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MAP SHOWING LATE QUATERNARY FAULTS AND 1978–84 SEISMICITY OF THE LOS ANGELES REGION, CALIFORNIA

By

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INTRODUCTION

The Los Angeles region of California faces the greatest seismic risk of any part of the United States. The region is inhabited by more than 11 million people and is one of the Nation's key commercial and industrial centers. It lies astride a web of potentially active faults, including those segments of the San Andreas fault with the highest probability for generating a great earthquake during the next 30 years (Lindh, 1983; Sykes and Nishenko, 1984; Wesson and Wallace, 1985; U.S. Geological Survey, 1988). Moreover, many potentially active faults that can generate moderate-size, but damaging earthquakes lie within the metropolitan areas. Earthquakes along some of these faults—for example, a magnitude 6.5 event on the Newport-Inglewood zone—could produce losses exceeding those from a great earthquake on the more distant San Andreas fault (Evernden and Thomson, 1985).

This map shows, at 1:250,000 scale, known or suspected late Quaternary faults of the Los Angeles region, the ages of their most recent surface movements, and the associated earthquake activity for a recent 7-year period (1978 through 1984). The geologic and seismologic character of these faults and their potential for generating damaging earthquakes recently were evaluated by Ziony and Yerkes (1985). The map is intended primarily to inform scientists, engineers, and planners of the distribution of those faults that may have a potential for generating damaging earthquakes and (or) displacements of the Earth's surface. The map data also should contribute to further investigations of the seismotectonic setting of the Los Angeles region.

The mapped area extends from lat 33°15' N. to 34°45' N. and from long 116°45' W. to 120°00' W. This region encompasses parts of the Transverse Ranges (including the Santa Ynez, Santa Susana, Santa Monica, San Gabriel, and San Bernardino Mountains), the Los Angeles basin, part of the Mojave Desert, and segments of the Peninsular Ranges (including the Puente Hills, Santa Ana Mountains, and the northern San Jacinto Mountains). Offshore, it includes the eastern Santa Barbara Channel, several of the Channel Islands, the Santa Monica and San Pedro basins, Santa Catalina Island, and part of the Gulf of Santa Catalina.

In addition to the Los Angeles metropolitan area, the cities of Santa Barbara, Ventura, Riverside, and San Bernardino are within the map area.

SEISMOTECTONIC SETTING

Southern California straddles a broad boundary between two horizontally moving crustal plates. Continuing deformation along that boundary, associated with north-south compression derived from relative motion of the Pacific and North American plates, is expressed by dominantly right-lateral strike slip on vertical faults of the northwest-trending San Andreas fault system and by reverse or reverse-oblique slip along east-trending inclined faults principally within the Transverse Ranges (Yerkes, 1985). Earthquake activity currently is associated with both systems of faults.

Earthquake epicenters north and south of the Transverse Ranges commonly form relatively dense alignments coincident with elements of the San Andreas fault system. The alignments are most pronounced for the San Jacinto fault zone and, to a lesser degree, for the Whittier-Elsinore and Newport-Inglewood zones. Within the Transverse Ranges, in contrast, the pattern of seismicity is much more diffuse and complex, only locally being clearly associated with mapped surface faults. Spatial and temporal aspects of seismicity for the period 1932 through 1972 are presented by Hileman and others (1973) in a series of page-size maps of the entire southern California region.

Earthquakes in the Los Angeles region generally occur within the upper 10 to 15 km of the crust, but there are significant exceptions in parts of the Transverse Ranges. The base of the seismogenic layer, for example, may be as deep as 22 km along the south margin of the San Bernardino Mountains (Corbett and Hearn, 1984; Green, 1983; Webb and Kanamori, 1985).

Earthquake focal-mechanism solutions, from which the sense and orientation of seismogenic fault slip can be deduced, have been determined for several sectors of the Los Angeles region (Lee and others, 1979; Yerkes and Lee, 1979a, b; Webb and Kanamori, 1985; Yerkes, 1985; Hauksson, 1987; Jones, 1988.). The focal-mechanism solutions generally agree with what is known about the late Quaternary slip characteristics of the major exposed faults. Across much of the San Bernardino Mountains, however, fault-plane solutions and geologic data on faulting styles for the exposed faults commonly disagree (Webb and Kanamori, 1985).

DISTRIBUTION OF LATE QUATERNARY FAULTS

Locations of faults with known or inferred late Quaternary surface displacements have been compiled from published and unpublished sources (table 1). We assign each fault or fault segment to an age class (late Quaternary, Holocene, or historical) that most closely brackets the time span containing its youngest known surface movement. Our analysis of the stratigraphic or geomorphic evidence indicating the recency of surface faulting followed the approach described in considerable detail in Ziony and others (1974), except that we have not shown the location and type of constraining geologic evidence on this map.

Faults shown are those segments believed to have slipped during late Quaternary time (herein regarded as approximately the last 750,000 years). Late Quaternary time commonly is used to designate the time span since the Brunhes-Matuyama magnetic polarity reversal separating the Brunhes Normal-Polarity and Matuyama Reversed-Polarity Chrons, which also marks the herein-considered boundary between early and middle Pleistocene time. This magnetic polarity reversal has not been dated directly by radiometric methods but, in California, it must closely predate the age of the widespread Bishop ash bed (738,000 yr B.P., according to Izett, 1982).

Many of the faults displace stratigraphic or physiographic features formed during Holocene time (the past 10,000 years). A few faults have displaced the ground surface during historical time, which for southern California begins with the Spanish explorations in 1769. Several of the historically active faults probably slipped because of nontectonic processes, for example, subsidence due to withdrawal of ground water or of oil and gas. A full discussion of these nontectonic surface ruptures appears in Ziony and Yerkes (1985).

The California Division of Mines and Geology (CDMG), in evaluating potential fault-rupture hazard zones as mandated by the Alquist-Priolo Special Studies Zones Act of 1972, regards faults that have had surface displacements during Holocene time as "active faults" (Hart, 1985). CDMG fault investigations have provided a valuable data base on Quaternary and Holocene faults in California (see Hart, 1985, fig. 4 and Hart and others, 1986, fig. 2 for index maps to CDMG fault studies in the Los Angeles region). We consulted many of these data in preparing our map.

We consider those faults in the region that show evidence of displacement during late Quaternary time to be candidates for future rupture in response to the present tectonic stress field. The reasons for selecting the late Quaternary as the appropriate time span for assessing the potential activity of faults in the Los Angeles region are listed below:

(1) Time spans of less than several hundred thousand years may be too short for judging the potential for future activity. Major historical earthquakes have occurred along faults elsewhere in the world that lacked evidence of Holocene or historical activity.

(2) Late Quaternary deposits occur widely across the Los Angeles region and commonly contain datable markers for evaluating fault activity. Coastal sequences of marine terrace deposits are reliably dated back to 120,000 yr B.P. using various dating methods (Lajoie and others, 1979; Lajoie, 1986). The ages of ash layers within the Pleistocene marine and nonmarine sedimentary rocks between Ventura and the San Fernando Valley are accurately determined (Sarna-Wojcicki and others, 1984). Further inland, nonmarine alluvial fan deposits as old as about 750,000 yr B.P. are exposed along the faulted margins of major upland areas; the relative ages of these deposits in many places can be estimated by comparing the degree of soil-profile development associated with the surfaces of such alluvial deposits (see, for example, McFadden and Tinsley, 1982; Rockwell and others, 1985; Millman and Rockwell, 1986; Vaughan and Rockwell, 1986).

(3) Major changes in the tectonic stress field of the Los Angeles region probably occurred during early Pleistocene time (herein regarded as between about 1.7 m.y. B.P. and about 750,000 yr B.P.). These changes resulted in accelerated uplift and subsidence of major elements of the Transverse Ranges, by the initiation of slip along some faults and by the sharply accelerated rates of slip along other faults (Yeats, 1977, 1983; Stein and Thatcher, 1981; Meisling and Weldon, 1982b; Treiman and Saul, 1986). Many faults that were developed under earlier stress conditions thus may not be able to slip in the current stress field.

The late Quaternary faults shown on the map presumably are susceptible to future slip events. Not all of them, however, are capable of generating earthquakes. The dimensions of some faults may be too small in terms of potential rupture surface to produce significant earthquakes. Some faults in the western Transverse Ranges may be shallow features and do not penetrate high-shear-strength rocks that can store large amounts of elastic strain energy. In the Ventura area, for example, several faults cutting late Quaternary or Holocene strata probably result from flexural-slip folding that involves only shallow strata (Yeats and others, 1981; Yeats, 1982; Rockwell and others, 1984). Faults like these may pose little earthquake hazard, although slip along them may rupture the ground surface.

More than 95 late Quaternary faults have been identified in the Los Angeles region. The following is an overview of the major faults shown on the map. For comprehensive discussions of their geologic and seismologic character (including estimates of their slip rates and recurrence intervals between major earthquakes), readers are referred to Ziony and Yerkes (1985), especially their tables 5, 10, and 11. Yerkes (1985) has analyzed the occurrence of historical (1800–1980) damaging earthquakes in relation to the principal Quaternary faults for the Los Angeles region and surrounding parts of southern California.

San Andreas fault zone.—This zone, the principal surface boundary in California between the Pacific and the North American plates, borders the San Gabriel Mountains on the northeast and bounds the south edge of the San Bernardino Mountains. It is composed of subparallel right-lateral strike-slip faults of varied length in a belt 0.3–1.5 km wide (4 km wide near Palmdale). Within the area of the map, the zone strikes N. 65°–70° W. except east of Yucaipa, where it strikes N. 40° W. and apparently merges with the Banning fault. Most fault segments are approximately vertical, but along the San Bernardino Mountains the most recently active trace appears to dip 55°–60° NE. locally. Surface rupture associated with the estimated moment magnitude **M**=7.9 1857 Fort Tejon earthquake (whose epicenter probably was in the Parkfield-Cholame area of central California (Sieh, 1978b)) extends southeastward to near Wrightwood.

San Jacinto fault zone.—The San Jacinto fault zone extends southeastward from near Cajon Canyon more than 300 km into northern Baja California, Mexico. Seven echelon segments, from about 10 km to 85 km in length, are found in the Los Angeles region; most of these have Holocene surface displacements and are either right-lateral strike-slip or reverse-right-oblique-slip faults. These segments have generated 6 earthquakes of M_L=6.0 or greater since 1890. Near Hemet, historical creep possibly related to subsidence due to ground-water withdrawal is associated with the Casa Loma fault, a normal-right-oblique-slip fault.

Elsinore fault zone and related faults.—The Elsinore fault zone forms the northeast boundary of the Santa Ana Mountains and extends nearly 200 km from Corona to the Mexican border. Individual segments within the Los Angeles region are 3–20 km long and display reverse-right-oblique, right-lateral strike-slip, and normal-right-oblique-slip late Quaternary or Holocene offsets. The Glen Ivy North fault is the probable source for the May 15, 1910, earthquake with an estimated magnitude M_L=6.0.

The late Quaternary Chino fault, a southwest-dipping reverse-right-oblique-slip fault, continues the trend of this zone toward Pomona. The Whittier fault, a northeast-dipping reverse-right-oblique-slip fault that projects northwestward into the east margin of the Los Angeles basin, may intersect the Elsinore fault zone near the Santa Ana River; it apparently cuts Holocene deposits as far north as Brea Canyon.

Newport-Inglewood fault zone.—The Newport-Inglewood fault zone, composed of discontinuous faults and folds that presumably overlie a through-going right-lateral strike-slip fault in the basement rocks, trends southeastward from near Santa Monica across the Los Angeles basin to Newport Beach. Faults having similar trends and projections occur offshore of San Clemente and in San Diego (the Rose Canyon and La Nacion faults). Altogether, these various faults constitute a system more than 240 km long that extends into Baja California, Mexico. A near-shore segment of the fault zone was the probable source of the **M**=6.2 1933 Long Beach earthquake, a right-lateral strike-slip event that may have produced secondary surface faulting northeast of Newport.

Faults with possible Holocene offsets occur along the entire Newport-Inglewood fault zone. At the north end of the zone, these faults dip steeply westward and probably have normal-right-oblique slip. Fault segments further south are near vertical or dip steeply eastward and are dominantly right-lateral strike-slip faults. Historical surface faulting has occurred in the Baldwin Hills east of the Inglewood fault; these offsets are attributed to subsidence associated with withdrawals of oil and gas from the adjacent oil field.

Palos Verdes Hills fault zone.—This zone of faults extends at least 80 km southeastward from Santa Monica Bay; it may join the Coronado Banks fault zone, which continues southward offshore of San Diego. Onshore, the zone is represented by a southwest-dipping fault with inferred reverse-right-oblique displacement that has elevated the Palos Verdes Hills. Elements of the zone in Santa Monica Bay and San Pedro Bay, in contrast, probably are dominantly right-lateral strike-slip faults. Holocene faulting has been documented for a broad zone of faults that cross the San Pedro shelf.

San Pedro Basin fault zone.—A series of separate, left-stepping echelon faults, striking N. 35°–50° W., occurs from near Point Dume at least 70 km into the San Pedro Channel east of Santa Catalina Island. These faults of the the San Pedro Basin fault zone have not been studied in detail but apparently offset deposits considered to be of late Pleistocene age. Their slip characteristics are poorly understood, but presumably they are right-lateral strike-slip or reverse-right-oblique-slip faults.

Santa Cruz-Santa Catalina Ridge fault zone.—A number of faults that generally coincide with a prominent escarpment on the sea floor that extends southeastward from the east end of Santa Cruz Island are believed to be late Quaternary in age, although definitive evidence from acoustic-reflection profiling has not yet been obtained. The 1981 M_L=5.3 Santa Barbara Island earthquake, which indicated right-lateral strike slip, and aftershocks occurred along this escarpment.

Faults of the Mojave Desert.—Within the map area several parallel prominent faults, the Mirage Valley, Helendale, and Lenwood faults, trend northwestward from the

San Bernardino Mountains for several tens of kilometers. Although these faults uniformly strike more northerly than does the San Andreas fault zone, they probably also are right-lateral strike-slip faults. Segments of the Helendale fault are Holocene in age.

Faults within the western and central Transverse Ranges.—A broad band of late Quaternary faults traverses the interior of the Transverse Ranges from beyond Santa Barbara eastward to Pasadena, where it merges with the south boundary of the Transverse Ranges. The faults comprising the band are discrete arcuate segments that chiefly dip northward.

The faults in the area around Santa Barbara, Ventura, and the Oxnard Plain have east to northeast strikes. The Santa Ynez fault, a left-lateral strike-slip fault that dips steeply both to the north and to the south along strike, has recognizable late Quaternary displacements along at least 80 km of its 130-km length (as far east as California Highway 33) and offsets Holocene deposits near Lake Cachuma. A group of south-dipping reverse-slip faults (including the More Ranch and Mesa-Rincon Creek faults) is bordered on the north by the presumed normal-slip Mission Ridge-Arroyo Parida fault and on the south by the north-dipping reverse-left-oblique-slip Red Mountain, Pitas Point-Ventura, and North Channel faults; the latter two features may have been the sources for the estimated **M**=7.1 earthquake of December 21, 1812 (Evernden and Thomson, 1985, p. 181). The Holocene San Cayetano fault, a north-dipping thrust fault, extends for 40 km eastward from Ojai.

A major late Quaternary reverse-slip element in the Ventura basin is the Oak Ridge fault, segments of which extend for approximately 100 km from the Santa Barbara Channel to near Piru. This fault generally dips 65°–80° S., but near Fillmore it is a shallow thrust fault. Southeast of Oak Ridge is the Simi fault, a north-dipping reverse-slip fault, and similar faults near Camarillo.

Late Quaternary faults adjacent to and within the San Fernando Valley mostly strike west-northwest. The Santa Susana, San Fernando, and Sierra Madre faults are approximately 20-km-long segments of a system of northeast-dipping reverse and thrust faults extending to Pasadena. Reverse-left-oblique-slip surface faulting along the San Fernando fault, and the east end of the Santa Susana fault, accompanied the 1971 San Fernando earthquake. The central part of the San Fernando Valley is transected by the Northridge fault, a north-dipping reverse(?) fault that may connect with the Verdugo and Eagle Rock faults, segments of which have Holocene offsets.

The San Gabriel fault, one of the principal structural elements of the Transverse Ranges, extends more than 130 km in an arcuate path from the headwaters of Piru Creek to the eastern San Gabriel Mountains. Between about 12 m.y. and 5 m.y. ago, the fault was the dominant right-lateral strike-slip fault of the region (Crowell, 1982). Late Quaternary displacements, however, have been demonstrated only for the 75-km-long section of the fault trending northwestward from Big Tujunga Canyon. Holocene offsets have been documented near Castaic; the sense of slip is not known with certainty, but a significant strike-slip component is suspected.

Faults along the south margin of the Transverse Ranges.—The south boundary of the Transverse Ranges is formed by a group of west- to east-northeast-trending late Quaternary faults. These faults, which dip steeply to moderately northward, comprise an essentially continuous narrow belt more than 300 km long that adjoins many of the urban centers of the Los Angeles region.

Offshore, these faults include the Santa Rosa Island fault, the Santa Cruz Island fault, the Anacapa fault, and a segment of the Santa Monica fault. Geologic relations can be directly observed only for the Santa Cruz Island fault, which extends for more than 70 km and is a steeply north dipping left-lateral strike-slip (or reverse-left-oblique-slip) fault. The 45-km-long Anacapa fault, mapped solely on the basis of acoustic-reflection profiles, is inferred to dip moderately northward; it is the probable source of the reverse-slip 1973 Point Mugu earthquake (**M**=5.3). Onshore, the north margin of the Los Angeles basin is delineated by the Santa Monica fault, the Hollywood fault, and the Raymond fault, all believed to be north-dipping reverse-oblique-slip faults. The Santa Monica fault offsets late Pleistocene deposits eastward to its intersection with the northwest-trending Newport-Inglewood zone, but further east late Quaternary deposits apparently are undisturbed although the fault is present in the subsurface. Holocene surface displacements are well documented for the Raymond fault, possible source for the July 11, 1855, earthquake of Modified Mercalli Intensity VIII, and are inferred for the less well exposed Hollywood fault.

Eastward from Pasadena, the densely populated San Gabriel Valley is separated from the San Gabriel Mountains on the north by the geometrically complex zones of the Sierra Madre and Cucamonga faults. The former, which merges with the San Fernando fault to the northwest, is composed of four distinct segments totaling 65 km in length that dip 35°–60° N. The Cucamonga fault is a north-dipping reverse-slip fault with Holocene segments extending for more than 20 km.

Several isolated late Quaternary faults that probably are north-dipping Transverse Ranges structures lie south of the mountain front. These include the Indian Hill fault, the San Jose (B) fault, and the Red Hill fault. The latter offsets Holocene deposits at its east end.

Faults along margins of the San Bernardino Mountains.—The north edge of the San Bernardino Mountains is marked by an arcuate group of faults of varied strike, dip, and style of slip that have served to elevate the mountain mass. A prominent southeast-dipping reverse-slip late Quaternary element is the Ord Mountains fault. The latter apparently changes strike and links (through a series of folds) with the west-trending Sky Hi Ranch fault zone, a complex of vertical right-lateral strike-slip faults and south-dipping reverse-slip faults cutting late Pleistocene deposits. The Holocene Cleghorn fault is a left-lateral strike-slip fault whose displacements probably are distributed to the northeast along the Tunnel Ridge lineament, the Bowen Ranch fault, and the Arrastre Canyon Narrows fault (Meisling, 1984).

The San Andreas fault zone, described previously, delineates the southwest edge of the San Bernardino Mountains. North of the San Andreas fault zone and subparallel with it is the Mill Creek fault, a near-vertical structure considered by Matti and others (1985) to have been the principal strand of the San Andreas fault zone during middle and late Pleistocene time.

South of the San Andreas fault zone is a complex group of late Quaternary and Holocene faults. Northeast-striking normal-slip faults of the Crafton Hills fault zone form the east margin of the San Bernardino Valley. The west-striking north-dipping reverse-slip and thrust faults of the Banning fault and the San Gorgonio Pass fault zone are major structural elements that extend eastward beyond the map area. The Banning fault was the source of the M_L=5.9 North Palm Springs earthquake of July 8, 1986, a right-lateral strike-slip event on a north-dipping fault (Jones and others, 1986).

Unrecognized late Quaternary faults.—We emphasize that the map is not a final and complete accounting of the late Quaternary faults in the region. Although nearly 100 such faults have been identified, others probably exist but are not now recognizable. The map is most reliable for the onshore area but even there young faults may be hidden beneath Holocene alluvial deposits or, such as in the Los Angeles basin, by urban development. The distribution and Quaternary history of many faults within and flanking the San Bernardino Mountains, Agua Tibia Mountain, and the mountainous area north of the Santa Ynez and San Cayetano faults requires additional evaluation.

The occurrence of the October 1, 1987, Whittier Narrows earthquake (M_L=5.9) demonstrated that damaging earthquakes can occur at the north margin of the Los Angeles basin along concealed thrust faults (Hauksson and others, 1988; Davis and Yerkes, 1988; Namson and Davis, 1988). These faults are at depths of 10 to 15 km and within crystalline basement rocks. The only shallow expression of these thrust faults appears to be local folding within the thick sedimentary rock section that overlies the crystalline basement.

Information on late Quaternary faults offshore is much less complete and reliable than onshore. Acoustic-reflection profiles are the chief data available for deducing the recency of faulting offshore. Fault evaluation there is particularly difficult because of sparseness of data points and because of uncertainties in detecting the presence of faults in young sediments and in determining the ages of offset rocks and sediments (Clarke and others, 1985).

We expect that additional late Quaternary faults will be delineated for the Los Angeles region as additional geologic and seismologic research is conducted. Moreover, continuing field studies along the faults already identified undoubtedly will result in modification of the assigned ages of latest surface rupture.

1978–84 SEISMICITY

The earthquakes shown on the map are all earthquakes recorded by the Southern California Seismic Network (SCSN) between 1978 and 1984 that measured a local magnitude (M_L) of 2.0 or greater and had a statistical horizontal location accuracy of 5 km or less. The SCSN is operated jointly by the Seismological Laboratory of the California Institute of Technology (CIT) and the U.S. Geological Survey (USGS). The seismic stations recorded by the network in 1984 are shown in figure 1. The size of the network has increased over the last two decades from 30 stations in 1970, to 125 stations in 1977, and to 238 stations in 1984. Most of the stations are operated by the USGS or CIT except in the Los Angeles basin and the Santa Barbara Channel. The University of Southern California operates two smaller seismic networks in those regions, and data from some of the USC stations are recorded by SCSN.

Digital recording of seismograms by the SCSN began during 1977. Since that time, routine processing and analysis of earthquakes has been accomplished with various computer-processing systems, including CEDAR (Johnson, 1979) and the CIT-USGS Seismic Processing system or CUSP (Johnson, 1983). For some periods, computer processing is incomplete and the catalog is based on helicorder records. These changes have led to variations in the estimated magnitude levels for completeness of the catalog (table 2; from Norris and others, 1986). The map shows earthquakes occurring from 1978, the year of completely computer analyzed data, to 1984. It includes earthquakes of $M_L \geq 2.0$, for which the catalog is complete during most, but not all, of the 1978–84 period. We felt that a higher cutoff magnitude would limit the data set too severely.

The hypocenters of earthquakes recorded by the SCSN were determined using a computer algorithm for earthquake locations (Johnson, 1979) and the seismic velocity model in table 3. This model is based on crustal studies of Hadley and Kanamori (1977) in the area of the southern Mojave Desert. It was adopted as the standard model for SCSN locations in 1978. Earthquakes located by SCSN are assigned a location quality depending on the estimated errors in the epicentral determination (table 4). The map shows a total of 2,945 earthquakes assigned a quality of A (1,294 events), B (772 events), C (847 events), or P (32 events). Some of the largest earthquakes in the catalog are poorly located because of processing difficulties during periods of high seismic activity or because the events occurred on the periphery of the network area. C- and P-quality earthquakes were plotted on the map to ensure that all $M_L \geq 4.0$ earthquakes were included.

The locational, magnitude, and quality data for earthquakes of $M_L \geq 4.0$ that appear on the map are shown in table 5. Hutton and others (1984) provide similar information for earthquakes of $M_L \geq 3.0$ occurring within a broader area of southern California during the time period 1975 through 1983 (1984 is not included). The full catalog of earthquakes appearing on the map of the Los Angeles region is available in EBCDIC format on 9-track tape. Prospective users should send a blank tape to the following address and specify the time period (1978 through 1984) and geographic area of the map (lat 33°15' N. to 34°45' N.; long 116°45' W. to 120°00' W.):

Seismological Laboratory
California Institute of Technology
Pasadena, CA 91125
Attention: L. K. Hutton, Staff Seismologist

Norris and others (1986) describe the procedures for obtaining various types of data (catalogs, analog and digital seismograms, and phase information) for earthquakes recorded by the SCSN. CIT charges modest fees for services in formatting some of these data.

Calculated depths of earthquakes are not shown on the map. Because depth determination is more sensitive than epicentral locations to the velocity model, the use of an average model over an area of widely varying seismic velocities such as southern California can lead to large errors in the calculated depths. The calculated depths of C- and P-quality earthquakes in particular are poorly constrained. Analysis of the A- and B-quality events in the 1978–84 earthquake data set indicates that 88 percent of the recorded events have calculated depths between 2 km and 16 km (fig. 2). The distribution of earthquakes with depth is not as smooth as might be expected, but we do not believe that this has any geologic significance. The apparent concentration between 4 km and 5 km could reflect the large number of shallow aftershocks associated with the August 13, 1978, earthquake (M_L=5.1) in the Santa Barbara Channel. The relative deficiency for events between 6- and 7-km depth could be an artifact of the velocity model used (a *P*-wave velocity boundary at 5.5 km): presence of a strong velocity contrast would tend to locate earthquakes below this depth closer to the boundary.

We compared the calculated depths for the higher quality (A and B) earthquake locations for different depth intervals across the Los Angeles region (fig. 3). There are no obvious regional differences in occurrences of events less than 13 km deep, but significant regional differences exist for earthquakes 14 km or deeper (fig. 3C). Most noticeable is that events ≥14 km in depth do not occur along the San Andreas fault, within the Mojave Desert, in the San Bernardino Mountains, or along the central sector of the Whittier-Elsinore fault zone. Concentrations of the deeper earthquakes are most prominent along the San Jacinto fault, the Banning fault, and the San Gorgonio Pass fault zone.

DISCUSSION

Late Quaternary faults and earthquake epicenters in southern California do not generally exhibit the close spatial correspondence typical of other parts of California such as the San Francisco Bay region (for example, see Ellsworth and others, 1982). Moreover, a 7-year time span represented by the earthquakes shown on this map is an inadequate "snapshot" of seismic-energy release for analyzing the regional seismotectonics. Several important observations, however, result from comparing the patterns of 1978–84 seismicity with the distribution of mapped late Quaternary faults in the Los Angeles region.

Distinct alignments of epicenters follow some, but not all, of the northwest-trending faults and fault zones. Seismicity is clustered around part of the San Andreas fault zone between Lake Hughes and Cajon Canyon, the San Jacinto fault zone, and the Elsinore fault zone south to Agua Tibia Mountain. Less well developed concentrations of earthquakes are associated with the Helendale and Lenwood faults in the Mojave Desert. Offshore, a linear trend of earthquake epicenters parallels, but generally lies west of, the Santa Cruz-Santa Catalina Ridge fault zone.

For the remaining northwest-trending faults, however, close spatial correlations with the 1978–84 seismicity are lacking. No distinct alignments of earthquakes are evident in the seismicity of the Los Angeles basin and adjacent offshore area. An irregular "cloud" of earthquake epicenters, rather than linear trends, characterizes the sector that spans the San Pedro Basin fault zone, the Palos Verdes Hills fault zone, the Newport-Inglewood fault zone, and the Los Alamitos fault. A recent detailed study that more precisely relocated the 1973–85 seismicity for the Newport-Inglewood fault zone (Hauksson, 1987) did not greatly tighten the diffuse belt of earthquakes along that zone. The dispersion of epicenters within the Los Angeles basin sector suggests that, at the magnitude M_L=4.0 level or lower, seismic energy is being released by widely scattered small faults rather than by the principal late Quaternary faults.

Seismicity within the dominantly reverse-slip regime of the Transverse Ranges generally occurs as irregular concentrations. Only a few of the concentrations appear spatially coincident with individual mapped late Quaternary faults. The western segment of the Oak Ridge fault, for example, has a dense grouping of small earthquakes. The earthquake pattern within the Santa Susana Mountains is compatible with the north-dipping Santa Susana fault. At the east end of the San Gabriel Mountains, a cluster of earthquake epicenters apparently is associated with the north-dipping Cucamonga fault.

Twenty-one earthquakes of M_L=4.0 or larger (table 5) appear on the map and 11 of them are offshore. The pattern of seismicity during the 1978–84 period locally is dominated by three M_L=5.0 or larger events and their aftershocks: the August 13, 1978, Santa Barbara earthquake (M_L=5.1), the January 1, 1979, Malibu earthquake (M_L=5.0), and the September 4, 1981, Santa Barbara Island earthquake (M_L=5.3). All of these occurred on or near mapped late Quaternary faults offshore. The 1978 Santa Barbara earthquake, interpreted as a reverse-slip event on a fault dipping 30°–60° N. (Yerkes and Lee, 1979a, b), may be associated with the Pitas Point-Ventura fault or the North Channel fault. The epicenter of the 1979 Malibu earthquake is located south of our mapped trace of the north-dipping Anacapa fault near its intersection with the Palos Verdes Hills fault zone: Hauksson and Saldivar (1986) determined a north-dipping reverse-faulting solution for the event; they suggested that the east end of the Anacapa fault may be located further south than we mapped and may be en echelon, rather than continuous, with the Santa Monica fault. We believe that a more likely seismotectonic explanation is that an unrecognized late Quaternary fault paralleling the Anacapa fault on the south generated this earthquake. The 1981 Santa Barbara Island earthquake and aftershocks plot southwest of the Santa Cruz-Santa Catalina Ridge fault zone but, because earthquake locations are poorly constrained in that sector, these events probably were produced by that fault zone.

Finally, concentrations of epicenters occur in several sectors of the map where late Quaternary surface faults have not been identified. The most prominent of these areas are the San Bernardino Mountains (the site of 4 events of $M_L \geq 4.0$), the area south of Cahuilla Mountain, and the mountains southwest of Aguanga near the Elsinore fault zone. The presence of relatively high levels of seismicity in these areas suggests that further exploration for the possible presence of unrecognized late Quaternary faults would be useful.

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Table 1. Sources of geologic data that are the bases for identifying faults as late Quaternary in age on the map and for determining their ages of latest surface displacement. See list of references for a complete citation

Fault, fault zone, or fault group	Sources of information
San Andreas fault zone	Barrows and others (1985) Matti and others (1985) Miller (1979) Morton and Miller (1975) Ross (1969) Schubert and Crowell (1980) Sieh (1978a)
San Jacinto fault zone:	
Glen Helen	Matti and others (1985) Sharp (1972)
San Jacinto	Matti and others (1985) Morton (1975, 1976)
Lytle Creek	Matti and others (1985) Mezger and Weldon (1983) Morton (1975, 1976)
Claremont	Hart and others (1979) Matti and others (1985) Morton (1978) Sharp (1972)
Casa Loma	Fett and others (1967) Hart and others (1979) Matti and others (1985) Morton (1978) Proctor (1962, 1974) Rasmussen (1981, 1982)
Hot Springs	Hart and others (1979) Matti and others (1985) Sharp (1967)
Clark	Matti and others (1985) Sharp (1967, 1972)
Beaumont Plain fault zone	Matti and others (1985)
Rialto-Colton	California Department of Water Resources (1970)
Central Avenue	Morton (1976) Ziony and others (1974)
Chino	Durham and Yerkes (1964) Heath and others (1982) Weber (1977)
Elsinore fault zone:	
Fresno, Tin Mine, Main Street	Hart and others (1979) Weber (1977)
Elsinore fault zone—*Continued*:	
Glen Ivy North, Glen Ivy South	Hart and others (1979) Millman and Rockwell (1986) Rockwell and others (1986) Weber (1977)
Wildomar, Willard	Hart and others (1979) Kennedy (1977) Weber (1977)
Faults flanking Agua Tibia Mountain	Vaughan and Rockwell (1986)
Murrieta Hot Springs	Hart and others (1979) Kennedy (1977)
Whittier	Durham and Yerkes (1964) Hannan and others (1979) Hart and others (1979) Tan and others (1984) Yerkes (1972)
Norwalk	Yerkes (1972) Tan and others (1984)
Coyote Hills	Yerkes (1972) Tan and others (1984)
Peralta Hills	Bryant and Fife (1982) Fife and others (1980) Schoellhamer and others (1981)
Los Alamitos	California Department of Water Resources (1961)
Newport-Inglewood fault zone:	
Inglewood	Castle and Yerkes (1976) Hart and others (1986) Poland and others (1959) Weber, editor (1982)
Potrero, Avalon-Compton	Hart and others (1986) Poland and others (1959)
Cherry-Hill, Reservoir Hill, Seal Beach	Hart and others (1986) Poland and Piper (1956)
North Branch	California Department of Water Resources (1966, 1968)

Table 1. Sources of geologic data that are the bases for identifying faults as late Quaternary in age on the map and for determining their ages of latest surface displacement. See list of references for a complete citation—*Continued*

Fault, fault zone, or fault group	Sources of information
Newport-Inglewood fault zone—*Continued*:	
North Branch—*Continued*	Guptill and Heath (1981) Hart and others (1986)
South Branch	California Department of Water Resources (1968) Hart and others (1986) Poland and Piper (1956)
Pelican Hill	Clark and others (1986) Ziony and others (1974)
Faults offshore of San Clemente	Clarke and others (1985; 1987)
Charnock, Overland Avenue	Poland and others (1959)
Palos Verdes Hills fault zone	Clarke and others (1985) Darrow and Fischer (1983) Nardin and Henyey (1978) Poland and others (1959) Vedder and others (1986) Woodring and others (1946)
Cabrillo	Clarke and others (1985) Darrow and Fischer (1983) Vedder and others (1986) Woodring and others (1946)
Redondo Canyon	Clarke and others (1985) Nardin and Henyey (1978) Vedder and others (1986) Yerkes and others (1967)
San Pedro Basin fault zone	Clarke and others (1985) Junger and Wagner (1977) Nardin (1981) Vedder and others (1986)
Santa Cruz-Santa Catalina Ridge fault zone	Clarke and others (1985) Junger and Wagner (1977) Vedder and others (1986)
Faults of the Mojave Desert:	
Llano	Guptill and others (1979) Ponti and Burke (1980)
Mirage Valley	Ponti and Burke (1980)
Helendale, Lenwood	Morton and others (1980)

Fault, fault zone, or fault group	Sources of information
Faults within the western and central Transverse Ranges:	
Santa Ynez	Darrow and Sylvester (1983) Dibblee (1966) Keaton (1978) Troutman and others (1986)
Mission Ridge-Arroyo Parida	Jackson and Yeats (1982) Rockwell (1983) Rockwell and others (1984) Yeats and Olson (1984)
San Jose (A), More Ranch, Lavigia	Olson (1982) Upson (1951)
Mesa-Rincon Creek, Shepard Mesa	Jackson and Yeats (1982)
Carpinteria	Jackson and Yeats (1982)
Red Mountain	Jackson and Yeats (1982) Yeats and others (1981; 1987)
Javon Canyon	Sarna-Wojcicki and others (1987)
North Channel	Yerkes and others (1981)
Pitas Point-Ventura	Greene and others (1978) Sarna-Wojcicki and others (1976) Yerkes and others (1981)
Santa Ana	Hart and others (1986) Rockwell and others (1984)
Faults near Oak View	Hart and others (1986) Rockwell (1983) Rockwell and others (1984) Yeats and others (1981)
Lion Canyon	Hart and others (1986) Rockwell (1983) Schleuter (1976)
San Cayetano	Hart and others (1986) Rockwell (1983) Schleuter (1976)
Faults of Orcutt and Timber Canyons	Hart and others (1986) Rockwell (1983) Yeats and others (1981)

Table 1. Sources of geologic data that are the bases for identifying faults as late Quaternary in age on the map and for determining their ages of latest surface displacement. See list of references for a complete citation—*Continued*

Fault, fault zone, or fault group	Sources of information
Faults within the western and central Transverse Ranges—*Continued*:	
Santa Felicia, Holser, Del Valle	Weber (1978; 1982) Yeats and others (1986)
Clearwater	Los Angeles County Engineer (unpublished data, 1965) Stanley (1966)
San Gabriel	Cotton (1986) Cotton and others (1983) Weber (1978, 1982, 1986)
Oak Ridge	Clarke and others (1985) Greene and others (1978) Yeats and others (1981, 1982)
McGrath	Clarke and others (1985) Greene and others (1978)
Springville	Jakes (1979)
Camarillo	Gardner (1982) Jakes (1979)
Simi	Jakes (1979) Hanson (1981)
Santa Susana	Leighton and others (1977) Lung and Weick (1978) Weber (1975) Yeats and others (1977)
San Fernando	Barrows (1975) Kahle (1975) Sharp (1975) USGS Staff (1971) Weber (1975)
Mission Hills	Kowalewsky (1978) Saul (1975) Shields (1978)
Northridge	Barnhart and Slosson (1973) Shields (1978) Weber (1980)
Verdugo, Eagle Rock	Weber (1980)
Possible fault in North Hollywood	Weber (1980)

Fault, fault zone, or fault group	Sources of information
Faults along southern margin of Transverse Ranges:	
Santa Rosa Island	Junger (1976, 1979) Kew (1927)
Santa Cruz Island	Clarke and others (1985) Junger (1976, 1979) Patterson (1979)
Anacapa	Clarke and others (1985) Junger and Wagner (1977)
Malibu Coast	K.R. Lajoie (USGS, unpublished data, 1983) Yerkes and Wentworth (1965)
Santa Monica	Crook and others (1983) Hill (1979) Hill and others (1979) McGill (1981, 1982)
Hollywood	Crook and others (1983) Hill and others (1979) Weber (1980)
Raymond	Bryant (1978) Crook and others (1987) Weber (1980)
Sierra Madre	Crook and others (1987)
Duarte	Crook and others (1987)
Clamshell-Sawpit fault zone	Crook and others (1987)
Cucamonga	Matti and others (1982, 1985) Morton and Matti (1987) Morton and others (1982)
Indian Hill	California Department of Water Resources (1970)
San Jose (B)	California Department of Water Resources (1970)
Red Hill	California Department of Water Resources (1970) Matti and others (1985) Morton (1976)
Inferred fault near Fontana	Cramer and Harrington (1984, 1987)

Table 1. Sources of geologic data that are the bases for identifying faults as late Quaternary in age on the map and for determining their ages of latest surface displacement. See list of references for a complete citation—*Continued*

Fault, fault zone, or fault group	Sources of information
Faults along margins of San Bernardino Mountains:	
Cleghorn, Grass Valley	Meisling and Weldon (1982a, b) Meisling (1984)
Ord Mountains	Meisling (1984) Miller (1987)
Sky Hi Ranch fault zone	Meisling (1984) Miller (1987)
Tunnel Ridge lineament, Bowen Ranch, Arrastre Canyon Narrows	Meisling (1984)
Faults along margins of San Bernardino Mountains—*Continued*:	
Mill Creek	Matti and others (1985)
Crafton Hills fault zone	Matti and others (1985) Morton (1976)
Banning	Allen (1957) Matti and others (1985)
San Gorgonio Pass fault zone	Matti and others (1985)

Table 2. Estimated minimum magnitude for completeness of the catalog of the Southern California Seismic Network

From	To	Minimum magnitude
1977	May 1980	2.0
May 1980	March 1981	2.4
March 1981	March 1983	1.8
April 1983	June 1983	2.4
July 1983	1984	1.5

Table 3. Seismic-velocity model used for routine earthquake locations in the Southern California Seismic

P-wave velocity (km/s)	Depth to top of layer (km)
5.5	0.0
6.3	5.5
6.7	16.0
7.8	37.0

Table 4. Qualities of earthquake locations in the Southern California Seismic Network

Quality	Calculated Epicentral error (km)	Calculated Hypocentral error (km)
A	<1.0	<2.0
B	<2.0	<5.0
C	<5.0	>5.0
D	>5.0	
P		Preliminary determination

Table 5. List of $M_L \geq 4.0$ earthquakes in the Los Angeles region, 1978–84

Year	Month	Day	Hr	S	Latitude	Longitude	Depth	Mag	Qual
1978	4	1	1052	27.41	34 11.84	116 57.57	7.96	4.0	A
1978	5	23	916	50.83	33 54.32	119 9.93	6.00	4.0	C
1978	8	13	2254	53.42	34 20.82	119 41.75	12.75	5.1	B
1978	11	20	655	9.50	34 9.06	116 58.34	6.07	4.3	A
1979	1	1	2314	38.93	33 56.65	118 40.88	11.28	5.0	B
1979	6	29	553	20.45	34 14.78	116 54.07	5.65	4.6	B
1979	6	30	034	11.64	34 14.56	116 53.75	5.75	4.9	B
1979	6	30	7 3	52.95	34 14.92	116 54.01	5.56	4.5	B
1979	8	22	2 1	36.33	33 42.06	116 50.20	5.04	4.1	B
1979	10	17	2052	37.29	33 55.97	118 40.17	5.51	4.2	C
1979	10	19	1222	37.75	34 12.64	117 31.83	4.88	4.1	B
1981	9	4	1550	50.33	33 40.26	119 6.67	5.00	5.3	C
1981	10	23	1728	16.87	33 37.81	119 1.18	12.00	4.6	C
1981	10	23	1915	52.48	33 38.22	119 3.34	6.28	4.6	C
1982	4	13	11 2	12.16	34 3.25	118 57.87	16.61	4.0	A
1982	5	25	1344	30.28	33 32.27	118 12.44	13.66	4.1	A
1983	1	8	719	30.37	34 8.12	117 26.86	4.61	4.1	A
1984	2	27	1018	15.02	33 28.25	118 3.66	6.00	4.0	C
1984	5	7	1932	32.75	34 39.63	119 58.35	9.88	4.2	A
1984	6	12	027	52.38	34 32.44	118 59.35	11.71	4.1	A
1984	10	26	1720	43.53	34 0.98	118 59.30	13.33	4.6	A

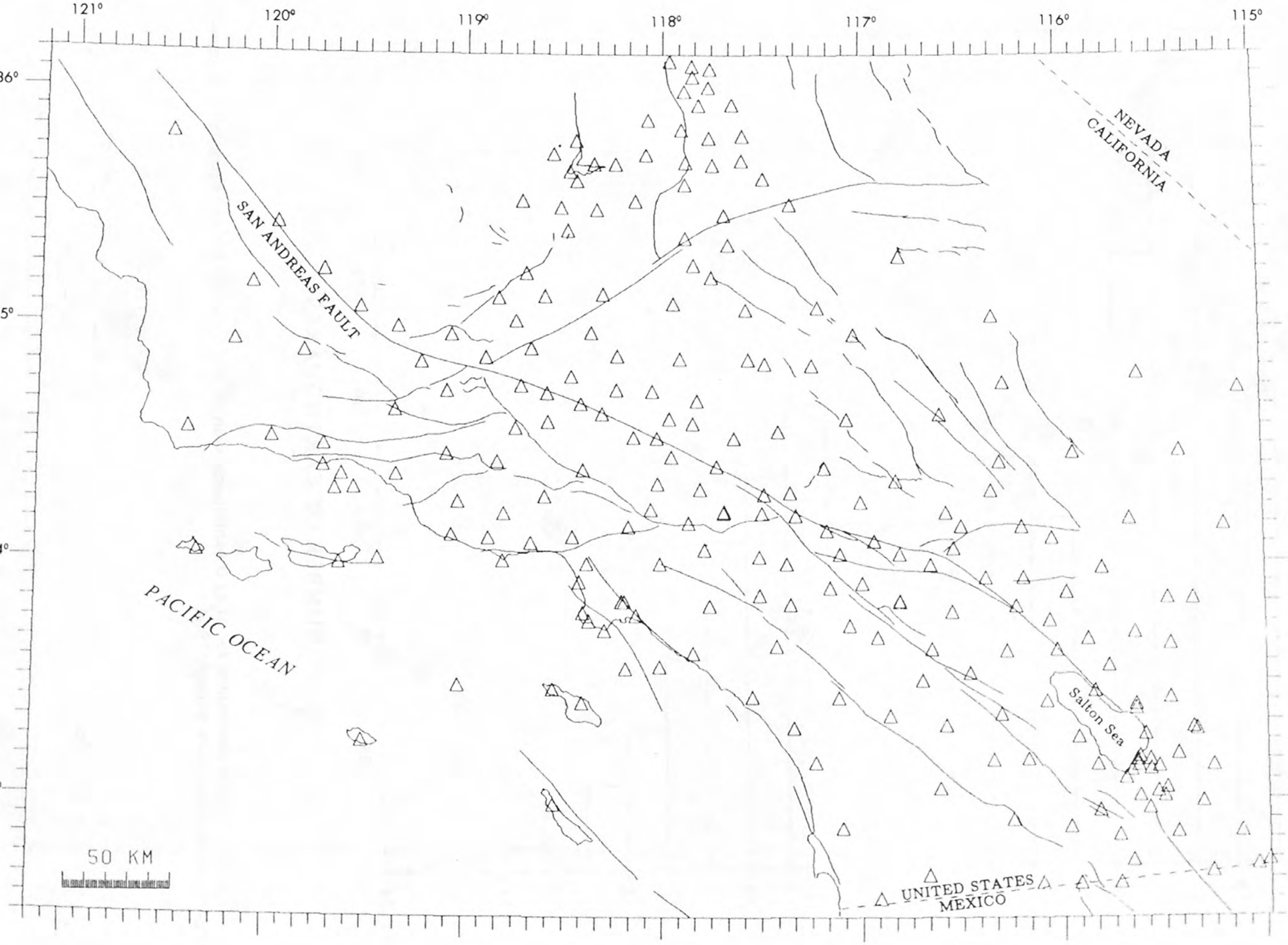

Figure 1. Locations of seismic stations recorded by the Southern California Seismic Network in 1984. Lines indicate faults as generalized from Jennings (1975).

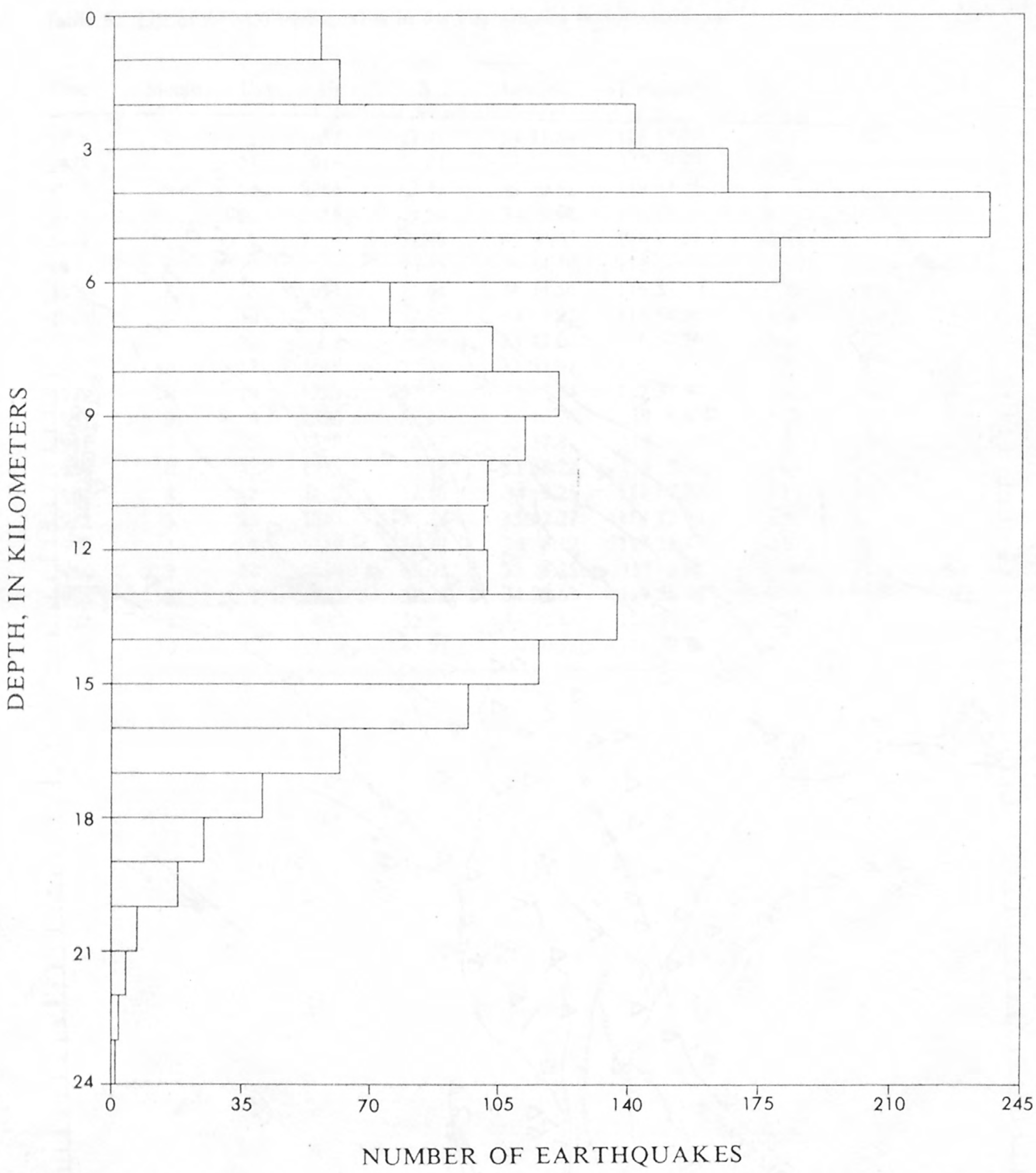

Figure 2. Histogram of depths determined for $M_L \geq 2.0$ earthquakes with A- and B-quality locations (see table 4) recorded for the Los Angeles region from 1978 through 1984.

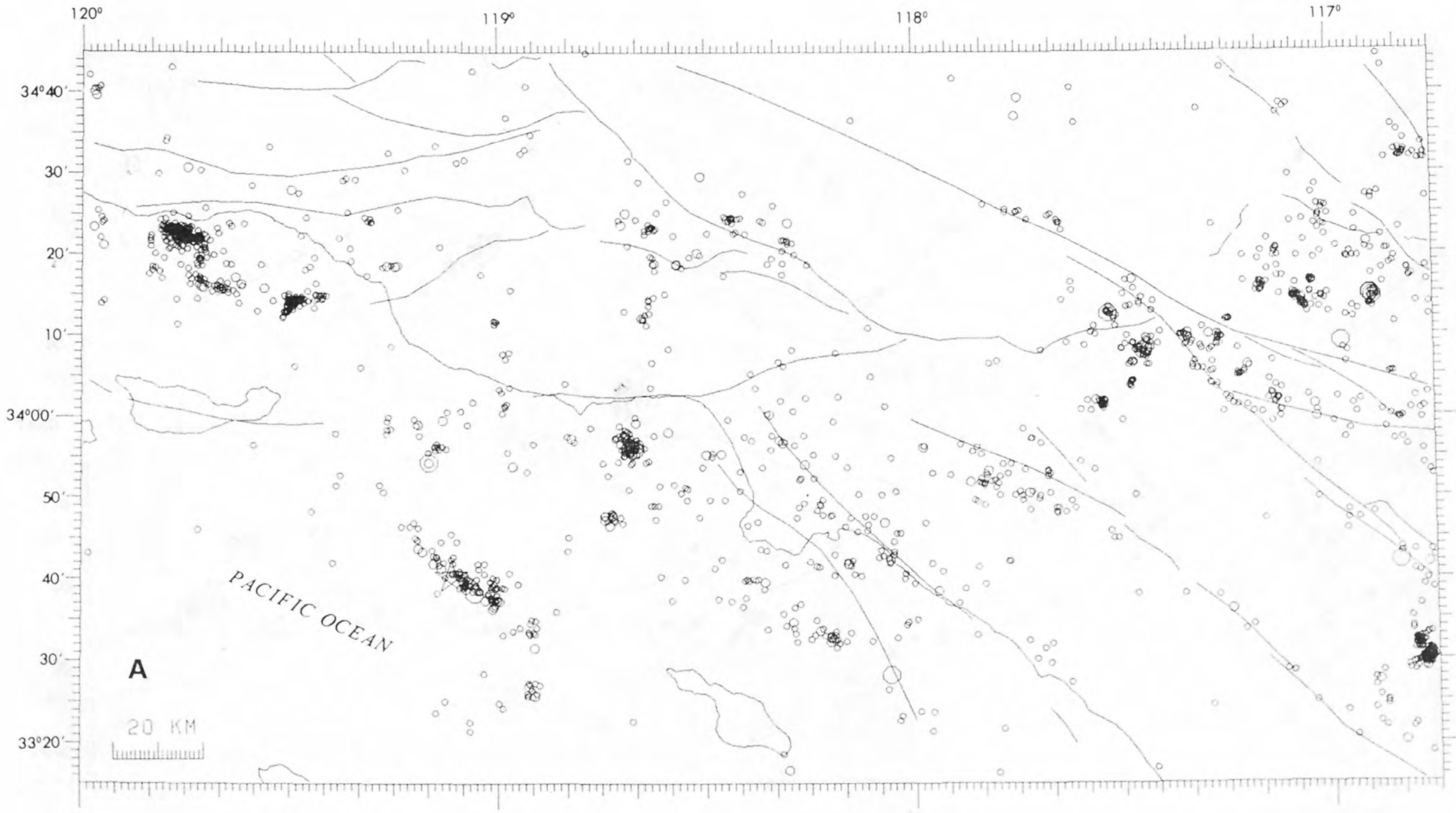

Figure 3. Los Angeles region, showing depths of $M_L \geq 2.0$ earthquakes with A- and B-quality locations (see table 4) recorded from 1978 through 1984. Earthquake magnitude indicated by relative size of symbol; star, **M**=5.0–5.9. Fault traces are generalized from Jennings (1975) and differ from those on map sheet. *A*, Epicenters for earthquakes with depths of 0–6 km. *B*, Epicenters for earthquakes with depths of 7–13 km. *C*, Epicenters for earthquakes with depths ≥14 km.

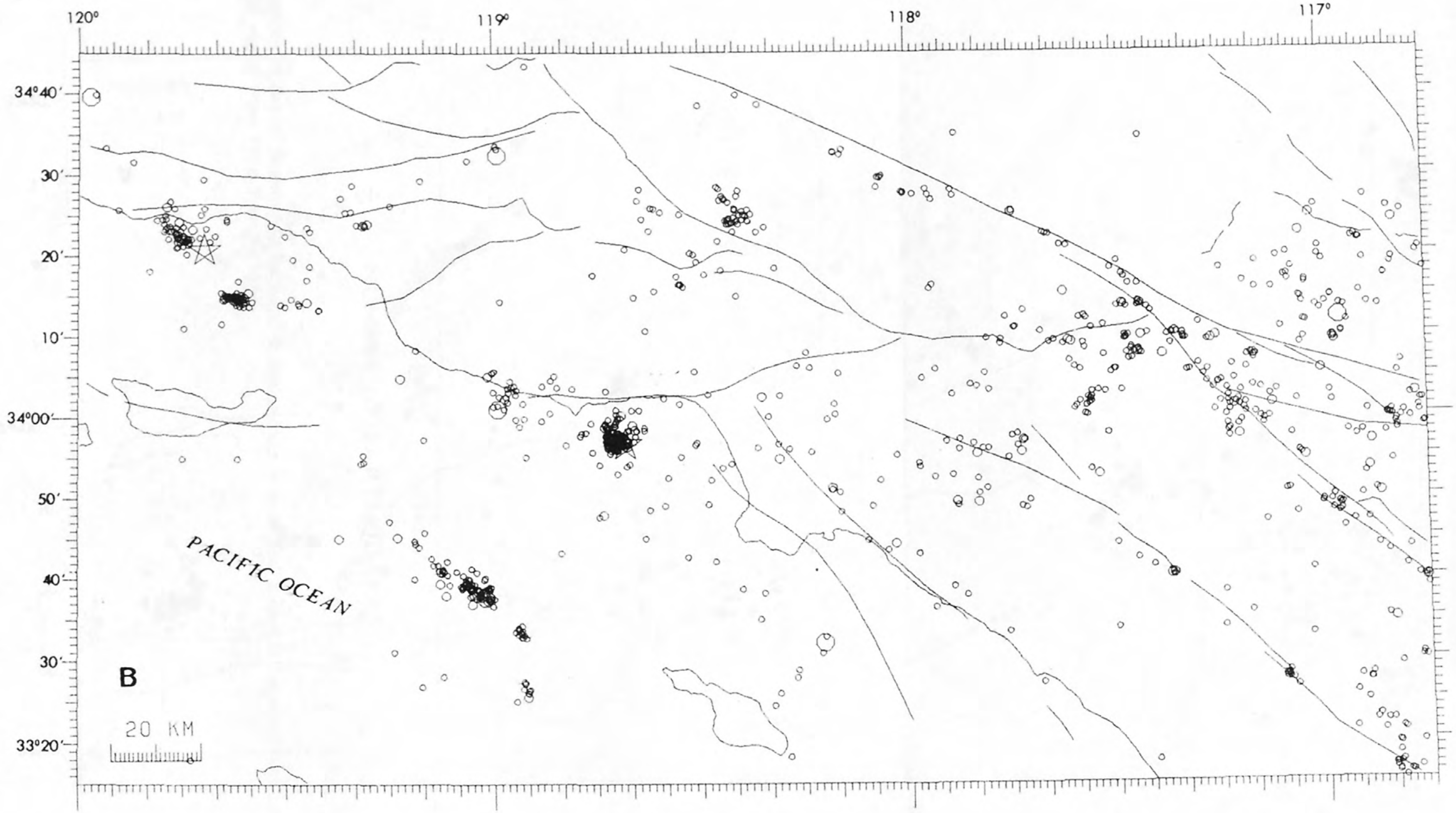

Figure 3. Continued.

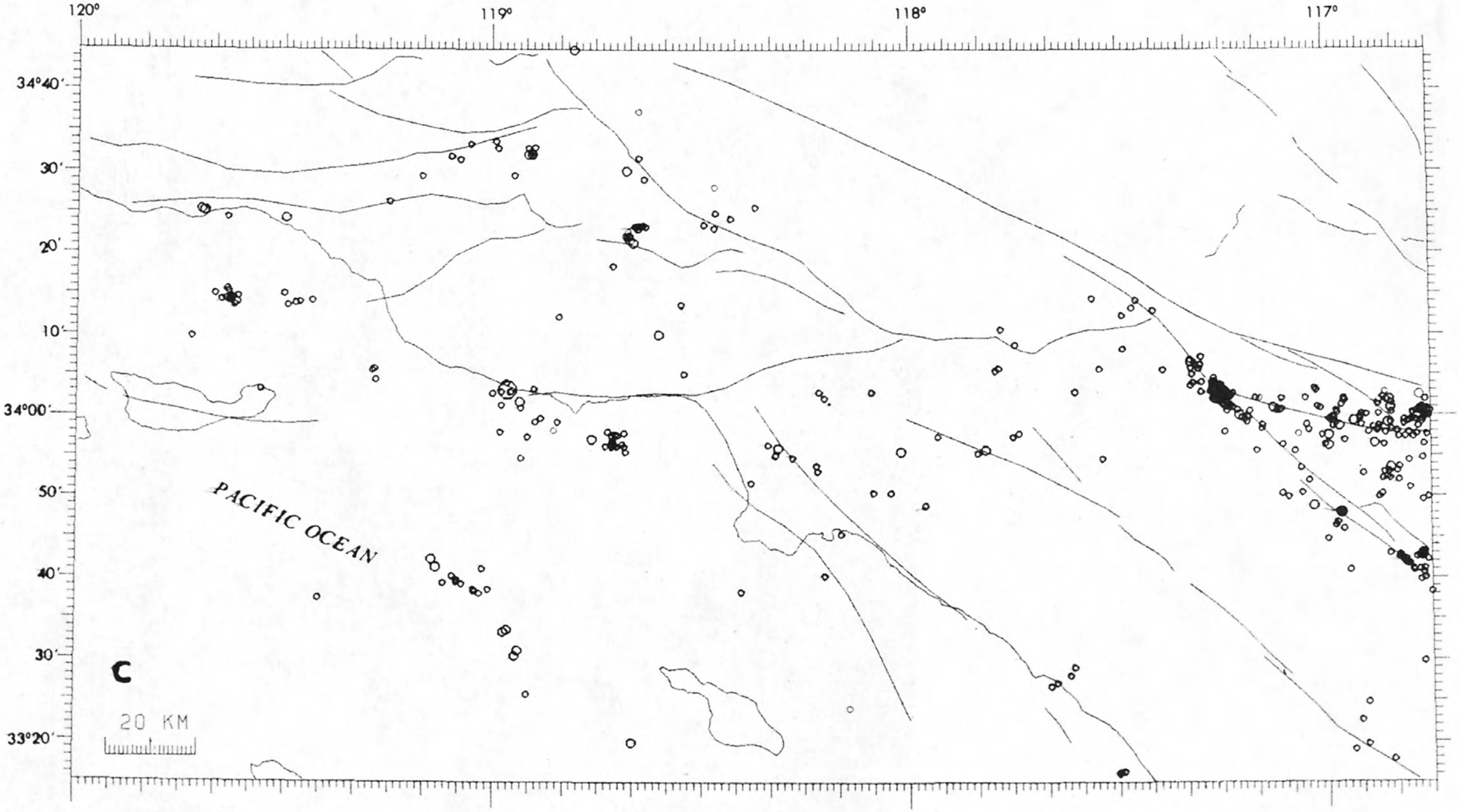

Figure 3. Continued.