intersects the horizontal.

Strike-slip fault. A generally vertical fault along which the two sides move horizontally past each other. If the block opposite an observer looking across the fault moves to the right, the slip style is termed "right lateral." If the block moves to the left, the motion is termed "left lateral." California's San Andreas Fault is the most famous example of a right-lateral strike-slip fault. Strike-slip faults produce produce a variety of landforms including *shutterridges, pull-apart basins, sag ponds,* and *deflected streams*.

Subduction zone. A boundary along which one plate of the Earth's outer shell descends (sub-ducts) at an angle beneath another. A subduction zone is usually marked by a deep trench on the sea floor. An example is the Cascadia Subduction Zone offshore of Washington, Oregon, and northern California. Most tsunamis are generated by subduction-zone-related earthquakes.

Terrace. A relatively level bench or step-like surface breaking the continuity of a slope. Natural bench-like terrace features include elevated-marine terraces (along rising sea coasts), stream terraces (along incising streams), or structural terraces (such as along a *fault*).

Tertiary. The first period of the *Cenozoic* Era (after the *Cretaceous* Period of the *Mesozoic* Era). The Tertiary Period spans the time of about 65 to 1.8 million years ago. The Tertiary Period is subdivided into 5 epochs—Paleocene, Eocene, Oligocene, *Miocene*, and *Pliocene*). It is followed by the *Pleistocene* Epoch of the *Quaternary* Period.

Thrust fault. A fault with a dip angle of 45º or less over its extent on which the hanging wall appears to have moved upward relative to the foot wall. Horizontal compression or rotational shear is responsible for displacement. (See also *reverse fault* and *oblique-slip fault*.)

Transform fault. A special variety of *strike-slip fault* along which the displacement suddenly stops or changes form. Many transform faults are associated with mid-oceanic ridges and plate boundaries that show pure strike-slip displacement, like the San Andreas Fault.

Ultramafic. A rock composed chiefly of *mafic* minerals (rich in iron and magnesium, and less than about 45 percent silica, such as olivine, augite, or hypersthene. Pyroxene and serpentinite are ultramafic rocks.

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