Introduction

This volume is a general geology field guide to the San Andreas Fault in the San Francisco Bay Area. The first section provides a brief overview of the San Andreas Fault in context to regional California geology, the Bay Area, and earthquake history with emphasis of the section of the fault that ruptured in the Great San Francisco Earthquake of 1906. This first section also contains information useful for discussion and making field observations associated with fault-related landforms, landslides and mass-wasting features, and the plant ecology in the study region. The second section contains field trips and recommended hikes on public lands in the Santa Cruz Mountains, along the San Mateo Coast, and at Point Reyes National Seashore. These trips provide access to the San Andreas Fault and associated faults, and to significant rock exposures and landforms in the vicinity. Note that more stops are provided in each of the sections than might be possible to visit in a day. The extra material is intended to provide optional choices to visit in a region with a wealth of natural resources, and to support discussions and provide information about additional field exploration in the Santa Cruz Mountains region. An early version of the guidebook was used in conjunction with the Pacific SEPM 2004 Fall Field Trip. Selected references provide a more technical and exhaustive overview of the fault system and geology in this field area; for instance, see USGS Professional Paper 1550-E (Wells, 2004).

San Andreas Fault: An Overview

The catastrophe caused by the 1906 earthquake in the San Francisco region started the study of earthquakes and California geology in earnest. Three days after the earthquake, Andrew C. Lawson, the chairman of the geology department of University of California, Berkeley, organized (and was appointed head of by the governor) a State Earthquake Investigation Commission. In 1908 the "Lawson Report" was released. This massive volume contains detailed engineering studies of urban damage caused by the earthquake and fire, and includes studies of the surface rupture and ground failure along the San Andreas Fault and throughout the region. The Lawson Report is still regarded as a significant scientific resource and is hailed as the first organized effort to study earthquake hazards and fault geology in America. In the century that followed, several thousand technical reports and articles have been written about the San Andreas Fault System alone, and this body of knowledge was a fundamental part of the development of the theory of plate tectonics.

A Right-Lateral Strike-Slip Fault Motion

A major question raised by the 1906 earthquake investigations was why did the surface rupture along the San Andreas Fault show mostly horizontal offset? Although the surface rupture along the fault was highly variable, it was obvious that the west side of the fault had moved northward relative to the east side as much as 20 feet near Point Reyes. This right-lateral offset observed in the 1906 earthquake was not typical of previously studied earthquake surface ruptures, and was contradictory to existing theories of earth processes responsible for the evolution of the landscape. Studies of the San Andreas Fault and California geology have since demonstrated that some great blocks of rock have indeed moved laterally long distances over geologic time. Landscape features such as streams as well as geologically similar bedrock blocks (including distinct volcanic and plutonic rocks, and unique sedimentary deposits of all ages) are all offset along the fault, with youngest rocks offset less than older rocks. The amount and rate of offset along the fault is not consistent from place to place, partly because at the surface the San Andreas often consists of a complex system of parallel and interconnecting faults. Some sections of the fault are constantly creeping along, whereas other sections are locked during periods between episodic large earthquakes. In general, the western Pacific Plate is moving northward at about two inches per year relative to the North American Plate, and much of this motion is accommodated along the San Andreas Fault and is responsible for many large magnitude earthquakes (see figs 1-1 and 1-2). However, the physical offset of the brittle crust near the earth's surface occurs along a number of known and unknown faults, often in an unpredictable fashion. In addition, movement along the San Andreas Fault is not purely right-lateral. There is a component attributed to compressional forces developed across the fault trace as the two plates grind against each other. This compression helped produce the coastal mountain ranges along the fault system through California. The ratio of compression to horizontal displacement typically ranges from 1:10 to 1:20 but varies considerably from one section or strand of the fault to another.

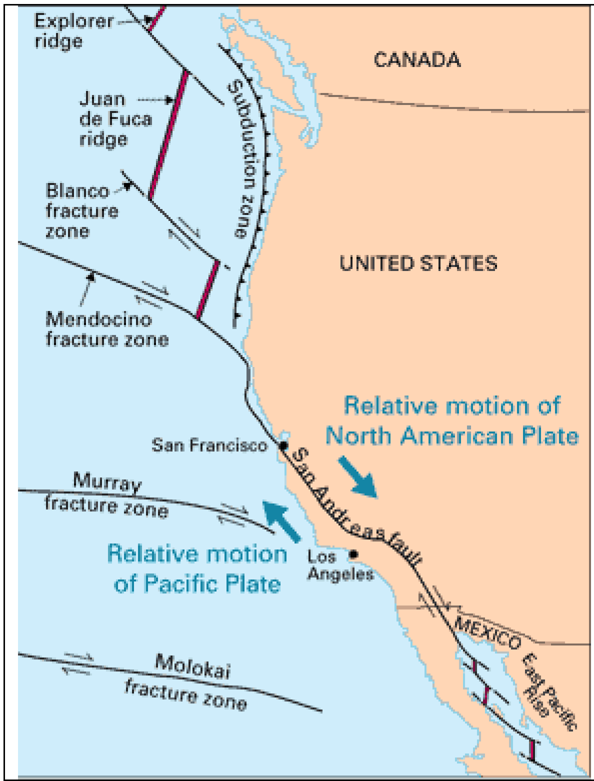


Figure 1-1. The San Andreas Fault System has gradually evolved since middle Tertiary time (beginning ~28 million years ago). The San Andreas Fault System grew as a remnant of a oceanic crustal plate and a spreading ridge (like the Juan de Fuca Ridge) were subducted beneath the North American Plate as it moved west relative to the Pacific Plate. The result was the development of a crustal fracture zone with right-lateral offset that propagated along the continental margin (see fig. 1-3 below). This action also slivered off pieces of the North American Plate and added them to the Pacific Plate. Although estimates vary, the maximum offset along the San Andreas Fault is on the order of 470 km (282 miles). However, the fault system which consists of many strands that have experienced different amounts of offset over geologic time. In the San Francisco Bay Area, much of the offset along the San Andreas Fault System has occurred along the East Bay faults (Calaveras and Hayward fault) rather than along the San Andreas Fault itself in the Peninsula region. One fault strand may creep gradually or move episodically through a period of its geologic history, then may later remain locked for thousands of years while motion is transferred to a nearby or evolving strand.

Image from ***This Dynamic Earth, Understanding Plate Motions***, available on-line at: http://pubs.usgs.gov/publications/text/understanding.html.

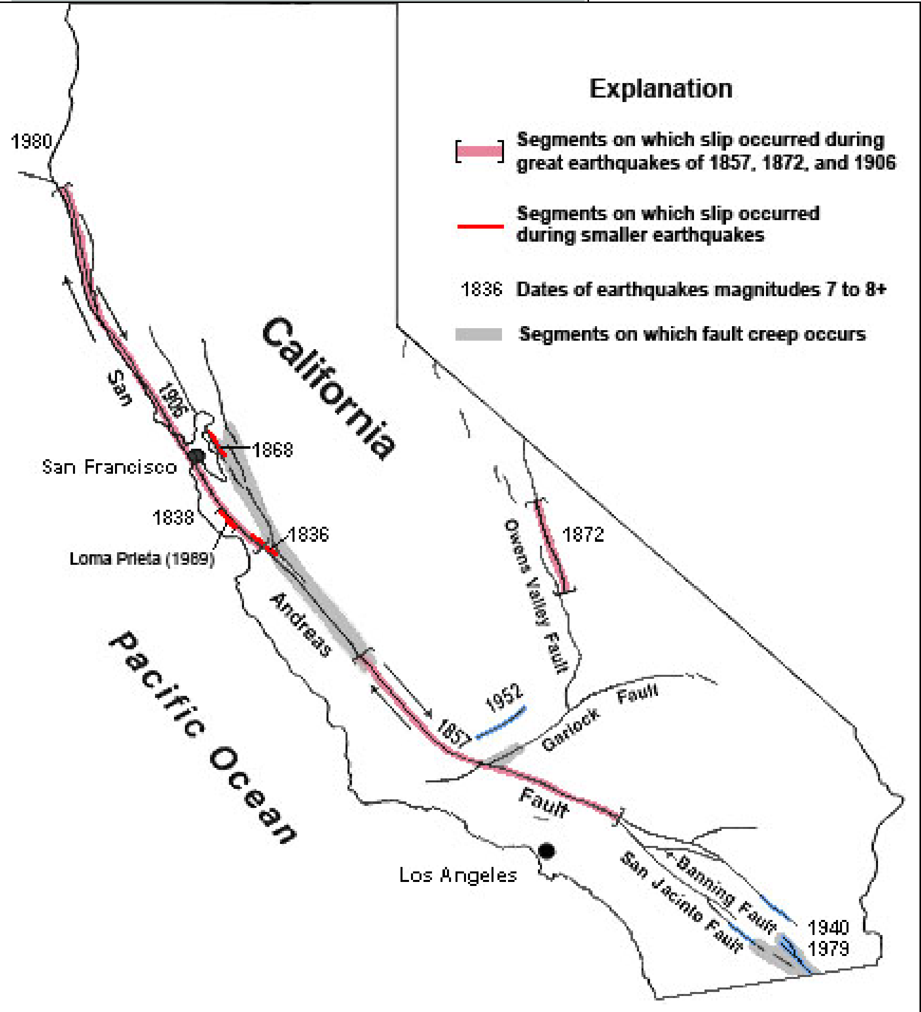


Figure 1-2. The San Andreas Fault System has a historic record of moderate to great earthquakes. The surficial expressions of the two greatest historic earthquakes on the San Andreas are fairly well documented. The great San Francisco earthquake of 1906 was similar in magnitude to the great Fort Tejon earthquake of 1857. Both are traditionally reported to have been in the M = 7.8 to 8.3 range. The 1906 quake was documented by many witnesses and by the Lawson Report. In contrast, the 1857 earthquake occurred in a very sparely populated region, but arid conditions have helped to preserve geomorphic features associated with the fault and the earthquake (including in what is now Carrizo Plain National Monument). A land survey conducted in the Carrizo Plain region shortly before the 1857 earthquake has provided a baseline for modern investigations in that area. Map source modified from Schulz, S.S. and Wallace, R.E., [1997], The San Andreas Fault: U.S. Geological Survey, General Interest Publication: http://pubs.usgs.gov/gip/earthq3/.

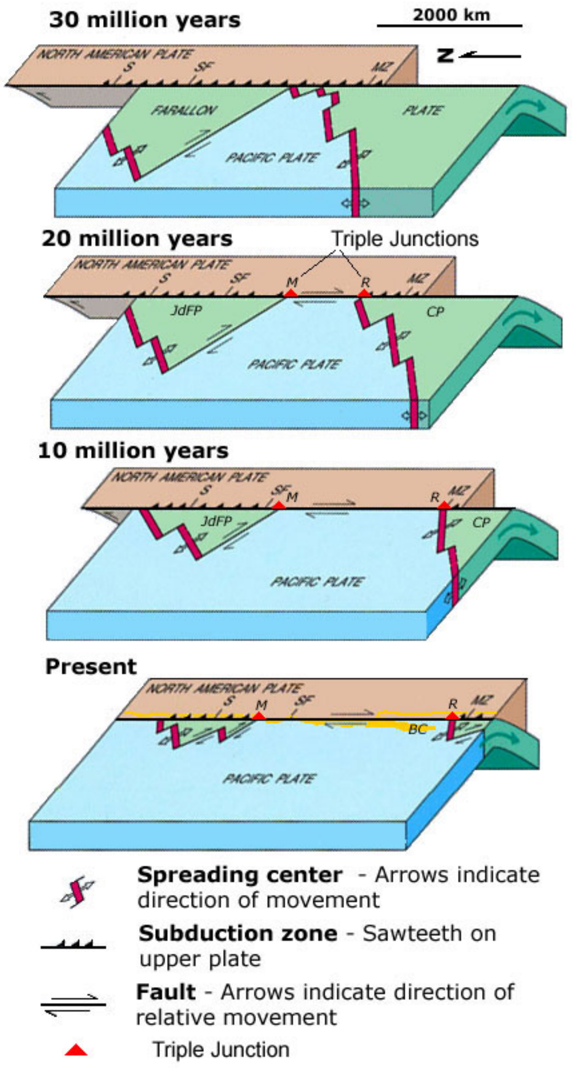


Figure 1-3. Evolution of the San Andreas Fault.

This series of block diagrams shows how the subduction zone along the west coast of North America transformed into the San Andreas Fault over the period from 30 million years ago to the present. Starting at 30 million years ago, the westward-moving North American Plate began to override the spreading ridge between the Farallon Plate and the Pacific Plate. This action divided the Farallon Plate into two smaller plates, the northern Juan de Fuca Plate (JdFP) and the southern Cocos Plate (CP). By 20 million years ago, two triple junctions began to migrate north and south along the western margin of the west coast. [Triple junctions are intersections between three tectonic plates; shown as red triangles in the diagrams.] The change in plate configuration as North American Plate began to encounter the Pacific Plate resulted in the formation of the San Andreas Fault. The northern Mendicino Triple Junction (M) migrated through the San Francisco Bay region roughly 12 to 5 million years ago and is presently located off the coast of northern California, roughly midway between San Francisco (SF) and Seattle (S). The Mendicino Triple Junction represents the intersection of the North American, Pacific, and Juan de Fuca plates. The southern Rivera Triple Junction (R) is presently located in the Pacific Ocean between of Baja California (BC) and Manzanillo, Mexico (MZ).

Evidence of the migration of the Mendicino Triple Junction northward through the San Francisco Bay region is preserved as a series of volcanic centers that grow progressively younger toward the north. Volcanic rocks in the Hollister region are roughly 12 million years old whereas the volcanic rocks in the Sonoma-Clear Lake region north of San Francisco Bay ranges from only few million to as little as 10,000 years ago. Both of these volcanic areas, and older volcanic rocks in the region, are offset by the modern regional fault system.

[Image modified from USGS Professional Paper 1515.]

Bay Area Faults and Earthquakes

The Earth's crust in the San Francisco Bay region is broken by hundreds of known faults (and perhaps thousands of unmapped or undiscovered faults). However, only a small percentage of faults extend for distances measurable in miles, and of these, only a few are associated with historic earthquake activity. The most active fault in the region is the San Andreas Fault; however, all of the large faults in the San Francisco Bay region that display recent earthquake activity, or that display Quaternary offset, are part of the greater San Andreas Fault System. Many Bay Area faults are described in detail in the Quaternary Faults and Fold Database of the United States: http://earthquakes.usgs.gov/qfaults/. Geologic maps and subsurface fault information in the Bay Area is available via the San Francisco Bay Region Geology website at http://sfgeo.wr.usgs.gov.

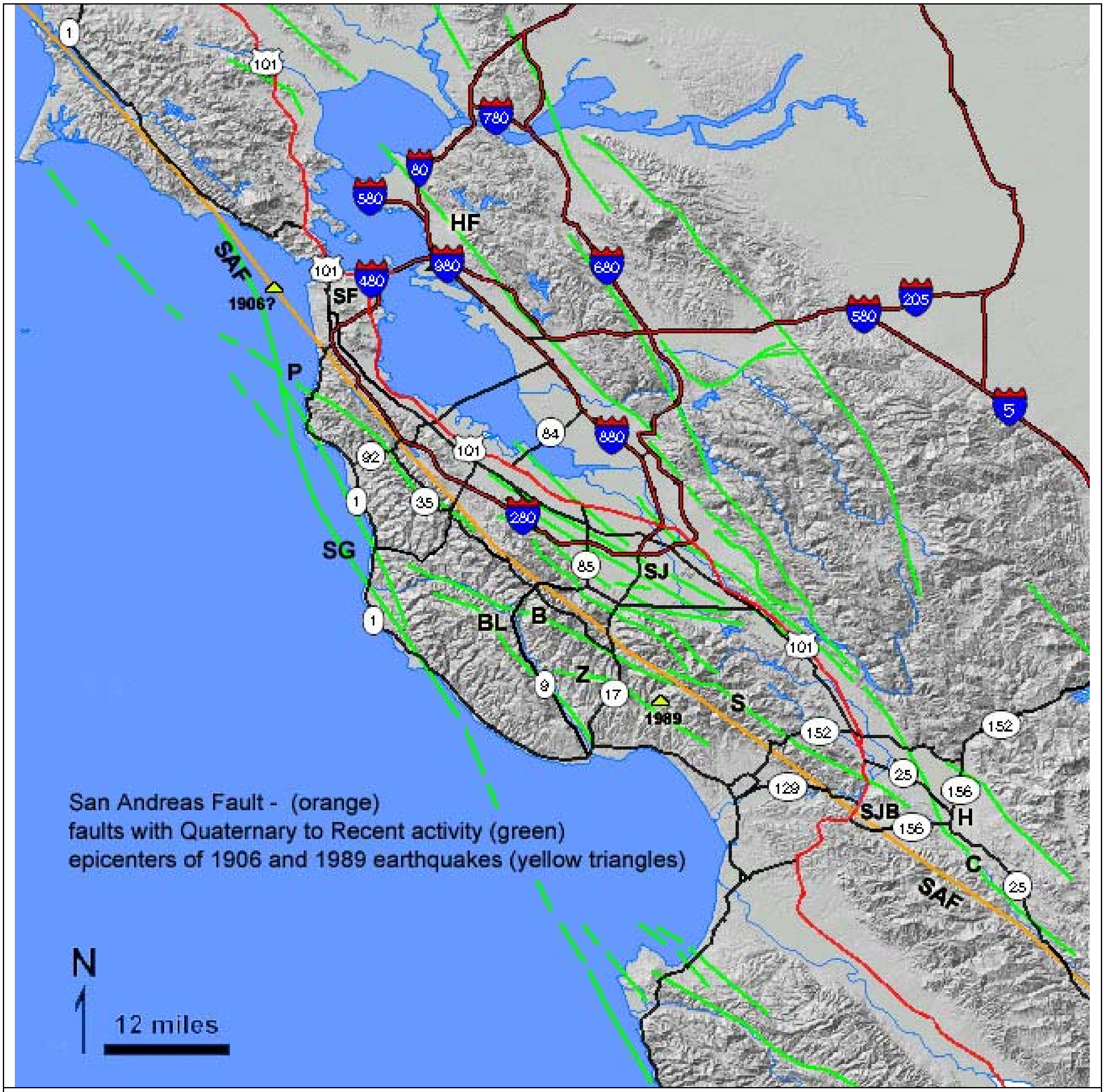


Figure 1-4. Map highlighting the trace of the San Andreas Fault through the San Francisco Bay region (shown in orange). Additional faults that have had Quaternary and historic earthquake activity or movement are shown in green. The location of the epicenter of the 1989 Loma Prieta earthquake and the possible offshore epicenter of the 1906 earthquake are shown

as yellow triangles. The 1906 earthquake produced surface rupture from San Juan Bautista northward to where it extends offshore at Cape Arena. The 1906 earthquake probably also ruptured offshore northward along the seabed toward the Mendicino Triple Junction located offshore from the California-Oregon border. In contrast, the surficial effect of the Loma Prieta earthquake were mostly limited to the region between California highways 17 and 152. The San Andreas Fault south of San Juan Bautista is part of the "creeping section" of the fault. Letter labels of selected faults include the San Andreas Fault (SAF), Calaveras Fault (C), Hayward Fault (HF), San Gregorio Fault System (SG), Zayente Fault (Z), Butano Fault (B), Ben Lomond Fault (BL), Sargent Fault (S), and Pilarcitos Fault (P). Cities include San Francisco (SF), San Jose (SJ), Hollister (H), and San Juan Bautista (SJB). Source: http://earthquake.usgs.gov/qfaults.

Thousands of small, almost imperceptible earthquakes occur in the Bay Area each year, only a handful of which make local news. However, in the period from 1800 to the present, the San Francisco Bay region has been shaken by twenty-one earthquakes of Richter M = 6.0 or greater. Of these, six were in the range of M = 6.5 to 7.0. An earthquake of damaging magnitude could happen at any time on any number of candidate faults. It is the faults located in urbanized areas that most concern geologists (and should concern the public), particularly the Hayward, Calaveras, and Rogers Creek faults, but there are many more known (and potentially unknown candidates). However, the San Andreas Fault has historically produced the largest earthquakes: the Loma Prieta Earthquake of 1989 was probably a M = 7.1, and the Great San Francisco Earthquake of 1906 was in the range of M = 7.8 (or greater). Another earthquake in the M = 7.0 range occurred along the Peninsula section of the San Andreas Fault in 1838, and others preceded it, but very little is known about these events. [Source: California Earthquake History 1769-Present: http://pasadena.wr.usgs.gov/info/cahist_eqs.html.]

Comparison of the Bay Area earthquakes: 1906 and 1989

Great San Francisco Earthquake (1906)	**Loma Prieta Earthquake (1989)**
Time: 5:12 AM - April 18,1906	**Time**: 4:15 PM - October 17, 1989
Duration: 45 to 60 seconds	**Duration:** 10 to 15 seconds
Magnitude (Richter): M = ~7.8, although traditional estimates were as high as 8.3, whereas modern estimates range from 7.7 to 7.9.	**Magnitude (Richter):** M=~7.0 with reported variation from 6.9 to 7.1. The 1989 earthquake was only ~1/16 as intense as the 1906 earthquake.
Highest Modified Mercalli Intensities: Shaking intensities of VIII (moderate damage) to IX (heavy damage) extending as much as 60 miles inland along a broad band paralleling the fault trace -- depending of competence of subsurface materials [soils or fill vs. bedrock]. Heavy shaking and damage occurred throughout the San Francisco Bay region with the greatest amount of damage affecting the existing urban areas of San Francisco, Santa Rosa, Hayward, San Jose, and San Juan Bautista.	**Highest Modified Mercalli Intensities:** X (extreme damage) to IX (heavy damage) was limited to the vicinity of the San Andreas Fault trace in the southern Santa Cruz Mountains from Highway 17 to near Aromas in Santa Cruz County. Most of the Bay Area only experienced V (strongly felt) to VII (light damage). VIII (moderate damage) occurred throughout much of eastern Santa Cruz County and in areas around San Francisco Bay underlain by poorly consolidated sediments and artificial fill. Some of the heaviest damage occurred in San Francisco's Marina District and China Basin (the same areas built on fill heavily shaken during the 1906 earthquake).
Length of fault rupture: ~300 miles (480 km) from the San Juan Bautista area northward to the Mendicino Triple Junction (offshore).	**Length of fault rupture:** ~25 miles (40 km) in the southern Santa Cruz Mountains east of Highway 17.
Epicenter: Current thought is that the epicenter may have been west of San Francisco in the Pacific Ocean west of Thornton Beach. Earlier reports suggest the epicenter may have been closer to Point Reyes where the greatest offset was reported.	**Epicenter:** Located in the Forest of Nisene Marks State Park between Loma Prieta Peak and Santa Cruz (37.040N, 121.877W). The earthquake hypocenter occurred at a depth of 11 miles (18 km) located approximately 4 miles west of the surface trace of the San Andreas Fault (the fault plane dips at an angle of about 75 degrees to the west).

Fault rupture characteristics: As much as 20 feet of right-lateral offset was reported near Point Reyes (Lawson report), with greater amount projected at depth. More recent projections include up to 24 feet at depth at Point Reyes and up to 28 feet near Shelter Cove. In the Peninsula region offset was in the order 9-12 feet and diminished southward. Offset of about 3-5 feet was reported in the Pajaro Gap to San Juan Bautista area. No surface rupture was reported farther south, but strong earthquake shaking was reported in this largely uninhabited region.	**Fault rupture characteristics:** Estimates of 6.2 feet of horizontal right-lateral displacement with 4.2 feet of vertical (reverse) displacement with uplift on the west side relative to the east side of the fault. Debate still continues whether the 1989 earthquake actually occurred within the San Andreas Fault Zone.
Great San Francisco Earthquake (1906)	**Loma Prieta Earthquake (1989)**
People killed or injured: 700 deaths were initially reported, but revised estimates are closer to +3,000 killed by the earthquake and fire. Many thousands were injured.	**People killed or injured:** 62 to 67 deaths were reported, and nearly 400 people were severely injured. Total reported injuries were ~4,000.
Bay Area population in 1906: ~400,000	**Bay Area population in 1989:** ~6,000,000
Number of people left homeless: ~250,000	**Number of people left homeless:** ~3,000
Buildings damaged: ~28,000 building were destroyed (mostly by extensive fires after the earthquake).	**Buildings damaged:** ~12,000 homes and 2,600 businesses were damaged or destroyed. Images of damage are available at: http://wrgis.wr.usgs.gov/dds/dds-29
Cost: (1906 dollars): ~400 million dollars	**Cost: (1989 dollars):** ~6 billion dollars
Source: The Great San Francisco Earthquake: U.S. Geological Survey, Earthquake Hazards Program - Northern California: http://quake.wr.usgs.gov/info/1906/. .	**Source:** Calif. Div. Mines & Geology Special Publication 104; USGS PP 1551-A; http://www.seismo.berkeley.edu/seismo/faq/1989_0.html.

Comparison of Earthquake Magnitude and Intensity

The effects of earthquakes are reported in two ways: magnitude (the amount of energy released by an earthquake), and Intensity (a measure of the shaking produced by an earthquake). Magnitude is determined from the study of seismograms, which are a record of Earth motion recorded by seismographs. The Richter Scale is the mostly widely reported measure of earthquake magnitude. The scale is a logarithmic measure of seismic amplitude, with each whole number representing a 10 fold increase in seismic amplitude, and about 31 times the amount of energy released. For instance a strong earthquake of M=6.4 would have amplitude ten times greater than a moderate earthquake of M=5.4. Great earthquakes are in the range of M=8 or more.

Intensity is determined from the effects on people, buildings, infrastructure, and other factors related to the physical setting (for instance, whether a structure is built on unconsolidated bay mud versus solid bedrock). The Modified Mercalli Intensity Scale is used to report shaking intensity.

Magnitude/Intensity Comparison

Richter Magnitude Scale (M)	Modified Mercalli Intensity Scale (MMI)	Magnitude/Intensity felt near an earthquake epicenter
1.0- 1.9	**I**	An M=1 is roughly equivalent to a quarry blast and can be generated by non-earthquake related events (such as a rock fall). Earthquakes of this intensity are generally not felt.
2.0-2.9	**II**	Felt by only a few people at rest, especially on the upper floors of buildings.
3.0-3.9	**III**	Felt noticeably by people indoors or on upper floors of buildings, but may not be recognized as an earthquake (similar to shaking by a passing truck, typically very short in duration).
4.0-4.9	**IV-V**	Felt noticeably by people both indoors and outdoors. Will wake some sleeping people. Walls will make cracking noises, and dishes, doors, and windows will rattle or move. Motor vehicles will rock noticeably. MMI=5 will cause unstable objects to fall or overturn; pendulum clocks may stop.
5	**VI-VII**	An M=5 earthquake is roughly equivalent to the force of a 10 kiloton nuclear blast (like Hiroshima). Earthquakes of this magnitude are felt by practically everyone. Damage is negligible in well-constructed buildings. Plaster may crack and fall; some chimneys may be broken.
6	**V11-IX**	Damage negligible in well-designed buildings. Slight to great damage to buildings and infrastructure of poor design.
7	**VIII and higher**	Well designed buildings may experience some damage. Building and bridges may shift off their foundations or partially collapse.
8	**X and higher**	Wooden building may be destroyed. Few masonry structures remain standing. Bridges destroyed; rail lines are bent.
9	**XII**	Damage total. The ground is distorted. Objects are thrown into the air.

There are other methods of measure of earthquake magnitude and intensity used by seismologists. Many factors come into play (such as the number and proximity of seismic stations to an earthquake epicenter, the direction of seismic motion, and other factors). For more information see the USGS Earthquake Facts & Lists websites on magnitude and intensity at: http://earthquake.usgs.gov/bytopic/mag_int.html.

Geologic Features of the San Andreas Fault

Broken up into slivers, like a moving van after being caught between two passing freight trains... pieces left everywhere along the rails.

This analogy certainly applies to the bedrock along the San Andreas Fault System! Great blocks of the earth's crust have split away from their place of origin and have been carried northward along the fault system. However, much of this material had already been displaced long distances from their place of origin by plate tectonic motion long before the modern San Andreas Fault had formed. Fig. 1-5 below is a selected list of prominent geologic features that support evidence about timing, rate of development, and cumulative amount of offset along the San Andreas Fault and associated faults throughout California. Rocks discussed in this section formed before and concurrent with the ongoing development of the San Andreas Fault. Examples of offset geologic features in fig. 1-5 and information derived from selected references [1 to 6] are a selection of well known or heavily investigated features. However, the fault system is far more complex and the wealth of observable features in the field is much more diverse than presented here. For more information about fault-bounded blocks (also called *terranes*) in the Santa Cruz Mountains see Wells (2000) and Wentworth and others (1998).

Rocks West of the Fault

Mesozoic granitic basement lie west of the San Andreas Fault from southern California northward to the San Francisco Bay region. These rocks occur as great crustal blocks that were carried northward along the western continental margin by plate tectonic motion both before and during the development of the San Andreas Fault System. These granitic rocks, called Sur Series and Salinian Complex, are exposed in the Gavilan Range, the Monterey Peninsula, Ben Lomond Mountain, Montara Mountain, and Point Reyes. These granites are overlain by marine sedimentary rocks of latest Cretaceous to Tertiary age (yet predate the faults) and represent environments ranging from deep abyssal fan to shelf and nearshore environments. These are in turn overlain by sediments that accumulated in shelf, marginal marine, river, and inland bay environments that developed as the regional fault system formed.

Rocks East of the Fault

East of the San Andreas Fault, rocks that predate the fault system include the Coast Range Ophiolite (CRO consists mostly of serpentinized ultramafic rocks and greenstone), Franciscan Complex (ribbon chert, limestone, greenstone, pillow basalt, mudrocks and sandstone). These are juxtaposed or overlain by sedimentary rocks of the Great Valley Sequence (mostly sandstone, shale, conglomerate) that were deposited concurrently with material being thrust downward into a subduction zone (Franciscan Complex) in the region along what is now coastal California but was in a deep water setting at the time. When subduction ended after the Mid-Pacific Ridge was subducted, a series of volcanoes formed along a northward propagating rift, the incipient San Andreas Fault System. Through this period, the dominantly marine conditions of the Cretaceous gave way to estuaries, river deltas, and to terrestrial environments. Since late Tertiary time, coastal California must have appeared somewhat as it does today, a mix of low mountains (or islands), hills, lowland valleys, and bays, but with no similarities to the modern configuration of the coastal landscape. For instance, a great bay extended northward from the Los Angeles region into the southern San Joaquin Valley until as recently as 4 million years ago. Since then the Coast Ranges have experienced both significant uplift and unroofing by erosion. Coastal marine terraces cut by the rise and fall of sea level as continental glaciers formed and melted during the Quaternary ice ages. Studies of marine terraces have shown that portions of the modern coastline are simultaneously rising or sinking and that these tectonic changes are associated with the regional fault system.

Interpreted History of Fault Motion

The northward transport of rocks was occurring before the San Andreas formed, as recorded by some of the oldest rocks in the Bay Area - the best examples include ribbon cherts that must have accumulated in clear, mid ocean equatorial waters during Jurassic time. The Cretaceous-age Calera Limestone is thought to have formed on seamounts in warm equatorial waters. These rocks were transported northward before being accreted onto the continental margin, and are now exposed today throughout the Santa Cruz Mountains and near Point Reyes. These rocks that predate the San Andreas

Fault were moved, in part, north by older fault systems. During Cretaceous to mid Tertiary time much of this motion was associated with northeastward movement of the Farallon and Pacific Plate and their subduction Plate beneath the North American continental margin [6, see fig. 1-3]. In mid Tertiary time subduction was replaced with right-lateral transform faulting that resulted in the propagation of the San Andreas Fault northward from the Los Angeles region starting about 28 million years ago. The leading edge of the fault system propagated through the Bay Area beginning about 12 million years ago, but the modern trace of the San Andreas Fault didn't develop until much more recently, probably in the 5 to 7 million year range. Meanwhile other faults in the Bay Area have been, and currently are, more active in terms of rates of relative offset motion over time. Higher rates of fault motion are estimated for parts of the East Bay fault system and possibly along the San Gregorio fault system that runs along the coast and offshore [1][2][3][5]. Of the 300 km miles of offset determined in the mid section of the San Andreas Fault (based on A-A' and B-B'), about 174 km of offset in the Bay Area has occurred along the East Bay fault system, whereas the remaining 127 km of offset has been along the San Andreas Fault in the Santa Cruz Mountains on the San Francisco Peninsula. Of this 22 km has been absorbed on the modern San Andreas after 100 to 105 km of offset occurred on the Pilarcitos/Montara Fault [3]. Another estimate suggests that as much as 150 km of offset has occurred along the San Andreas Fault in the southern Santa Cruz Mountains since Miocene time, of which 27 km has occurred in the past 3 million years [4].

Estimations of slip rates along the San Andreas Fault System vary from one location to the next, and from one period of time to another. The separation of equivalent rocks in Baja California and the coast of Mexico demonstrate that the relative motion between the North American Plate and the Pacific Plate is in the range of about 5 cm per year for post-Pliocene time. Along the northern section of San Andreas Fault System, the belt of late Tertiary and Quaternary faulting is up to 120 km wide (extending from the eastern side of the Diablo Range to offshore)[5]. In the southern Bay Area associated major faults include the San Gregorio, San Andreas, Hayward, Calaveras, and possibly a range-front fault system on the east side of the Diablo Range. All of these faults display Quaternary offset and are seismically active. As a result, the nearly 5 cm/year of ongoing offset determined to take place across North American and Pacific plate boundary is distributed between all of these faults. Slip rate estimates on the San Francisco peninsula section of the San Andreas Fault are in the range of 1.6 to 1.7 cm per year (based on fig. 5 sites I and J). A rate for the southern Santa Cruz Mountains is between 1 and 3 cm per year (based on site H). As a result, the potential for damaging earthquakes is distributed across the Bay Area’s fault system.

Information resources

[1] Irwin, W.P., 1990, Geology and plate-tectonic development: In *The San Andreas Fault System, California*: Wallace, R.E., ed., U.S. Geological Survey Professional Paper 1515, p. 61-80.

[2] Wentworth, C.M., Jones, D.L., and Brabb, E.E., 1998, Geology and regional correlation of the Cretaceous and Paleogene rocks of the Gualala block, California: In *Geology and Tectonics of the Gualala Block, Northern California*: Elder, W.P, ed., Society of Economic Paleontologists and Mineralologists, Pacific Section, Book 84, p. 3-26.

[3] Jachens, R.C., Wentworth, C.M., and McLaughlin, R.J., 1998, Pre-San Andreas location of the Gualala block inferred from magnetic and gravity anomalies: In *Geology and Tectonics of the Gualala Block, Northern California*: Elder, W.P, ed., Society of Economic Paleontologists and Mineralologists, Pacific Section, Book 84, p. 27-63.

[4] McLauglin, R.J., Clark, J.C., Brabb, E.E., Helley, E.J., and Colon, C.J., 2002, Geologic Maps and Structure Sections of the southwestern Santa Clara Valley and southern Santa Cruz Mountains, Santa Clara and Santa Cruz Counties, California: U.S. Geological Survey Miscellaneous Field Studies 2373: http://geopubs.wr.usgs.gov/map-mf/mf2373/.

[5] Brown, R.D., Jr., 1990, Quaternary deformation: In *The San Andreas Fault System, California*: Wallace, R.E., ed., U.S. Geological Survey Professional Paper 1515, p. 83-113.

[6] U.S. Geological Survey, 1996 [2003 rev.], Farallon Plate: *This Dynamic Earth* website: http://pubs.usgs.gov/publications/text/Farallon.html.

Well, Ray E., (ed.), 2004, *The Loma Prieta, California Earthquake of October 17,1989—Geologic Setting and Crustal Structure*: U.S. Geological Survey Professional Paper 1550-E, 204 p.

Wentworth, C.M., M.C. Black, R.J. McLaughlin, and R.W. Graymer, 1998, *Preliminary Geologic Map of the San Jose 30 X 60-Minute Quadrangle, California*: U.S. Geological Survey Open File Report 98-795; available on-line at: http://wrgis.wr.usgs.gov/open-file/of98-795.

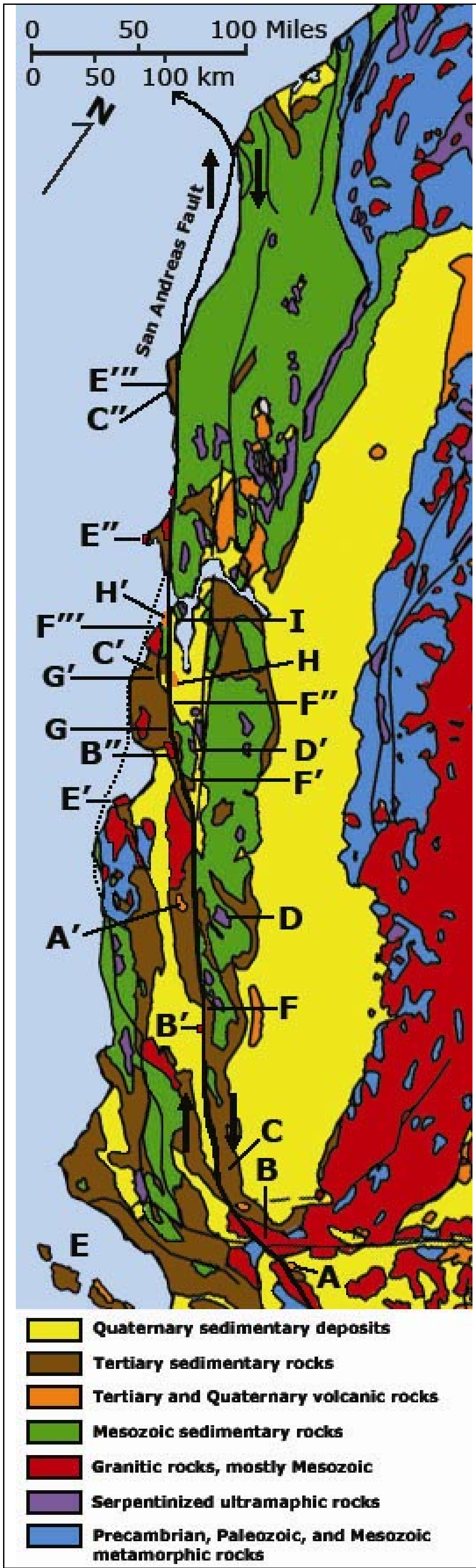


Figure 1-5. Selected geologic ties across the San Andreas Fault System that help define the age, and the rate and amount of offset along the system. These "large scale" features are visible on a map or from space, but require travel to see them on the ground.

A - Early Miocene volcanic rocks [~23 million years]: A - Neenach Volcanic Area, A' - Pinnacles Volcanic Area; (A-A' offset distance: 315 km)[1]

B - Cretaceous plutonic rocks: B - gabbro at Eagle Rest Peak, B' - Gold Hill gabbro in the Parkfield area, B" - Logan gabbro quarry; (B-B" offset distance: 320 km)[1]

C - Eocene sedimentary rocks: C - Butano and Point of Rocks formations in the San Joaquin Basin, C' Butano Formation in the La Honda Basin in the Santa Cruz Mountains, C" - Eocene sedimentary rocks in the Gualala block[2]: (C-C' offset distance: ~320 km, C'-C" offset distance: ~150 km, total C-C" offset ~470 km)

D - Miocene mercury deposits [18 to 10 million years](silica-carbonate rocks): D - Clear Creek and New Idria Mining District, D' - New Almaden Mining District; (D to D' offset distance: ~265 km)

E - Paleocene gravels bearing mafic clasts: E - Ventura River, E' - Point Lobos, E" - Point Reyes, E'"- Gualala block, Anchor Bay Formation; some of this offset is along the Sur-Nacimiento-Hosgri-San Gregorio Fault System (E to E'" offset distance: 585 km)

F - Permanente Terrane (limestone and volcanic rocks of Cretaceous age): F - Parkfield, Bay Area occurrences include the Calera Limestone in the Santa Cruz Mountains region: F' - Morgan Hill area (El Toro Peak), F" - Stevens Creek quarry, and F'" - Rockaway Beach quarry; (F to F'" offset distance: ~350 km). Some of this offset, between F" and F'", is along the Pilarcitos Fault (which is an older and possibly inactive segment of San Andreas Fault in the Peninsula region of the Bay Area[4]

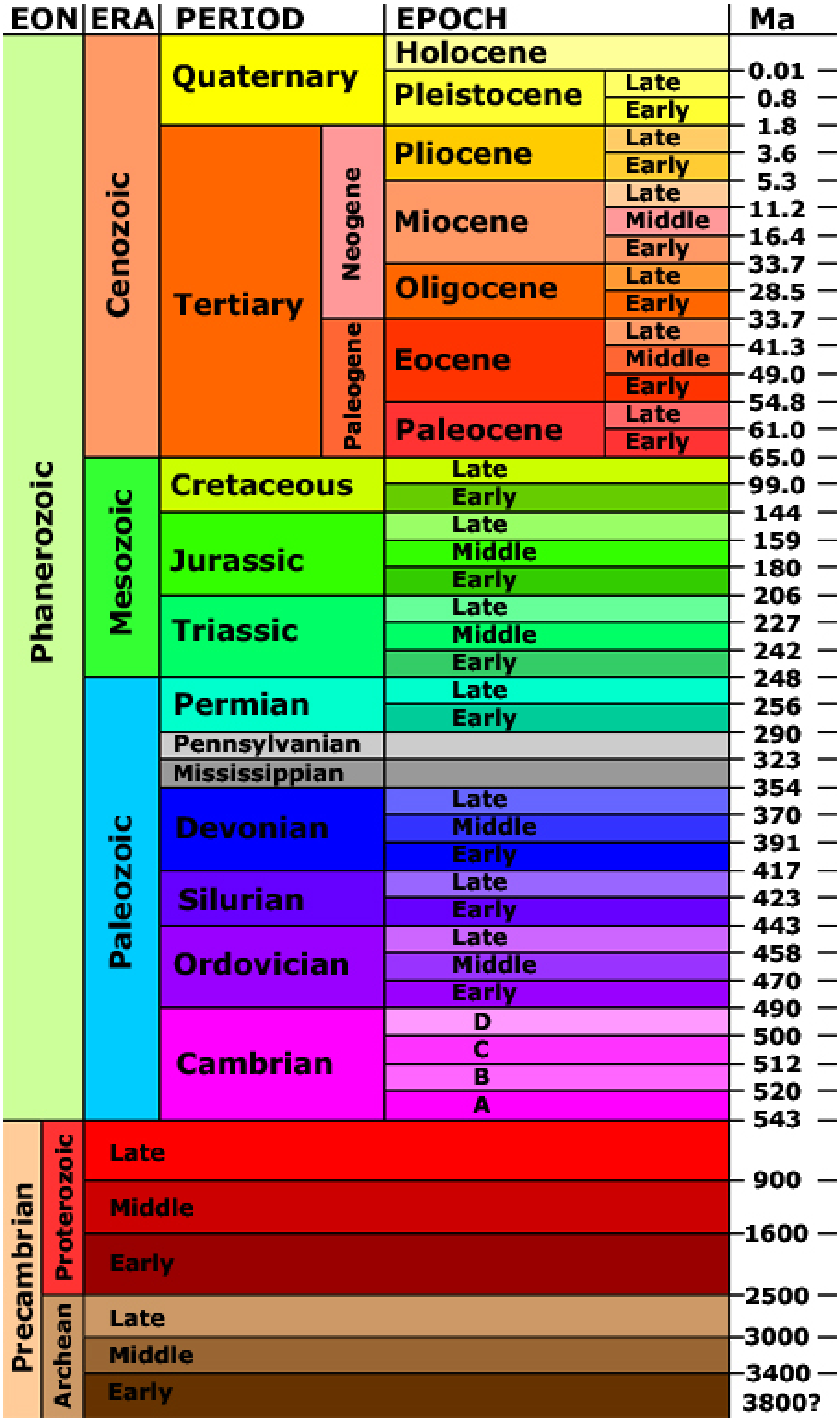
G - Gravels the Corte Madera facies of the Santa Clara Formation of Plio-Pleistocene age [3 to 1 million years]derived from the Loma Prieta and Mt. Umunhum summit areas (G) occur in old alluvial fan deposits preserved in the Los Trancos and Monte Bello preserves area (G') 23 km to the north; (offset distance: 28 km)[5]

H - A coastal embayment that existed 2 to 3 million years ago in the Stanford Hills area (H - east of the fault) is offset 35 to 40 km to the north (H' - west of the fault) [5]

I - Offset Merced Formation on the San Francisco Peninsula displays a minimum offset of 11 kilometers for material 0.4 to 2.0 million years old [5]

[References 1-5 are listed below in information resources.] The base map of this image is modified after a generalized geologic map of California produced by the California Geological Survey. See Fig. 1-6 for a geologic time scale.

Figure 1-6. Geologic Time Scale. Time subdivisions and geologic ages in millions of years (Ma) are after the Geological Society of America 1999 Geologic Time Scale: http://www.geosociety.org/science/timescale/timescl.pdf.



EON	ERA	PERIOD		EPOCH		Ma
Phanerozoic	Cenozoic	Quaternary		Holocene		0.01
				Pleistocene	Late	0.8
					Early	1.8
		Tertiary	Neogene	Pliocene	Late	3.6
					Early	5.3
				Miocene	Late	11.2
					Middle	16.4
					Early	33.7
				Oligocene	Late	28.5
					Early	33.7
			Paleogene	Eocene	Late	41.3
					Middle	49.0
					Early	54.8
				Paleocene	Late	61.0
					Early	65.0
	Mesozoic	Cretaceous		Late		99.0
				Early		144
		Jurassic		Late		159
				Middle		180
				Early		206
		Triassic		Late		227
				Middle		242
				Early		248
	Paleozoic	Permian		Late		256
				Early		290
		Pennsylvanian				323
		Mississippian				354
		Devonian		Late		370
				Middle		391
				Early		417
		Silurian		Late		423
				Early		443
		Ordovician		Late		458
				Middle		470
				Early		490
		Cambrian		D		500
				C		512
				B		520
				A		543
Precambrian	Proterozoic	Late				900
		Middle				1600
		Early				2500
	Archean	Late				3000
		Middle				3400
		Early				3800?

Types of Faults

A **fault** is a fracture between blocks of the Earth's crust across which movement has occurred (see fig. 1-7). Types of faults include:

Strike-slip faults are vertical (or nearly vertical) fractures where the blocks have mostly moved horizontally. 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.

Dip-slip faults are 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*** (or ***thrust***). Oblique-slip faults have significant components of both slip styles.

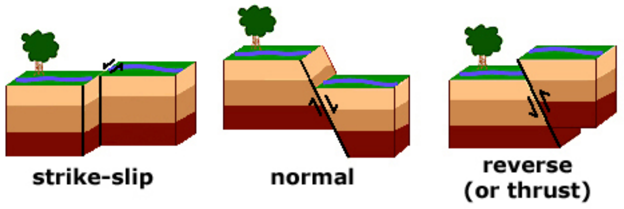


Figure 1-7. The strike-slip fault shown here displays right-lateral offset. Dip-slip faults include normal and reverse (or thrust) faults. Although strike-slip motion dominates, all three types of faulting and combinations of strike-slip and dip-slip can be observed along the San Andreas Fault and other faults in the region.

A **fault line** is 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.

A **fault zone** is 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 as wide as hundreds of meters.

A **fault system** is a collection of parallel and/or interconnected faults that display a related pattern of relative offset and activity across an entire region (e.g. San Andreas Fault System throughout California).

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

Geomorphic Features Observable Along Faults

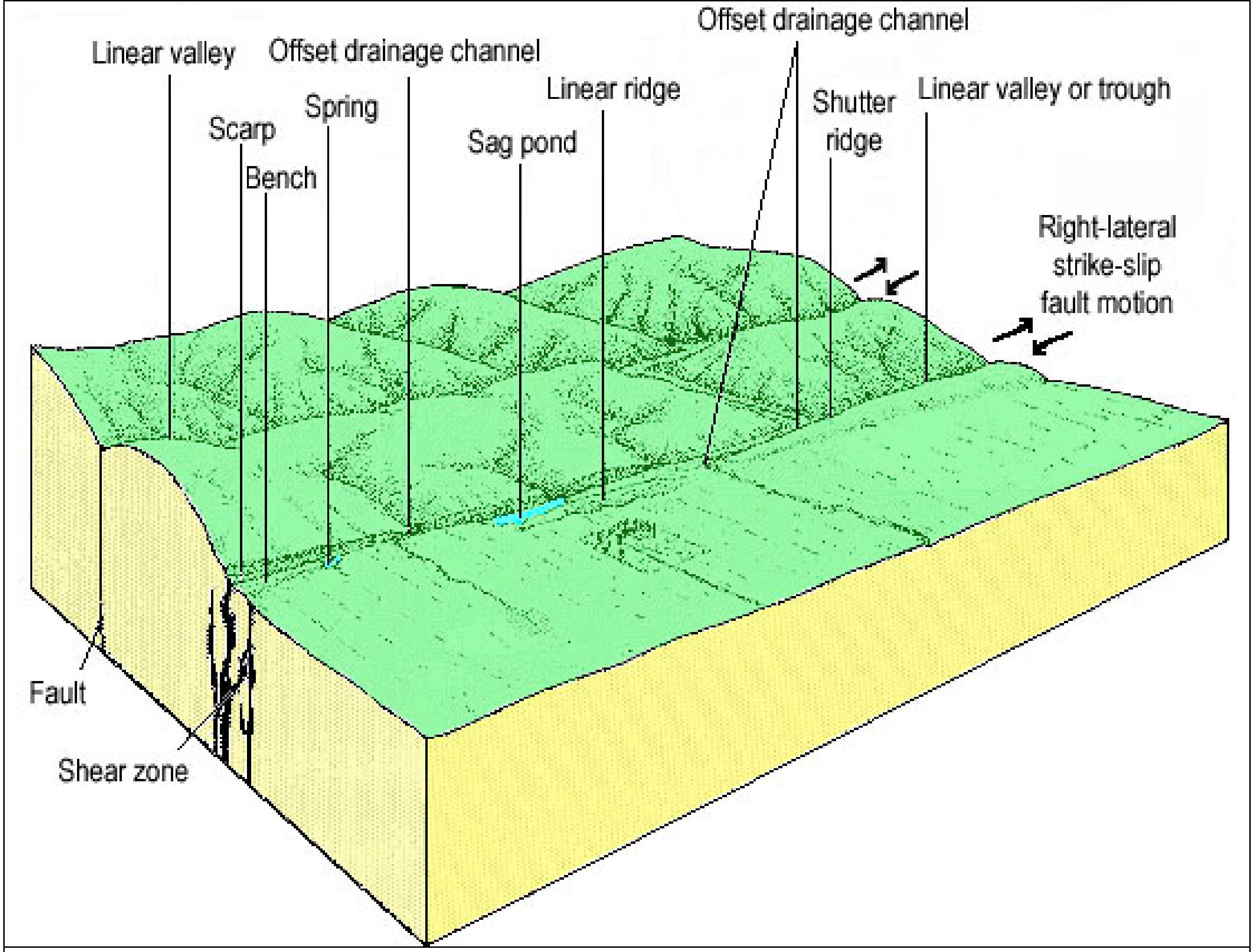


Figure 1-8. Geomorphic features associated with the San Andreas Fault System in California (after Vedder and Wallace, 1970; Wallace, 1990).

The most conspicuous landscape features that reveal the location of the San Andreas Fault, and many other regional faults, are structures that display evidence of right-lateral offset. Other characteristics include juxtaposed bedrock types, linear landscape features, springs, stream patterns, and natural catchment basins with ponds. Vertical uplift along the fault (on one or both sides), or bifurcating or echelon fault patterns, folding, and the varying width and erosion along a active and past-active fault zone can create challenges in finding and following a fault trace. Stream patterns are typically revealing, but must be verified by other lines of evidence. The fault trace is often obscured by topography (such as where a fault crosses hill slopes and stream divides), by ground cover, by landslides and colluvium, or by surface disruption from human activity. Fig. 1-8 provides many of the key landscape features that form as fault motion impacts an eroding or changing landscape surface over time.

Offset manmade features: Offset roads, pipelines, fences, tree rows, buildings, and other damaged infrastructure may reveal the location of faults. The Bay Area has many famous examples of offset features, including examples along the San Andreas and Calaveras faults in the Hollister region (illustrated in this guidebook), the historic City Hall in Hayward (on the creeping Hayward Fault). Restored examples of offset fences can be seen at Los Trancos Open Space Preserve and along the Earthquake Trail near the Visitor Center at Point Reyes National Seashore.

Bedrock contrasts and evidence of faulting: Changes in lithology are not always fault related, but major lithologic changes can be observed across faults throughout the San Francisco Bay region. These contrasts in bedrock may reflect both ancient and more recent fault activity. Bedrock contrasts are typically reflected by associated changes in weathering and erosion pattern (geomorphology), and differences in soil and vegetation characteristics. More direct evidence of faulting include slickensides (a polished and striated rock surface produced by friction along a fault), and pulverized and fractured rock (or clay where weathering has occurred). It is important to note that surficial processes associated with slumping and landslides often produce features that can be easily confused with faulting. However, the two processes are commonly associated.

Offset drainages: Offset drainages are perhaps the most conspicuous evidence of recent movement along a strike-slip fault. It is important to note that not all bends in stream channels are fault related; additional lines of evidence are necessary to prove that a stream channel was offset by fault motion. Notable examples include Bird Creek in the Hollister Hills State Vehicular Recreation Area, Coyote Creek (along the Calaveras Fault between Coyote and Anderson reservoirs in the South Bay region), and Sanborn Creek in Sanborn County Park (Santa Clara County).

Beheaded stream channels: 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. Examples can be seen at Sanborn County Park.

Linear troughs: The San Andreas Fault Zone ranges in width from meters to about a kilometer. Both tectonic extension and the erosion of sheared and softer rock along the fault zone result in the development of linear troughs along the San Andreas Fault. Linear troughs are typically valleys bounded by linear fault scarps. On many USGS topographic maps these linear troughs are labeled "San Andreas Rift Zone." Notable Bay Area examples include the San Andreas Rift Valley at Crystal Springs and San Andreas reservoirs along I-280 and at Tomales Bay at Point Reyes National Seashore.

Linear drainages: A stream drainage that follows the trace of a fault. Stream alignment may be a result of strike-slip fault motion or from the erosion of sheared and pulverized rock along the fault trace. Bay Area examples include upper Steven Creek Canyon in the Santa Cruz Mountains and Olema Creek at Point Reyes National Seashore.

Linear scarps: Linear scarps may form 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.

Sidehill benches: Both recent fault activity or erosional differences of bedrock lithology across a fault may produce sidehill benches and associated linear scarps. Sidehill benches may form from slumping as well (that may or may not be associated with faulting).

Linear ridges: A linear ridge is a long hill or crest of land that stretches in a straight line. It may indicate the presence of a fold or fault. If it is found along a strike-slip fault it may be a shutter ridge or a pressure ridge.

Shutter ridges: A shutter ridge is 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. Shutter ridges typically are found in association with offset streams.

Pressure ridges: A pressure ridge is a topographic ridge produced by compressional bends or stepovers along a strike-slip fault zone (see fig. 1-9).

Closed depressions (pull-apart basins): Closed depressions can form along fault zones where extensional bends or stepovers occur along a strike-slip fault zone (see fig. 1-9). 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). If the pull-apart can hold water, even temporarily, it is called a sag pond.

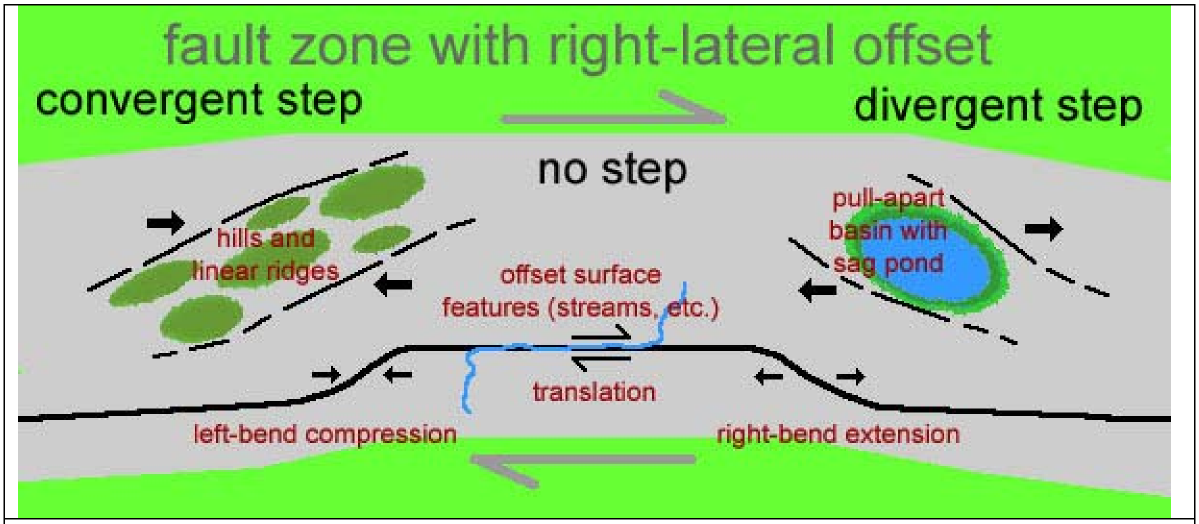


Figure 1-9. Geomorphic features associated with divergent and convergent step in a fault zone. Active faults (black) are shown within a broader fault zone (gray). These examples are in a right-lateral strike slip fault zone like the San Andreas Fault.

Linear vegetation contrasts: The natural landscape along the fault zone may show changes in vegetation across the fault trace. This typically reflects changes in the physical character of soils associated with the weathering of the underlying bedrock. For example, well-drained alluvium might be overlain by grass. Oak woodlands may prefer a soil formed on weathered shale that can retain more water, or a conifer forest will more likely develop where more acidic conditions occur in sandy soils derived from the weathering of sandstone. Manzanita often thrives in areas underlain by serpentinite. In many places throughout the Bay Area, vegetation contrasts are perhaps the most revealing evidence of the location of faults. However, historic fence lines, fires, logging, and other activity may be responsible for linear vegetation contrasts.

Regional Scale Features

Regional scale features associated with the San Andreas Fault System are typically too big to observe from the ground and require observation from maps, aerial photographs, and satellite images. From the air, the San Andreas Fault often appears as a linear trace across the landscape even though it might not be obvious to observers on the ground. The San Andreas Fault is not perfectly straight, but bends gently in some locations. Where the fault bends to the left (where observed from the south), enhanced compressional forces produced uplifts like the Santa Cruz Mountains and Gavilan Range. Where the fault bends to the right the lands surface is downwarped, such as in the region around San Francisco Bay where the San Andreas Fault runs under the Pacific Ocean. In areas where the fault is relatively straight there may be little or no relief such as in the region around the Carrizo Plain in central California. The complexity of the interconnected fault system in the San Francisco Bay region can arguably be responsible for nearly all the prominent landscape features. The Santa Cruz Mountains can be viewed as a great pressure ridge along the San Andreas Fault, and the Diablo Range and East Bay Hills are pressure ridges along the Calaveras and Hayward faults of the East Bay fault system. In many places, thrust faults splay away from these major faults (at depths of many kilometers), and extend laterally into surrounding areas. Some thrust faults are exposed along the range fronts or extend into the basin areas around San Francisco Bay and along the Santa Clara Valley. Some thrust faults (called *blind thrusts*) may not be exposed at the surface and could potentially produce severe earthquake damage to urbanized areas.

Vedder, J.D. and Wallace, R.E., 1970, Map showing recently active breaks along the San Andreas and related faults between Cholame Valley and Tejon Pass, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-574, scale 1:24,000.

Wallace, R.E., 1990, Geomorphic expressions: In, The San Andreas Fault System, California, Wallace, R.E., ed., U.S. Geological Survey Professional Paper 1515, p. 15-58.

Geomorphic Features Associated With Landslides

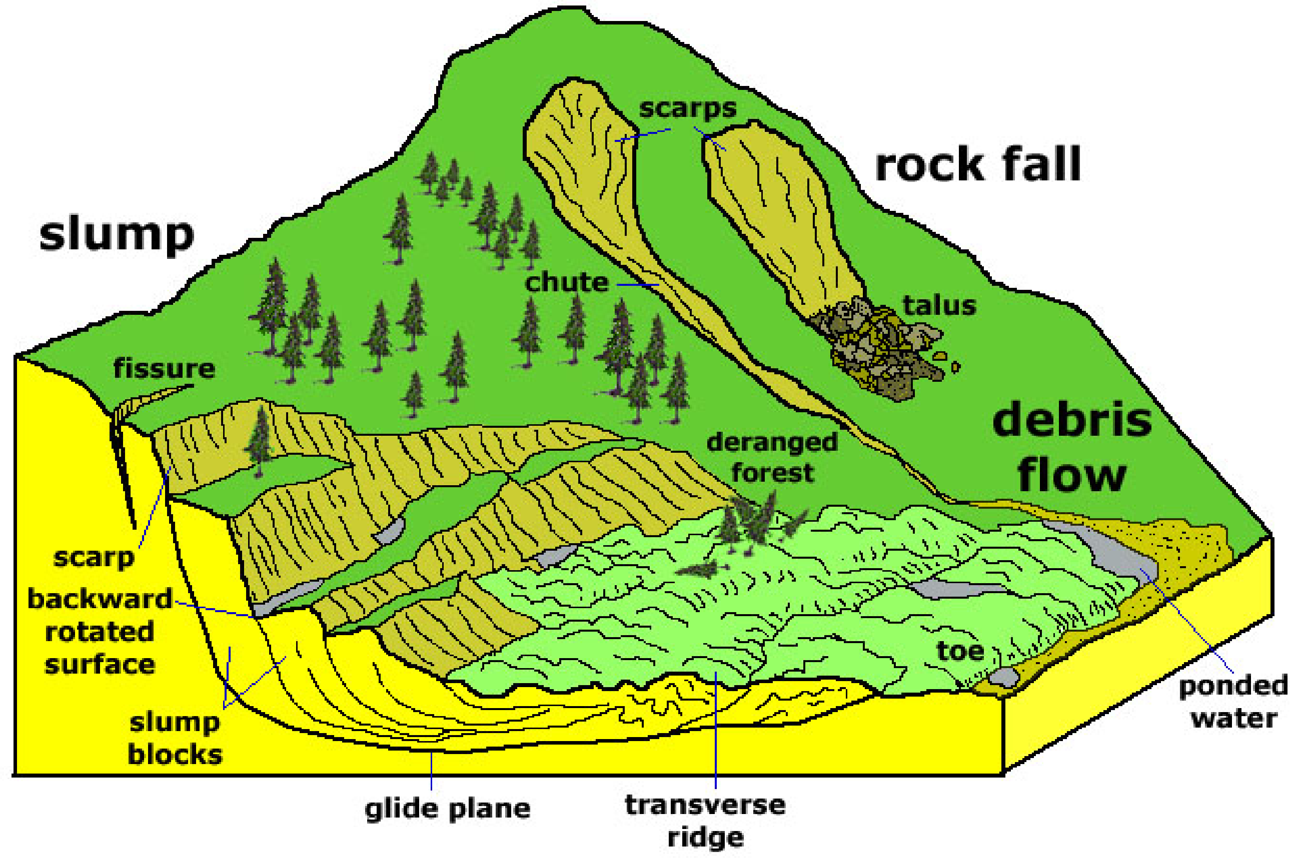


Figure 1-10. Landscape features associated with landsliding and slumping.

Landslides produce many of the same geomorphic features as those associated with faults of tectonic origin. In fact, it is often difficult to differentiate tectonic faulting from landsliding, which is a result of gravitational forces. These different processes are defined:

A **landslide** is a general term covering a wide variety of mass-movement landforms and processes involving the downslope transport, under gravitational influence, of soil and rock *en masse*. Usually the displaced material moves over a relatively confined zone or surface of shear. Landslides have a great range of morphologies, rates, patterns of movement, and scale. Their occurrence reflects bedrock and soil characteristics and structures, 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, mudflows are all various forms of landslides. A slump is the downward slipping of a mass of rock or unconsolidated material, moving as a unit, usually with backward rotation on a more or less horizontal axis parallel to a slope or cliff from which it descends. Slumps typically form a fault-like escarpment and may occur at the head of a landslide.

A **rockfall** is 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 mountain areas and during spring when there is repeated freezing and thawing of water in cracks of 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.

A **debris flow** is a moving mass of rock fragments, soil, and mud, more than half of the particles being larger than sand size (otherwise it would be a mudflow), and is 70 to 90 percent sediment load (the rest is water). Slow debris flows may move less than 1 meter per year, whereas rapid ones can reach speeds greater than 100 miles per hour. Debris flows can display both turbulent or laminar flow characteristics.

A **debris flood** is a typically disastrous flood, intermediate between the turbid flood of a mountain stream and a debris flow, ranging in sediment load between 40-70 percent.

Creep is the slow, more or less continuous downslope movement of surface materials (mineral, rock, and soil particles) under gravitational stresses. Trees on a slow creeping hillside tend to gradually realign themselves upward as the massive root stocks slowly rotate downhill over time. Contrast this with earthquake terminology, where creep is the slow, more or less continuous movement occurring on faults due to ongoing tectonic deformation.
(Definitions are derived from the AGI Glossary of Geology and USGS usage).

Cruden, D. M. and Varnes, D. J., 1996, Landslide types and processes: In *Landslides investigation and mitigation:* Turner, A. K., and Schuster, R. L., eds.,Washington, D. C.: Transportation Research Board, National Research Council, Special Report 247 p. 36-75.

U.S. Geological Survey, 2004, *Landslide Types and Processes* (Fact Sheet): http://pubs.usgs.gov/fs/2004/3072/fs-2004-3072.html.

Plant Communities of the San Francisco Bay Region

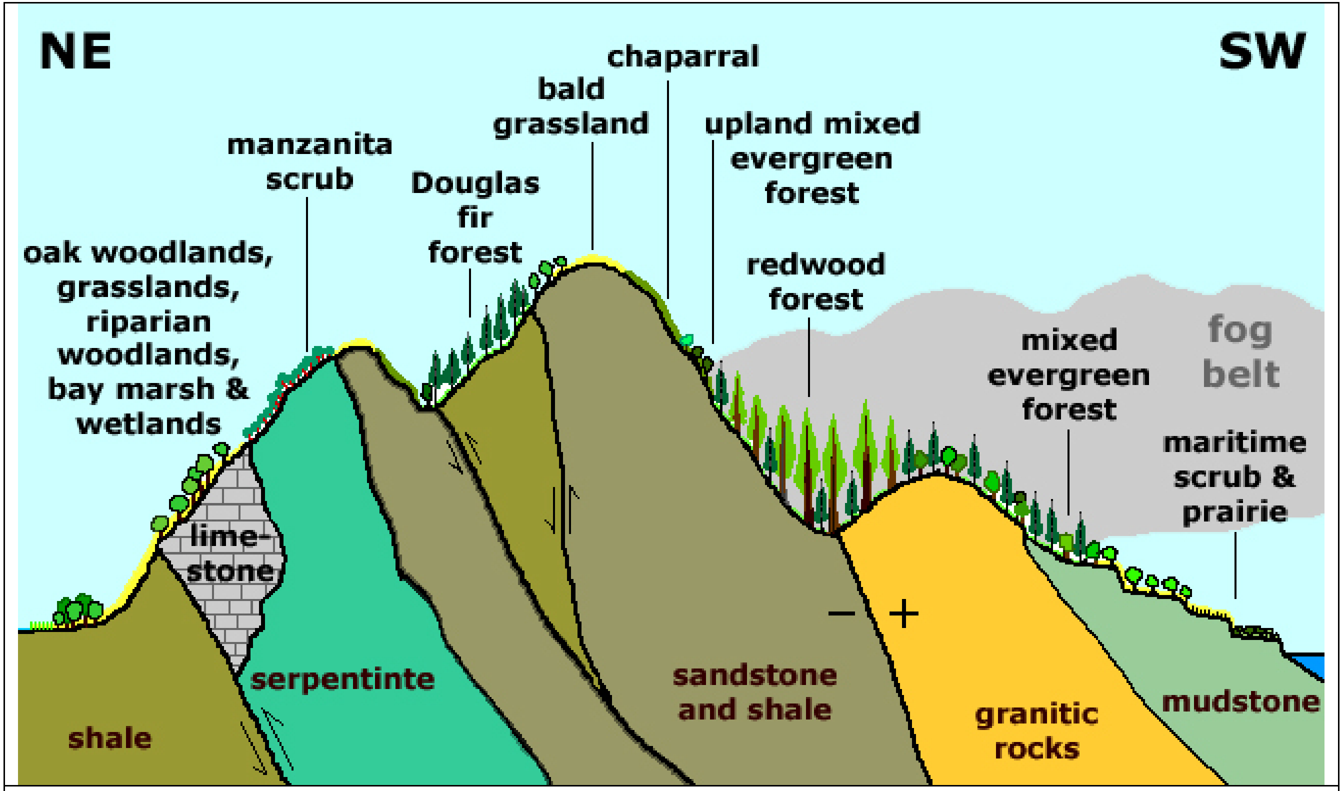


Figure 1-11. Plant habitats of the Santa Cruz Mountains. The diagram also shows a generalized bedrock character of the Santa Cruz Mountains. Arrows show thrust faults, and the -\+ designation shows the San Andreas Fault with its right-lateral offset. Note that vegetation characteristics are also influenced by slope angle and aspect (i.e., north or south facing slopes), precipitation, elevation, land-use history, and other factors.

Dense plant cover in the Santa Cruz Mountains makes geologic mapping difficult. However, variations in both plant cover and surface topography reveal patterns that often help make geologic interpretations possible, even where bedrock is not exposed. This guide to plant communities in the San Francisco Bay Area is included here to assist locating geologic features in the field based on vegetation and soil associations with bedrock lithologies. Bedrock and soil associations are perhaps as important as slope and moisture aspects in the establishment of plant communities. However, human impacts and fire history also define the character of the plant cover. Common plant communities (or habitats or ecosystems, depending of usage of the terminology) in the region are presented below.

Precipitation is highly variable across the Santa Cruz Mountains. Nearly all precipitation falls in the late fall to early spring (November to April) and during occasional late summer storms. Forests in the "fog belt" generate precipitation by trapping moisture with foliage (redwoods and Douglas fir do this). The highest areas within the Santa Cruz Mountains receive 50 to 60 inches of precipitation annually, with only a small amount as snow in the winter. The coast receives 15 to 20 inches of rain and includes some salt concentration derived from wind-blown seawater spray. The driest parts of the Bay Area are in the central Santa Clara Valley and around southern San Francisco Bay where precipitation averages less than 8 inches per year. Northeast facing slopes are cooler and wetter than south and west facing slopes, and slope aspect is typically reflected by vegetative cover.

The weathering of bedrock produces characteristic soils that influence vegetative cover. Coastal California is well known for it unique flora and fauna associated with serpentinite terrane. Low calcium, a plant nutrient, and high magnesium and other metal concentrations from the weathering of serpentinite have a toxic effect on most plants. Plants that successfully adapted in these difficult serpentine conditions are often rare and unique to specific outcrop areas. Sandstone and conglomerate typically weather to produce well-drained soils, whereas shale weathers to produce clay-rich soil that retains moisture. Soils in upland areas tend to be depleted in nutrients, resulting in subdued vegetation or bald grassland areas. Steep slopes are prone to landslides and erosional effects of precipitation, so soils tend to be thin or poorly developed. Shallow water tables along streams or on flood plains allow phreatophytes to flourish (cottonwood, willow, and poplar). Decaying vegetation, particularly in oak and evergreen forests, produce organic acids that weather bedrock and establish acidic soils. Limestone bedrock produces basic soils and terra cotta (red clay) soil that, like serpentinite, also supports unique flora.

However, the character of vegetation of any particular area may be a result of many different factors relating to the local history and land use. Much of the region was subjected to intense lumbering and grazing. Vegetation boundaries may reflect the location of old fence lines or property boundaries. Burn areas may go through a succession of different floral habitats in the period of a century. For example a large section of Douglas fir forest near Lexington Reservoir burned in 1985. Today the same area is now dominantly chaparral habitat but may one day again be a Douglas fir forest. Historic grazing has taken a heavy toll on oak woodland habitats (now mostly replaced by grasslands). Agriculture, urban development, and the introduction of foreign species have changed or decimated riparian, lowland, and coastal wetland habitats. Fortunately, the combined effects of Bay Area wealth, environmentalism, and educated leadership have resulted in the conversion of large tracts of upland and coastal habitats to park and open space. Many hundreds of thousands of acres have been salvaged and set aside for watershed protection, and ecosystem restoration and preservation.

Figure 1-12. Maritime scrub habitat (or maritime chaparral). Beach, sea cliffs, dunes, estuaries, and marine terraces support a mixed coastal shrub, deciduous meadows, grassland, riparian, marsh, and other habitats. The coastal area is a highly moderated climate (neither hot nor cold), and is characterized by salt tolerant species and semi-arid conditions. The habitat is typically established on sandy soils on elevated terraces or stabilized dunes. Monterey cypress groves commonly occur alongside maritime scrub. Higher winter precipitation yields a bounty of annual and perennial wildflowers. Summer days are often fog bound. Fall is typically sunny but very dry. Much of the coastal prairie habitat on the marine terraces has been lost to agricultural activity and development. This view is of Cove Beach at Año Nuevo State Park.

Figure 1-13. Coastal prairie habitat. Semi-arid conditions along sections of the coast support grassland prairies that host a variety of flowering sedges and grasses. Yellow brush lupines and poison oak are among perennials that flourish on coastal dunes. This view shows the coastal prairie in the Tule Elk Reserve in Point Reyes National Seashore near Tomales Point.

Figure 1-14. Mixed evergreen forest. The name mixed evergreen forest best applies to the diverse forests that cover much of the upland areas of the Santa Cruz Mountains. Species from nearly every other type of floral habitat can be found interspersed in areas with complex topography underlain with a mix of bedrock and soils. Mixed evergreen forest includes oaks, redwoods, Douglas fir, pines, chaparral, laurel, madrone, and other trees and shrubs. The name, mixed evergreen forest, is useful where other habitat names don't best apply. This view is at Calero County Park in Santa Clara County.

Figure 1-15. Coastal redwood forest. Coastal redwood groves thrive in the coastal "fog belt" that extends from the coastal valleys to the crest of the northern Santa Cruz Mountains. These areas receive ample winter precipitation and as much as a foot of summer precipitation derived from fog. Most of the coastal redwoods were cut in the late 19th and early 20th century, but second growth forests are thriving in many areas. Large groves of ancient trees can be seen at Big Basin State Park and in Henry Cowell State Park in Santa Cruz County (shown in this view).

Figure 1-16. Upland evergreen forest. Mixed evergreen forest (with common bay laurel and madrone), yellow pine, scrub oak, chaparral, manzanita, and a variety other shrubs grow in upland areas. Thicker patches of growth occur around hillside springs and drainages. This view is along Loma Prieta Avenue in Santa Cruz County in the upland area near Loma Prieta Peak.

Figure 1-17. Bald grassland. Grass-covered hilltops in the Santa Cruz Mountains are called balds. Windy, dry conditions and nutrient depleted soils favor the development of grass cover in upland areas. This view is in Calero County Park in Santa Clara County.

Figure 1-18. Chaparral. Chaparral thrives on dry, south facing slopes with thin or well-drained soil. Chaparral habitat includes many species of shrubs adapted to summer drought conditions, with Chamise being the most common plant. This shrub community is typically brown during the summer and fall autumnal drought season. Hillsides covered with chaparral will turn dark green with winter rains. Chaparral replaces burned Douglas fir and oak woodlands, and it will also burn well under drought conditions. This view is in Uvas Canyon County Park in Santa Clara County. Clouds hang over Loma Prieta Peak in the distance.

Figure 1-19. Douglas fir forest. Douglas fir forests grow in elevations above the coastal oak woodlands and on the north-facing slopes in upland canyons. Douglas fir forests typically grow more inland and at higher elevations than coastal redwoods. Oaks, laurel, madrone, and occasional spruce grow amongst the firs. Most of the old growth forests were cut during the late 19th and early 20th century. This view is along the San Andreas Rift Valley on upper Soquel Creek in Santa Cruz County. This re-growth forest is part of the Soquel Demonstration Forest and the Forest of Nisene Marks.

Figure 1-20. Oak woodlands and valley grasslands. Oak woodland habitats grow in the Coastal Ranges and the Sierra Foothills regions and thrive in semi-arid conditions. Nearly twenty species of oaks, buckeye, poison oak, gray pines (or knob cone pines), and other drought tolerant species share this habitat. Oak woodlands typically occur along with open grasslands and chaparral. This view is looking east from the top of Bald Mountain in the Sierra Azul Preserve toward Mine Hill in Almaden-Quicksilver County Park in Santa Clara County.

Figure 1-21. Manzanita scrub (or chaparral). Manzanita forest thrives in areas with serpentinite bedrock in foothills on both sides of the Santa Clara Valley (but is not limited to serpentinite terrane). This view is near the dam at Chesbro Reservoir County Park in Santa Clara County.

Figure 1-22. Riparian habitat. Riparian woodlands along streams include sycamore, willow, cottonwood, oak, and a variety of shrubs. Where preserved, valley grassland habitat covers ancient alluvial fan deposits in valleys. Development, flood control and water management, and past agricultural activity have heavily modified this habitat. This view is looking east over Coyote Creek County Park toward El Toro Peak beyond Morgan Hill in Santa Clara Valley.

Figure 1-23. Bay wetlands. Coastal wetlands range from freshwater, to brackish, or marine conditions, and each sub-habitat supports a different variety of fauna and flora. Most of the coastal wetlands and marshes (or baylands) around San Francisco Bay have been heavily disturbed or destroyed by salt production, urban growth, fill, and other human activities, but efforts are underway to restore some of them. This view shows stream- and spring-fed wetlands in Coyote Hills Regional Park near Fremont, California. Valley grasslands cover the hills in the distance. This area is one of the most arid regions in the San Francisco Bay region, averaging only 6 to 8 inches of precipitation per year.

Figure 1-24. Salt marsh. Brackish, marine, to hypersaline condition can persist in this tidal-influenced habitat. In undisturbed areas tidal channels feed onto mudflats covered with saltbush that can become partly to complete submerged during high tides. Salt marshes can have some of the highest organic productivity anywhere. Pickleweed and other halophytes (salt-loving plants) thrive in the intertidal to supratidal zones. Rich plankton and invertebrate production in estuarine conditions support fish spawning, bird feeding and nesting activity, and marine mammal birthing and feeding grounds. Many of these areas have been highly modified by past human activity, but great efforts are being made to restore them throughout the Bay Area. This view is of Elkhorn Slough National Estuarine Research Reserve. Loma Prieta Peak is in the distant center.

Selected Resources

National Audubon Society, 2002, Field Guide to California: Alfred A. Knopf, Inc., 447 p.

Starratt, Scot W., 2001,...And the fog will burn off by noon -- A brief introduction to the weather of the San Francisco Bay Area: In *Geology and Natural History of the San Francisco Bay Area*: U.S. Geological Survey Bulletin 2188 [National Association of Geoscience Teachers annual field trip guidebook], p. 165-172; Available on-line at http://geopubs.wr.usgs.gov/bulletin/b2188/.

Schoenherr, Allan, 1992, *A Natural History of California*: California Natural History Guides #56: University of California Press, 772 p.