DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I—522

EXPLANATION

Approximate location of fault traces within the Hayward fault zone

Location of surface rupture formed during the earthquake of October 21, 1868; as shown on unpublished map prepared for the California State Earthquake Investigation Commission of 1906*

Approximate location of surface ruptures formed during the earthquake of October 21, 1868; based on published descriptions and on locations of cracks shown on unpublished maps prepared for the California State Earthquake Investigation Commission of 1906*

× Locality of a crack ⊗ Probable locality of a crack

Location of cracks formed during the earthquake of October 21, 1868; as shown on unpublished maps prepared for the California State Earthquake Investigation Commission of 1906.*

In some places the location of symbols may be as much as 250 feet in error, due to difficulties in transferring data from old township maps

Case, 1963

Source of published maps used to determine approximate location of fault traces (not including 1868 surface ruptures) and portion of fault covered by source indicated

A–D

Localities mentioned in text where evidence of tectonic creep has been documented

①

Source of supplemental information used to modify and(or) extend published maps where indicated

① *Fieldwork*
② *Aerial photographs*
③ *Buwalda, 1929*
④ *G. D. Louderback, unpublished data*
⑤ *Old topographic maps*
⑥ *W. T. Steilberg, oral communication, 1965 (see text)*

*Maps courtesy of Dr. Perry Byerly, University of California

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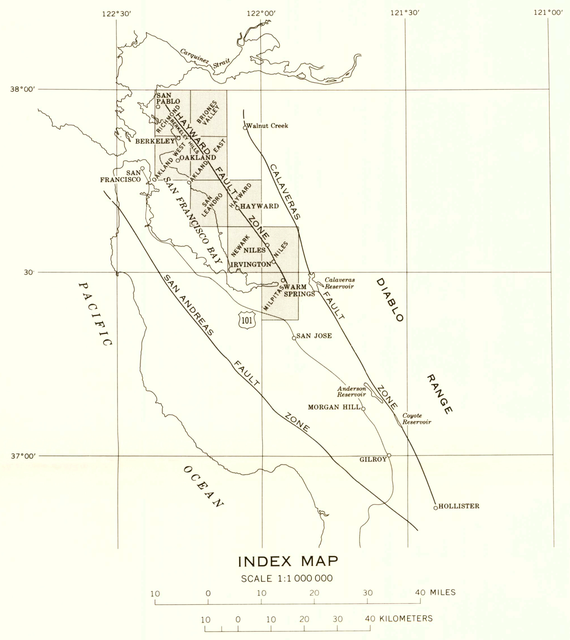

THE HAYWARD FAULT ZONE

GENERAL FEATURES

The Hayward fault zone comprises a northwest-trending zone of faults along the western front of the hills bordering the east side of San Francisco Bay, California. It extends northwestward from Warm Springs on the south to San Pablo on the north, and may extend in either direction beyond these limits. Movement along faults within this zone has caused two major historic earthquakes with accompanying surface ruptures, one in 1836 and one in 1868 (Wood, 1916), and recent observations indicate that locally the rocks on either side of and adjacent to faults within the zone are very slowly creeping in opposite directions, with the northeast side moving southeast with respect to the southwest side.

The Hayward fault zone lies in a broad band of acute deformation which was described by Lawson in the San Francisco folio (1914). Lawson suggested that the Hayward fault zone formed after the development of this wider belt of deformation. Some authors (Crittenden, 1951; Case, 1963) have suggested that apparently inactive faults--such as the Chabot fault (Case, 1963)--within this broad faulted band may be "ancestral Hayward faults." It would probably be more appropriate to regard the movement within the currently active Hayward fault zone as the most recent episode of movement within a larger band of deformation where faulting has been taking place for an unknown length of geologic time.

No attempt has been made to show the entire width of the Hayward fault zone, which may range from a few tens of feet near the Niles District to about 1-3/4 miles near Mission San Jose. Traces of faults within the zone are shown on the map. For the purposes of this report, a fault trace is defined as the visible surface expression of recent fault movement. The locations of the fault traces are taken largely from published sources (Case, 1963; California Department of Water Resources, 1960; Crittenden, 1951; Hall, 1958; Robinson, 1956), and were determined primarily from geologic and geomorphic evidence of displacement. The traces shown on the published maps were extended and slightly modified in places by the present author through additional field work; utilization of aerial photographs; compilation of information from miscellaneous old records and unpublished data; and through use of maps of earth breakage and descriptive accounts of the 1868 earthquake, both published and unpublished.

Some of the fault traces which have been recognized (many more probably exist within the zone) mark the position of surface rupture at the time of the 1868 earthquake; others, like that immediately southwest of the Oak Knoll Naval Hospital, seem to be the result of much earlier movement. In 1964 an excavation along the fault trace northwest of the hospital exposed a peat bog that filled a depression which probably was an old sag pond. The remains of a late Pleistocene bison were found in the peat, which indicates that the depression was formed, probably by fault movement, no later than Pleistocene time.

Geologic and geomorphic evidence of the fault traces is abundant. In some places rocks of very different ages are exposed on opposite sides of the trace. Near Irvington, fault gouge acts as a barrier to ground-water movement, so that the water level is higher on the east side than on the west side of the fault (Clark, 1924). Locally fault traces are marked by trenches or topographic sags, the most pronounced being the trench occupied in part by Lake Temescal, in Oakland. In other places, fault traces are indicated by shutter ridges, fault scarps of various heights, offset streams, lines of springs, sag ponds, and bands of intensely sheared rock or fault gouge.

Known surface breakage and visible expressions of movement within the Hayward fault zone extend from near Warm Springs northwestward to the shore of San Pablo Bay and may continue on the north side of the bay (Weaver, 1949, p. 67; Clement, 1965). Between Warm Springs and the hills east of Gilroy there is no clear evidence of recent surface rupture along the west front of the Diablo Range. The Calaveras fault zone emerges from the hills east of Gilroy, and from this point southward to Hollister there is abundant surface expression of recent faulting along the Calaveras fault zone. Apparent horizontal displacements along the Calaveras fault zone, which may extend as far north as the Carquinez Straits, have been noted near the Calaveras Reservoir (Crittenden, 1951, p. 52). Indications of recent movement are most pronounced southward from the vicinity of Anderson Reservoir, northeast of Morgan Hill (Lloyd Cluff, of Woodward, Clyde, Sherard and Associates, oral communication, 1965). It is not known whether these indications actually represent movement along the Calaveras fault zone or the southern extension of the Hayward fault zone. Louderback (1937) suggested that the two zones joined north of Coyote Reservoir, whereas some published maps have shown the Hayward fault zone extending southward from Warm Springs to join the Calaveras fault zone northeast of Morgan Hill (Bowen and Crippen, 1951) and their combined traces continuing southward to merge with the San Andreas fault zone south of Hollister (California Department of Water Resources, 1964). However, the nature of recent movement along the Hayward fault zone is uncertain south of Warm Springs, so fault traces are not shown south of Warm Springs on the map.

Sense of movement along the Hayward fault zone has apparently been both horizontal and vertical. Where the Hayward fault zone lies at the base of the Berkeley Hills, the steep westward-facing front of the hills is thought to be a dissected fault scarp (Buwalda, 1929), where the rocks forming the hills moved upward with respect to those west of the scarp. Recent measurements across the fault zone near San Jose by the Coast and Geodetic Survey show that between 1948 and 1963 the land on the northeast side of the fault zone raised about 65 mm (approx. 2.6 inches) with respect to that on the southwest side (Small, 1963). South of Niles, an eastward-facing fault scarp can be seen southwest of Tule Pond and Stivers Lagoon (Clark, 1924), indicating that along this stretch the land on the west side of a fault has moved up with respect to the east side, whereas in the vicinity of Irvington a westward-facing scarp indicates the reverse relationship. Offset streams, such as Strawberry Creek on the campus of the University of California (Buwalda, 1929) and numerous small ravines between Hayward and Niles (Russell, 1926), indicate that movement along faults has been right lateral; that is, rocks on the northeast side of the faults have moved southeast with respect to those on the southwest side.

The general location of surface breakage during recorded earthquakes originating within the fault zone is fairly well known, but information regarding the direction and magnitude of displacement is scanty. The displacement was probably both horizontal and vertical.

EARTHQUAKE OF 1836

The 1836 earthquake is thought to have had an intensity of X on the Rossi Forel scale (Lawson, 1908; Louderback, 1947). However, the area was sparsely populated at the time of the 1836 earthquake, and little evidence is available regarding either the kind or amount of damage to manmade structures, or the nature of surface breakage associated with the quake. Cracks reportedly opened between San Pablo and Mission San Jose (Louderback, 1947).

EARTHQUAKE OF 1868

The population along both the east and west sides of San Francisco Bay had grown substantially by 1868, and earthquake damage to manmade structures was greater than in 1836. However, very little evidence regarding earth breakage was published at the time of the earthquake, and any that may have been compiled at the time was subsequently lost (Lawson, 1908). After the 1906 earthquake, which originated on the San Andreas fault, the California State Earthquake Investigation Commission prepared a report on the 1906 disaster (Lawson, 1908). This report contains a review of other severe earthquakes in the San Francisco Bay region, including the earthquake of October 21, 1868. In the course of gathering facts relating to the 1868 earthquake, a representative of the commission reviewed periodicals of the time, obtained eyewitness accounts from residents who experienced the shock, and visited the area of maximum intensity. The results of this investigation were included in the report of the 1906 earthquake and constitute the main body of published information regarding the earthquake of 1868.

Damage to structures was recorded as far away as Santa Rosa, Sacramento, and Santa Cruz. Damage was extensive in San Francisco, particularly on "made ground," and in Hayward many buildings were completely demolished. According to the 1906 report, "The fault-trace was characterized for the most part by a crack which in places, particularly on the lower ground, was superficially gaping. Associated with this main crack there were auxiliary branching cracks; and on the alluvial bottom-lands about San Francisco Bay there were numerous secondary cracks which were usually not discriminated by the observers of that day from the fault trace" (Lawson, 1908, p. 447). According to Lawson (1908, p. 434), a crack extended from the vicinity of Mills College, Oakland, to Warm Springs, but evidence of its existence north of San Leandro was obscure. Louderback (1937) stated that it seems quite certain that no rupture of the ground took place in the vicinity of the Temescal Dam (Oakland) in 1868. However, according to Mr. Walter T. Steilberg, architect (oral communication, 1965), Joseph LeConte, professor of mechanical engineering at the University of California, told him about 1925 or 1930 that his (LeConte's) father had taken him (LeConte) to see the fault trace of the 1868 earthquake which extended across the westerly end of the California School for Blind and Deaf and along what is now Warring Street, or between Warring and Prospect, in Berkeley. LeConte said that he was a small boy at the time, and that the trace looked like a plowed furrow.

From San Leandro to Warm Springs, several cracks were reported. The main fault trace, trending N. 37°W., lay in general near the base of the hills and in most places was within the hill slope, although in other places it cut across the alluvium west of the hills.

An eyewitness account by Mrs. William Haywards (given in the 1906 investigation report) described in detail the course of the main fault rupture through the center of Hayward, as follows: "The crack past diagonally up the Haywards Hill and crost 3 feet from the south corner of the old hotel; past just east of the Odd Fellows' Building, through the Castro lot, tearing off a corner of the adobe house which stood where the jail now is, on through Walpert's Hill toward Decoto. By the hotel the crack first opened 18 to 20 inches, but soon closed to 5 or 6. It was of unknown depth; several balls of twine, tied together, with an iron sinker, failed to find bottom. There was no water in the fissure, for the iron came up dry" (Lawson, 1908, p. 441). This description places the main fault rupture about midway between Main Street and Mission Boulevard, approximately parallel to Mission Boulevard.[1]

Mr. Decoto reported that "Opposite Decoto a crack appeared about one-third of the way up the slope. It opened 10 or 12 inches at the surface and faulted about as much on the plains side" (Lawson, 1908, p. 443).

South of Niles the main break extended across the alluvial fan of Alameda Creek, and according to Clark (1915, p. 149), "Mr. J. C. Shinn reports that during the severe earthquake of 1868 his father's house, standing directly on the fault line, was torn in two and the eastern part dropped about a foot below the western part." The rupture passed through the long axis of Tyson's Lagoon, now called Tule Pond, where a scarp southwest of the Pond (Clark, 1915, p. 131) indicates that older fault movement occurred in a slightly different place. Mrs. William Tyson stated that "The lagoon parted lengthwise down the middle and threw water and mud both ways" (Lawson, 1908, p. 443). The main break went through Irvington, where according to one eyewitness "The railroad tracks north of the station were badly twisted for several hundred yards" (Lawson, 1908, p. 443). It was not observed farther south than Agua Caliente Creek (Lawson, 1908, p. 435).

Lawson (1908, p. 435, 447) wrote that the eyewitness statements indicate a slight downthrow on the southwest side of the fault. Possibly the northeastern side of the fault was downthrown in the vicinity of Niles, as indicated by the 1915 account of damage to the Shinn house, whereas the southwestern side was downthrown in other places, as described by Mr. Decoto.

Lawson (1908, p. 447) remarks that "The amount of horizontal movement, if any, was much less than on the San Andreas fault in 1906, and its direction is unknown." Three accounts of local residents who experienced the 1868 shock mention horizontal offset of fences at Hayward: "On a certain piece of ground near the Haywards Hotel there was a common board fence, the boards abutting on the post. After the quake the boards lapt one over the other about 5 inches, the ground seeming to have been prest together that much." "A fence which traversed a hill from north to south was crost by the crack, and had the ends of the boards loosened from the posts. Gradually these boards lapt over one another, until within a couple of weeks they overlapt several inches, the progress of the overlapping being noted from time to time by a pencil mark." "The fence passing diagonally up the hill was shortened 6 inches" (Lawson, 1908, p. 442). Townley and Allen (1939) mention 3 feet of horizontal displacement at the time of the 1868 quake.

A branch crack in Hayward was described as follows: "A crack 3 to 4 inches wide started from the Powell place and struck across toward the county bridge next to Nettleton's, passing west of it; crost the creek, demolisht a fence completely, and past on toward the Strowbridge residence, where the house was badly shattered" (Lawson, 1908, p. 442). The description indicates that the branch crack extended from near the corner of B and First Streets toward the northwest, a distance of at least 1,400 feet and probably farther, approximately along the line of the easternmost trace of the Hayward fault zone shown on the Hayward quadrangle by Robinson (1956).[1] Another branch crack was reported extending from the corner of B and First Streets, eastward toward the hills, fading out by the sulfur spring about 1.5 miles distant; the sulfur spring is assumed to be the spring in the Hayward Memorial Park, southeast of the present central district of Hayward. This crack is not shown on the accompanying map, because evidence of its location is scanty.

An auxiliary crack east of Warm Springs was described by Lawson (1908, p. 435) as follows: "Immediately to the east of Mission San Jose, entirely within the hills, another crack opened with a strike of N. 18° to 20° W., which, converging upon the crack thus far traced, extended south as far as the county line." Several eyewitnesses at Mission San Jose and Warm Springs gave the following descriptions of it: "On the mountain above the old Mission, just above a place called Peacock Springs, a great crack in the earth appeared, which lookt as if the lower part of the mountain had parted and slipt down." "Along the hills back of the town and southward, passing thru the present Sinclair and Stanford ranches, the crack opened. Generally it was 10 or 20 inches wide, and faulted some 18 inches on the valley side." "Crack * * * on the side of Mission Peak confirmed." "The crack past along the foothills at an elevation of 350 to 450 feet from Niles southward, back of Mission San Jose, disappearing near the county line. In some places the fissure showed a fault of 10 to 12 inches." (Lawson, 1908, p. 444).

The approximate location of the auxiliary crack east of Warm Springs and Mission San Jose was determined from the above accounts plus unpublished notes on old maps compiled at the time of the 1906 investigation, and its general trend is shown on the accompanying map.

The course of the main break followed old fault traces for part of its length, but apparently did not always follow the same trace, as for example north of Hayward and near the Masonic Home east of Decoto, where it seems to have swung from one old trace to another or followed an entirely new path.

The greatest damage was reported to be along or in the vicinity of the main break. The Earthquake Commission report (Lawson, 1908) further states, "On projection of this line southward into Santa Clara County, the intensity diminisht steadily as far as Morgan Hill, where it again rose." Although there was no report of surface rupture in the hills east of Morgan Hill where geomorphic evidence of recent movement is clear (Lloyd Cluff, oral communication, 1965), the possibility should not be ignored that unrecognized movement (with resultant breakage) in this area may have caused the reported rise in intensity.

Aside from examples quoted above, there was apparently little damage resulting from structures being torn apart by differential movement along the fault in 1868, no doubt because there were relatively few structures directly on the fault line. A photograph of the city of Hayward in 1875,[2] taken from a point north of A Street between Mission Boulevard and Main Street, looking south past the Odd Fellows' Building toward Walpert's Hill (where the Bret Harte School now stands) almost directly along the 1868 fault trace, shows few buildings along the line of faulting.

PRESENT-DAY SLIPPAGE

Recent studies along the Hayward fault zone have revealed evidence of tectonic creep or slippage. The term "slippage" is defined by Bonilla (1966) as "slight seemingly continuous movement along a fault, usually not accompanied by felt earthquakes." This slow movement along faults within the Hayward fault zone has damaged a culvert under the Memorial Stadium at the University of California, and possibly the stadium itself (locality A on map) (Radbruch and Lennert, 1966); cracked the lining of the Claremont water tunnel (locality B) (Blanchard and Laverty, 1966); distorted railroad tracks in the Niles District of Fremont (locality C) (Bonilla, 1966); and severely damaged a warehouse and bent underground water pipes in the Irvington District (locality D) (Cluff and Steinbrugge, 1966). Movement in all these places has been right lateral.

The exact width of the fault or shear zone along which slippage is taking place is not known, but it is thought to be rather narrow, probably not more than a few tens of feet.

The average rate of slippage has been estimated to be from 0.1 to 0.21 inch per year (Radbruch and Lennert, 1966; Bolt and Marion, 1966). The movement at Irvington is thought by Cluff and Steinbrugge (1966) to be intermittent; however, at the University of California a displacement meter installed across a crack in the damaged culvert under the Memorial Stadium recorded continuous right-lateral slippage from October 1965 to January 1966 (Bolt and Marion, 1966).

Slippage is probably occurring in other places along the Hayward fault zone. Slight discrepancies recently noted in rechecks of survey lines crossing the zone at 98th Street and at Lincoln Avenue in Oakland may indicate right-lateral movement in the fault zone of approximately 0.1 to 0.15 foot in 10 years (Earl Buckingham, Supervising Civil Engineer, city of Oakland, oral communication, 1966). Cracking and offsets of curbs observed in Richmond, and cracking, right-lateral offsets, and distortion of curbs, streets, and buildings in Hayward are probably also the result of creep along the Hayward fault zone.

DAMAGE TO STRUCTURES

If another earthquake should take place, with surface rupture in the fault zone, the damage caused by shearing of structures directly on the line of rupture would no doubt be very great, in addition to damage throughout the Bay area caused by shaking. The land along the entire length of the fault zone, from San Pablo to Fremont, is now heavily populated and covered with structures in most places, and those sites which are still not built up are rapidly being developed. The 1868 fault trace in Hayward, from Haywards Hill to Walpert's Hill, passes through the center of the main business district.

Builders of structures which lie within or cross the Hayward fault zone should take into account the possibility that such structures not only may be damaged by sudden movement, offset, and rupture at the time of an earthquake originating in the fault zone, but may also be subject to constant strain and damage due to the opposite sides of faults within the zone continuously moving very slowly in opposite directions.

[1] The locations of landmarks described in the 1906 report were supplied by Mrs. Zelda Riggs of the Hayward Area Historical Society.

[2] Hayward Daily Review, June 25, 1926; courtesy of the Hayward Area Historical Society.

APPROXIMATE LOCATION OF FAULT TRACES AND HISTORIC SURFACE RUPTURES WITHIN THE HAYWARD FAULT ZONE BETWEEN SAN PABLO AND WARM SPRINGS, CALIFORNIA

By
Dorothy H. Radbruch

SCALE 1:62 500

1 ½ 0 1 2 3 4 MILES
1 .5 0 1 2 3 4 KILOMETERS

CONTOUR INTERVAL 25 AND 40 FEET
DATUM IS MEAN SEA LEVEL

1967

Compiled largely from published sources

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D.C.—1967—667293

For sale by U.S. Geological Survey, price $1.00