DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Preliminary isoseismal map for the Santa Cruz (Loma Prieta), California, earthquake of October 18, 1989 UTC

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by
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Introduction

The Santa Cruz (Loma Prieta) earthquake, occurred on October 18, 1989 UTC (October 17, 1989 PST). This major earthquake was felt over a contiguous land area of approximately 170,000 km^2; this includes most of central California and a portion of western Nevada (fig. 1). The hypocenter parameters computed by the U.S. Geological Survey (USGS) are:

Origin time: 00 04 15.2 UTC
Location: 37.036^0N., 121.883^0W.
Depth: 19 km
Magnitude: $6.6m_b$, $7.1M_S$.

The University of California, Berkeley assigned the earthquake a local magnitude of 7.0ML.

The earthquake caused at least 62 deaths, 3,757 injuries, and over $6 billion in property damage (Plafker and Galloway, 1989). The earthquake was the most damaging in the San Francisco Bay area since April 18, 1906. A major arterial traffic link, the double–decked San Francisco–Oakland Bay Bridge, was closed because a single fifty–foot span of the upper deck collapsed onto the lower deck. In addition, the approaches to the bridge were damaged in Oakland and in San Francisco. Other severe earthquake damage was mapped at San Francisco, Oakland, Los Gatos, Santa Cruz, Hollister, Watsonville, Moss Landing, and in the smaller communities in the Santa Cruz Mountains.

The Santa Cruz earthquake has been assigned a Modified Mercalli Intensity (MMI, Wood and Neumann, 1931) of VIII in the epicentral area; an MMI of IX was assigned to San Francisco's Marina District and to four areas that experienced damage to reinforced–concrete viaducts. These areas are: the Nimitz Freeway (Interstate 880, Cypress Section) in Oakland; the Embarcadero, Highway 101, and Interstate 280 in San Francisco (fig. 2).

Two previous large earthquakes with high MM intensities in the San Francisco Bay area have occurred along the San Andreas fault zone. The most widely known is the April 18, 1906, San Francisco earthquake that was located about 1.5 miles south of Daly City. This event had a magnitude of 8.3 (Richter, 1958), a MMI of XI, and an epicenter location at 37.67^oN., 122.48^oW. (Bolt, 1968). The other large earthquake occurred on October 8, 1865; it was located near San Jose. This tremor had a magnitude of 6.3 (Toppozada and others, 1981), a MMI of VIII (Toppozada, personal communication), and an epicenter, inferred from an isoseismal map, at 37.2^0N., 121.9^0W.

The effects produced by the 1865 tremor (Townley and Allen, 1939) show a damage pattern similar to the 1989 Santa Cruz earthquake. These data and the epicenter inferred by Toppozada and others (1981) suggests that the 1865 earthquake has a location near the epicenter of the 1989 earthquake. The effects caused by the 1865 earthquake indicate that the highest intensities occurred in San Francisco and in the Santa Cruz Mountains; a pattern that was observed for the 1989 earthquake. In 1865, the areas that received serious damage in San Francisco was south of Market Street and in the vicinity of Battery and Washington Streets. These two areas include some of the same neighborhoods that suffered damage in 1989. For example, the old Merchant Exchange Building (corner of Battery and Washington Streets) was completely ruined; in 1989, an older, masonry–walled, 8–story

building on Battery Street was damaged and later demolished (Pflaker and Galloway, 1989). South of Market Street, the 1865 earthquake produced ground failure on Howard Street between 7th and 9th Streets where lamp posts, water pipes and gas pipes were broken and thrown out of position; on Mission Street, Popper's building was damaged; on Third Street, window glass was broken in many places. Pflaker and Galloway (1989) indicated several buildings between 5– and 10–stories high were damaged; old masonry buildings were badly damaged, including a 4–story warehouse where the collapse of exterior walls killed 5 people.

According to Townley and Allen, other locations that were affected by the 1865 earthquake were Santa Clara, San Jose, and in the Santa Cruz Mountains (Santa Cruz Gap Road). The region near Santa Cruz Gap Road sustained effects similar to those caused by the 1989 earthquake (fig. 3): downed chimneys, many landslides, and large fissures. While no damage data are listed for Los Gatos in 1865, artesian wells were reported disturbed causing water flow to increase in area streams.

Although no comparison can be made between the felt areas of the 1865 and 1989 earthquakes, a qualitative comparison of intensity levels, at selected sites that reported effects from both earthquakes, is listed in table 1. For both earthquakes the intensity levels are comparable and indicate a similar distribution of damage. The single largest MMI difference between the two earthquakes is at New Almaden, located south of San Jose. The MMI of VIII, assigned at New Almaden for the 1865 event (Toppozada, personal communication), was based on the description of "several houses were thrown down". This report assigns an MMI of VI at New Almaden for the 1989 tremor since we found no evidence of damage as severe as that described for the 1865 earthquake.

Isoseismal Map

Figure 1 shows the areal distribution of intensities for the 1989 Santa Cruz earthquake. The intensities are based on data from field notes by the authors of this report; mail questionnaires from postmasters, fire and police departments; newspaper accounts; and a damage report provided by the Scotts Valley, California fire district. A final version of the isoseismal map that includes the data used here and the data from many studies that are presently being done will be published in the USGS Bulletin "United States Earthquakes, 1989".

The MMI II–III isoseismal that defines the limit of perceptibility in figure 1 is drawn to enclose contiguous localities that felt the earthquake. The contiguous felt area extends northward from Santa Barbara along the California coast to Fort Bragg and eastward to Lovelock, Nevada. This felt area, approximates 170,000 km^2 on land, is less than one third the size of the land felt area of the 1906 earthquake, which was about 550,000 km^2. On figure 1, isoseismals have been drawn around outlying areas near Eureka and Redding to the north and in the Los Angeles–Ventura region to the south.

Figure 2 shows the distribution of intensities from the San Francisco Bay area south to Monterey. The maximum intensity shown on the map is MMI IX in parts of San Francisco and in Oakland, as mentioned in the introduction. The MMI IX and MMI VIII values are anomalous and represent small areas of damage; no MMI IX or MMI VIII isoseismals are drawn.

The maximum intensity in the epicentral area is MMI VIII as shown in figure 2. The area inclosed by the MMI VIII isoseismal is in close alignment with the fault–plane orientation of N.50^{0}W. $\pm$ 8^0. The NW–SE elongation of the MMI VIII isoseismal includes the length of the inferred fault

rupture that extends from State Highway 17 southeastward to the vicinity of Watsonville (Plafker and Galloway, 1989).

The general configuration of the MMI VII (fig. 2) isoseismal encompasses most of the region west and south of San Francisco Bay southward to Monterey Bay. The southwestern part of San Francisco County and the northern area of San Mateo County, that lies west of the San Francisco International Airport, is outlined by the MMI VI isoseismal.

Intensities and Damage

On Figure 1, the MMI VI isoseismal outlines 22,000 km^2 of land area in California which encompasses the region associated with damage to structures. This damage ranges from minor (broken windows, cracked chimneys, cracked plaster, etc.) to severe (collapsed freeways, destroyed buildings, buildings rendered uninhabitable, buildings thrown off foundations, etc.). The dollar damage estimated by the State of California, Governor's Office of Emergency Services as of November 21, 1989 for the Santa Cruz earthquake is in excess of $6 billion in property damage (Plafker and Galloway, 1989).

The following subsection highlights the more significant aspects of earthquake damage associated with MM intensity levels of VIII and IX:

Intensity IX—

The Nimitz Freeway in Oakland (Interstate 880) along Cypress Street— Approximately 1.25 miles of the double–decked, five–lane, freeway of reinforced concrete collapsed. This collapse killed 41 people and injured many others (Plafker and Galloway, 1989). The upper deck collapsed onto the lower deck when the reinforced–concrete columns failed (fig. 4).

San Francisco (I–280 near 7th Street)— A double–decked viaduct, of similar construction to the Cypress Street area of the Nimitz Freeway, sustained shear failures to columns and joints when two separate freeway structures pounded each other (Moehle, 1989).

San Francisco (Embarcadero Freeway just north of the Bay Bridge)— A double–decked viaduct, similar in construction to the portion of the Nimitz Freeway in Oakland that collapsed, sustained column failure and connection damage of the same type as the Nimitz Freeway—however, to a lesser degree.

San Francisco (Highway 101 near Fell Street)— A double–decked viaduct that had column failures similar to the column failures on Interstate 280 and the Embarcadero Freeway.

San Francisco (Marina District)— The most severe and intense area of earthquake damage, due to liquefaction, occurred in this expensive district of San Francisco. The district is located on the landfilled site of the 1915 International Exposition Fair which celebrated the rejuvenation of San Francisco following the 1906 earthquake. Residential construction began in the 1920's with the final construction stage beginning after WWII. The area of damage was bounded by Lyon Street on the west, Fillmore Street on the east, Chestnut Street on the south, and Marina Boulevard on the north along the bay. The earthquake–related damage was variable and scattered throughout the district. The damage in this area was mostly to 2– and 4–story houses with large garages on the ground

floor. Some of these houses collapsed resulting in the 2nd floors being at ground level. Other houses partially collapsed, causing the buildings to be wracked and twisted. These buildings were a total loss. Other types of buildings were not so severely damaged. One of the areas of heaviest damage was located along Divisadero Street in the vicinity of Jefferson, Beech, and North Point Streets. Some of this damage in the Marina District was due to ground failure (Plafker and Galloway, 1989). Lateral spreading caused streets to buckle, sand boils to erupt in basements streets, yards, and, parks; also, lateral spreading was responsible for broken underground gas lines and watermains. A major fire (fed by a ruptured gas line) occurred near the intersction of Jefferson and Divisadero. As in the 1906 earthquake, where a fire, that raged out of control, caused heavy damage on Market Street was due to failed watermains that were broken by lateral spreading.

Intensity VIII—

Boulder Creek— Eighty–two houses were destroyed or severely damaged (fig. 5), and an estimated 300 houses sustained major damage. Three houses burned from earthquake–related fires. The most severe damage occurred at the following locations: Rebecca Drive in Boulder Creek where 9 houses were destroyed, 5 slid downhill when the ground failed; Madrone Drive in Forest Park where 8 houses were shaken down; and Blue Ridge Drive and Wildwood Road where 12 and 16 houses respectively, were reported destroyed. Along Highway 9 ground failures and landslides were common. Following the earthquake, waterflow was reported to increase in Foreman Creek. Throuhgout the Boulder Creek area windows, chimneys, and items in homes and businesses were broken.

Brookdale— Buildings were reported destroyed, some by the collapse of brick walls, others by partial collapse of brick walls. Other damage included fallen chimneys, chimneys broken at the roof line, cracked streets, broken underground pipes, large amounts of fallen plaster, overturned heavy furniture, and many items thrown off shelves in homes and businesses with many of the glassware broken.

Corralitos— Houses were shaken off their foundations; most were older houses (fig.6). One home had part of a gable thrown down. The Holy Eucharist Church rectory collapsed, and the ceiling in the church fell. The asphalt approaches to the closed Corralitos Creek bridge, on Browns Valley Road, were down in relation to the concrete bridge. The greatest downward offset at the bridge was a few inches on the west side and about a foot on the east side. A block west of Corralitos Creek bridge (Browns Valley Road) one of the oldest homes in Corralitos was condemned—it had survived the 1906 earthquake. It was a wood–frame house that shifted on it's wood foundation. Water flow increased in the area artesian springs and in Corralitos Creek (California Division of Forestry's Corralitos Fire Station personnel, personal communication). A Corralitos fireman, who was outside at the time of the earthquake onset, described the sound as being similar to a distant shotgun blast; it was followed by a noise like that of an approaching freight train. He also stated that it was difficult to stand. No foreshocks were reported felt in Corralitos.

Glenwood (Big Redwood Park, a 67–home community)— Seven houses were destroyed; 20 suffered major structural damage; several homes were thrown off their foundations;

many chimneys were broken. A large, new, fissure and a slump were observed on Main Boulevard downslope from the community's new steel water tank.

Hollister— The most severe damage occurred in a 6–block area of the main business area (San Benito Street between Fourth and Seventh Streets). The entire front of the I.O.O.F. building on San Benito Street collapsed. Other buildings along San Benito Street sustained cracks and bulging of brick walls, with sections of the walls falling. Several houses were thrown off their foundations. Forty–two buildings were damaged so severely that they could not be occupied until major repairs were made. Water and gas lines were broken; many windows were broken, and two canneries had major structural damage. Considerable damage occurred to the contents of homes and businesses.

Laurel (A sparsely populated area in the Santa Cruz Mountains near Highway 17)— Houses were shaken off their foundations; porches collapsed; one house was overturned; chimneys were broken. Fissures cracked the roads throughout the area, and two municipal water tanks were destroyed.

Lompico (north of Scotts Valley in the Santa Cruz Mountains)— This community is an area of mostly wood houses built on slopes. Houses were thrown off their foundations; other houses that stayed on their foundatons were wracked; chimneys were broken and collapsed. One house tumbled downhill, wrecking the home below.

Los Gatos— Brick buildings in the business area (East Main Street) were cracked; walls bulged, and a few walls partially collapsed (fig. 7). Many houses were thrown off their foundations along Tait, Wilder, and Massol Avenues. Chimneys throughout this area were shaken down or broken at roof lines. In other areas of Los Gatos, less severe damage to buildings occurred west of Highway 17. Gas and water lines were broken throughout the town; sidewalks were buckled, and many of the contents of houses and businesses were broken or damaged.

Mission Springs (about 1.5 miles north of Scotts Valley)— Houses were thrown off their foundations; some of the chimneys were broken in half; others were broken at the roof line, and windows were broken. A modern church on a concrete foundation extending across a creek was severely cracked.

Oakland (Hotel Oakland at 13th and Harrison Streets)— The west wing of the seven–story brick structure was severely cracked and some of the exterior brick wall had fallen into the street (fig. 8). Much of the west wall exhibited X–fractures between windows. The west wing was closed. Other parts of the hotel walls were cracked, but less severely than the west wing. Plaster fell into the courtyard from the east wing. Many windows were broken.

Oakland (Peralta Hospital)— Suffered major structural damage and was closed. The hospital was built in 1929.

Redwood Estates— Thirty–seven houses were shaken off their foundations; at least eight houses were destroyed; one house burned down. Most of the other homes had moderate to severe damage; including broken decks or fallen chimneys. Two of the five water sup-

ply reservoirs were cracked and drained. The 380–home, mountain community reported some type of damage to all the houses.

Santa Cruz Mountains (Redwood Lodge area about 1.5 miles south of the San Andreas fault zone and about 1.5 miles east of Highway 17)— Several houses were thrown off their foundations; asphalt roads were criss–crossed with fissures; landslides and rockslides were common.

Santa Cruz Mountains (Villa Del Monte just south of Highway 17 on the south side of Summit Road)— This is an area of 87 modern homes. Fissures and ground cracks were common throughout the area; they cut through hillsides and yards and severely cracked driveways, roads, pools, and houses. Some houses were pulled apart; others slid downhill. Four miles of water mains were broken, and a water reservoir was severely cracked.

Santa Cruz Mountains (junction of Morrell Cut–Off and Soquel–San Jose Road)— A two–story, Victorian–style, wood house and the nearby barn were thrown off their foundations and severely damaged.

Santa Cruz Mountains (Stetson Road about 1.0 miles south of Redwood Lodge)— A modern wood–frame house was wracked and exterior walls separated at points of juncture. The top third of a large tree in front of the house was broken off and fell to the ground.

Santa Cruz Mountains (Skyland Community Church located about 0.7 miles east of Redwood Lodge)— A two–building, wood church connected by a wood passageway. The main church building was shaken off its foundation toward the smaller building. The porch of the church collapsed, and a chimney on the smaller building broke at the roof line and tore away part of the wood siding (fig. 9).

Santa Cruz— The most severe damage occurred along the Pacific Garden Mall (a six–block shopping mall on Pacific Street) in the older downtown area, where three people were killed. Many businesses on the mall were old, refurbished–brick structures. The worst damage was to the unreinforced brick and masonry buildings, where walls or parts of walls had collapsed (fig. 10); in other buildings roofs had fallen, destroying the interiors. Many plate glass windows shattered and building walls were severely cracked. Masonry buildings in other areas of the city sustained structural damage; some buildings were condemned. Many of the houses on Myrtle Street were shaken off their foundations; had chimneys collapse; had walls severely cracked, and had furniture overturned. Water and gas mains and sewer lines were broken in the city.

Santa Cruz (I.O.O.F. Cemetery on Graham Hill Road)— Many monuments were toppled or rotated. Some of the larger, multiple–segment monuments had only the top segment (urns, statues, etc.) shaken off. Some monuments had both fallen and rotated segments (fig. 11).

Scotts Valley (Jarvis Road)— Nine houses either partially collapsed or were shifted off their foundations; ten houses sustained moderate damage but were inhabitable. Fourteen homes had minor damage, such as cracked foundations and chimneys, broken windows, and damage to contents.

Scotts Valley (Bean Creek Road)— Seven houses were damaged, by either partial collapse or shifting off their foundations, by separation of porches or rooms from the house, or by fallen chimneys. One house shifted on the foundation but did not fall. Sixteen houses had minor damage such as cracked foundations or chimneys; broken windows, and damage to the contents. A large landslide about 1.0 miles north of Scotts Valley completely closed Bean Creek Road.

Scotts Valley (Redwood Drive about 1.5 miles south of Scotts Valley)— One house was destroyed; three houses were shaken off their foundation; another had the foundation move two inches; six houses had either cracked or fallen chimneys; one house sustained a collapsed front porch.

Soquel— Three downtown business buildings were condemned. One business had a partially collapsed wall; the other two buildings were severely damaged when a huge brick smokestack collapsed. Chimneys were broken at the roof line and fell; others completely collapsed. Other types of damage in Soquel were: cracked highways and streets; fallen tombstones; fallen water tanks; broken windows; many glass articles broken in homes and stores.

Watsonville— Many of the unreinforced–masonry buildings on Main Street were severely damaged; either from severely cracked exterior walls, partially collapsed exterior walls (fig. 12), or other major structural damage. The I.O.O.F. Building on Beech Street had the upper portion of the front, brick wall collapse killing one person (fig. 13). Saint Patricks Catholic Church was severely damaged by fallen sections of the exterior brick walls. Over 50 homes were knocked off their foundations; most of these were located on Brennen, Lincoln, and Jefferson Streets, and Stanford Avenue (fig. 14 and 15).

Zayante— Some houses collapsed; others had structural damage; a few had slid downhill or had fallen off foundations; chimneys were broken.

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Table 1. List of MM intensities for localities affected by both the October 8, 1865 and October 18, 1989, California, earthquakes.

City	1865 (Toppozada and others, 1981)	1989 (this report)
Alamo	6	6
Corralitos	7	8
Half Moon Bay	6+	7
Martinez	6	6
Napa	7	6
New Almaden	8	6+
Sacramento	5	5
San Francisco	8	7–9
San Jose	8	7
San Juan Bautista	5+	6
San Leandro	6	7
San Rafael	5–6	6
Stockton	6	5

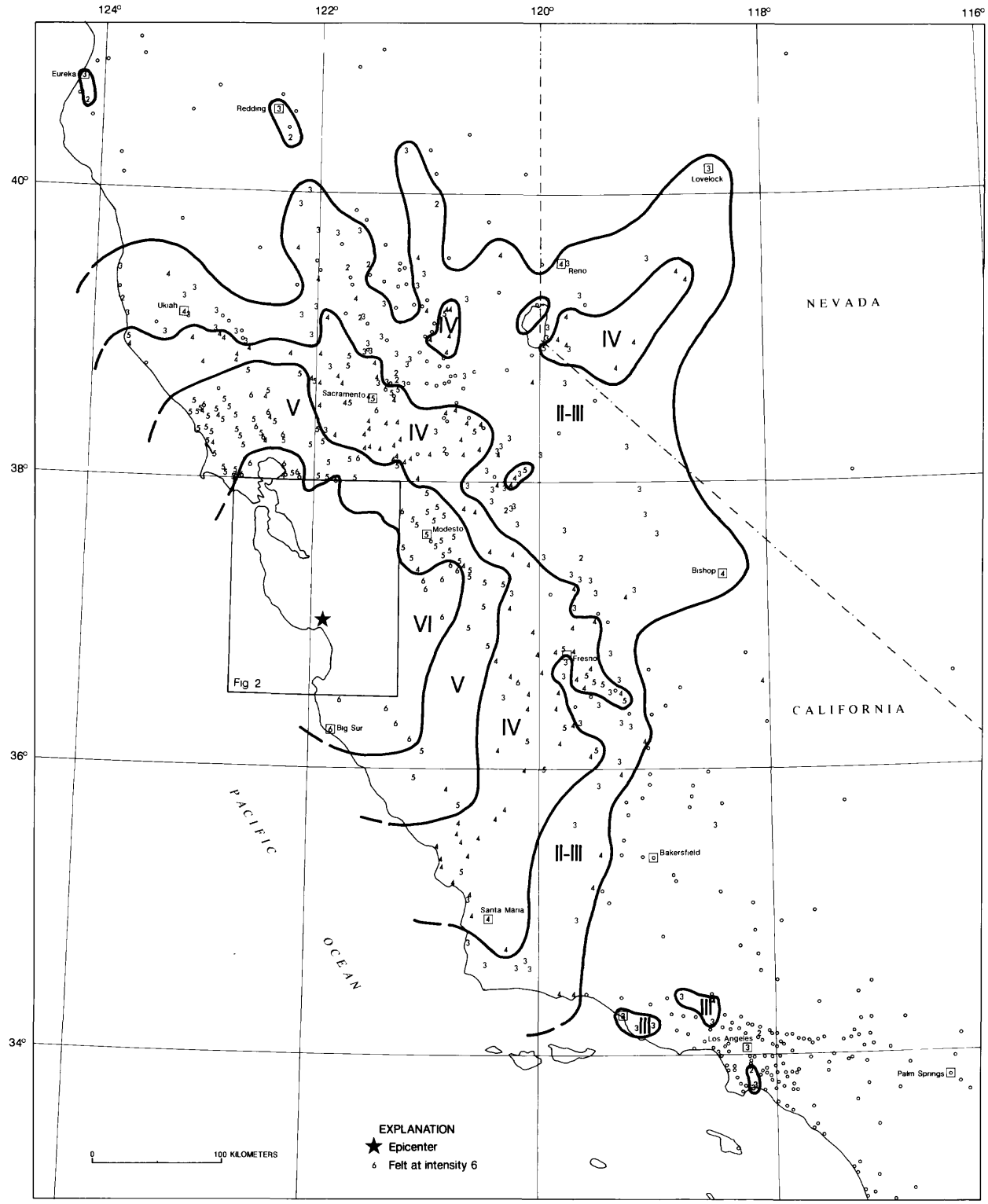

Figure 1. Isoseismal map for the Santa Cruz (Loma Prieta), California, earthquake of October 18, 1989 UTC.

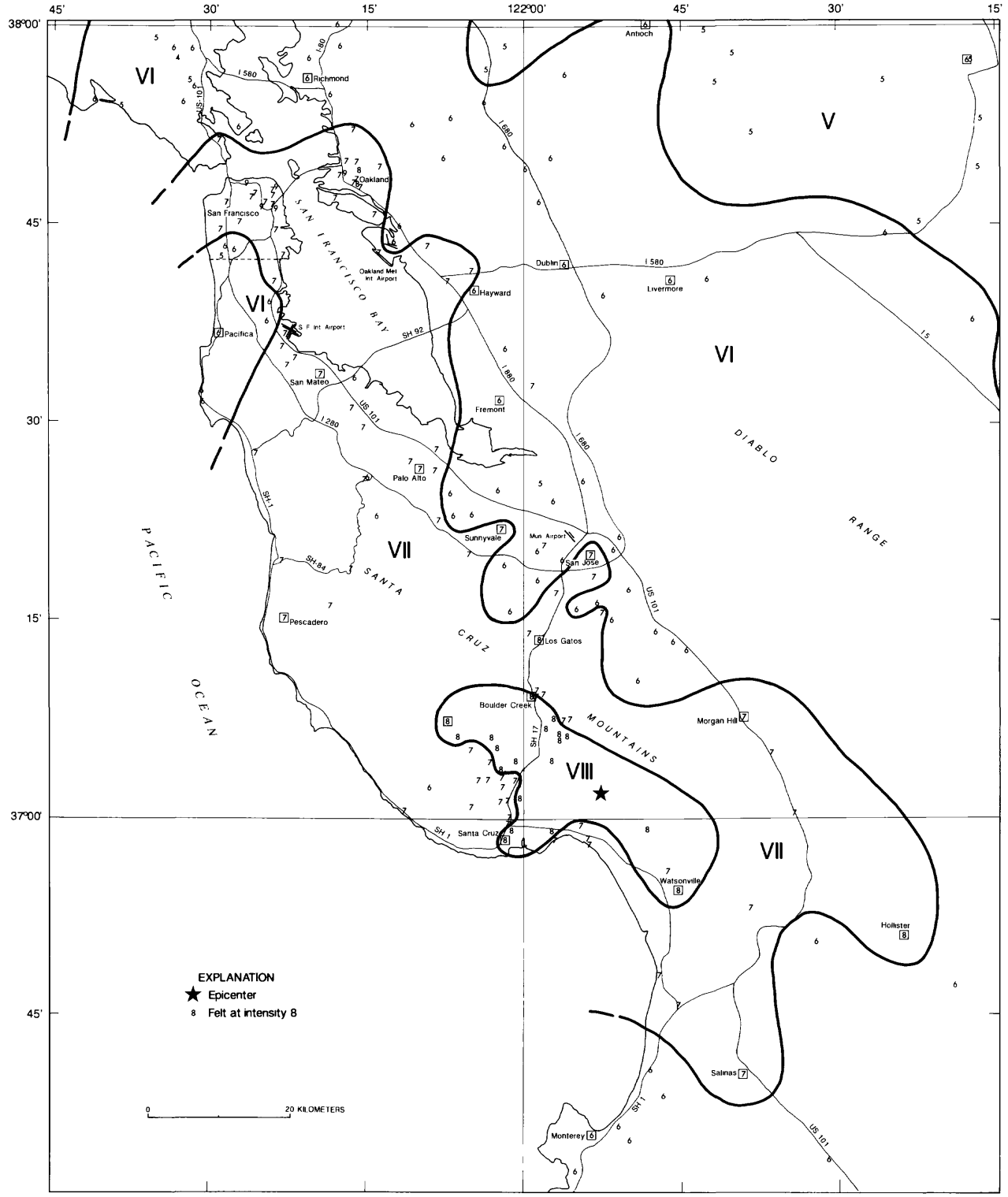

Figure 2. Isoseismal map for the San Francisco Bay region for the Santa Cruz (Loma Prieta), California, earthquake of October 18, 1989 UTC.

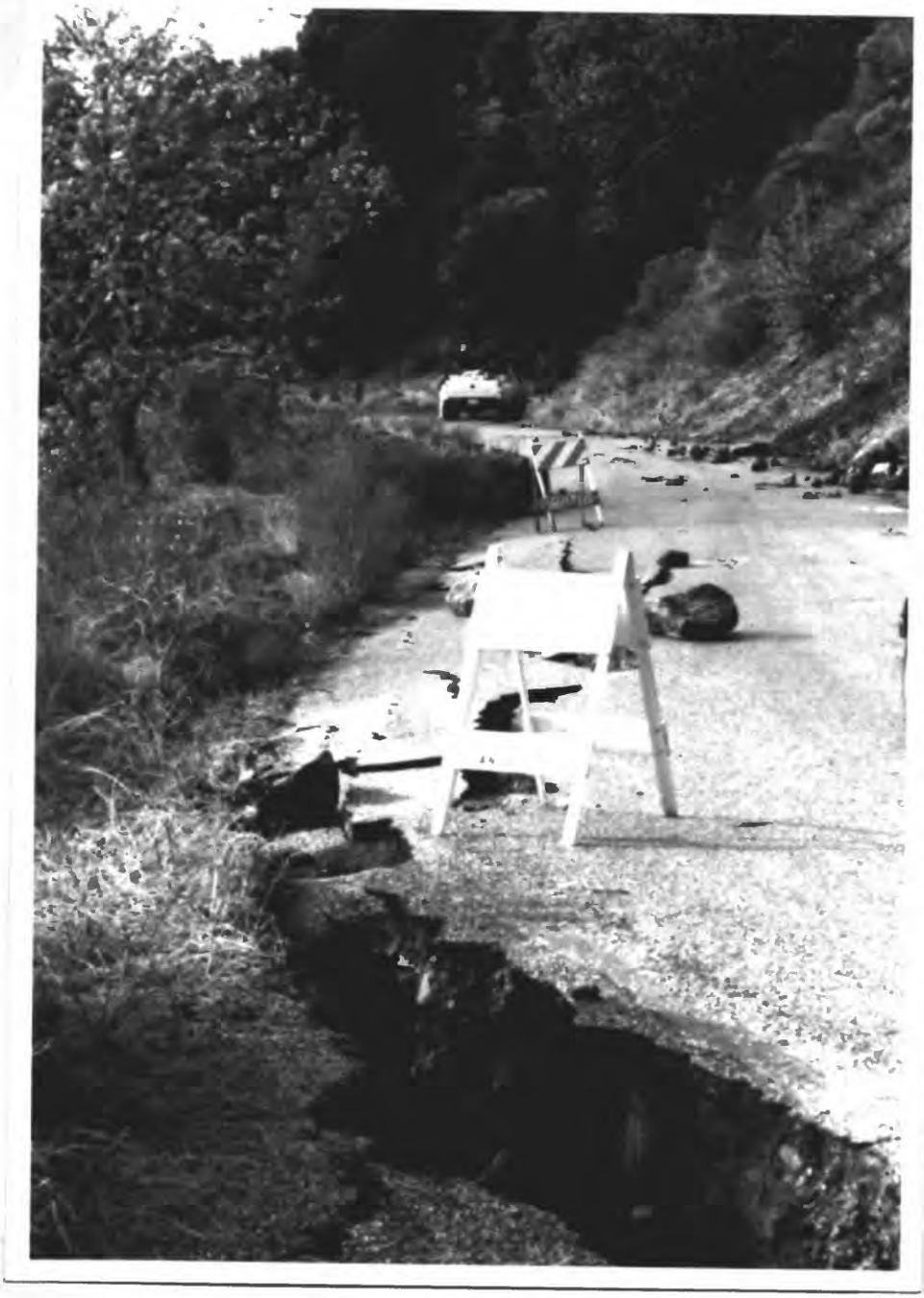

Figure 3. Fissures along Highland Way (south extension of Summit Road) about 5 miles southeast of highway 17.

Figure 4. Collapsed Nimitz Freeway along Cypress Street (Interstate 880) in Oakland (photo by E. V. Leyendecker).

Figure 5. Collapsed home on Rebecca Drive in Boulder Creek.

Figure 6. House in Corralitos thrown off its foundation breaking the chimney.

Figure 7. Wracked, twisted, and broken brick building on East Main Street in Los Gatos.

Figure 8. Damage to Hotel Oakland at the corner of 13th and Harrison Streets in Oakland.

Figure 9. Damage to Skyland Community Church at the intersection of Skyland and Miller Roads in the Santa Cruz Mountains.

Figure 10. Damage to a business on the Pacific Garden Mall, Santa Cruz, at Pacific Avenue and Lincoln Street.

Figure 11. Fallen monument at the I.O.O.F. Cemetery in Santa Cruz.

Figure 12. Damage to a commercial building on Main Street in the downtown area of Watsonville.

Figure 13. Damage to the I.O.O.F. Building on East Beach Street in Watsonville.

Figure 14. A house shaken off its foundation on Jefferson Street in Watsonville.

Figure 15. Collapsed porch on a house on Fifth and Jefferson Streets in Watsonville.