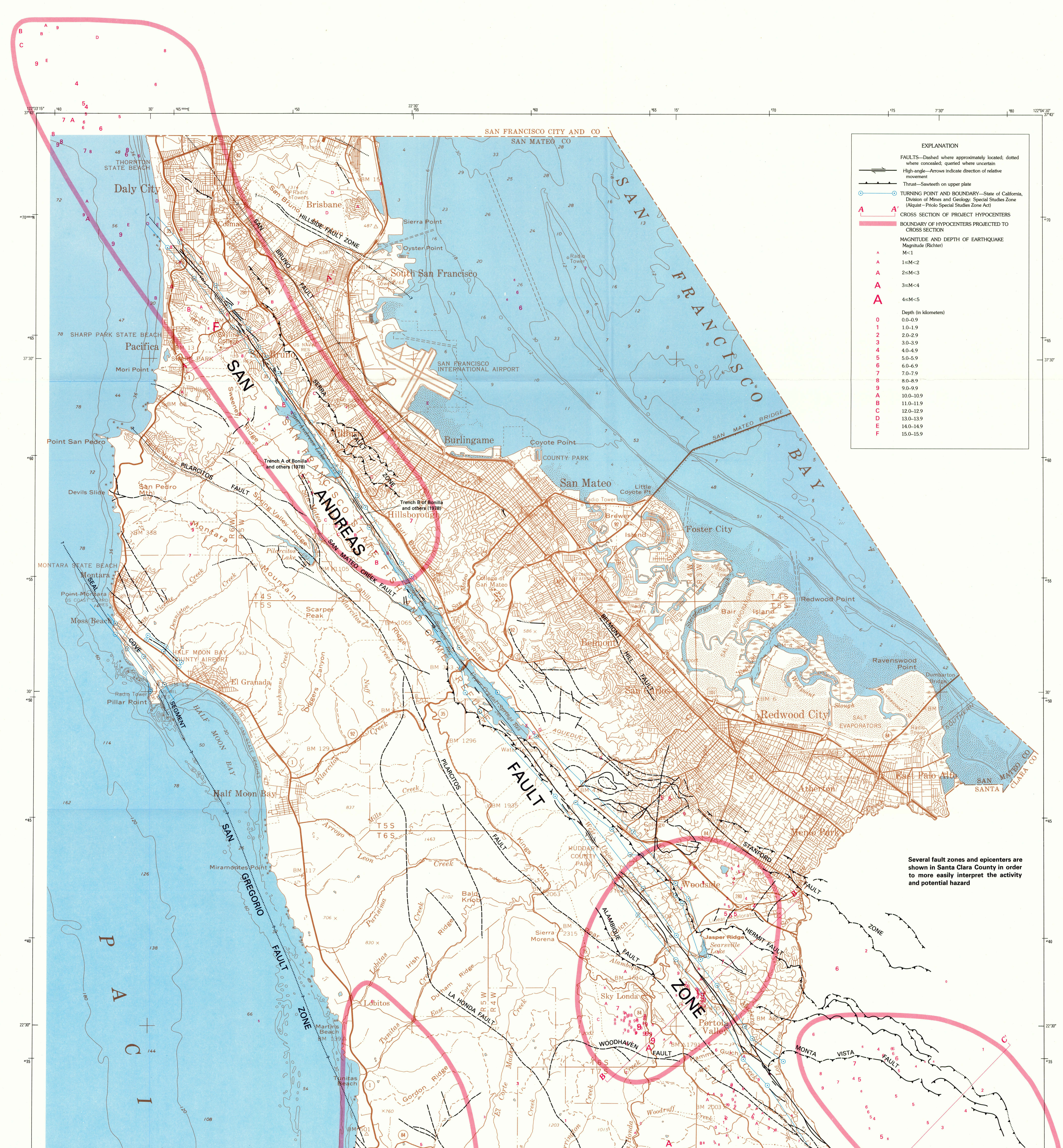

MAP SHOWING FAULTS AND EARTHQUAKE EPICENTERS IN SAN MATEO COUNTY, CALIFORNIA

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INTRODUCTION

Maps showing earthquake epicenters and major faults, such as the one published by Tocher (1959a), have been available for San Mateo County for several years, but most of these maps lacked sufficient detail to be useful for determining the potential hazard to any particular area. They showed few seismograph stations in the region and thus, epicenters could not be located precisely. By 1970, the network of seismograph stations had increased substantially, thereby permitting greater precision in locating epicenters and more sensitivity in recording and locating earthquakes of small magnitudes. The map of Brown and Lee (1971) at a 1:250,000 scale shows this information in a format that is easily understood, and it has been widely used by many regional, county, and city planning agencies, including those in San Mateo County (Kockelman, 1975, 1976, 1979, 1980) and throughout the San Francisco Bay region. Brown (1972) mapped active and potentially active faults in San Mateo County at a 1:62,500 scale that has been used by San Mateo County (1973) to restrict development within the zone of potential surface deformation. Epicenters were not shown on that map, there was little discussion of seismicity, and several major faults, like the Pilarcitos, were not mentioned. Since 1972, much more information on seismicity in the county has been accumulated, along with new data provided by studies of aeromagnetic anomalies and by trenching across several faults.

The purpose of this map is to provide an overall assessment of the activity of all faults in San Mateo County. Different techniques for studying faults, such as correlating epicenters, looking for geomorphic expression of young faults, mapping the termination or disruption of bedrock, interpreting aeromagnetic anomalies, and identifying the dislocation of geologic units in trenches across faults, are evaluated, incorporated on the map, or discussed. Because this map is generalized, it can not be used to determine the specific hazard potential at any particular site. It can be used only to determine the relative fault activity potential from area to area.

We use the term "fault zone" to indicate those fault traces that consists of en echelon and discontinuous fractures that may or may not be related to a major throughgoing fault. The exact area of the zone and, therefore, the area of potential hazard is purposely not defined because we believe the data are not sufficient to do this. The State of California, however, has delineated special-studies zones along faults that appear to have been active during Holocene time and appear to have a relatively high potential for surface rupture. These special-studies zones are depicted on our map.

Much of the information on the seismology of the area could not be accommodated on this map. Studies are continuing to provide information of fault-plane solutions, details about the location, magnitude, and depth of the earthquakes, and general information about the seismic network. A classification of fault activity, prepared from seismicity data, is summarized in Table 1. Data about historic large earthquakes are summarized in Table 2.

Faults and epicenters in adjoining parts of Santa Clara and San Francisco Counties are provided in order to improve our assessment of the fault hazard near the borders of San Mateo County.

DESCRIPTION OF FAULTS

SAN ANDREAS FAULT ZONE

The San Andreas fault zone is one of the major geologic structures in the world, extending approximately 600 mi (900 km) from the north coast of California to Mexico. It is thought to have been active for at least the past 20 million years, differentially offsetting the rocks on opposite sides of the fault at least 100 mi (160 km) in a right-lateral sense (Hill and Dibblee, 1953; Dibblee, 1966a). Large earthquakes (Richter magnitude 7 or more) occurred along the fault zone in 1906, 1857, and 1838 (Tocher, 1959a).

Geology

In San Mateo County, the San Andreas fault zone is expressed topographically as a series of long linear valleys separated by low rolling hills. Sag ponds and other landforms characteristic of active fault zones (fig. 1) were common, but many have been destroyed or modified by housing construction since World War II. Pre-World War II photography and extensive field investigations by a number of geologists (see "Sources of Information for Fault Lines and Zones") were used to delineate the fault traces shown on the map.

The San Andreas fault generally separates sandstone, shale, limestone, chert, greenstone and metamorphic rocks of the Franciscan assemblage of Late Jurassic and Cretaceous age east of the fault from sedimentary and volcanic rocks of Mesozoic and Cenozoic age overlying granitic rocks west of the fault, but in San Mateo County the San Andreas lies within the Franciscan assemblage.

Movement along the San Andreas fault zone in 1838 (Louderback, 1947), 1890, and 1906 (Lawson and others, 1908; Willis, 1938) broke the surface of the ground. The 1906 fault rupture extended at least the length of the county. Maps by Lawson and others (1908, maps 4 and 5) depicted the 1906 movement as a single continuous rupture, but the accompanying text (especially p. 92–106) and some of the detailed maps (figs. 29, 35, 36, and 40) and a map by Taber (1906, fig. 2) indicate that the fault broke the ground in a complex, discontinuous, en echelon fashion with many subsidiary cracks. Most of the movement along the main fault trace was right lateral; thrusting was reported at several localities, but these movements could have been associated with landsliding or differential settlement rather than faulting. The maximum offset reported in San Mateo County (Lawson and others, 1908, fig. 31) was 16.9 ft (5.1 m) near San Andreas Lake; however, this amount of movement is anomalous in relation to movement nearby, and it may not have been measured correctly (Reid, 1910, p. 35). At most other localities, the displacement was 7 to 10 ft (2.1 to 3 m). The total width of the zone of faulting is in dispute; deformation of a fence over a distance of 2,200 ft (667 m) was reported by Lawson and others (1908, p. 100) and disputed by Reid (1910, p. 36). Two statements are conspicuous (Lawson and others, 1908, p. 93, 95): "There were, in general, furrows on either side of the main fault at various distances up to 200 ft (75 m). Some of these were persistent for considerable distances." And, near Lower Crystal Springs Dam, "cracks emerged from the lake and ran northward up the hill for several hundred yards, breaking fences where they crossed." These statements and other data indicate that most ground breakage during major earthquakes along the San Andreas fault zone will take place within 200 ft (60 m) from the main fault break, but that some fault movement may take place at greater distances.

The problem of identifying the main fault is not easy, as Pampeyan (1975) has pointed out. Where detailed maps are available, as in Lawson and others (1908), the main fault can be located within a few tens of feet. At other localities in the county, especially in areas where houses have been or are being built, the exact location of the fault is doubtful. Even trenching in combination with the interpretation of aerial photographs, the most widely used method for locating fault traces, may not be successful in locating the main fault (Bonilla and others, 1978). Caution and conservatism are appropriate, therefore, in constructing any building within the fault zone.

Actual exposures of the fault surface along the San Andreas fault zone are rare and ephemeral. A nearly vertical fault surface, possibly the main fault, with horizontal slickensides was exposed after the 1906 earthquake in what appears to be alluvial materials at the north end of Lower Crystal Springs Reservoir (Lawson and others, 1908, p. 103 and pl. 62A). Two trenches excavated by Bonilla and others (1978) near this locality (see note on map) and along the zone between San Andreas Lake and Lower Crystal Springs Reservoir show complex geology with several faults, some of which are interpreted as slip surfaces of ancient landslides. The faults interpreted as the main trace of the 1906 movement are vertical or steeply dipping, consistent with the overall straight trace of the San Andreas fault in most of San Mateo County.

Seismicity

Seismic activity in the San Andreas fault zone in San Mateo County from 1969 to 1980 occurred in two areas, one in the northwestern part of the county and the other near the town of Portola Valley. In the northwestern part of the county, the magnitudes of most of the earthquakes were less than 2.5. Hypocenters indicate that the fault plane is vertical and movement is 3–10 mi (5–16 km) deep (cross section *A–A'*); one event measured 4.4 during April 1979. Near Portola Valley a swarm of 30 earthquakes occurred during a 9-day period in March 1972 with hypocenters between 4 and 7 mi (7 and 11 km) deep on a vertical fault plane (cross section *B–B'*). With few exceptions, focal mechanisms of all the earthquakes in the San Andreas fault zone within the county indicate right-lateral strike-slip motion on northwest-trending, vertical to steeply dipping fault planes, consistent with the 1906 fault rupture.

Following the 1906 earthquake, the San Andreas fault in the San Francisco Bay region produced no earthquakes of magnitude 5 or greater until an M 5.3 event occurred near Pacifica in 1957. Tocher (1959a) noted the relatively high seismic-activity levels prior to the 1868 and 1906 earthquakes and suggested that the increased activity prior to a large earthquake reflects a buildup in the regional strain, rather than a gradual release of elastic strain. Furthermore, he suggested that the recurrence of earthquakes of intensity (Modified Mercalli) VII in the San Francisco Bay region during 1954–1957 might be a possible prelude to increased activity which might culminate in a future large event. Although there have been no moderate (M 5–6) earthquakes occurring on the San Andreas fault in the San Francisco Bay region since 1957, several M 5–6 earthquakes have occurred on other active faults. Ellsworth and others (1981) have analyzed historic seismic activity between 1855 and 1980 in the San Francisco Bay region and concluded that the region is entering a stage when earthquakes as large as M 6, to perhaps M 7, can be expected. Geodetic strain measurements along the San Francisco peninsula indicate that appreciable strain is accumulating over a broad region encompassing the San Andreas fault zone (Prescott and others, 1981). Although the San Andreas seems locked to a depth of about 4 mi (7 km) as indicated by the geodetic strain data and microseismicity (Olson and others, 1980; Olson, 1981), right-lateral slip is occurring below that depth to 10 mi (16 km). The long-term slip rates and contemporary strain data independently imply an average recurrence interval of roughly 150 years for a large earthquake on the northern locked segment of the San Andreas (Ellsworth and others, 1981).

Future movement in the San Andreas fault zone in San Mateo County has been predicted by Ellsworth and others (1981). They pointed out that M 6–7 earthquakes occurred every decade in the San Francisco Bay area prior to the 1906 event, but that the San Andreas was relatively quiet for 50 years after the 1906 earthquake, until the 1957 M 5.3 event. They noted that earthquake activity greater than M 5 has picked up since 1957, probably presaging the reappearance of large earthquakes in the M 6–7 range. Although another M 8.25 1906-type event is not impossible today, they believe events that large are not likely for the next several decades.

The San Andreas fault is classified as seismically active.

SERRA FAULT ZONE

Geology

The Serra fault zone parallels the San Andreas fault zone for at least 6 mi (10 km) from San Bruno to Hillsborough. It consists of a series of northwest-trending southwest-dipping thrust faults in a zone as much as 0.6 mi wide (Donley and others, 1975; Smith, 1981; Pampeyan, 1981a, b; and D. G. Herd, written commun., 1982). The fault cuts the Colma Formation of Pleistocene age.

Several trenches have been dug across strands of the Serra fault zone in response to Chapter 7.5, Division 2, Section 2623 of the California Public Resources Code, more popularly known as the Alquist-Priolo Act. Purcell, Rhoades and Associates (1976) determined that the Serra fault is a zone 8 ft wide of sheared shale and siltstone belonging to the Franciscan assemblage of Late Jurassic and Cretaceous age near La Prenda Drive in Millbrae. The fault there dips about 40° SW.

Seismicity

The epicenters of a few earthquakes are plotted close to the Serra fault zone traces, but they could be in the San Andreas fault zone. The seismic information is insufficient to determine fault activity.

STANFORD FAULT ZONE

Geology

Geologically young thrust faults in the area between the San Andreas fault zone and the margin of San Francisco Bay were recognized in 1916 by Willis (1924), who thought the thrusting was associated with movement on the San Andreas fault. One of these thrusts, in San Mateo and Santa Clara Counties, was named the Stanford fault for an exposure (since covered) near Stanford University. The Stanford fault zone has not generally been recognized by geologists who worked in the area after 1924. However, Dibblee (1966b) mapped a high-angle thrust fault near Stanford University that is within the zone, and D. G. Herd (written commun., 1982) recently recognized the zone as a series of en echelon southwest-dipping thrust faults. The faults cut the Santa Clara Formation of late Pliocene and early Pleistocene age and possibly also cut Holocene alluvium. The work by Herd and the seismicity data indicate that young thrust faulting between the San Andreas fault and San Francisco Bay is much more extensive than previously recognized, raising the possibility that the Stanford and Serra fault zones are interconnected and part of a much more extensive thrust fault system that has not yet been fully mapped.

Seismicity

Abundant shallow (2–4 mi; 3–7 km) earthquake activity between Woodside and Menlo Park seems to be related to the Stanford fault zone. Hypocenters (see cross section *B–B'*) suggest that the faults dip approximately 40° SW. Fault-plane solutions to determine the orientation of the fault plane and the direction of slip motion from seismograph records suggest a complex and poorly understood pattern of strain release, including thrusting.

The Stanford fault zone is classified as probably seismically active.

HERMIT FAULT

Geology

Willis (1924) inferred a thrust fault between the Stanford fault zone and the San Andreas fault zone which he named the Hermit fault. The name is derived from Hermit Ridge, which is apparently somewhere in the vicinity of Jasper Ridge. The Hermit fault was mapped for the first time by D. G. Herd (written commun., 1982), who believes that this thrust fault extends from the Pulgas Water Temple near San Carlos to Woodside, the Searsville Lake area, and south into Santa Clara County. For much of its extent, it coincides approximately with the Cañada trace of the San Andreas fault zone of Dickinson (1970; unpub. data, 1971). A small part of the Hermit fault coincides with an unnamed decollement(?) surface and an unnamed thrust fault mapped by Page and Tabor (1967) in the Jasper Ridge area.

Seismicity

Seismic information is insufficient to determine the present activity of the Hermit fault. Some of the epicenters attributed to the Monta Vista fault could be related instead to the Hermit fault, but the data are not sufficient to make this distinction.

MONTA VISTA FAULT

Geology

Only a small part of the Monta Vista fault as mapped by D. G. Herd (written commun., 1982) occurs in the San Mateo County. Most of it occurs in Santa Clara County, where it was named and mapped by Sorg and McLaughlin (1975), who determined that the fault offsets the Santa Clara Formation of late Pliocene and early Pleistocene age and may have offset alluvium of late Pleistocene or Holocene age. The fault is part of a system of faults at least 60 mi long. Cross sections by Dibblee (1966b) suggest that the Monta Vista fault dips 40–60° south-southwest. D. G. Herd (written commun., 1982) indicates that the Monta Vista fault joins the Hermit fault in a zone of imbricate thrusting at least 1 mi wide.

Seismicity

Several dozen earthquakes east of Borel Hill in Santa Clara County appear to have taken place either on the Monta Vista fault or the zone where the Monta Vista and Hermit faults join. The hypocenters are shallower to the northeast (cross section C–C'), consistent with the southwest-dipping Monta Vista fault. Fault-plane solutions are also consistent with a southwest-dipping thrust plane. The Monta Vista fault, therefore, is classified as seismically active.

WOODHAVEN FAULT

Geology

The Woodhaven fault (Brabb and Pampeyan, 1972) truncates the west-trending Weeks Creek syncline and other folds in rocks of Oligocene and Miocene age. The extent and dip of the fault are not well established. Map relations suggest that the Woodhaven is a thrust fault dipping to the south. The youngest rocks cut by the fault belong to the Mindego Basalt of Oligocene and (or) Miocene age. The Purisima Formation of late Miocene and Pliocene age appears to extend without interruption across the fault.

Seismicity

A few hypocenters 1–7 mi (1–12 km) deep (see cross section B–B') have been located within 2.5 mi (4 km) southwest of the Woodhaven fault. One focal mechanism solution indicates thrusting on a fault dipping about 10° SW compatible with the geologic evidence. Additional earthquakes occurred 4–6 mi (7–10 km) beneath the southeast end of the Woodhaven fault where it is almost parallel to the Pilarcitos fault. The epicentral precision is not adequate enough to determine which of these two faults caused this activity. In addition, a large cluster of epicenters is located about 1 mi northeast of the Woodhaven fault trace, but it may also be related to the Pilarcitos fault. The data do not conclusively show activity on the Woodhaven fault, but suggest the fault is possibly seismically active.

ALAMBIQUE FAULT

Geology

The Alambique fault was recognized by D. G. Herd (written commun., 1982) on the basis of landforms in the Alambique Creek area. Part of the fault, especially discontinuous segments mapped by Herd but not shown on this map, coincides with the Pilarcitos fault, which is considered to be a high-angle and possibly right-lateral fault whereas the Alambique was considered by Herd to be a low-angle thrust fault.

Seismicity

None of the epicenters located in the vicinity of the Alambique fault have low-angle thrust fault fault-plane solutions, and all can be attributed to movement on the Pilarcitos fault. The seismic information, therefore, is insufficient to determine present activity on the Alambique fault.

LA HONDA FAULT

Geology

The La Honda fault was recognized first by Branner and others, (1909). It was mapped and named by Touring (1959), who considered it a relatively minor structure. Brabb and Pampeyan (1972), extended the La Honda fault north to California Highway 92, a total length of at least 16 mi. The fault is inferred from the abrupt truncation of several geologic formations, but no exposures of the trace have yet been found. Physical evidence for the fault includes (1) slickensided and highly sheared rocks close to the inferred fault trace along Tunitas and Mill Creeks (Mack, 1959, p. 61–63) and along El Corte Madera Creek (Touring, 1959, p. 155), and (2) an eroded scarp between Lobitas and Purisima Creeks (Mack, 1959, p. 62–63). The dip of the fault has not been established, but it appears from the straight linear trace over varied topography to be nearly vertical. The apparent sense of movement is west side down along the northern part of the fault but west side up along the southern part.

Seismicity

A few epicenters located near the south end of the La Honda fault are probably associated with the fault. The hypocentral-depth distribution indicates that the fault dips steeply. One focal mechanism solution indicates either left-lateral motion on a vertical west-northwest-trending plane or right-lateral motion on a steeply east-dipping north-northeast-trending fault plane. Neither type of motion is consistent with the regional stress field. Right-lateral motion on the La Honda fault is a more probable explanation.

The fault is classified as possibly seismically active.

BUTANO FAULT ZONE

Geology

The Butano fault zone, named by Branner and others, (1909), extends 12 mi (19 km) southeastward from the Loma Mar area to where it joins the San Andreas fault zone near Laurel, in Santa Clara County. It probably extends another 4 mi (6 km) westward to the San Gregorio fault zone, but it has not yet been recognized in that area. According to Touring (1959, p. 154), the Butano fault zone "is a high-angle reverse fault along the north flank of the Butano anticline, and it was caused by the same intense compressive forces which overturned the anticline." The fault zone is exposed in Pescadero Creek 3 mi (4.5 km) east of Loma Mar where the Butano Sandstone of early and middle Eocene age is in vertical fault contact with glauconitic sandstone of the Tahana Member of the Purisima Fomation of late Miocene and Pliocene age. These Purisima strata are the youngest rocks cut by the Butano fault zone. Touring (1959) indicates that the fault dips steeply to the southwest and has about 1,500–2,000 ft (450–600 m) of dip slip (southwest block up).

Stream terraces of Pleistocene age seem to extend across the fault zone without interruption, suggesting that movement on the fault has not occurred since the Pleistocene. In Santa Clara County, however, one trace of the fault may have moved during the 1906 earthquake. Lawson and others (1908, p. 110, 277, pls. 64 B, 65A, and fig. 57) described and illustrated about 6 ft (2 m) of left-lateral movement along a fault that is close to the projection of the Butano fault zone in that area (see Dibblee and Brabb, 1978). The displacement did not offset a railroad tunnel 550 ft (200 m) directly below the break, however, so it may have been associated with superficial movement of the ground by lurching rather than with tectonic movement.

Seismicity

Several epicenters have been located near Butano fault zone traces. Most of the events are near the southeast end of the fault zone in Santa Clara County, outside the map area. Some activity occurred between the west end of the Butano fault zone and the Coastways segment of the San Gregorio fault zone, suggesting that the Butano fault zone continues farther to the west than mapped. The focal depths (see cross section D–D') range from 1–8 mi (1–12 km). The activity is on, and north of, the fault zone, but there is not enough data to determine the dip of the fault planes with any confidence. One fault-plane solution agrees with the trend of the fault zone near Portola State Park and indicates left-lateral strike-slip motion on a vertical fault plane.

Earthquake activity near the southeast end of the fault zone indicates that the Butano fault zone is probably seismically active.

PILARCITOS FAULT

Geology

At most localities in central California, the San Andreas fault separates "continental" granitic basement rocks of the Salinian block to the west from "oceanic" basement rocks and the Franciscan assemblage to the east. In the San Francisco peninsula, however, the Pilarcitos fault forms this boundary. The Pilarcitos fault is a branch of the San Andreas fault system that splits from the main fault near Portola Valley and presumably rejoins it north of San Francisco. Dibblee (1966a) believed that progressive right-lateral movement in the San Andreas fault system from Mesozoic to Miocene time in this part of California occurred primarily along the Pilarcitos fault.

If the Pilarcitos is a right-lateral strike-slip fault like the San Andreas, the fault surface should be nearly vertical. The only field measurement of the fault plane was by Darrow (1963), who reported a 40° NE dip at Pilarcitos Lake. The exact location of the fault measured by Darrow is in doubt, however, and it is more probably a minor fault within the Franciscan assemblage. E. H. Pampeyan, who examined the rocks in the vicinity of Pilarcitos Lake during a low stage of water in the 1970's, reported (oral commun., 1981) that the straight character of the Pilarcitos fault trace in that area and the few exposures available indicate that the fault plane there is vertical, or nearly so.

The youngest deposits definitely cut by the Pilarcitos fault belong to the Santa Clara Formation of late Pliocene and early Pleistocene age. Smith (1960) indicated that the Pilarcitos fault has moved about 3 mi (5 km) in a right-lateral sense during the late Pleistocene, judging from the offset of marine-terrace surfaces and the offset of the coast near Point San Pedro, but these features could be related instead to differential erosion without faulting. K. R. Lajoie stated (oral commun., 1981) that vertical movement, south-side up, may have taken place along the Pilarcitos fault near Pedro Valley during the Pleistocene, judging from the projection of marine-terrace surfaces. Alluvial deposits of Holocene age extend across the fault without disruption in the Pedro Valley (Lajoie and others, 1974), indicating that no substantial movement has occurred along the Pilarcitos during the Holocene. Marchand (1962) believed that parts of the Sanchez Adobe, located in Pedro Valley close to the projected trace of the Pilarcitos fault, was deformed about 12 in. (30 cm) from 1846 to 1962, indicating that the Pilarcitos fault may be creeping, but his observations have not been confirmed by independent analysis or other data. Observations of the fault trace near Pilarcitos Lake after the 1906 earthquake (Lawson and others, 1908, p. 253) indicate that the fault did not move during that event.

Seismicity

Several epicenters that are possibly related to the Pilarcitos fault have been located near the northwest end of the fault trace between Montara Mountain and the projection of the fault trace offshore. The events near Montara Mountain, southwest of the fault trace, could also be associated with movement on the San Gregorio fault zone. One of the fault-plane solutions indicates right-lateral strike-slip motion on a north—northwest-trending fault plane.

A dense cluster of epicenters located about one-half mile (1 km) southwest of the Pilarcitos fault trace near Sky Londa is well outside the range for San Andreas events. Thirty-nine of these earthquakes (including three over M 3.0) occurred over a 10-day period during June 1975. These events define a vertical fault plane, like the Pilarcitos fault (see cross section B–B'). Another possible source is the Woodhaven fault, which is located just southwest of the epicenters. However, the seismicity does not agree with a southwest dip on this fault-the dip direction inferred from map relations.

The seismic evidence suggests that the Pilarcitos fault is possibly seismically active.

SAN BRUNO FAULT

Geology

The San Bruno fault was proposed by Lawson (1914) to explain the juxtaposition of a thick northeast-dipping section of the Merced Formation against sandstone of the Franciscan assemblage on San Bruno Mountain. The fault was inferred by him to be steeply dipping, southwest side down.

However, the San Bruno fault may not exist. Bonilla (1959, p. 33–44) indicated that an unconformity within the Merced Formation and folding negate the evidence for the San Bruno fault entirely, or at least reduce the significance proposed by Lawson. After the 1906 earthquake, Lawson and others (1908, p. 248) looked unsuccessfully for surface movement on the San Bruno fault.

Seismicity

There are a few epicenters near the San Bruno fault trace north of San Mateo County, and one near its southern end, but these cannot be differentiated from San Andreas fault activity. There is also some activity 2 mi (4 km) northeast of the fault trace, but this activity could be associated with the Hillside fault zone. Seismic information is insufficient to determine the present activity of the San Bruno fault.

HILLSIDE FAULT ZONE

Geology

The Hillside fault zone on the south side of San Bruno Mountain separates a fairly coherent block of unnamed sandstone of Jurassic or Cretaceous age to the northeast from extensively deformed sandstone and shale of the Franciscan assemblage (Jurasssic and Cretaceous) on the southwest. The fault, as mapped by Bonilla (1971), consists of a zone 300–3,000 ft (100–1,000 m) wide of very intensely sheared shale and sandstone with exotic blocks of serpentinite and metamorphic rocks, generally referred to as melange. The straight trace of the fault across varied topography suggest that the Hillside fault zone is steeply dipping; the sense of movement is not known.

Seismicity

The few epicenters in the general vicinity of the Hillside fault zone could have been produced by other faults. Seismic information is insufficient to determine the present activity of the Hillside fault zone.

SAN MATEO CREEK FAULT

Geology

The San Mateo Creek fault was mapped first by Lawson (1914) and named by Taber (1923). Neither geologist discussed evidence for the fault. According to E. H. Pampeyan (oral commun., 1982), the fault is marked by sheared and truncated Franciscan rocks and serpentinite. None of the Quaternary deposits appears to have been affected by the fault.

Seismicity

No epicenters have been plotted in the vicinity of the San Mateo Creek fault, so the seismic information is insufficient to determine fault present activity.

BELMONT HILL FAULT

Geology

The Belmont Hill fault and an unnamed fault parallel to and about one-half mile (1 km) northeast of the Belmont Hill fault were first mapped by Pampeyan (1981a). According to E. H. Pampeyan (oral commun., 1982), both faults are recognized by a thin zone of hydrothermally altered rocks. None of the Quaternary sediments in the vicinity of the faults appears to have been affected by the faulting or hydrothermal alteration.

Seismicity

No epicenters have been plotted in the vicinity of the Belmont Hills and unnamed faults, so the seismic information is insufficient to determine present fault activity.

SAN GREGORIO FAULT ZONE

Geology

The San Gregorio fault was recognized and named by Branner and others (1909), but they did not attach any particular significance to the fault. Hill and Dibblee (1953, p. 455) mentioned, without documentation, that the San Gregorio fault might have substantial right-lateral displacement. Cummings and others (1962) argued against extensive lateral movement along the San Gregorio fault on the basis of similar members of the Purisima Formation on both sides of the fault, but Graham and Dickinson (1978a, b) presented several lines of evidence for about 72 mi (115 km) of right-lateral slip between 6 and 20 m.y. ago. The extent and significance of the San Gregorio fault were debated in a series of papers edited by Silver and Normark (1978).

Brown (1972) pointed out the potential hazard to structures from surface rupture within the San Gregorio fault zone. San Mateo County (1973) has limited development within this zone to one dwelling unit per 40 acres.

Several investigations have been made recently to more accurately determine the hazard associated with potential movement on the San Gregorio fault. Of these, the reports by Weber and Lajoie (1980), Weber and Cotton (1981) and Ellsworth and others (1981) are the most useful.

The San Gregorio fault zone extends from offshore of San Francisco, where it separates from the San Andreas fault (Cooper, 1973), southward at least to the Point Sur area, about 50 mi (80 km) south of the south border of San Mateo County. The San Gregorio fault zone may turn inland to join the Palo Colorado fault in Monterey County (Greene and others, 1973) or it may continue south and join the Hosgri fault (Graham and Dickinson, 1978b). The fault is at least 100 mi (170 km) long and may be 230 mi (370 km) long or more if it joins the Hosgri fault.

Weber and Lajoie (1980) divided the San Gregorio fault zone into several segments and indicated the geomorphic evidence for Pleistocene and (or) Holocene movement on each segment; their terminology for the segments and the age of movement are adopted here. Most of the information for the fault segments is taken directly from their report.

Seal Cove Segment

Glen (1959) was the first to recognize the Seal Cove segment of the San Gregorio fault zone. The subsea projection of the Seal Cove segment south to join the San Gregorio fault zone near San Gregorio State Beach is speculative and is based soley on the general alignment of these faults.

McCulloch and others (1977, fig. 5; and oral commun., 1977) indicated that the Seal Cove segment may be subordinate to a more pronounced strand of the San Gregorio fault zone that is offshore and a few miles west of and parallel to the Seal Cove segment.

The onshore part of the Seal Cove segment is about 2 mi (3 km) long and may be nearly 2 mi (3 km) wide if the faults shown on the map are part of the same zone. Near Moss Beach the fault is vertical and has juxtaposed terrace sands approximately 125,000(?) years old against sheared mudstone of the Purisima Formation of late Miocene and Pliocene age. The 100 ft (30 m) cliff along the fault at the southwest edge of Half Moon Bay airport is a fault scarp with about 150 ft (50 m) of apparent vertical offset of the marine-terrace platform. A 3-ft-high scarp in an alluvial fan of Holocene age along Denniston Creek may be of tectonic origin and related to the Seal Cove segment. Additional lineaments that may also be related to movement on the Seal Cove segment were mapped in the area from Denniston Creek to Montara, but all of these are covered by unfaulted sedimentary deposits or Holocene age. Thus, there is no definitive evidence that either the Seal Cove segment of faults in the general vicinity cut Holocene deposits, although one Holocene scarp may be of tectonic origin.

Leighton and Associates (1971) inferred several additional faults in the vicinity of the Seal Cove segment based primarily on the basis of information from borings. These inferred faults cut terrace deposits that Lajoie and others (1974) believed are late Pleistocene in age. One fault is reported to cut Holocene stream gravel and colluvium at Moss Beach, but this observation has not been confirmed independently.

Galehouse (1981) began theodolite measurements across the Seal Cove segment in November 1979. He indicated that the fault moved with left-lateral slip of less than 1 in. (a few mm) until February 1980 when the movement changed to right-lateral slip. From February 1980 until April 1981, the cumulative right lateral slip was about 0.4 in. (1 cm).

Coastways segment

The Coastways segment, as mapped by Weber and Lajoie (1981) using mainly geomorphic evidence, corresponds reasonably well to the San Gregorio fault of Touring (1959) and Brabb and Pampeyan (1972), who mapped the fault mainly on the basis of disrupted and truncated bedrock units. On our map the dashed lines by Weber and Lajoie (1980) are used on the supposition that these lines represent the latest fault movement and are potentially the most likely places for future fault movement. The Coastways segment is probably part of a major throughgoing fault system that has juxtaposed two tectonic blocks with markedly different stratigraphic sequences (Clark and Brabb, 1978).

The onshore part of the Coastways segment is about 16 mi (26 km) long. Offshore, to the southeast, the Coastways segment projects into the easternmost of two major offshore segments of the Palo Colorado-San Gregorio fault zone mapped by Greene and others (1973); this easternmost segment is at least 14 mi (23 km) long. The northwest offshore extension of the Coastways segment has not been documented, so the only reasonably well established length is a minimum of 30 mi (50 km).

The dip of the Coastways segment is not well established, but it appears from the mapped traces to be steep. In sea cliffs near San Gregorio, Weber and Lajoie (1980) measured a 68° SW dip, southwest-side down 180–200 ft (55–60 m), indicating a normal component to the fault movement. They also reported 15 ft (5 m) of vertical slip, west-side down, near Año Nuevo. They believed the Coastways segment has progressively offset marine-terrace surfaces in a right-lateral sense 4,300–5,800 ft (1,300–1,800 m) from 450,000 to 340,000 years B. P., and 5,000–6,000 ft (1,500–1,800 m) from 125,000 to 85,000 years B. P., indicating a slip rate of about 0.3–0.4 in./yr (0.6–1 cm/yr).

Frijoles segment

The Frijoles segment of the San Gregorio fault zone, as mapped by Weber and Lajoie (1980), extends north-northwest from the sea cliffs near Point Año Nuevo for about 13 mi (20 km) to the Pescadero State Beach area. At the latter locality, it consists of at least three northeast-dipping thrust faults, one of which dips 28° NE, and a postulated major fault of unknown dip near the mouth of Pescadero Creek. Weber and Lajoie (1980) reported that the thrust faults have displaced the wave-cut platform 120 ft (vertical separation) from 125,000 to 85,000 years B. P. In the area from Whitehouse Creek to the sea cliffs near Año Nuevo Bay, according to Weber and Cotton (1981), movement on the Frijoles segment is complex, with both reverse and right-lateral faulting. The latest movement took place during the Holocene. Weber and Cotton (1981, p. 91) concluded, after extensive analysis, that the Frijoles segment has an activity recurrence interval of about 365 years.

Other faults near Point Año Nuevo

Several faults in the Año Nuevo State Reserve are important, either because they reveal significant information about the movement history of the San Gregorio fault zone or because they appear to be part of a larger fault segment. The easternmost of these faults, shown on the map as a largely concealed fault about 1 mi (2 km) long, was named the Green Oaks fault by Brabb and others (1977, fig. 29). According to Weber and Lajoie (1980), it is a reverse fault that offsets marine terrace deposits about 10 ft (3 m). The fault is along the projection of the westernmost and most extensive fault in the Palo Colorado-San Gregorio fault zone mapped by Greene and others (1973), and thus the movement may be much more extensive than that implied by Weber and Lajoie.

The Año Nuevo thrust fault, about 1,500 ft (400 m) NE. of Point Año Nuevo, has been studied in considerable detail by Weber and Cotton (1981). Siliceous mudstone of the Monterey Formation of middle Miocene age has been thrust along a fault dipping 37° NE. over terrace deposits of late Pleistocene age. Terrace deposits in the footwall block record at least six and possibly nine faulting events in the past 105,000 years, averaging about 0.002 in. (0.05 mm) of movement per year, with latest movement during the Holocene. The average recurrence interval is about 16,500 years. Weber and Cotton believed that the Año Nuevo thrust fault is a secondary trace within the San Gregorio fault zone, possibly connected at depth with the Green Oaks fault.

Two small faults between Point Año Nuevo and Año Nuevo Island have been mapped by Weber and Lajoie (1980) on the basis of linear channels and differences in the elevation of the marine terrace platform.

Summary

Weber and Cotton (1981) discussed the earthquake magnitude, recurrence, slip rate, and amount of displacement expected along the San Gregorio fault in considerable detail; their principal conclusions are summarized below:

(1) The recurrence interval for major earthquakes (M 7.5 or greater) along the San Gregorio fault zone is between 225 and 400 years, with a best estimate of 300–325 years.

(2) The maximum credible earthquake is probably between M 7.7 and M 7.9 but could exceed M 8.0.

(3) Right-lateral offsets of marine terrace shoreline angles suggest an average late Pleistocene rate of movement ranging from 0.26–0.48 in./yr (6–11 mm/yr). That rate compares favorably with the 0.22–0.40 in. (5–9 mm) rate determined from stream-channel offsets and the 0.31–0.40 in./yr (7–9 mm) long-term rate determined by Graham and Dickinson (1978a).

(4) Surface displacements may be greater on secondary faults than on the principal fault.

(5) Total surface displacements on various segments of the San Gregorio fault zone have been as large as 8 ft (2.4 m) vertically and 13 ft (3.9 m) horizontally during a single event.

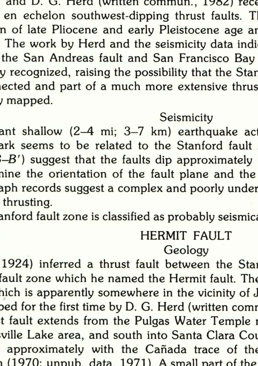
Seismicity

Several earthquakes have been located within 2 mi (3 km) of the Coastways segment of the San Gregorio fault zone. The focal depths range from 2–8 mi (3–12 km). One focal mechanism solution for an area about 2 mi (3 km) northeast of Point Año Nuevo is compatible with right-lateral strike-slip movement on a vertical fault plane and is in agreement with the trend of the fault trace. A second focal mechanism solution for an area about 3 mi (5 km) southeast of Point Año Nuevo suggests either thrust or reverse faulting. The focal mechanism solutions, therefore, support the geologic observation that both right-lateral and thrust motion have taken place along the San Gregorio fault zone. The hypocenters (see cross section E–E') are scattered and show no consistent pattern.

We conclude that at least the southern part of the San Gregorio fault zone in San Mateo County is seismically active.

GEOPHYSICAL ANOMALIES

Many of the aeromagnetic anomalies in the San Francisco Bay region have been interpreted by Brabb and Hanna (1981) to be related to steeply dipping masses of serpentinite and other ultramafic rocks emplaced along faults. Similarly, several gravity anomalies are interpreted as faults by the California Department of Water Resources (1967). None of these inferred faults are shown on our map, pending independent verification for the presence of these structures.



INDEX MAP SHOWING AREA OF THIS REPORT

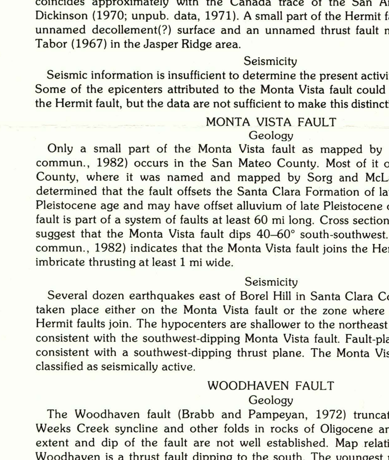
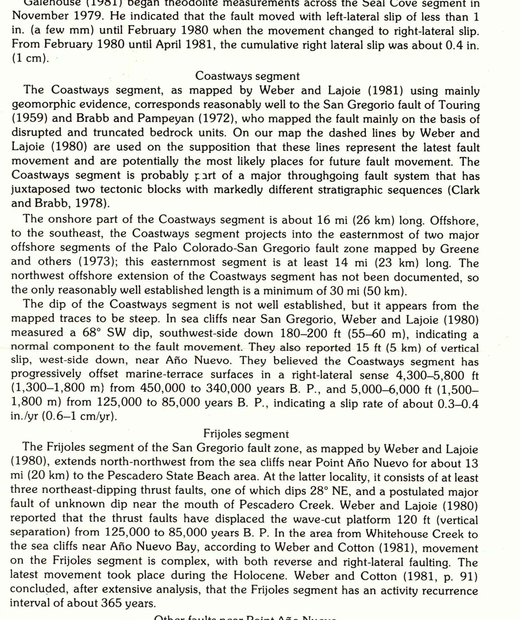


FIGURE 1.—Block diagram showing landforms produced along recently active faults (from Brown, 1970).



EPICENTERS OF MODERATE AND LARGE EARTHQUAKES THAT OCCURRED IN OR NEAR SAN MATEO COUNTY BETWEEN 1800 AND 1980