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Preliminary assessment of the seismicity of the Malibu Coast Fault Zone, southern California, and related issues of philosophy and practice

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ABSTRACT

The Malibu Coast Fault Zone (MCFZ) is an east-west–trending fault system that marks the southern boundary of the western Transverse Ranges along the Santa Monica Mountains of southern California. Focal mechanism solutions for 107 earthquakes in the study area are mostly associated with thrusts or thrust-dominated oblique faults with a small left-lateral component of strike slip. The average azimuth of hanging-wall slip is 206°, which is approximately perpendicular to the trace of the San Andreas fault through the Transverse Ranges. Approximately 60% of the inferred slip vectors had azimuths between 180° and 240°. Six $M_L \geq 5$ earthquakes have been located along the MCFZ, most or all of which are attributed to the offshore Anacapa fault or to nonemergent structures to the south of the Anacapa fault. Hundreds of smaller earthquakes have been located in the vicinity of the MCFZ.

The MCFZ merges eastward with the active Potrero, Santa Monica, Hollywood, Raymond, and Cucamonga faults of the western and central Transverse Ranges. Offshore west of Sequit Point, the MCFZ merges with the active Santa Cruz Island and Santa Rosa Island faults. As part of the complex boundary zone between the Pacific and North American plates, the western Transverse Ranges is characterized by rates of uplift and crustal convergence that are comparable to the rates observed in the Himalayan Mountains, between the Indian and Eurasian plates. Documented Holocene slip, large gradients in topography and isostatic residual gravity, fault-related geomorphology, active uplift, distribution of micro- and macroearthquakes, and its position along a major structural/tectonic boundary are evidence that the MCFZ is an active fault zone.

The Malibu Coast fault of the MCFZ is an anastamosing zone of fault strands within a few kilometers of the Malibu coastline between longitudes 118.5° and 119°W. The Solstice and Winter Mesa strands of the Malibu Coast fault have been officially recognized as active faults under California's Alquist-Priolo Act. Rupture of the entire zoned length of the Solstice strand could have been generated by a M_L ~5.3 to 5.7 earthquake along the Malibu Coast fault: comparable in size to several historical earthquakes that have been attributed to the Anacapa fault. Although Holocene displacements have been officially recognized across only two strands of the Malibu Coast fault to date, we consider the Malibu Coast fault to be active and capable of producing a magnitude 6.5 to 7 earthquake.

Fault-zone studies involve scientific problems as well as problems of law and applied professional/scientific ethics. In addition to the basic ethics of science, a pri-

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mary ethic in the engineering geosciences involves the legal and moral necessity to protect the public's safety. The incomplete nature of the geologic record and technical difficulties associated with dating Holocene geologic materials can make it difficult or impossible to establish the age of the most recent movement on a fault. The dilemma in fault-zone studies involves the potential conflict between the need to protect the safety of the public and the need to protect the property and wealth of the public by not mistakenly zoning fossil faults as active. The resolution of this dilemma must come through the evolution of public policy and professional practice concerning the assessment of fault-zone hazards. The formal reintroduction of the category *potentially active*, to characterize faults whose most recent displacement is ambiguous but that are likely to be active, might provide a useful intermediate category between *active* and *inactive* faults.

INTRODUCTION

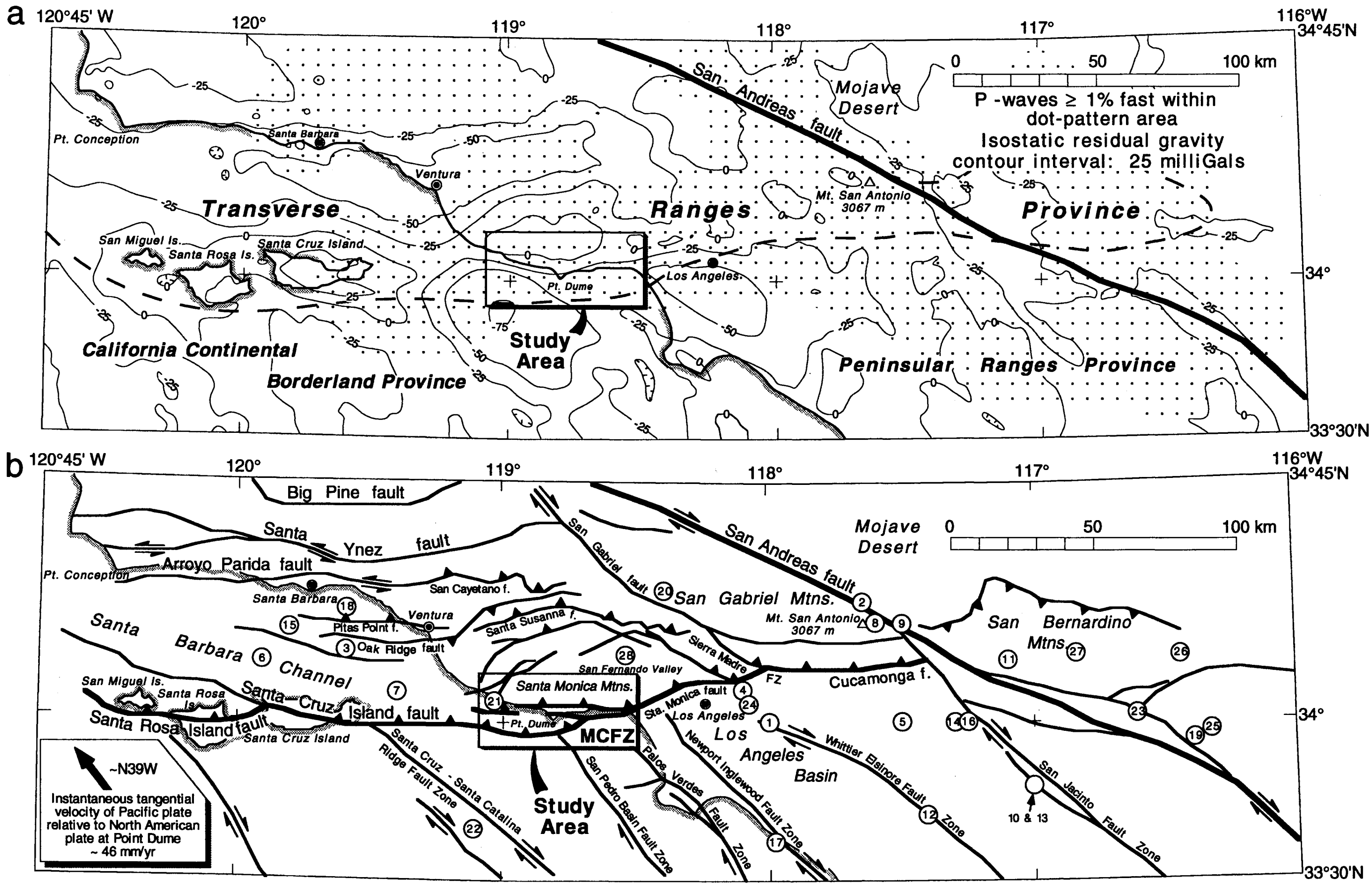
This paper has two general purposes: (1) to review a spectrum of published data concerning the activity of the Malibu Coast Fault Zone (MCFZ) and offer a preliminary assessment of its Holocene activity, and (2) to engage in a brief discussion of issues related to the identification of significant seismogenic faults in populated areas. Discussions of issues that involve applied ethics in the engineering geosciences literature are as important as discussions of technical issues. We emphasize from the outset that we are not directly, obliquely, or tacitly questioning the ethics or scientific competency of any individuals, groups, companies, or governmental entities involved in fault-zone studies, particularly along the MCFZ. Where scientific interpretations are challenged in this paper, it is in the spirit of normal scientific discourse.

The study area for this paper lies within a geographic box between latitudes 33°55′–34°10′N and longitudes 118°30′–119°5′W (Figs. 1 and 2). The MCFZ includes the family of subparallel, east-west–trending faults adjacent to the Malibu coastline within the study area, many of which have been active during the Quaternary (Fig. 2). The MCFZ includes the Potrero fault, the various strands of the Malibu Coast fault (e.g., Puerco Canyon fault, Ramirez thrust, Escondido thrust, Point Dume fault, Latigo fault, Solstice fault, Paradise Cove fault), the Anacapa fault ("Dume fault" of Junger, 1976), Fault Z, and several unnamed offshore faults interpreted from marine geophysical data (see references in Table 1).

The Malibu Coast fault is mapped from Sequit Point along the Malibu coastline to a point between Carbon Canyon and Las Flores Canyon, where the fault trace extends offshore toward the Santa Monica coastline (Fig. 2). Nomenclature for the various strands of the Malibu Coast fault is not yet consistent. For example, the Solstice fault and Puerco Canyon fault (Treiman, 1994) are coincident with the southern strand of the Malibu Coast fault, as mapped by Dibblee (1993). The northern strand of the Malibu Coast fault (Dibblee, 1993; Dibblee and Ehrenspeck, 1993) is sometimes called the *main* branch—a term that is imprecise and potentially misleading. If, for example, a fault strand known as the *main* branch has not been active in the Quaternary, one might reasonably assume that the entire fault lacks Quaternary displacement. In the case of the Malibu Coast fault, two strands that are south of the main or northern strand of the fault have been officially recognized as active during the Holocene (Division of Mines and Geology, 1995a, b). We prefer to use the term *Malibu Coast fault* to include the structurally interrelated fault strands that have been active during the Quaternary and that are located within ~3 km of the Malibu coastline between longitudes 118.5° and 119°W.

The subaerially exposed strands of the Malibu Coast fault are typically marked by gouge/breccia zones ranging in width from less than a meter to tens of meters. The gouge/breccia within the faults is typical of low-temperature deformation in the upper crust. Strands of the Malibu Coast fault generally dip toward the north at 30° to 70° and show evidence of reverse oblique slip, typically with a left-lateral strike-slip component. Field observations concerning Quaternary or Holocene activity along the Malibu Coast fault have recently been compiled by Treiman (1994).

The Malibu Coast fault is a fundamental boundary separating terranes with near-surface lithologies that appear to be quite different from one another and that were first juxtaposed through major rotations and horizontal translations in the late middle Miocene (Campbell, 1990; Campbell and Yerkes, 1976; Hornafius et al., 1986). The crystalline basement complex of the block north of the Malibu Coast fault is inferred to consist of Mesozoic igneous and metamorphic units similar to those exposed east of the study area in the Santa Monica Mountains. The basement complex is covered by marine and nonmarine strata of Late Cretaceous to middle Miocene age, which are locally interbedded or overlain by basaltic-andesitic volcanic rocks of middle Miocene age. The cover sequence of the northern block is locally mantled by Pleistocene marine terraces and other Quaternary deposits. South of the Malibu Coast fault are Miocene marine formations atop the Catalina schist (Campbell et al., 1966; Keller and Prothero, 1987). Total vertical displacement across the Malibu Coast fault has not been determined and may be indeterminate due to the differences in formations across the fault. Vertical separation of middle Miocene units to the east along the Santa Monica fault is approximately 2.1 km (Wright, 1991). The total amount of left-lateral slip along the Santa Monica/Hollywood–Malibu Coast



1 = 1796 Los Angeles (~6)
2 = 1812 Wrightwood (~7)
3 = 1812 Santa Barbara Channel (~7.1)
4 = 1855 Los Angeles (~6)
5 = 1858 San Bernardino (~6)
6 = 1883 Santa Barbara Channel (6.0)
7 = 1893 Pico Canyon (5.9)
8 = 1894 Lytle Creek (5.9)
9 = 1899 Lytle Creek (6.5)
10 = 1899 San Jacinto/Hemet (6.6)
11 = 1907 San Bernardino Mtns. (6.0)
12 = 1910 Elsinore (6.0)
13 = 1918 San Jacinto (6.9)
14 = 1923 San Bernardino (6)
15 = 1925 Santa Barbara (6.3)
16 = 1927 San Bernardino/Hemet (6.2)
17 = 1933 Long Beach (6.4)
18 = 1941 Santa Barbara (5.5)
19 = 1948 Desert Hot Springs (6.0)
20 = 1971 San Fernando (6.6)
21 = 1973 Point Mugu (5.3)
22 = 1981 Santa Barbara Island (5.5)
23 = 1986 North Palm Springs (5.6)
24 = 1987 Whittier Narrows (5.9)
25 = 1992 Joshua Tree (6.1)
26 = 1992 Landers (7.4)
27 = 1992 Big Bear (6.5)
28 = 1994 Northridge (6.7)

Figure 1. Maps of southern California locating the study area and the Malibu Coast Fault Zone (MCFZ). a, Location of physiographic provinces, contoured isostatic residual gravity (Roberts et al., 1990), and dot-patterned area within which *P*-wave velocities are 1–3% faster than normal (Humphreys and Clayton, 1990; Humphreys and Hager, 1990). Dashed curve is the approximate boundary of the Transverse Ranges Province. b, Location of selected major faults (Jennings, 1994; Wallace, 1990) and earthquake epicenters (Real et al., 1978; Hileman et al., 1973; Ellsworth, 1990; Hutton and Jones, 1993; Glen Reagor of NEIC, written communication, 1996). Epicenters for the numbered earthquakes listed at bottom are shown on map b. The Santa Cruz Island fault, MCFZ, Santa Monica fault, and Cucamonga fault are along the southern boundary of the Transverse Ranges Province. Inset box shows the present-day instantaneous tangential velocity of the Pacific plate relative to the North American plate, determined for Point Dume based on plate-motion data from NUVEL-1a (DeMets et al., 1994).

fault trend is estimated to be as much as 60 to 90 km (Lamar, 1961; Yeats, 1968; Colburn, 1973; Sage, 1973; Campbell and Yerkes, 1976; Link et al., 1984; Hornafius et al., 1986; Yerkes and Lee, 1987).

Late Cenozoic setting

The MCFZ is a fundamental physiographic boundary forming the southern edge of the Transverse Ranges Province and separating it from the California Continental Borderland Province to the southwest and the Peninsular Ranges Province to the southeast (e.g., Jahns, 1954). The California Continental Borderland and Peninsular Ranges are part of a compound terrane of continental crust that extends from the southern edge of the Transverse Ranges south to the tip of the Baja California Peninsula. The MCFZ is also a fundamental structural-tectonic boundary. The surface traces of the northwest-trending strike-slip faults of southern California terminate along the north-dipping thrust faults at the southern edge of the Transverse Ranges (Fig. 1b). Only the San Andreas fault among these northwest-trending strike-slip faults passes through the Transverse Ranges (Hutton et al., 1991).

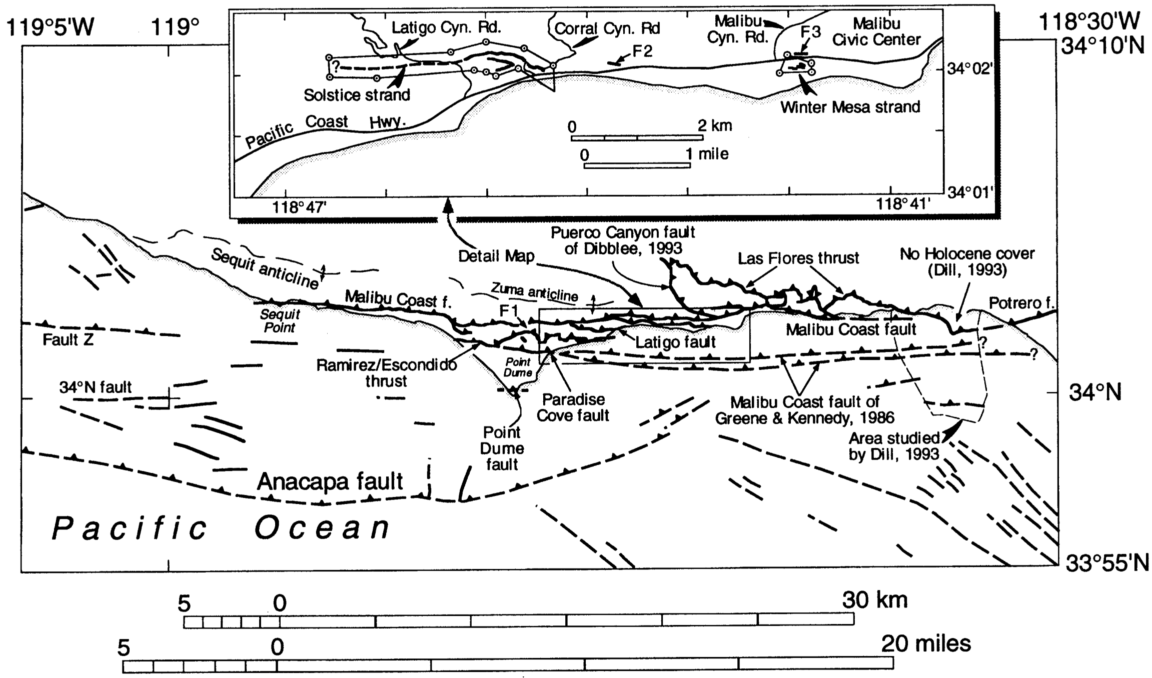


Figure 2. Map of principal faults in study area, after Dibblee (1992, 1993), Dibblee and Ehrenspeck (1990, 1993), Yerkes and Lee (1979b), Greene and Kennedy (1986), Yerkes and Campbell (1980), and Dill (1993). Inset detail map shows boundaries of Alquist-Priolo Special Studies Zones surrounding the Solstice and Winter Park strands of the Malibu Coast fault (Division of Mines and Geology, 1995a, b).

As the Baja California terrane has moved with the Pacific plate toward the northwest in the last ~4–5 million years, it has rotated clockwise relative to the North American plate, opening the Gulf of California in its wake and converging with other lithospheric elements to the north (e.g., Atwater, 1970; Bohannon and Parsons, 1995). The principal areas of convergence during the Quaternary are generally inferred to be along the Transverse Ranges and across the restraining bend in the San Andreas fault south of the "big bend" in its trace at ~35°N latitude (Hill and Dibblee, 1953; Hill, 1981; Wallace, 1990). The trend of the San Andreas fault along the restraining bend through the Transverse Ranges is ~25° anticlockwise from the direction in which the Pacific plate is currently moving relative to the North American plate: ~46 mm/yr toward N39°W, as computed for the coordinates of Point Dume using plate-motion data from NUVEL-1a (inset, Fig. 1b; DeMets et al., 1994).

The nature of the convergence in the Transverse Ranges and across the restraining bend of the San Andreas fault in southern California is still problematic. The western and central Transverse Ranges have been inferred to be a crustal flake/terrane/microplate that is in motion relative to both the Pacific and North American plates (Yeats, 1981). Weldon and Humphreys (1986) infer that this terrane is translating parallel to the trend of the San Andreas fault along the restraining bend, toward ~N60–65°W. The direction of maximum horizontal stress trends toward the north-northeast throughout the western Transverse Ranges and Santa Monica Bay (Hauksson and Saldivar, 1989; Zoback et al., 1990). The average slip azimuth for earthquakes in the western and central Transverse Ranges is approximately perpendicular to the trace of the San Andreas fault along the restraining bend through the Transverse Ranges (Jackson and Molnar, 1990).

A regional detachment is inferred to exist in the mid- to lower crust beneath southern California, based on focal mechanism solutions and the inferred kinematics of the upper crust (e.g., Anderson, 1971; Hadley and Kanamori, 1978; Sibson, 1983; Crouch et al., 1984; Webb and Kanamori, 1985; Weldon and Humphreys, 1986; Davis et al., 1989). Hearn and Clayton (1986a, b) developed a velocity model for the upper crust based on backprojection tomography using *Pg* arrivals and a second tomographic model for the lower crust based on *Pn* arrivals. The results for the upper crust differed significantly from those for the lower crust, from which they inferred that the upper crust is decoupled from the lower crust in southern California. Yeats (1981) speculated that a regional detachment exists beneath the Transverse Ranges that rises to the surface along two major subparallel thrust zones with concurrent Holocene activity: the Santa Cruz Island–MCFZ–Santa Monica–Raymond–Cucamonga fault zone and, to the north, the Red Mountain–San Cayetano–Santa Susanna–Sierra Madre–Cucamonga fault zone. Davis et al. (1989) named these two subparallel zones the Santa Ynez–San Gabriel zone and the Santa Monica zone. Hauksson (1990) has associated the Santa Monica zone with the Elysian Park fold and thrust belt of Davis et al. (1989).

Motion of the Transverse Ranges terrane has a significant

TABLE 1. ACTIVITY ASSESSMENT AND REFERENCES FOR FAULTS WITHIN OR ADJACENT TO THE MALIBU COAST FAULT ZONE

Fault	Status	Sources
Santa Rosa Island fault	Active	Kew, 1927; Hileman et al., 1973; Junger, 1976, 1979; Yerkes and Lee, 1979b; Ziony and Yerkes, 1985; Vedder et al., 1987.
Santa Cruz Island fault	Active	Junger, 1976, 1979; Patterson, 1979; Yerkes and Lee, 1979a, b; Ziony and Yerkes, 1985; Vedder et al., 1986; Ziony and Jones, 1989; Pinter and Sorlien, 1991.
Anacapa (Dume) fault	Active	Vedder et al., 1974; Junger, 1976; Junger and Wagner, 1977; Lee et al., 1979; Yerkes and Lee, 1979a, b; Greene and Kennedy, 1986.
Fault Z	Active	Yerkes and Lee, 1979b; Lee at el., 1979.
Malibu Coast fault	Active/potentially active	Yerkes and Wentworth, 1965; Campbell et al., 1970; Campbell and Yerkes, 1976; Yerkes and Campbell, 1980; Clark et al., 1984; Greene and Kennedy, 1986; Ziony and Yerkes, 1985; Vedder et al., 1986; Ziony and Jones, 1989; Dibblee and Ehrenspeck, 1990, 1993; Wright, 1991; Drumm, 1992; Dibblee, 1992, 1993; Treiman, 1994.
–Escondido strand	Potentially active	Campbell, et al., 1966; Dibblee and Ehrenspeck, 1993; Treiman, 1994.
–Las Flores strand	Potentially active	Yerkes and Campbell, 1980; Dibblee, 1992, 1993.
–Latigo strand	Potentially active	Yerkes and Campbell, 1980; Dibblee, 1993; Dibblee and Ehrenspeck, 1993; Treiman, 1994.
–Paradise Cove strand	Potentially active	Dibblee and Ehrenspeck, 1993; Treiman, 1994.
–Point Dume strand	Potentially active	Treiman, 1994.
–Puerco Canyon strand	Potentially active	Yerkes and Wentworth, 1965; Campbell et al., 1970; Yerkes et al., 1971; Birkeland, 1972; Yerkes and Campbell, 1980; Dibblee, 1993; Treiman, 1994.
–Solstice strand	Active	Cleveland and Troxel, 1965; Campbell et al., 1970; Birkeland, 1972; Yerkes and Campbell, 1980; Dibblee, 1993; Traiman, 1994.
–Winter Mesa strand	Active	Yerkes and Campbell, 1980; Rzonca et al., 1991; Dibblee, 1993; Treiman, 1994.
–Ramirez strand	Potentially active	Dibblee and Ehrenspeck, 1993; Treiman, 1994.
Potrero fault	Active/potentially active	Hill, 1979; McGill, 1981, 1982, 1989; McGill et al., 1987; Wright, 1991; Dibblee, 1992.
Santa Monica fault	Active/potentially active	Buika and Teng, 1979; Hill, 1979; Hill et al., 1979; McGill, 1981, 1982; Crook et al., 1983; Clark et al., 1984; Ziony and Yerkes, 1985; Real, 1987; Ziony and Jones, 1989; Wright, 1991; Dibblee, 1991a, b, 1992; Crook and Proctor, 1992.
Hollywood fault	Active	Hill et al., 1979; Weber, 1980; Crook et al., 1983; Wesnousky, 1986; Real, 1987; Dibblee, 1991a, b; Wright, 1991; Crook and Proctor, 1992.

After Jennings, 1994 and Ziony and Yerkes, 1985.

rotational component. Hornafius et al. (1986) infer a 78° ± 11° clockwise rotation of the Santa Monica Mountains since the early Miocene based on paleomagnetic data and 60 km of left-lateral slip along the Santa Monica/Hollywood–Malibu Coast fault trend. Northern Santa Cruz Island is inferred to have rotated by approximately the same amount (76° ± 9°) concurrently, so it is thought to be part of the same element of rigidly rotating and translating upper crust (Hornafius et al., 1986). Jackson and Molnar (1990) interpreted present-day rotation rates of 6°/Ma clockwise for the western Transverse Ranges, based on very long baseline interferometry (VLBI) experiments conducted over a five-year period in the 1980s. Feigl et al. (1993) described comparable angular velocities for the western Transverse Ranges, based on a larger dataset including VLBI and global positioning system observations made between 1984 and 1992. Jackson and Molnar (1990; after Lamb, 1987) suggest that the observed rotation and faulting in the western Transverse Ranges can be viewed as being similar to the rotation of essentially rigid blocks riding atop a viscous substratum that is homogeneously deforming across a wide boundary zone between two rigid plates. As applied to the Transverse Ranges, the modeled boundary zone between the Pacific and North American plates is ≥100 km wide.

The Transverse Ranges Province has several distinctive seismic attributes in comparison with surrounding provinces. The deepest earthquakes in southern California occur within the Transverse Ranges, with depths to ~30 km (Humphreys and Hager, 1990; Ziony and Jones, 1989; Bryant and Jones, 1992). These deep crustal earthquakes occur in areas of rapid crustal convergence (Weldon and Humphreys, 1986). Another distinctive feature is called the *Transverse Ranges velocity anomaly*: a volume of crust and upper mantle within/beneath the Transverse Ranges characterized by *P*-wave velocities that are 1–3% faster than average (Hadley and Kanamori, 1977, 1978; Raikes and Hadley, 1979; Raikes, 1980; Walck and Minster, 1982; Humphreys et al., 1984; Humphreys and Clayton, 1988, 1990; Humphreys and Hager, 1990). Perhaps not coincidentally, the deep crustal earthquakes occur within the Transverse Ranges velocity anomaly (Humphreys and Hager, 1990). A tomographic inversion on teleseismic *P*-wave delays indicates that the Transverse Ranges velocity anomaly is nearly vertical, approximately 200 km wide, and extends in depth to approximately 250 km (Humphreys et al., 1984; Humphreys and Clayton, 1988, 1990). The anomaly has been interpreted as resulting from upper-mantle lithosphere sinking vertically into the sublithospheric mantle (e.g., Bird and Rosenstock, 1984; Humphreys and Hager, 1990; cf. Griggs, 1939). If the rate at which the lithosphere sinks is approximately the same as the local rate at which the Pacific plate moves horizontally relative to the North American plate (~46 mm/yr; DeMets et al., 1994), then it would take ~5 million years for the slab(s) to reach a depth of 250 km, which is approximately the same time that Baja California and the parts of coastal California west of the San Andreas fault have been moving with the Pacific plate (Atwater, 1970).

The areal extent of the upper 30 km of this velocity anomaly is indicated by the dot-patterned area in Figure 1a (Humphreys and Clayton, 1990). It is significant to note that this velocity anomaly extends across the San Andreas fault. Although the Transverse Ranges velocity anomaly does not correlate well with surface topography or gravity anomalies, it is a further indication that the fault zones that mark the sharp southern edge of the Transverse Ranges are significant, active, crustal boundary structures.

ALQUIST-PRIOLO ACT

The Alquist-Priolo Earthquake Fault Zoning Act was developed in the immediate aftermath of the 1971 San Fernando earthquake (M_L 6.6) and was signed into law December 22, 1972, as part of California's Public Resources Code, sections 2621–2630 (Hart, 1994). Through 10 revisions to date, the purpose of the Alquist-Priolo Act is to "prohibit the location of most structures for human occupancy across the traces of active faults" and to facilitate "seismic retrofitting to strengthen buildings, including historical buildings, against ground shaking" (section 2621.5[a]).

Although the Alquist-Priolo Act mentions ground-shaking hazards, it is effectively limited to the identification and avoidance of ground-rupture hazards. As experience in the 1987 Whittier Narrows earthquake (M_L 5.9), 1989 Loma Prieta earthquake (M_L 7.1), and 1994 Northridge earthquake (M_L 6.7) clearly attests, ground shaking can cause loss of life and many billions of dollars in damage at significant distances from the epicenter without any ground rupture along the causative fault plane (see Yeats et al., 1981). Mitigation of ground-shaking hazards must be accomplished regionally, through the strengthening of building codes in seismically active areas.

The implementation of the Alquist-Priolo Act is "pursuant to the policies and criteria established and adopted by the (State Mining and Geology) Board" (section 2621.5[c]). It is the responsibility of the State Geologist to delineate "appropriately wide earthquake fault zones to encompass all potentially and recently active traces of the San Andreas, Calaveras, Hayward, and San Jacinto faults, and such other faults, or segments thereof, as the State Geologist determines to be sufficiently active and well-defined as to constitute a potential hazard to structures from surface faulting or fault creep" (section 2622[a]). The State Geologist utilizes fault-zone maps and written characterizations by geoscientists registered in the State of California, as well as studies by geoscientists of the Division of Mines and Geology, to evaluate the activity of fault zones.

The policies and criteria of the State Mining and Geology Board with respect to the Alquist-Priolo Act are established in the California Code of Regulations, Title 14, Division 2, sections 3600–3603. This chapter specifies that an active fault is one "that has had surface displacement within Holocene time (about the last 11,000 years)" (section 3601[a]). Also specified in this chapter is the prohibition against placing a structure across the trace of an active fault, or within 50 feet (~15 m) of the trace of an active fault (section 3603[a]).

The operational definitions used in the implementation of the Alquist-Priolo Act are noteworthy. "A *fault* is defined as a fracture or zone of closely associated fractures along which rocks on one side have been displaced with respect to those on the other side... A fault is distinguished from those fractures or shears caused by landsliding or other gravity-induced surficial failures" (Hart, 1994, p. 3). By this definition, a mode I extensional fracture or joint without shear displacement could be classified as a fault. The phrase "potentially and recently active traces" currently has no operational definition, although a potentially active fault was originally understood to mean a fault that had demonstrable movement during the Quaternary Period, within the last 1.6 million years.

Earthquake fault zones are currently established based on the operational definitions associated with the phrase "sufficiently active and well-defined" (Alquist-Priolo Act, section 2622[a]).

> *Sufficiently active.* A fault is deemed sufficiently active if there is evidence of Holocene surface displacement along one or more of its segments or branches. Holocene surface displacement may be directly observable or inferred; it need not be present everywhere along a fault to qualify that fault for zoning.
>
> *Well-defined.* A fault is considered well-defined if its trace is clearly detectable by a trained geologist as a physical feature at or just below the ground surface. The fault may be identified by direct observation or by indirect methods (e.g., geomorphic evidence...). The critical consideration is that the fault, or some part of it, can be located in the field with sufficient precision and confidence to indicate that the required site-specific investigations would meet with some success (Hart, 1994, p. 5).

Hence, there are effectively two classes of faults under the Alquist-Priolo Act: sufficiently active and well-defined faults with demonstrable Holocene displacement histories, and all other faults.

Hart (1994) lists guidelines for evaluating the hazard of surface fault rupture, which are derived largely from other published guidelines (Division of Mines and Geology, 1975a, b, 1982, 1986a–c; also see Slosson, 1984; Larson and Slosson, 1992). An evaluation of the historic record of earthquakes is not currently a requirement or significant suggestion in the development of fault evaluation studies under the Alquist-Priolo Act, which is somewhat curious given that it is explicitly called an *earthquake* fault zoning act that calls for the compilation and publication of maps of *earthquake* fault zones. Jennings (1994, p. 17) notes that "the Nuclear Regulatory Commission . . . defines a capable fault, in part, on macroseismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault." Aligned seismicity using both macro- and microearthquakes ($M_L \leq 3$) is used as an indicator of fault activity on the *Fault Activity Map of California and Adjacent Areas* (Jennings, 1994).

INDICATORS OF HOLOCENE ACTIVITY

Primary indicators of Holocene fault activity include instrumentally recorded earthquakes that can be associated with specific faults or fault zones, and offset markers that are datable as Holocene. Secondary indicators include a wide variety of data that tend to indicate fault activity, including fault-related geomorphology such as scarps or offset drainages, linear gradient anomalies in topographic or structural surfaces, linear gradient anomalies in gravity or magnetic potential fields, evidence of differential uplift provided by leveling surveys or mineral cooling ages, linear ground-water anomalies, and linear trends of hydrocarbon seeps. General criteria for identifying active faults are amply discussed elsewhere, and will not be repeated here (e.g., Taylor and Cluff, 1973; Allen, 1975; Slemmons, 1977; Wallace, 1977; Hatheway and Leighton, 1979; Bonilla, 1982; Ziony and Yerkes, 1985; Slemmons and dePolo, 1992; Hart, 1994; Keller and Pinter, 1996). The secondary indicators discussed below are not intended to be a comprehensive review of the topic with respect to the MCFZ. Analysis of the structural geomorphology of the MCFZ and a compilation of the many observations made by consulting geologists along the MCFZ have not been included in this paper. Some of these data are included by Treiman (1994) in the most current fault evaluation report concerning the Malibu Coast fault.

Primary indicators

Documented Holocene activity along MCFZ. Holocene or Quaternary activity has been documented by California's Division of Mines and Geology for several elements of the MCFZ exposed subaerially along the Malibu coastline (Treiman, 1994). The Solstice and Winter Mesa strands of the Malibu Coast fault have documented Holocene displacement and have been identified as Earthquake Fault Zones under California's Alquist-Priolo Earthquake Fault Zoning Act (inset map, Fig. 2; Hart, 1994; Division of Mines and Geology, 1995a, b; Rzonca et al., 1991). As defined in the Alquist-Priolo Act, the boundaries of the "official Earthquake Fault Zone are established about 500 ft away from major active faults and about 200 to 300 ft away from well-defined minor faults" with some exceptions where faults are locally complex or are not vertical (Hart 1994: p. 5 and 7). The fault traces used to determine the boundaries are shown on the official maps of the Earthquake Fault Zones published by the California Division of Mines and Geology.

Dill (1993) imaged an area that was devoid of Holocene sedimentary cover offshore of Topanga and Will Rogers Beaches, which may indicate Holocene tectonic uplift along the Malibu Coast fault (Fig. 2). The southern boundary of this anomalous sea floor is along the inferred offshore trend of the Malibu Coast fault and coincides to the east with the Potrero fault. Green et al. (1975) mapped a parallel pair of offshore strands of the Malibu Coast fault and inferred Holocene activity along them. The inferred Holocene age and the location of these faults have been questioned by Treiman (1994).

The offshore Anacapa fault is seismically active (e.g., "Santa Monica fault" of Ellsworth et al., 1973; Stierman and Ellsworth, 1976; Yerkes and Lee, 1979a). Holocene activity has also been indicated for most of the fault elements of the southern boundary of the western and central Transverse Ranges (Table 1), including the Santa Cruz Island fault (Pinter and Sorlien, 1991) and the Hollywood/Santa Monica faults (Hill et al., 1979; Real, 1987; Crook and Proctor, 1992; James Dolan, written communication, 1995), which are immediately adjacent to the MCFZ to the west and east, respectively.

MCFZ seismicity. A history of instrumentally recorded earthquakes is a strong indicator of fault activity. A database was compiled including 638 earthquakes reported to have occurred within the MCFZ study area through 1995 (Fig. 3; Appendix 1). The nucleus of the earthquake database was provided by Dr. Glen Reagor of the U.S. Geological Survey's National Earthquake Information Center (NEIC), whose data were supplied by the California Division of Mines and Geology (CDMG; Real et al., 1978; Toppozada et al., 1984; Seismological Laboratory of the California Institute of Technology, Seismological Stations of the University of California-Berkeley), the Geological Society of America's Decade of North American Geology Project (DNAG; Engdahl and Rinehart, 1988, 1991), Stover and Coffman (1993), and NEIC's Preliminary Determination of Epicenter files (PDE and PDE-W, which are weekly updates to PDE files). These data were augmented with other published data and, for the most recent two earthquakes, by data posted by Dr. L. K. Hutton of the Caltech Seismological Laboratory via Internet/World Wide Web (newsgroup ca. earthquakes; Caltech seismology home pages http://scec.gps.caltech.edu or http://www.gps.caltech.edu/seismo/seismo.page.html). NEIC data are now available (as of December 1997) via the World Wide Web at http://www.NEIC.cr.usgs.gov/neis/epic/epic.html. Another useful path to earthquake data on the web is available at http://www.geophys.washington.edu/seismosurfing.html.

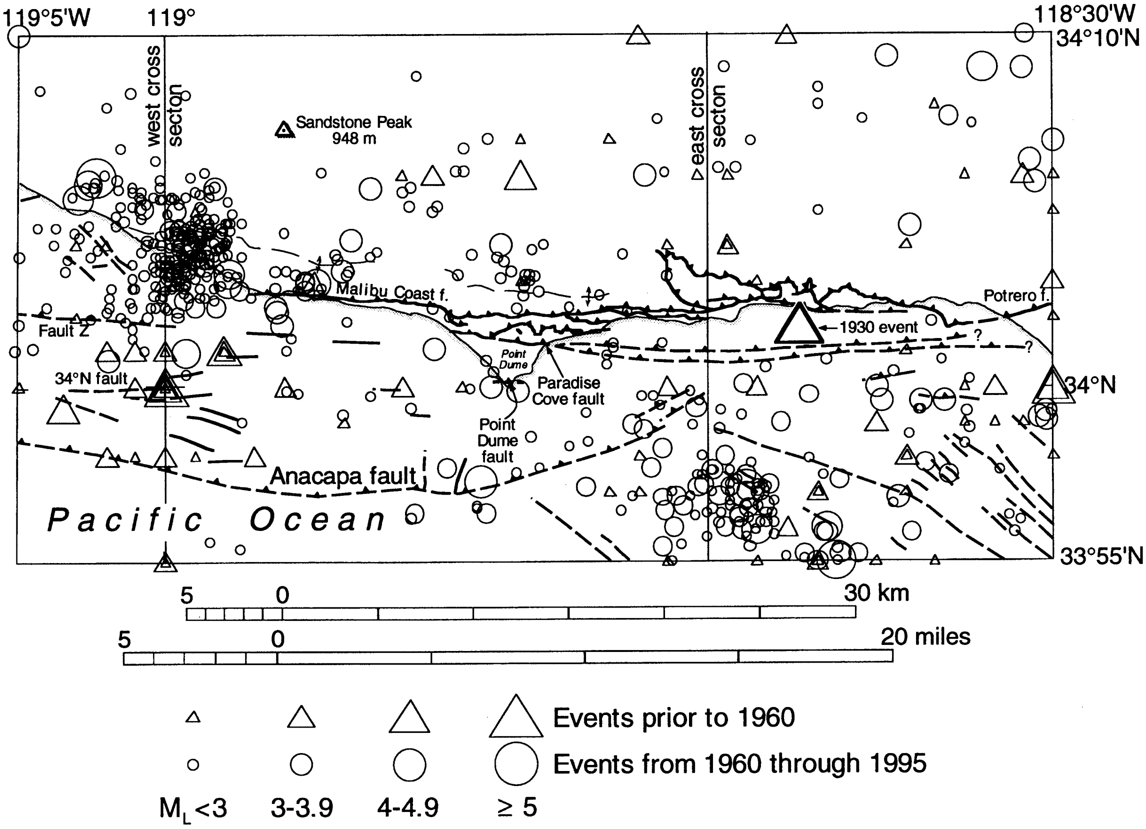


Figure 3. Historic earthquakes in study area. Since 1960, proliferation of seismographs has improved the detection and location of earthquakes; pre-1960 earthquakes are indicated by triangles. Corresponding data and sources are listed in Appendix 1.

The earliest reported earthquake within the study area occurred in 1827 and is estimated to have had a magnitude of 5.5 (Toppozada et al., 1981). Sixty-two percent of the earthquakes listed in Appendix 1 occurred in the 1970s and most were associated with the 1973 Point Mugu (M_L 5.3, as revised by Hutton and Jones, 1993) and 1979 Malibu (M_L 5.2) earthquakes. More than 80% of the earthquakes have occurred since 1960. Rather than necessarily indicating an increase in seismicity during recent decades, this increase in reported earthquakes is probably due in large part to the expansion in the number of seismographs installed in southern California and the consequent decrease in the threshold of detection for small earthquakes. Six of the reported earthquakes had magnitudes ≥5 (events 1, 11, 12, 181, 492, and 600), and 154 had magnitudes ≥3. Hypocenter depths range from 19.2 km to less than 1 km, with 26 events reported with depths of <2 km.

Focal mechanism solutions were compiled for 107 events (Fig. 4a–c, Appendix 1). More than one focal mechanism solution has been published for several of the earthquakes (events 176, 181, 259, 273, 325, 492, 495, and 547). Where published focal mechanism solutions did not include the inferred orientation of the slip vector (i.e., the direction that the hanging wall moved relative to the foot wall), the fault plane and slip vector were inferred based upon the orientation of mapped faults in the area. Nodal plane orientations for the earthquakes analyzed by Stierman and Ellsworth (1976) were estimated using the published focal mechanism diagrams and unpublished data provided by Donald Stierman and William Ellsworth (written communication, 1995, 1996).

Of the focal mechanism solutions compiled in this study, approximately 70% are associated with either the 1973 Point Mugu or 1979 Malibu earthquake sequences (Fig. 4b, c). The dip of fault planes inferred from the focal mechanisms range from 0 to 90°, averaging 51°. Almost 70% of the inferred fault planes dip between 30° and 60°, generally toward the north quadrant. Most of the focal mechanism solutions indicate thrust or thrust-dominated oblique faults, typically with left-lateral strike-slip components. Webb and Kanamori (1985) interpreted six of the focal mechanism solutions as indicating slip on low-angle detachments (events 176, 261, 273, 325, 495, and 547). The average azimuth of hanging-wall slip vectors inferred from the focal mechanism solutions is 206°, which is approximately perpendicular to the trend of the San Andreas fault through the Transverse Ranges. Just over 60% of the slip azimuths are between 180° and 240° (see inset rose diagram, Fig. 4a).

The relocated 1930 Santa Monica earthquake (M_L 5.2) has been attributed to the eastern end of the Anacapa fault or the western end of the Santa Monica fault (Hauksson and Saldivar, 1986). (As a matter of common usage, use of the term *Santa Monica fault* is generally restricted to the area east of longitude 118°30′; to the west, this fault is considered one of the strands of the Malibu Coast fault; (cf. Dibblee 1991a, b, 1992.) The relocated epicenter of the 1930 Santa Monica earthquake lies between the offshore trace of the Malibu Coast fault inferred by Dibblee (1992) and the offshore trace of the Malibu Coast fault inferred by Greene and Kennedy (1986; Figs. 2 and 3). If the 1930 Santa Monica earthquake occurred at a depth of 15 km as reported (Gutenberg et al., 1932; Hauksson and Saldivar, 1986), it is more likely to have occurred on either the Anacapa fault or another, structurally lower, fault surface (Fig. 5).

The 1973 Point Mugu earthquake was interpreted to have occurred along the Anacapa fault, with a slip surface dipping ~36 to 44°N (Ellsworth et al., 1973; Stierman and Ellsworth, 1976; Lee et al., 1979). The local magnitude of the Point Mugu earthquake was initially reported to be 5.9 to 6.0 (Ellsworth et al., 1973; Stierman and Ellsworth, 1976; Lee et al., 1979). Hutton and Jones (1993) reevaluated the local magnitudes of earthquakes that occurred in southern California since 1932 that had reported magnitudes of ≥4.8. The local magnitude of the Point Mugu earthquake was adjusted to 5.3 as a result of that reevaluation. Several of the more shallow aftershocks of the Point Mugu earthquake clustered along Fault Z, which is interpreted to dip 41°N (Fig. 5; Lee et al., 1979). Fault Z may be the western offshore extension of the Escondido/Ramirez thrust, Paradise Cove fault, or Point Dume fault that are exposed at Point. Dume (Fig. 2).

The 1979 Malibu earthquake (M_L 5.2) has been associated with the eastern end of the Anacapa fault (Hauksson and Saldivar, 1986). However, the Anacapa fault as it is typically mapped (e.g., Yerkes and Lee, 1979b; Greene and Kennedy, 1986) is above the reported hypocenter (Fig. 5), so the 1979 Malibu earthquake may have occurred along a nonemergent fault below the Anacapa fault, perhaps along a propagating thrust or within a duplex. Hauksson (1990, 1992) has suggested that thrust earthquakes south of the Malibu coastline may be associated with a westward extension of the Elysian Park fold-and-thrust belt (Davis et al., 1989).

Other selected indicators

Slip and convergence rates. Yeats (1981) estimated a convergence rate of 18 mm/yr across the central and western Transverse Ranges. He subsequently estimated the convergence across the Ventura basin within the western Transverse Ranges at 23 mm/yr during the past 200,000 years (Yeats, 1983), which compares favorably with the slightly smaller convergence-rate estimate of 17 ± 4 mm/yr by Rockwell (1983, cited in Weldon and Humphreys, 1986). Taking the average of the convergence rates reported by Yeats (1983) and Rockwell (1983), Weldon and Humphreys (1986) used a convergence rate of 20 mm/yr across the western Transverse Ranges. Namson and Davis (1988) suggest that the shortening of the western Transverse Ranges began during the late Pliocene, 2 to 3 million years ago, and has averaged 17.6 to 26.5 mm/yr since then for the area north of the Santa Monica Mountains. Bryant and Jones (1992) argue that the rapid shortening of the Ventura basin is not characteristic of the western Transverse Ranges as a whole, but rather that high rates of shortening are confined to a small region that is marked by anomalously thick crust, deep-crustal earthquakes to 30 km, and low heat flow. Dolan et al. (1995) estimate the current rate of shortening in the western Transverse Ranges to be ~10 mm/yr, based on geodetic measurements made between 1984 and 1992 (Donnellan et al., 1993a, b; Feigl et al., 1993). For comparison, the convergence rate across the Himalaya between India and Tibet is thought to be 18 ± 7 mm/yr (Molnar et al., 1987).

Clark et al. (1984) estimated the long-term minimum slip rate on the Malibu Coast fault to be 0.04 mm/yr, with an estimated maximum of 0.09 mm/yr. The estimated maximum slip rate seems inconsistent with the Quaternary uplift rates of ~0.3 to 0.4 mm/yr along the Malibu coastline (Birkeland, 1972; Lajoie et al., 1979), discussed more fully in the next section. The estimated maximum slip rate for the Malibu Coast fault is much less than the 0.27 to 0.39 mm/yr estimated slip rate for the Santa Monica fault immediately to the east, or the 0.2 to >0.56 mm/yr vertical component of slip for the Santa Cruz Island fault immediately to the west (Clark et al., 1984). Part of this apparent discrepancy may be accommodated by slip on the Anacapa fault or on other offshore or nonemergent structures such as blind thrusts or duplexes. Dolan et al. (1995) suggest a slip rate of 1 to 1.5 mm/yr along the Malibu Coast fault, primarily as strike-slip displacement, and 4 mm/yr across a hypothetical nonemergent structure that they call the Santa Monica Mountains thrust.

Uplift. Three prominent marine terraces that are exposed subaerially along the Malibu coastline have been termed the Dume terrace, Corral terrace, and the Malibu terrace, listed in order of increasing age and increasing elevation (Davis, 1933; Yerkes and Wentworth, 1965; Birkeland, 1972). Currently, the ages of the Dume, Corral, and Malibu terraces are thought to be 124,000 yr, 210,000 yr, and 320,000 yr, respectively (Lajoie, written communication, 1996; Lajoie et al., 1979; Treiman, 1994; cf. Szabo and Rosholt, 1969). The maximum elevations of the Dume, Corral, and Malibu terraces along the Malibu coastline west of Topanga Canyon (longitude ~118.58°W) are 40 m, 58 m, and 97 m, respectively (Birkeland, 1972). All three terraces increase in elevation from west to east along the Malibu coastline, at rates of ~0.3 m/km for the Dume terrace, ~0.8 m/km for the Corral terrace, and ~1.3 m/km for the Malibu terrace. Birkeland (1972) inferred that most of the differential uplift is younger than the Dume terrace based upon what he considered the parallel geometry of the Dume and Corral terraces; however, this supposed parallelism is not strongly supported by existing elevation data for these terraces (Yerkes and Wentworth, 1965; Lajoie, written communication, 1996).

Birkeland (1972; Yerkes and Wentworth, 1965) noted three

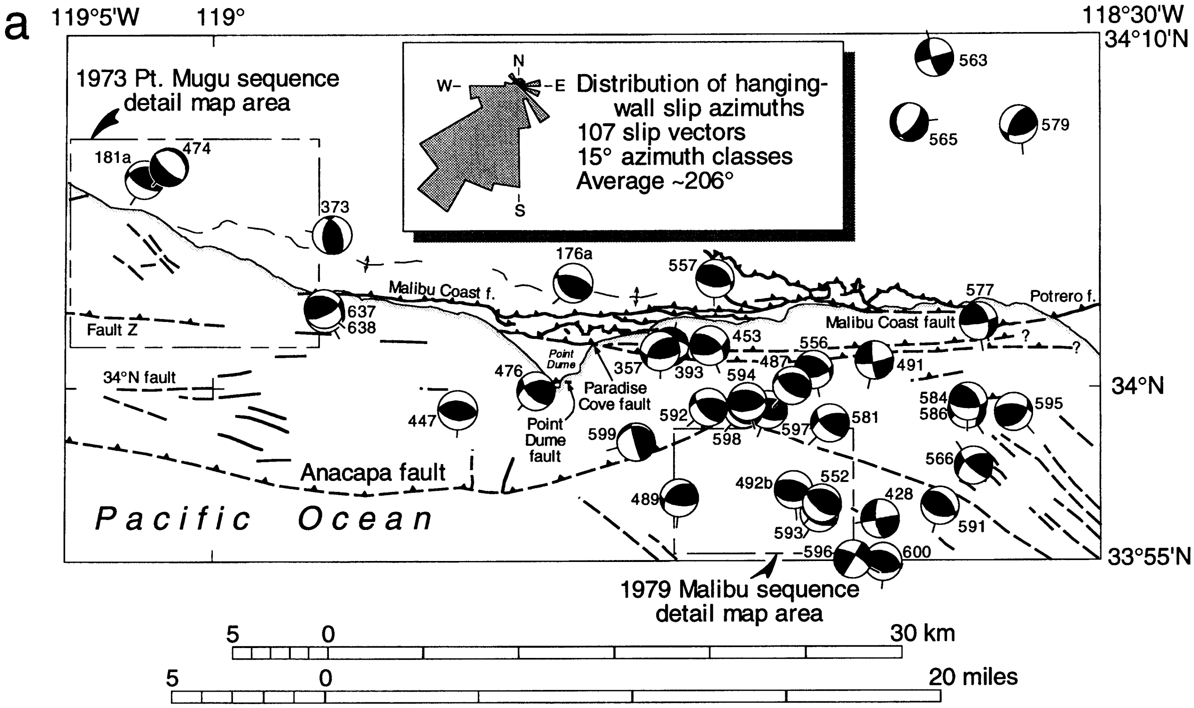
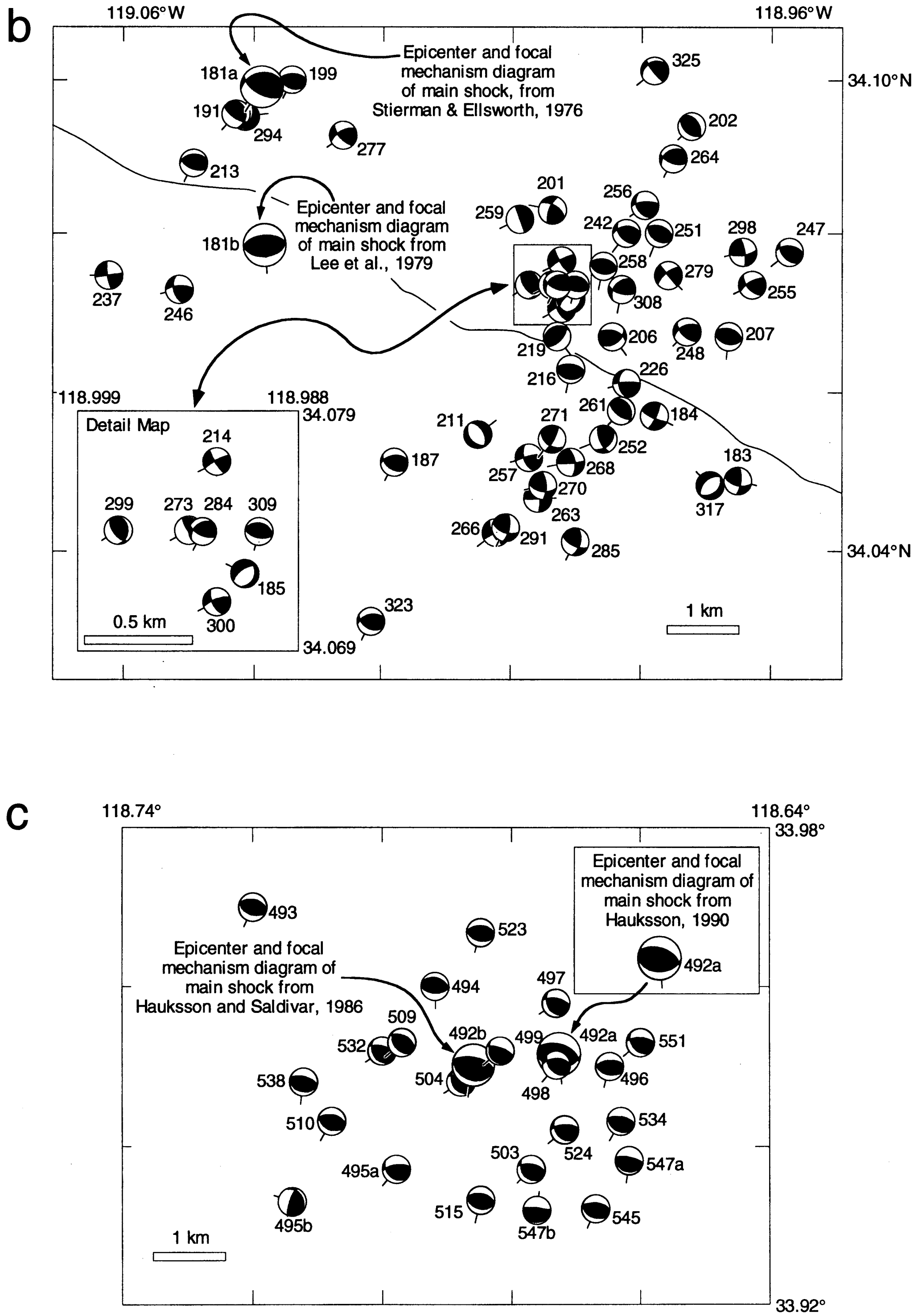


Figure 4 (on this and facing page). Focal mechanism solutions along the Malibu Coast Fault Zone. Focal mechanism solutions shown as lower hemisphere projections with compressional quadrants in black and the direction of hanging-wall slip indicated by the short line extending out from the edge of the projection. Adjacent number corresponds to the event number in Appendix 1, where sources and corresponding data are listed. a, Focal mechanism solutions for the entire study area, with the locations of the detail maps for the Point Mugu and Malibu earthquake sequences bounded by dashed lines. Inset box includes rose diagram of 107 hanging-wall slip directions derived from the focal mechanism solutions. b, Focal mechanism solutions associated with the 1973 Point Mugu earthquake, including two different solutions for the main earthquake. Inset map clarifies the positions and focal mechanisms of several tightly clustered aftershocks. c, Focal mechanism solutions associated with the 1979 Malibu earthquake, including two different solutions for the main earthquake. Inset box shows solution for the main earthquake by Hauksson (1990), which is obscured on the main map.

sites where Quaternary deposits are displaced vertically along a strand of the Malibu Coast fault (sites F1, F2, and F3 on Fig. 2). At site F1, just north of Point Dume, minimum vertical separation of "pre-Malibu nonmarine deposits" is 4 m (Birkeland, 1972, p. 441). Site F2 is located between the official Earthquake Fault Zone boundaries around the Solstice strand and Winter Mesa strands of the Malibu Coast fault (Division of Mines and Geology, 1995a, b). At site F2, vertical separation of the Corral terrace is 5.2 m across a strand of the Malibu Coast fault (Puerco Canyon fault of Treiman, 1994). Site F3 is located just north of the official Earthquake Fault Zone boundary around the Winter Mesa strand of the Malibu Coast fault (Division of Mines and Geology, 1995b). At site F3, vertical separation of the Corral terrace is 14 m across two fault strands. The north sides are uplifted relative to the south sides at sites F1 and F2, but the south side is up at F3.

After compensation for the effects of global variations in late Quaternary sea level, the altitudes of the marine terraces indicate that the Malibu coastline has been rising during the late Quaternary. When the Dume terrace was formed 124,000 years ago, sea level was ~6 m above current sea level (Lajoie et al., 1979, after Shackleton and Opdyke, 1973), so the average uplift rate over that time interval has been 0.27 mm/yr. As adjusted to reflect more recent dating of the Dume and Corral terraces, Birkeland's (1972) inferred uplift rate along the Malibu coastline is ~0.2–0.4 mm/yr. Yerkes and Lee (1979a, p. 34) refer to a ~105,000-yr marine terrace (the 124,000-yr Dume terrace?) thrust "more than 15 m over upper Miocene strata at one locality near Malibu Canyon" by the Malibu Coast fault, suggesting an uplift rate of ~0.1 mm/yr. Johnson (1932, in Hill, 1979) illustrated a marine terrace, inferred to be the Dume terrace by Lajoie (written communication, 1996), vertically offset by 47 m along the Potrero Canyon fault. Lajoie et al. (1979) estimated the long-term uplift rate of the Dume terrace to be 0.2 mm/yr south of the Malibu Coast fault and 0.6 mm/yr north of the fault, requiring 0.4 mm/yr of vertical displacement along the fault.

For comparison, the apparent uplift rates in the northwest Himalaya of Pakistan, as measured using fission-track and ^{40}Ar/^{39}Ar cooling ages, range from 0.2 to 0.9 mm/yr (Zeitler, 1985). Late Cenozoic uplift rates in the northwest Himalaya are



similar to the Quaternary uplift rates estimated along the Malibu coastline. The uplift rate for the massif that culminates in Nanga Parbat (8,126 m) is estimated to be ~5 mm/yr (Zeitler, 1985), a rate that is comparable to the 4 to 10 mm/yr uplift rate estimated by Lajoie et al. (1979) for parts of the western Transverse Ranges. On Santa Cruz Island, along trend to the west of the MCFZ, an uplift rate of 2.1 mm/yr can be inferred from the 25-m vertical displacement of a fluvial terrace that formed 11,780 ± 100 years ago across the Santa Cruz Island fault (Pinter and Sorlien, 1991).

Castle et al. (1977) measured changes in surface elevation associated with the 1973 Point Mugu earthquake. The region

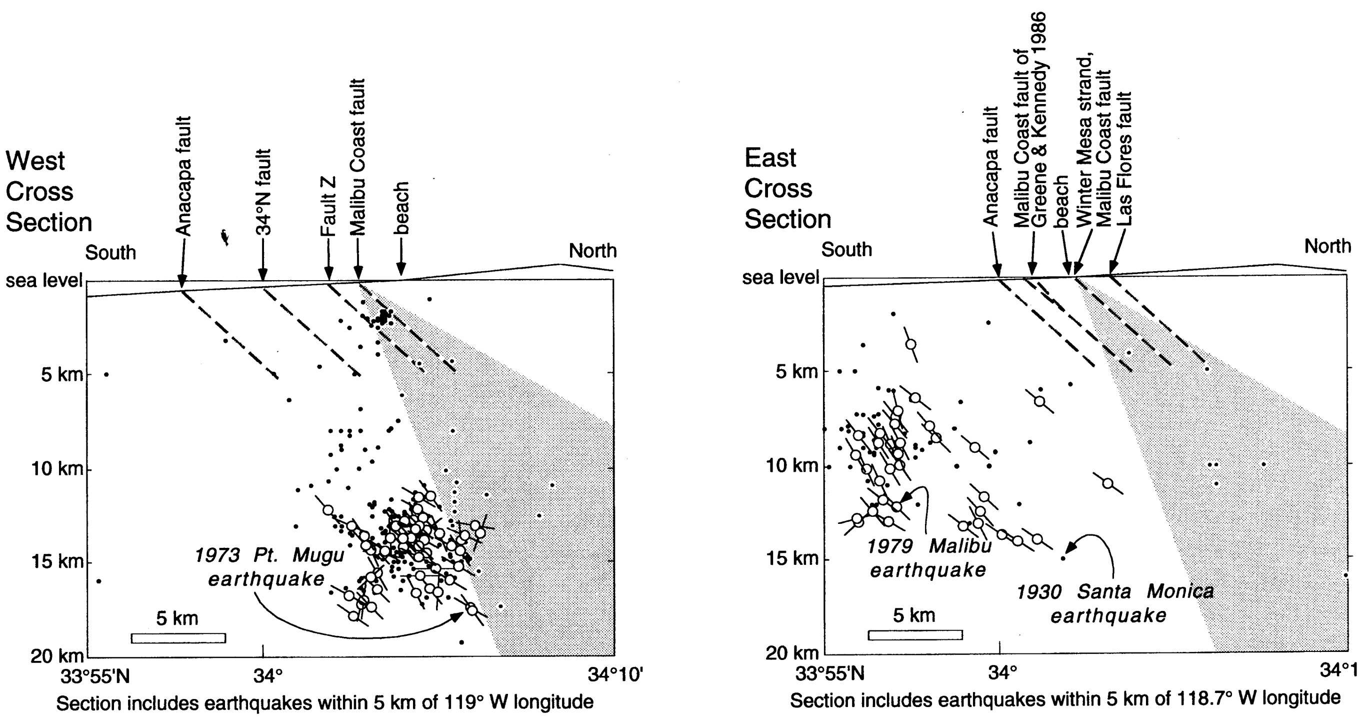


Figure 5. Cross sections showing earthquake hypocenters within 5 km of the lines of section. Section-line locations are shown on Figure 3. Hypocenters were projected due east/west to the line of cross section without change in reported depth. Open circles depict hypocenters of earthquakes for which focal mechanism solutions have been determined. The lines through the open circles indicate the apparent plunge of the interpreted slip vector in the plane of the cross section. Hypothetical fault orientations, based on the mapped surface trace of major faults that intersect the line of section, are dashed. Gray region extending from the surface trace of the Malibu Coast fault is bounded by lines dipping 30° and 60°, within which the actual Malibu Coast fault is likely to be located. Corresponding data and sources are listed in Appendix 1.

north of the Anacapa fault, called the "Santa Monica fault" in Castle et al. (1977), rose by 30 to 40 mm between 1960 and 1968, subsided by a similar amount between 1968 and 1971, and rose back to nearly its 1968 elevation between 1971 and 1973, for a total uplift along the Malibu coastline of 20 to 30 mm relative to the 1960 datum. It is unclear whether the uplift between 1971 and 1973 surveys was preseismic or coseismic with the 1973 Point Mugu earthquake sequence. Coincident with this episode of uplift in the Santa Monica Mountains was a subsidence of as much as 200 mm in the Oxnard Plain, ~5 to 10 km northwest of the epicenter of the 1973 Point Mugu main shock (Castle et al., 1977).

Topographic gradient. Along the south face of the Santa Monica Mountains at Malibu, from Sandstone Peak (elevation 948 m; Fig. 3) across the MCFZ to the floor of the Santa Monica basin between the San Pedro basin fault zone and the Santa Cruz–Santa Catalina Ridge fault zone (~2,550 m below sea level; Fig. 1), the average topographic gradient is ~80 m/km. In the San Gabriel Mountains from San Antonio Peak (3,067 m; Fig. 1) to the active Cucamonga fault (~600 m; Morton and Matti, 1987), the average topographic gradient is ~170 m/km. The topographic gradient along the south slope of the San Gabriel Mountains is approximately twice as steep as the topographic gradient of the south slope of the Santa Monica Mountains. The difference in topographic gradient may be due in part to the differing erosional characteristics of the two mountain ranges resulting from different lithologies exposed at the surface. The exposed core of the San Gabriel Mountains includes Precambrian-Mesozoic metamorphic and intrusive igneous rock units, whereas the surficial lithologies of the Santa Monica Mountains are Cretaceous-Quaternary sedimentary units and Miocene volcanics (Jennings and Strand, 1969; Dibblee, 1992, 1993; Dibblee and Ehrenspeck, 1990, 1993).

Gravity gradient. Isostatic residual gravity tends to reflect mass anomalies in the mid- to upper crust, correlating better with surface geology than Bouguer or free-air gravity (Jachens and Griscom, 1985; Simpson et al., 1986; Jachens et al., 1989; Griscom and Jachens, 1990). The isostatic regional gravity field is caused by masses that isostatically compensate the surface topography. When the isostatic *regional* gravity field is subtracted from the Bouguer gravity field, the remainder is the isostatic *residual* gravity field (Jachens et al., 1989). Faults that juxtapose rock of different physical properties generally coincide with steep gradients in the isostatic residual gravity field.

The range in isostatic residual gravity from the crest of the Santa Monica Mountains (+5 to +10 mGal) across the MCFZ to the regional gravity low in the Santa Monica basin (–75 mGal) is ~80–90 mGal (Fig. 1a; Roberts et al., 1990). The average isostatic residual gravity gradient across the MCFZ on the south slope of the Santa Monica Mountains is ~4.5 mGal/km, which contrasts with the 1 mGal/km gradient along the topographically steeper south slope of the San Gabriel Mountains across the active Cucamonga fault. The trend of the –25 mGal contour along the Malibu coastline parallels the surface trace of the Malibu Coast and Santa Monica faults.

Crustal thickness and crustal roots. The crustal thickness in the study area ranges from ~25 km in the southwest corner of the area to ~30–35 km along the axis of the Santa Monica Mountains (Mooney and Braile, 1989; Mooney and Weaver, 1989; Bryant and Jones, 1992). The average crustal thickness in southern California is 29 km (Hearn, 1984; Bryant and Jones, 1992). Bryant and Jones (1992) have inferred an anomalous crustal thickness of ~41 km in an east-trending oval centered on the Ventura basin, between the Santa Monica Mountains and the Santa Ynez Mountains. The crustal structure in this area is complex (e.g., Keller and Prothero, 1987). In general, surface topography as significant as the Transverse Ranges is isostatically compensated by a thick lower-crustal root zone. The eastern Transverse Ranges (San Bernardino Mountains, Fig. 1) have a small crustal root of 2–3 km thickness, while the central and western Transverse Ranges are generally considered to be essentially rootless (Hearn, 1984; Hearn and Clayton, 1986a, b; Mooney and Weaver, 1989).

The lack of a significant crustal root under the Transverse Ranges is an indicator of the youth and vigorous structural evolution of this province. In the kinematic model of Weldon and Humphreys (1986) the upper crust of the western and central Transverse Ranges is inferred to move essentially parallel to the San Andreas fault along a trajectory that is oblique to the motion of the Pacific plate relative to the North American plate. Hence, the western and central Transverse Ranges are thought to be moving with respect to the upper-mantle lithosphere beneath them, which would inhibit the development of a lower-crustal root. Sheffels and McNutt (1986) have developed an alternative explanation, based on a series of simple one-dimensional models of Bouguer gravity anomalies in the Transverse Ranges. They infer that the western Transverse Ranges are supported north of the Ventura basin by the flexural rigidity of a slab of upper-mantle lithosphere, modeled to be ≥40 km thick, on which they rest (cf. Lyon-Caen and Molnar, 1983). South of Ventura basin, the western Transverse Ranges are inferred to be supported by a thin (~5–15 km), northward-subducting, elastic slab of upper-mantle lithosphere as it bends downward and is resorbed into the upper mantle in the area of anomalously fast *P*-wave velocities (gray area in Fig. 1a; Humphreys et al., 1984; Humphreys and Clayton, 1990; Humphreys and Hager, 1990).

Thrust sequencing. Models for the evolution of thin-skinned thrust belts often incorporate the idea that older thrust faults rotate into steeper, mechanically disadvantageous orientations as newer faults develop below them, progressively farther from the axis of the mountain range. The term "out-of-sequence thrust," used to describe an active or reactivated thrust in the middle of a thrust system, illustrates the tendency to think that the usual sequence involves progressively younger faults with increasing distance from the axis of the mountain range. While this order of faulting is observed in many simple mountain belts as well as in many computational and physical models of thrust systems, it is not the only sequence possible in a compressional orogen. The critical Coulomb wedge model (Davis et al., 1983; Dahlen, 1984; Dahlen et al., 1984), in which the entire thrust system is simultaneously at the point of failure, is an example of an alternative thrust-belt model in which fault displacement is not assumed to be limited to the basal/frontal structure.

The aftershocks associated with both the 1973 Point Mugu earthquake and the 1979 Malibu earthquake are distributed within a volume of crust 5–10 km wide on either side of the inferred main fault plane (Fig. 5; Stierman and Ellsworth, 1976; Yerkes and Lee, 1979a, b; Hauksson and Saldivar, 1986). From the width of this distribution it is inferred that elastic strain was released along more than one fault surface during these sequences. Yerkes and Lee (1979a, b) located the 1973 Point Mugu earthquake along the Anacapa fault, but ascribed many of the more shallow aftershocks to Fault Z, which is parallel to and just above the Anacapa fault. The concurrent seismic activity along the Anacapa fault and Fault Z is inferred to reflect displacement within an active imbricate fan of subparallel thrust faults that reach the surface from a common detachment at depth (Boyer and Elliott, 1982). A similar distribution of seismicity has been described within an imbricate fan associated with the 1978 Tabas-e-Golshan, Iran, earthquake (Berberian, 1982). While the youngest, most outboard thrust in an imbricate fan is likely to be the most seismically active, compressive stress transmitted across the entire thrust system may excite activity along any favorably oriented thrust.

The simplification that the only thrust that is likely to be active is the one farthest from the axis of the mountain range does not apply to the Transverse Ranges where Holocene deformation is distributed across several active structures. The Anacapa fault may be the most active element of the MCFZ; however, it is not the only fault element with Holocene activity.

SEISMOLOGY

Event size–rupture length relationships

It would be useful to be able to relate the length of fault rupture and amount of slip to the size of the earthquake that generated the displacement (e.g., Ellsworth, 1990; Bonilla et al., 1984). Unfortunately, the relationships among these characteristics are not simple and vary from one locality to another.

The size of an earthquake is typically measured in one of two ways: either by the magnitude of the event or by its seismic moment. Earthquake magnitude is a relative measurement. The concept of magnitude is complicated by the fact that there are many different magnitude scales. Various scales have been devised to allow independent measurements from body and surface waves, and to measure the relative size of events that vary by depth, energy released, and geographic location. Commonly used magnitude scales include the local or Richter magnitude (M_L), *P*-wave or body-wave magnitude (m_b), and surface-wave magnitude (M_S). (It should be noted that the abbreviations used above for the various magnitude scales are those most commonly in use, but these abbreviations are not used consistently by all authors.) M_L and m_b are typically used for small- to intermediate-size events, or deep events, and are based on measurements of body waves. M_S is usually a better measure for large events that are shallow enough to generate strong surface waves. The following empirical relationships have been developed between these magnitudes:

$$m_b = 2.5 + (0.63\ M_S)$$
$$M_S = (1.59\ m_b) - 3.97$$
$$m_b = 1.7 + (0.8\ M_L) - (0.01\ M_L^2)$$

The seismic moment (M_o) is a direct measure of the amount of energy radiated by an earthquake. M_o has been described as "perhaps the most fundamental parameter we can use to measure the strength of an earthquake caused by fault slip" (Aki and Richards, 1980). M_o is the product of the area of fault slip in cm^2 (A), the average fault slip in cm (S), and the shear modulus of the faulted material in dyne/cm^2 (μ):

$$M_o = \mu AS$$

(Bullen and Bolt, 1985). Measured values of M_o range from about 10^{12} dyne-cm for microearthquakes to about 10^{30} dyne-cm for the largest earthquakes (e.g., 1960 Chilean and 1964 Anchorage earthquakes).

In general, M_S, M_L, and m_b are strongly dependent on wave period. This is a problem because each of these magnitude scales will saturate at the upper end when the dimensions of the rupture surface exceed the wavelength of the seismic waves used in the calculation. In addition, while the results of the magnitude calculations might be quite similar when they are based on records from stations that are relatively close to one another, significant variations in calculated magnitude can arise from the changes in wave amplitude and frequency that are related to distance, azimuth, and instrument response. A more uniform magnitude scale that does not have the same saturation problem, the moment magnitude (M_W) scale, was proposed by Kanamori (1977). This scale provides more stable estimates of magnitude, or the energy released by an event, and is related to M_o by:

$$M_W = [(2/3)\log_{10}(M_o)] - 10.7$$

(Hanks and Kanamori, 1979). In practice, however, it is generally sufficient for engineering purposes to consider M_L, M_S, M_W, and m_b to be roughly equivalent to one another for moderate size, shallow-focus events that cause damage at the surface (Bullen and Bolt, 1985, p. 377).

The relationship between magnitude and surface rupture length (L) has been investigated by Evernden et al. (1981) and Wells and Coppersmith (1994). Evernden et al. (1981) developed the following empirical relationship between local magnitude and surface rupture length:

$$M_L = [3.2667 + \log_{10}(L)]/0.711$$

Wells and Coppersmith (1994) used 244 historical earthquakes to develop empirical relationships between moment magnitude, surface rupture length, rupture width, rupture area, and surface displacement. They used a subset of 80 events to develop the following formula relating M_W to surface rupture length:

$$M_W = [1.16\log_{10}(L)] + 5.08$$

To the extent that these relationships are approximately valid, the entire 3.2-km-long segment of the Solstice fault that has been zoned as active (inset, Fig. 2) could have ruptured in a magnitude 5.3 to 5.7 earthquake. This magnitude is at least as great as the largest recorded earthquakes attributed to the Anacapa fault: 1930 Santa Monica earthquake (M_L 5.2), 1973 Point Mugu earthquake (M_L 5.3), and 1979 Malibu earthquake (M_L 5.2). Half of the Solstice strand could rupture in a magnitude 4.9 to 5.3 earthquake. The entire 0.25-km length of the zoned Winter Mesa strand of the Malibu Coast fault could have ruptured in a magnitude 3.7 to 4.4 earthquake.

Given the uncertainty in any computed magnitude or seismic moment, estimated rupture lengths based on these measures should be made with caution.

Maximum credible earthquake

Greensfelder (1972, 1973) assigned a maximum probable earthquake magnitude of 7.5 to the Malibu Coast fault, based on Bonilla's (1970) data on fault rupture length, in creating maps of maximum credible ground acceleration for California earthquakes (see description and reproduction of Greensfelder's map in Kockleman, 1985, p. 454–455). W. H. K. Lee and W. L. Ellsworth concluded, after reviewing the earthquake history of the Santa Barbara Channel region from 1800 through 1973, "that the maximum credible earthquake for engineering design purposes is an event of magnitude 7.5 occurring anywhere in the Santa Barbara Channel region" (Lee et al., 1979, p. 3). Ziony and Yerkes (1985, after Wesson et al., 1974) concluded that reasonable maximum earthquake magnitudes to be expected along the Santa Cruz Island–Anacapa–Santa Monica–Hollywood-Raymond fault system is M 7.5. For other late Quaternary reverse faults in the Transverse Ranges, Ziony and Yerkes (1985) suggested a design magnitude of 6.5 to 7 for noncritical structures. Mualchin and Jones (1992) assigned a maximum magnitude of 7.5 to the Malibu Coast–Santa Monica–Raymond fault system to estimate peak accelerations for the design purposes of the California Department of Transportation. Dolan et al. (1995) estimated moment magnitudes of between 6.9 and 7.3 for modeled earthquakes along faults of the MCFZ, with recurrence intervals ranging from 740 to >3,000 years.

Evernden et al. (1981, p. 50) chose the Malibu Coast fault as an example in their model to estimate the replacement value of constructed works damaged by earthquakes in California. In a hypothetical M 6.7 earthquake along the Malibu Coast fault, they predicted 31 km of surface rupture resulting in $760 million in damage in 1981 dollars—more than half as much as a repeat of the 1857 Fort Tejon earthquake (M 8.1) along the San Andreas fault.

PROFESSIONAL PRACTICE, MORAL PHILOSOPHY, AND FAULT-ZONE STUDIES

The investigation of potentially active faults seems to involve not only scientific problems, but also problems of law and applied professional/scientific ethics. There is a moral dimension to the work of engineering geoscientists, comparable to the moral dimensions of science and engineering in general (e.g., Martin and Schinzinger, 1989), because the work product of an engineering geoscientist affects the public's safety, property, and welfare.

An ethic is a moral principle or value that most, if not all, prudent individuals would accept and strive to follow. Ethical theories are developed to assist people in the resolution of moral dilemmas, in which two or more moral obligations, duties, rights, goods, or ideals conflict with one another. For example, an ethical conventionalist might assert that his/her moral and professional obligations are fulfilled when the requirements of applicable laws and customs are met. A utilitarian would choose the action that would result in the greatest benefit for the most people, or causes the least suffering (e.g., Quinton, 1988). Immanuel Kant (1785, 1788) advocated basing moral decisions on categorically imperative duties like "tell the truth" that are universally applicable and reflect an individual's autonomous commitment to morality. Act as if, by your actions, you are establishing universal law. It is clearly beyond the scope of this paper to provide a primer on ethical theory (e.g., Harman, 1977; Martin and Schinzinger, 1989); however, the personal study of ethics serves to prepare an individual to act rationally in accordance with definable moral principles when confronted with a moral dilemma.

A scientist seeks knowledge through the use of valid and reproducible methodology to collect and analyze relevant available data and to make a defensible interpretation. Implicit in this statement of what a scientist does is a fundamental scientific ethic: seek the truth and tell the truth (e.g., Bronowski, 1965, 1978; Woodford, 1956). As Einstein put it (Mackay, 1991), "Most people say that it is the intellect which makes a great scientist. They are wrong: it is the character."

In addition to the basic ethics of science, a primary ethic in the engineering geosciences involves the legal and moral necessity to protect the public's safety. Interpretations made by a geoscientist who follows a safety-based professional ethic should be the same regardless of whether the individual has a personal, professional, or financial stake in the outcome (cf. Rawls, 1971; Martin and Schinzinger, 1989). We assert that professional ethics in the engineering geosciences are based primarily on the underlying ethics of science and the necessity to protect human safety and secondarily on the protection of property.

One of the central purposes of engineering geoscience is to identify and characterize geologic conditions that represent a potential hazard to the public. The principal client of engineering geoscientists in fulfilling this purpose is the public. In California as in many other jurisdictions, the public through its government has established registration laws comparable to those that apply to other professionals whose work affects the public's safety and welfare, so there is a reasonable expectation that engineering geoscientists will use their knowledge and technical skills in the public interest.

Engineering geoscientists are at the base of the organizational pyramid in protecting the public from geologic hazards. Engineers and architects cannot design to mitigate hazards that they do not know exist. Similarly, public officials cannot make informed policy decisions concerning hazards that they do not understand or know exist. Ideally, there is an orderly flow through the process of hazard identification and risk management, which can be generalized as follows: (1) the geologic hazard is recognized; (2) the hazard is characterized using appropriate scientific methods; (3) the risk posed by the investigated hazard is assessed and described; (4) the risk associated with the hazard is evaluated by an informed public authority; (5) conditions that are unacceptably hazardous are mitigated, or the area is zoned to avoid the hazardous conditions; (6) hazardous conditions that are not considered to be unacceptibly dangerous are routinely monitored against the possibility of future adverse developments; and (7) data concerning the hazards are maintained within the public record. If the geoscientist fails in his/her responsibilities within this process, for whatever reason, the system is rendered inoperable.

Cost of seismic safety

Geoscientists fear being held liable, based on the legal theory of inverse condemnation, for the loss of resale value for properties adjacent to faults for which they are able to demonstrate Holocene activity. Allen (1976) mentioned a threatened lawsuit by the City of Los Angeles against seismologist James Whitcomb and his employer the California Institute of Technology for allegedly lowering property values in the San Fernando Valley through the public discussion of earthquake predictions. Most individuals fear the financial consequences of being sued for whatever reason, even if the case has no merit. Although such financial and legal concerns may be valid criteria for an individual geoscientist or company to use in deciding whether to become involved in fault-zone studies, they are not valid criteria to use in the scientific process of assessing fault activity. Faults are active or inactive without regard to the economic value of the ground that they traverse.

What is the cost of designing a structure for seismic safety? The shear walls, lateral bracing, shock-mounting of utilities, and other relatively minor adjustments to the design of a house would increase its cost by an estimated 1–2% for a structure valued at $300,000 to $600,000 (Larson and Slosson, 1992). Relative to the value of people and property that are exposed to risk in a structure that is not designed for seismic safety, this amount is a very small premium to pay in new-building construction or in retrofitting existing buildings. This minimal additional cost is probably even less of a burden in Malibu, where the median income is substantially above the national average.

The more costly aspect of seismic safety involves the mandated setbacks from the trace of an active fault that may render some lots unusable. The property is unusable for its intended purpose because of a natural condition of the property, not because of the geoscientist who observed and characterized that condition. A qualified geoscientist who locates and characterizes an active fault on a property, using sound scientific methods and meeting the standards of care as well as the standards imposed by law, should not be in a position of being held liable for the loss of real or potential property value. If geoscientists have reason to fear adverse legal action in response to their competent and necessary scientific work, then society through its legal system has made it impossible for geoscientists to function in the public interest.

Uncertainty and hazard assessment

Evaluating fault activity. When a Holocene earthquake produces coseismic surface rupture along a recognizable fault, it would appear that there is little room for uncertainty about whether the fault is seismically active. However, there may be some uncertainty in the interpretation even in this case. (1) The most obvious interpretation is that the slipped fault patch propagated outward from the hypocenter of the main shock until it intersected the ground surface, where it was manifested as surface rupture. That is, the surface displacement is along the same fault that generated the earthquake. (2) The coseismic surface rupture may have occurred along a fault other than the one that generated the earthquake, due to a kinematic adjustment or a secondary earthquake. (3) The fault that displayed coseismic surface rupture may be the slip surface of a landslide that moved during or after the earthquake; however, the earthquake focus was along another fault. While there may be several possible causes, the effect is still the same: coseismic surface rupture.

Ground-surface ruptures caused by landslides are specifically excluded from the zoning restrictions of the Alquist-Priolo Act (Hart, 1994) because landslide hazards can generally be mitigated whereas fault-rupture hazards can only be avoided. However, it is not always obvious whether a particular fault offset is related to the motion of a landslide or a crustal-scale fault. A landslide slip surface is a fault by common definition: a surface along which there is shear displacement. Landslide slip surfaces are marked by the same fault-zone structures and gouge/breccia found along any other fault in the shallow crust. Most of a landslide slip surface is a normal fault; however, the segment of the slip surface along the toe or base of a landslide is commonly a thrust fault. Some landslides in coastal southern California are hundreds of feet thick and have surface areas of many square kilometers. Some landslides slip on preexisting fault surfaces that are favorably oriented to facilitate slope instability. Coseismic landsliding associated with the 1989 Loma Prieta earthquake was observed in the Santa Cruz Mountains, where it caused significant property damage.

In the absence of instrumentally recorded earthquakes or historical accounts of surface rupture, it can be difficult to demonstrate the age of the most recent movement along a fault. Sometimes there is no datable material along the fault with which to evaluate the Holocene activity of the fault. The orientation of the net-slip vector may coincide with the plane of a datable horizon. Fault strands known to have slipped during the 1992 Landers earthquake (M_L 7.4) could not be recognized in some trenches cut across an unambiguous ground-surface trace, in spite of competent and diligent efforts to identify the fault trace in the trench exposure (James Slosson, oral communication, 1995; Murbach, 1994).

Some of the many difficulties encountered in interpreting fault activity from field data can be appreciated by considering a few scenarios based on the cross section in Figure 6a.

a. Unit A is Holocene, but elsewhere along the fault unit A does not appear to be displaced. Any future slip along the fault would probably cause the fault to propagate.

b. Unit A is Holocene, but elsewhere along the fault there are no Holocene units that cross the fault trace.

c. Unit A is Holocene, but the fault trace projects into urbanized areas in both directions. Pre-development geological reports for the urbanized areas are insufficient to evaluate possible Holocene slip along the fault in those areas.

d. Unit A is pre-Holocene, but a Holocene unit is cut by the fault elsewhere along the fault trace.

e. Unit A is pre-Holocene, no Holocene units exist along the trace of the fault, and there is no record of observed surface rupture along the fault.

f. Unit A is pre-Holocene, no Holocene units exist along the trace of the fault, and there is no record of observed surface rupture along the fault; however, there are geomorphic or geodetic indicators of structural activity across the fault.

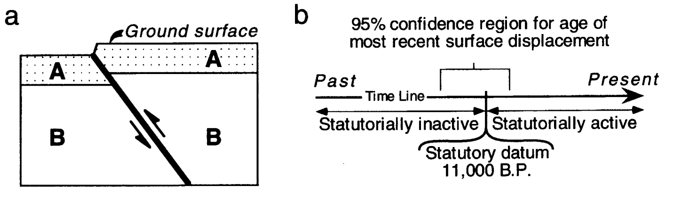


Figure 6. Dilemmas posed by legal definitions of fault activity. a, Fault exposure in a trench wall or outcrop. Unit A is younger than unit B. b, Error region for absolute age straddles a legally defined datum that separates *active* from *inactive* categories of fault.

g. Unit A is pre-Holocene, no Holocene units exist along the trace of the fault, and there is no record of observed surface rupture along the fault; however, a set of microearthquakes appears to coincide with the fault surface.

h. Unit A is pre-Holocene, no Holocene units exist along the trace of the fault, and there is no record of observed surface rupture along the fault; however, this fault surface is parallel to an adjacent fault surface on which there is demonstrable Holocene activity. Are two parallel faults in the same stress environment equally likely to experience future slip?

i. The statistical uncertainty in the absolute age of unit A makes it impossible to tell with certainty whether the unit is younger or older than the datum that statutorily differentiates active faults from inactive or potentially active faults (Fig. 6b).

In response to issues like these, there are two end-member approaches. Approach 1 is that a fault is to be considered *inactive* unless Holocene activity can be proven. Approach 2 is that a fault is to be considered *active* unless Holocene activity can be disproven. (In current practice, the only effective designations for a fault are *active* and *inactive*. This binary system will persist until the designation of a fault as *potentially active* results either in legally mandated restrictions on development or in legally mandated notification of potential fault activity included on real estate documents.)

Under approach 1, scenarios a through c would result in the fault being designated active, but the official Earthquake Fault Zone might include only the part of the fault that cuts a datable Holocene unit. Scenarios d through i would probably not result in an active designation for the fault shown in Figure 6a. Under approach 2, scenarios a through i might all result in the fault being designated active.

The problem with following approach 1 is that the hazard posed by at least some seismogenic faults will be discounted by labeling them inactive or just *potentially* active. The risk in approach 1 is borne by the individuals whose lives and property would be affected by coseismic surface rupture along the fault. These individuals do not generally have adequate knowledge or understanding of the risk they face, and so they cannot give their informed consent to the risk. These individuals rely on their public officials and the relevant technical professionals to recognize and manage the risk associated with geologic hazards on their behalf. In our opinion, approach 1 does not adequately protect the safety of the public.

Approach 2 would be effective in protecting the public from many potential fault-rupture hazards; however, it would also cause at least some faults that are actually fossil, inactive faults to be designated active. The inaccurate designation of a fault as active would result in the unnecessary imposition of setbacks from fault traces for new construction. Unnecessary setbacks make it needlessly expensive to develop some properties, and would make it impossible to develop other properties.

The dilemma. A classic moral/professional dilemma is presented by the problem of evaluating the Holocene activity of a fault given the incomplete nature of the geologic record as well as the technical limits on dating Holocene materials. In this dilemma the need to protect the safety of the public is potentially in conflict with the need not to waste the property/wealth of the public. Clearly, a balance needs to be struck between approaches 1 and 2 so that fault-rupture hazards are effectively identified and avoided with a minimum of collateral loss of usable property. Similar balances are prevalent in law and public policy as, for example, in the restrictions for hillside development in the Uniform Building Code (e.g., Scullin, 1983). Certain natural slope conditions, like high slope angles developed on weak materials or "daylighted" beds or joints that dip toward the slope face, are generally recognized as increasing the probability of future slope instability. Not every slope with adverse natural characteristics will fail during the useful life span of the adjacent structures, but development is still constrained by code when these conditions are present because of the reasonable expectation that these conditions will compromise the integrity of structures and the safety of their occupants.

The positive evolution of effective and appropriate public policy and professional practice concerning the assessment of fault-zone hazards requires an open and comprehensive dialog involving all of the stake-holders in the process: geoscience professionals, public servants, and the public. What can responsible geoscientists do to assess the hazard potential of potentially active faults and faults whose displacement history in the Quaternary is ambiguous? What can public officials do to expand statutory definitions and protections to include the hazards posed by potentially active faults? How can the public be better educated about seismic hazards, so that they can play a more effective role in enhancing their own seismic safety and in forming public policy?

Given a professional ethic that places the highest value on the protection of human life and safety, we prefer that public officials and geoscientists choose approach 2 as the starting point in the evolution of public policy and professional practice concerning the assessment of fault-zone hazards. The formal reintroduction of the category *potentially active* might provide a useful intermediate category between *active* and *inactive* faults to characterize faults that are likely to be active but whose most recent displacement is not unambiguously dated. The utility of designating a fault "potentially active" is contingent upon the legal effect of such a designation, which we feel should include clear notification on real estate documents associated with properties along the fault. The public cannot make an informed decision in evaluating the risk associated with a potentially active fault on a given property if they are not notified of the fault's existence and activity status.

IS THE MALIBU COAST FAULT ACTIVE?

Yerkes et al. (1987, p. 169) stated:

> The intensity and relative youth of regional deformation in the Transverse Ranges have been emphasized in comparative or qualitative terms for more than 30 years. Gilluly's advocacy is both long standing (1949, 1962, 1979) and emphatic (1979, p. 475): 'there is no escape from the fact that this orogeny is active and active at a rate comparable to that of the formation of any mountain chain we know about.'

Recent seismicity and documented Holocene displacements within the MCFZ demonstrate conclusively that it is an active fault zone. The range of ancillary evidence described herein is uniformly supportive of that conclusion. Holocene slip is typically oblique: primarily reverse, with a minor left-lateral component. The average azimuth of hanging-wall slip relative to the foot wall is ~206°. The active emergent faults of the MCFZ appear to be a set of east-west–trending, north-dipping faults that are interpreted to constitute an imbricate, locally anastamosing thrust fan rising from a common detachment zone in the lower crust. The Anacapa fault appears to be the most active fault within the MCFZ although there may be other active, perhaps nonemergent, structures below and to the south of the Anacapa fault. Reliable published data on the position and characteristics of offshore faults are still sparse. Concurrent Holocene deformation has been observed or documented on many structures throughout the width of the western Transverse Ranges, so there is little reason to assume that deformation within the MCFZ is currently limited to the Anacapa fault and other offshore faults.

It has been shown that elements of the MCFZ are active, and that at least some strands of the Malibu Coast fault are active. The principal ambiguity involves the assessment of activity for the many individual strands of the MCFZ exposed along the Malibu coastline. While not all fault surfaces within the MCFZ may display unambiguous evidence of Holocene displacement, we feel that any favorably oriented fault surface within the MCFZ should be considered potentially active unless it can be shown conclusively to be otherwise.

We concur with Ziony and Yerkes (1985) that the Malibu Coast fault should be considered active and capable of producing a magnitude 6.5 to 7 earthquake. We feel that structures to be occupied by humans along the Malibu coastline should be built, or retrofitted, to withstand a magnitude 7 earthquake along the MCFZ, regardless of the proximity of the structure to an active fault strand. We also feel that critical facilities along the MCFZ should be built to withstand a magnitude 7.5 earthquake, as suggested by Mualchin and Jones (1992).

Identifying a fault and assessing the associated earthquake hazard is a matter of science and is governed by the methodology and ethics of science. Once compelling scientific evidence has been acquired that a fault zone is active, engineering geoscientists have a professional and moral obligation to act in an appropriate manner to inform and protect the public. An informed public can rationally assess the level of risk that it is willing to assume and can take steps, individually and collectively through its government, to protect itself from earthquake hazards.

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APPENDIX 1. DATA FOR EARTHQUAKES REPORTED FROM LATITUDE 33°55' TO 34°10'N AND FROM LONGITUDE 118°30' TO 119°5'W ALONG THE MALIBU COAST FAULT ZONE

EQ Ref. No.	Year	Date Mo	Da	Hypocenter/Epicenter Location Lat (°N)	Long (°W)	Depth (km)	Mag	Reported Arrivals	Focal Mechanism Soln Dip Azim	Dip Angle	Slip Azim	Source
1	1827	9	24	34	119		5.5					Toppozada et al., 1981
2	1911	5	10	34.1	118.8		4					CDMG via NEIC, 1995
3	1912	12	14	34	119		4					CDMG via NEIC, 1995
4	1914	11	8	34	118.5		4.5					CDMG via NEIC, 1995
5	1918	3	6	34	118.5		4					CDMG via NEIC, 1995
6	1918	3	8	34	118.5		4					CDMG via NEIC, 1995
7	1918	11	19	34	118.5		4					CDMG via NEIC, 1995
8	1920	6	22	34	118.5		4.9					USHIS via NEIC, 1995
9	1920	6	22	34	118.5		4.9					CDMG via NEIC, 1995
10	1920	6	23	34	118.5		4					CDMG via NEIC, 1995
11	1927	8	4	34	118.5		5					CDMG via NEIC, 1995
12	1930	8	31	34.03	118.643	15	5.2					Hauksson and Saldivar, 1986
13	1932	12	3	34	118.667		3					CDMG via NEIC, 1995
14	1934	1	14	33.967	118.583		2					CDMG via NEIC, 1995
15	1934	2	12	33.95	118.633		2.5					CDMG via NEIC, 1995
16	1934	3	10	33.95	118.633		3.5					CDMG via NEIC, 1995
17	1934	8	6	34.117	118.75		2.5					CDMG via NEIC, 1995
18	1934	8	6	34.117	118.75		2					CDMG via NEIC, 1995
19	1934	8	6	34.117	118.75		2					CDMG via NEIC, 1995
20	1934	8	6	33.95	118.633		2					CDMG via NEIC, 1995
21	1934	8	20	33.95	118.633		2.5					CDMG via NEIC, 1995
22	1935	5	13	33.95	118.633		2					CDMG via NEIC, 1995
23	1935	7	23	34.017	118.583		2.5					CDMG via NEIC, 1995
24	1936	2	5	34.117	118.75		2					CDMG via NEIC, 1995
25	1936	2	7	33.95	118.633		2					CDMG via NEIC, 1995
26	1936	3	7	34.117	118.75		2.5					CDMG via NEIC, 1995
27	1936	3	27	34.05	118.917		3					CDMG via NEIC, 1995
28	1936	4	18	34.117	118.75		2					CDMG via NEIC, 1995
29	1936	5	17	34.117	118.75		2					CDMG via NEIC, 1995
30	1936	5	22	34.117	118.75		2.5					CDMG via NEIC, 1995
31	1936	5	24	34.117	118.75		2.5					CDMG via NEIC, 1995
32	1936	6	3	34.117	118.75		2					CDMG via NEIC, 1995
33	1936	7	5	33.95	118.633		2					CDMG via NEIC, 1995
34	1936	8	14	33.95	118.633		2					CDMG via NEIC, 1995
35	1936	9	17	33.95	118.633		2					CDMG via NEIC, 1995
36	1936	10	8	34	118.533		3					CDMG via NEIC, 1995
37	1936	12	10	34.1	118.7		2					CDMG via NEIC, 1995
38	1937	5	11	33.95	118.633		2.5					CDMG via NEIC, 1995
39	1937	5	12	33.95	118.633		2.5					CDMG via NEIC, 1995
40	1937	5	24	33.95	118.633		2.5					CDMG via NEIC, 1995
41	1937	7	6	33.95	118.633		3					CDMG via NEIC, 1995
42	1937	11	7	33.95	118.633		2					CDMG via NEIC, 1995
43	1938	1	16	33.95	118.633		2.5					CDMG via NEIC, 1995
44	1938	5	24	34.117	118.75		2.5					CDMG via NEIC, 1995
45	1939	8	28	33.95	118.633		3.5					CDMG via NEIC, 1995
46	1940	8	16	33.95	118.633		3					CDMG via NEIC, 1995
47	1940	9	5	34.117	118.75		2.5					CDMG via NEIC, 1995
48	1940	10	16	33.95	118.583		2.5					CDMG via NEIC, 1995
49	1941	4	12	33.95	118.633		2.5					CDMG via NEIC, 1995
50	1941	7	13	34.1	118.85		3					CDMG via NEIC, 1995
51	1941	7	16	33.95	118.633		2.5					CDMG via NEIC, 1995
52	1942	10	9	34	118.717		3					CDMG via NEIC, 1995
53	1945	7	24	34	118.55		2.5					CDMG via NEIC, 1995
54	1945	12	19	34.1	118.683		2.7					CDMG via NEIC, 1995
55	1946	2	4	33.917	119		2.8					CDMG via NEIC, 1995
56	1946	4	27	34.017	119.017		3.1					CDMG via NEIC, 1995
57	1946	9	7	34.1	118.55		2.5					CDMG via NEIC, 1995
58	1947	6	30	33.983	118.9		2.4					CDMG via NEIC, 1995
59	1947	7	23	33.917	119		3.6					CDMG via NEIC, 1995
60	1947	7	27	34.117	118.8		2.8					CDMG via NEIC, 1995
61	1947	12	6	33.917	118.6		2.7					CDMG via NEIC, 1995
62	1948	4	16	34	118.933		3.3					CDMG via NEIC, 1995
63	1948	4	16	34.017	118.967		4.7					CDMG via NEIC, 1995
64	1948	4	17	34.017	118.967		2.9					CDMG via NEIC, 1995
65	1948	4	17	34.017	118.967		3.5					CDMG via NEIC, 1995

EQ Ref. No.	Year	Date Mo	Da	Hypocenter/Epicenter Location Lat (°N)	Long (°W)	Depth (km)	Mag	Reported Arrivals	Focal Mechanism Soln Dip Azim	Dip Angle	Slip Azim	Source
66	1948	4	17	34.017	118.967		2.7					CDMG via NEIC, 1995
67	1948	9	30	33.967	119		3.3					CDMG via NEIC, 1995
68	1948	9	30	33.967	119.033		3.1					CDMG via NEIC, 1995
69	1948	9	30	33.967	119.017		2.8					CDMG via NEIC, 1995
70	1948	10	4	34.017	119		3.8					CDMG via NEIC, 1995
71	1948	11	30	34	118.833		2.5					CDMG via NEIC, 1995
72	1949	2	9	33.933	118.65		3					CDMG via NEIC, 1995
73	1949	3	13	34	119		2.7					CDMG via NEIC, 1995
74	1949	4	23	34.05	118.8		2.9					CDMG via NEIC, 1995
75	1949	5	11	34.067	119.05		2.8					CDMG via NEIC, 1995
76	1949	6	28	34.067	119.033		2.7					CDMG via NEIC, 1995
77	1949	7	1	34.1	118.5		2.5					CDMG via NEIC, 1995
78	1949	9	23	33.967	118.95		3.2					CDMG via NEIC, 1995
79	1949	11	10	34.1	118.517		3					CDMG via NEIC, 1995
80	1949	11	16	33.983	118.533		2.4					CDMG via NEIC, 1995
81	1949	12	3	33.983	118.55		2.2					CDMG via NEIC, 1995
82	1949	12	10	34.05	118.5		3.2					CDMG via NEIC, 1995
83	1950	1	16	34.083	118.983		2.8					CDMG via NEIC, 1995
84	1950	10	9	33.917	118.717		2.7					CDMG via NEIC, 1995
85	1950	11	8	34.067	118.683		3.1					CDMG via NEIC, 1995
86	1950	11	8	34.067	118.717		2.6					CDMG via NEIC, 1995
87	1950	11	9	34.067	118.683		2.6					CDMG via NEIC, 1995
88	1951	3	6	34.017	119		2.9					CDMG via NEIC, 1995
89	1951	4	13	33.983	118.6		3.4					CDMG via NEIC, 1995
90	1951	4	25	34.166	118.733	16	3.2					DNAG via NEIC, 1995
91	1951	7	11	34	118.867		3.4					CDMG via NEIC, 1995
92	1951	10	21	34.133	118.567		2.2					CDMG via NEIC, 1995
93	1951	12	24	34	119.083		2.4					CDMG via NEIC, 1995
94	1952	2	12	34	119		3.2					CDMG via NEIC, 1995
95	1952	4	26	33.917	118.567		2.3					CDMG via NEIC, 1995
96	1952	11	18	34.1	118.5		2.5					CDMG via NEIC, 1995
97	1953	1	6	34	119.017		3.4					CDMG via NEIC, 1995
98	1953	9	7	34.083	118.5		2.1					CDMG via NEIC, 1995
99	1953	12	31	33.95	118.733		2.4					CDMG via NEIC, 1995
100	1954	1	22	33.95	118.75		2.3					CDMG via NEIC, 1995
101	1954	1	22	33.95	118.75		2.7					CDMG via NEIC, 1995
102	1954	7	24	34.166	118.65	16	3.2					DNAG via NEIC, 1995
103	1954	12	20	33.967	118.733		2.5					CDMG via NEIC, 1995
104	1955	5	29	33.99	119.058	17	4.1					CDMG via NEIC, 1995
105	1955	12	5	34.067	118.583		2.3					CDMG via NEIC, 1995
106	1955	12	13	34.033	119.05		2.8					CDMG via NEIC, 1995
107	1956	7	29	33.967	118.983		2.8					CDMG via NEIC, 1995
108	1956	10	22	33.967	118.5		2.3					CDMG via NEIC, 1995
109	1957	2	13	33.983	118.517		2.3					CDMG via NEIC, 1995
110	1957	4	26	34.1	118.867		2.7					CDMG via NEIC, 1995
111	1957	8	6	33.917	118.633		3.3					CDMG via NEIC, 1995
112	1957	8	6	33.917	118.633		2.9					CDMG via NEIC, 1995
113	1957	11	30	33.967	118.583		3.6					CDMG via NEIC, 1995
114	1958	5	19	34.05	119		3.1					CDMG via NEIC, 1995
115	1958	8	17	34.083	118.5		2					CDMG via NEIC, 1995
116	1958	12	15	33.917	118.667		2.6					CDMG via NEIC, 1995
117	1959	1	7	34.017	119.033		3					CDMG via NEIC, 1995
118	1959	3	29	34.033	118.5		2.7					CDMG via NEIC, 1995
119	1959	12	31	34.05	118.667		2.2					CDMG via NEIC, 1995
120	1960	1	29	34.083	118.633		2.3					CDMG via NEIC, 1995
121	1960	6	27	34	118.817		3.1					CDMG via NEIC, 1995
122	1960	12	26	34.133	118.633		2.6					CDMG via NEIC, 1995
123	1961	10	2	34.101	118.719	10	2.7					CDMG via NEIC, 1995
124	1961	11	13	34.018	118.849	13	3.8					CDMG via NEIC, 1995
125	1961	12	28	34.14	119.071	13	2.3					CDMG via NEIC, 1995
126	1962	1	16	34.166	119.083	13	3					DNAG via NEIC, 1995
127	1962	2	4	34.043	118.755		2.9					CDMG via NEIC, 1995
128	1962	2	6	34.1	118.73	5	3.1					CDMG via NEIC, 1995
129	1962	2	6	34.01	118.751	12	2.9					CDMG via NEIC, 1995
130	1962	3	19	34.069	118.896	15	3					CDMG via NEIC, 1995
131	1962	9	14	34.151	118.685		2.1					CDMG via NEIC, 1995
132	1962	12	9	34.007	118.59	14	2.7					CDMG via NEIC, 1995
133	1963	5	26	33.961	118.727	12	3.4					CDMG via NEIC, 1995
134	1963	8	27	34.139	119.019		2.6					CDMG via NEIC, 1995

EQ Ref. No.	Year	Date Mo	Da	Hypocenter/Epicenter Location			Mag	Reported Arrivals	Focal Mechanism Soln			Source
				Lat (°N)	Long (°W)	Depth (km)			Dip Azim	Dip Angle	Slip Azim	
135	1965	4	6	34.101	118.913	10	2.5					CDMG via NEIC, 1995
136	1965	5	2	33.989	118.575	10	2.7					CDMG via NEIC, 1995
137	1965	6	25	34.08	119.013	1	2.6					CDMG via NEIC, 1995
138	1965	10	5	33.919	118.651	10	2.8					CDMG via NEIC, 1995
139	1965	10	6	34	118.6	0	3.7					DNAG via NEIC, 1995
140	1965	10	6	34	118.6	0	3.7					DNAG via NEIC, 1995
141	1965	11	10	34.076	118.581	4	3					CDMG via NEIC, 1995
142	1965	12	9	34.104	118.688	11	2.7					CDMG via NEIC, 1995
143	1965	12	26	33.922	118.958	16	2.8					CDMG via NEIC, 1995
144	1966	9	4	33.938	118.525	10	2.7					CDMG via NEIC, 1995
145	1966	9	12	33.958	118.559	13	3.4					CDMG via NEIC, 1995
146	1966	9	12	33.993	118.562	5	3.2					CDMG via NEIC, 1995
147	1966	9	26	34.147	118.859	1	2					CDMG via NEIC, 1995
148	1966	10	1	33.959	118.803		2.3					CDMG via NEIC, 1995
149	1966	10	19	33.936	118.519		2.1					CDMG via NEIC, 1995
150	1966	12	20	33.961	118.842	10	3.3					CDMG via NEIC, 1995
151	1966	12	26	33.993	118.597	10	3.6					CDMG via NEIC, 1995
152	1966	12	27	33.958	118.63	0	2.9					CDMG via NEIC, 1995
153	1967	4	2	33.966	118.638	10	2.6					CDMG via NEIC, 1995
154	1968	3	13	33.96	118.531	13	2.5					CDMG via NEIC, 1995
155	1968	5	21	34.067	118.811	5	3.1					CDMG via NEIC, 1995
156	1968	6	6	33.98	118.688	10	2.7					CDMG via NEIC, 1995
157	1968	8	13	34.036	118.999	10	2.8					CDMG via NEIC, 1995
158	1969	6	22	33.924	118.72	9	3.6					CDMG via NEIC, 1995
159	1969	6	22	33.941	118.744		2.8					CDMG via NEIC, 1995
160	1970	3	7	33.942	118.825	5.3	2.7	9				Lee et al., 1979 (#10)
161	1970	3	29	34.06	118.987	8	1.9	5				Lee et al., 1979 (#16)
162	1970	7	1	34.037	118.85	0.5	1.8	6				Lee et al., 1979 (#36)
163	1970	11	22	34.132	119.033	12.6	1.9	5				Lee et al., 1979 (#50)
164	1971	2	9	34.166	118.516	7	3.7					DNAG via NEIC, 1995
165	1971	4	1	34.116	118.67		2.8					CDMG via NEIC, 1995
166	1971	4	15	34.15	118.54	8	4.2					Lee et al., 1979 (#79)
167	1971	4	15	34.15	118.518	9.1	3.2					Lee et al., 1979 (#80)
168	1971	11	16	34.102	118.832	3.2	2.1	6				Lee et al., 1979 (#130)
169	1971	11	23	34.063	118.827	0.5	2.1	6				Lee et al., 1979 (#131)
170	1971	12	18	34.117	118.818	3.4	2.1	8				Lee et al., 1979 (#134)
171	1972	1	13	34.052	118.792	6.1	2.1	7				Lee et al., 1979 (#140)
172	1972	1	15	34.113	118.832	0.5	2.1	7				Lee et al., 1979 (#141)
173	1972	1	20	34.102	118.837	1.8	2.2	8				Lee et al., 1979 (#147)
174	1972	3	2	34.013	118.563	3.5	1.9	7				Lee et al., 1979 (#153)
175	1972	4	27	34.07	118.982	12.8	3.1	11				Lee et al., 1979 (#163)
176a	1972	7	14	34.05	118.797	6.6	2.7	10	17	70	226	Lee et al., 1979 (#172)
176b	1972	7	14	34.05	118.797	6.6	2.7	10	227	22.8	17	Webb and Kanamori, 1985 (#60)
177	1972	11	9	34.053	118.795	5.1	2.5	11				Lee et al., 1979 (#184)
178	1972	12	22	34.003	118.548	8	2.6	8				Lee et al., 1979 (#189)
179	1973	2	8	33.982	118.703	6.6	2.8	16				Lee et al., 1979 (#194)
180	1973	2	14	34.09	119.053	14	2.2	6				Lee et al., 1979 (#195)
181a	1973	2	21	34.099	119.039	17.4	6	9	350	36	212	Stierman and Ellsworth, 1976 (#1)
181b	1973	2	21	34.078	119.038	12.2	5.9	16	356	44	167	Lee et al., 1979 (#197)
181c	1973	2	21	34.065	119.035	8	5.9		350	36	211	Hill et al., 1990 (#59)
181d	1973	2	21	34.099	119.039	17	6.0		339	49	181	Bent and Helmberger, 1991
181e	1973	2	21	34.065	119.035		5.3					Hutton and Jones, 1993
182	1973	2	21	34.061	118.967	15.4	2.9	8				Stierman and Ellsworth, 1976 (#2)
183	1973	2	21	34.049	118.965	14.1	4.1	10	209	62	108	Stierman and Ellsworth, 1976 (#3)
184	1973	2	21	34.057	118.978	14.6	3.8	9	207	78	116	Stierman and Ellsworth, 1976 (#4)
185	1973	2	21	34.072	118.991	12.7	2.1	9	327	64	290	Stierman and Ellsworth, 1976 (#5)
186	1973	2	21	34.066	118.992	14.5	2	8				Stierman and Ellsworth, 1976 (#6)
187	1973	2	21	34.051	119.018	17.3	2.9	9	354	50	214	Stierman and Ellsworth, 1976 (#7)
188	1973	2	21	34.079	118.983	12.6	2.9	7				Stierman and Ellsworth, 1976 (#8)
189	1973	2	21	34.098	119.003	15	2.1	8				Stierman and Ellsworth, 1976 (#9)
190	1973	2	21	34.107	119.005	11.4	2.5	8				Stierman and Ellsworth, 1976 (#10)
191	1973	2	21	34.096	119.043	13.6	4.2	10	87	30	217	Stierman and Ellsworth, 1976 (#11)
192	1973	2	21	34.095	118.972	14.2	2.3	9				Stierman and Ellsworth, 1976 (#12)
193	1973	2	21	34.066	118.97	14.6	2.9	9				Stierman and Ellsworth, 1976 (#13)
194	1973	2	21	34.099	118.986	14.8	2.1	7				Stierman and Ellsworth, 1976 (#14)
195	1973	2	21	34.07	118.965	14	2.5	8				Stierman and Ellsworth, 1976 (#15)
196	1973	2	21	34.063	118.976	15	2.6	7				Stierman and Ellsworth, 1976 (#16)
197	1973	2	21	34.061	118.988	13.8	2.6	9				Stierman and Ellsworth, 1976 (#17)
198	1973	2	21	34.053	119.012	16.6	2.3	7				Stierman and Ellsworth, 1976 (#18)

EQ				Hypocenter/Epicenter Location					Focal Mechanism Soln			
Ref. No.	Year	Date Mo	Da	Lat (°N)	Long (°W)	Depth (km)	Mag	Reported Arrivals	Dip Azim	Dip Angle	Slip Azim	Source
199	1973	2	21	34.1	119.034	17.5	2.7	9	360	54	214	Stierman and Ellsworth, 1976 (#19)
200	1973	2	21	34.089	118.997	12.8	2.4	8				Stierman and Ellsworth, 1976 (#20)
201	1973	2	21	34.083	118.994	16.6	3.4	9	34	54	272	Stierman and Ellsworth, 1976 (#21)
202	1973	2	22	34.094	118.972	14.4	3.4	9	60	45	222	Stierman and Ellsworth, 1976 (#22)
203	1973	2	22	34.087	118.992	15.6	2.5	8				Stierman and Ellsworth, 1976 (#23)
204	1973	2	22	34.09	118.996	13	2.4	9				Stierman and Ellsworth, 1976 (#24)
205	1973	2	22	34.055	119.056	13.1	2.4	9				Stierman and Ellsworth, 1976 (#25)
206	1973	2	22	34.067	118.984	13.7	3	9	18	54	148	Stierman and Ellsworth, 1976 (#26)
207	1973	2	22	34.067	118.966	14.2	2.5	9	18	50	196	Stierman and Ellsworth, 1976 (#27)
208	1973	2	22	34.064	119.013	14.5	2.2	9				Stierman and Ellsworth, 1976 (#28)
209	1973	2	22	34.056	118.993	14.2	2.5	9				Stierman and Ellsworth, 1976 (#29)
210	1973	2	22	34.072	118.985	12.7	2.5	9				Stierman and Ellsworth, 1976 (#30)
211	1973	2	22	34.055	119.005	15.6	2.2	7	62	50	51	Stierman and Ellsworth, 1976 (#31)
212	1973	2	22	34.072	118.993	14.2	2.4	9				Stierman and Ellsworth, 1976 (#32)
213	1973	2	22	34.089	119.049	15.9	4	12	356	36	204	Stierman and Ellsworth, 1976 (#33)
214	1973	2	22	34.077	118.992	13.8	2.3	11	335	80	242	Stierman and Ellsworth, 1976 (#34)
215	1973	2	22	34.067	118.967	14.5	2.3	11				Stierman and Ellsworth, 1976 (#35)
216	1973	2	22	34.063	118.991	13	2	8	10	60	190	Stierman and Ellsworth, 1976 (#36)
217	1973	2	22	34.043	119.006	13.5	2.5	11				Stierman and Ellsworth, 1976 (#37)
218	1973	2	22	33.983	118.957	3.2	2.1	6				Lee et al., 1979 (#234)
219	1973	2	22	34.067	118.993	13.7	2.9	10	335	30	136	Stierman and Ellsworth, 1976 (#38)
220	1973	2	22	34.071	118.984	13.8	1.7	10				Stierman and Ellsworth, 1976 (#39)
221	1973	2	22	34.069	118.981	14	1.9	8				Stierman and Ellsworth, 1976 (#40)
222	1973	2	22	34.058	118.986	13.9	2	10				Stierman and Ellsworth, 1976 (#41)
223	1973	2	23	34.069	118.987	13	1.3	6				Stierman and Ellsworth, 1976 (#42)
224	1973	2	23	34.073	118.98	11.9	1.1	6				Stierman and Ellsworth, 1976 (#43)
225	1973	2	23	34.092	118.983	12.3	1	8				Stierman and Ellsworth, 1976 (#44)
226	1973	2	23	34.061	118.982	13.7	3	19	0	84	264	Stierman and Ellsworth, 1976 (#45)
227	1973	2	23	34.061	118.983	12.3	0.5	9				Stierman and Ellsworth, 1976 (#46)
228	1973	2	23	34.057	118.988	13.4	1.2	7				Stierman and Ellsworth, 1976 (#47)
229	1973	2	23	34.07	118.988	14.4	0.9	10				Stierman and Ellsworth, 1976 (#48)
230	1973	2	23	34.087	119.011	10.1	1.3	7				Stierman and Ellsworth, 1976 (#49)
231	1973	2	23	34.073	118.974	12	1.1	6				Stierman and Ellsworth, 1976 (#50)
232	1973	2	23	34.047	119.017	13.4	1.4	7				Stierman and Ellsworth, 1976 (#51)
233	1973	2	23	34.051	118.983	11.9	1.4	10				Stierman and Ellsworth, 1976 (#52)
234	1973	2	23	34.058	119	14.7	1.6	9				Stierman and Ellsworth, 1976 (#53)
235	1973	2	23	34.08	118.973	13.2	1.5	10				Stierman and Ellsworth, 1976 (#54)
236	1973	2	23	34.081	119.028	15.1	1.5	9				Stierman and Ellsworth, 1976 (#55)
237	1973	2	24	34.075	119.062	10	2.1	15	353	90	262	Stierman and Ellsworth, 1976 (#56)
238	1973	2	24	34.055	118.981	14.1	1.6	11				Stierman and Ellsworth, 1976 (#57)
239	1973	2	24	34.084	119.013	14	1.7	14				Stierman and Ellsworth, 1976 (#58)
240	1973	2	24	34.063	118.981	14.7	0.7	6				Stierman and Ellsworth, 1976 (#59)
241	1973	2	24	34.057	118.989	14.8	1.5	13				Stierman and Ellsworth, 1976 (#60)
242	1973	2	24	34.08	118.982	16.4	2.1	22	1	50	228	Stierman and Ellsworth, 1976 (#61)
243	1973	2	24	34.066	118.998	16.5	1.7	16				Stierman and Ellsworth, 1976 (#62)
244	1973	2	24	34.093	118.975	10.8	0.9	7				Stierman and Ellsworth, 1976 (#63)
245	1973	2	24	34.085	118.98	13.3	0.9	10				Stierman and Ellsworth, 1976 (#64)
246	1973	2	24	34.073	119.051	16.6	1.8	14	0	60	256	Stierman and Ellsworth, 1976 (#65)
247	1973	2	24	34.078	118.957	14.5	1.9	20	6	50	230	Stierman and Ellsworth, 1976 (#66)
248	1973	2	24	34.068	118.973	12.8	2.2	21	340	52	224	Stierman and Ellsworth, 1976 (#67)
249	1973	2	24	34.082	118.962	13.2	1.6	10				Stierman and Ellsworth, 1976 (#68)
250	1973	2	24	34.095	119.018	14.2	1.5	14				Stierman and Ellsworth, 1976 (#69)
251	1973	2	24	34.08	118.977	11.5	1.7	13	22	52	216	Stierman and Ellsworth, 1976 (#70)
252	1973	2	24	34.054	118.986	14.3	1.6	9	133	42	249	Stierman and Ellsworth, 1976 (#71)
253	1973	2	25	34.072	119.002	15.3	1.1	13				Stierman and Ellsworth, 1976 (#72)
254	1973	2	25	34.091	118.98	11.8	0.9	9				Stierman and Ellsworth, 1976 (#73)
255	1973	2	25	34.074	118.963	14.1	0.9	20	332	70	230	Stierman and Ellsworth, 1976 (#74)
256	1973	2	25	34.084	118.979	13.4	0.8	21	356	70	240	Stierman and Ellsworth, 1976 (#75)
257	1973	2	25	34.052	118.997	14.3	1.2	14	348	82	252	Stierman and Ellsworth, 1976 (#76)
258	1973	2	25	34.076	118.986	12.6	1.5	13	13	50	193	Stierman and Ellsworth, 1976 (#77)
259a	1973	2	26	34.082	118.999	15.4	2.7	21	72	0	252	Stierman and Ellsworth, 1976 (#78)
259b	1973	2	26	34.082	118.999	15.4	2.7	21	65	0	245	Webb and Kanamori, 1985 (#62)
260	1973	2	26	34.062	118.99	15.2	1.2	9				Stierman and Ellsworth, 1976 (#79)
261	1973	2	26	34.058	118.983	14.4	1.7	19	58	33	218	Stierman and Ellsworth, 1976 (#80)
262	1973	2	27	34.089	118.995	14.7	1.5	19				Stierman and Ellsworth, 1976 (#81)
263	1973	2	27	34.047	118.996	17.2	2.3	22	177	85	85	Stierman and Ellsworth, 1976 (#82)
264	1973	2	27	34.09	118.975	14.1	2.5	25	330	38	201	Stierman and Ellsworth, 1976 (#83)
265	1973	2	27	34.066	118.969	14.6	1.9	17				Stierman and Ellsworth, 1976 (#84)
266	1973	2	27	34.042	119.002	13	1.9	17	332	90	222	Stierman and Ellsworth, 1976 (#85)

EQ				Hypocenter/Epicenter Location					Focal Mechanism Soln			
Ref. No.	Year	Date Mo	Da	Lat (°N)	Long (°W)	Depth (km)	Mag	Reported Arrivals	Dip Azim	Dip Angle	Slip Azim	Source
267	1973	2	28	34.089	119.003	13.8	0.8	7				Stierman and Ellsworth, 1976 (#86)
268	1973	2	28	34.051	118.991	15.8	1.6	14	176	65	262	Stierman and Ellsworth, 1976 (#87)
269	1973	2	28	34.067	118.98	15.9	0.7	11				Stierman and Ellsworth, 1976 (#88)
270	1973	2	28	34.048	118.995	17	2.7	26	192	55	268	Stierman and Ellsworth, 1976 (#89)
271	1973	3	1	34.054	118.994	16.4	1.1	13	119	80	218	Stierman and Ellsworth, 1976 (#90)
272	1973	3	1	34.056	118.97	14.3	0.9	12				Stierman and Ellsworth, 1976 (#91)
273a	1973	3	1	34.074	118.994	14.7	2.5	22	56	16	236	Stierman and Ellsworth, 1976 (#92)
273b	1973	3	1	34.074	118.994	14.7	2.5	22	60	5	240	Webb and Kanamori, 1985 (#63)
274	1973	3	1	34.074	118.967	13.4	1.2	12				Stierman and Ellsworth, 1976 (#93)
275	1973	3	1	34.075	118.968	13.4	0.8	12				Stierman and Ellsworth, 1976 (#94)
276	1973	3	1	34.074	118.975	12.9	0.5	11				Stierman and Ellsworth, 1976 (#95)
277	1973	3	2	34.093	119.026	15.2	1.9	20	332	62	230	Stierman and Ellsworth, 1976 (#96)
278	1973	3	2	34.071	119.048	15.1	1.1	13				Stierman and Ellsworth, 1976 (#97)
279	1973	3	2	34.075	118.976	15.7	1.3	12	322	70	232	Stierman and Ellsworth, 1976 (#98)
280	1973	3	2	34.095	119.003	14.9	1.2	13				Stierman and Ellsworth, 1976 (#99)
281	1973	3	3	34.017	119.085	9.5	1.3	22				Stierman and Ellsworth, 1976 (#100)
282	1973	3	3	34.076	119.028	14.2	0.8	16				Stierman and Ellsworth, 1976 (#101)
283	1973	3	4	34.063	118.982	13.3	0.8	14				Stierman and Ellsworth, 1976 (#102)
284	1973	3	5	34.074	118.993	12.2	1.3	20	329	34	171	Stierman and Ellsworth, 1976 (#103)
285	1973	3	5	34.041	118.99	16.7	3.5	24	102	60	208	Stierman and Ellsworth, 1976 (#104)
286	1973	3	5	34.066	118.982	13	1	8				Stierman and Ellsworth, 1976 (#105)
287	1973	3	6	34.065	118.977	12.5	0.9	9				Stierman and Ellsworth, 1976 (#106)
288	1973	3	6	34.061	118.979	12.9	0.2	6				Stierman and Ellsworth, 1976 (#107)
289	1973	3	6	33.93	118.522	16	2.3	11				Lee et al., 1979 (#275)
290	1973	3	6	34.073	118.976	11.6	0.8	12				Stierman and Ellsworth, 1976 (#108)
291	1973	3	7	34.043	119.001	17.8	2.5	19	100	70	202	Stierman and Ellsworth, 1976 (#109)
292	1973	3	7	34.058	118.975	12.3	1.1	16				Stierman and Ellsworth, 1976 (#110)
293	1973	3	7	34.079	119.023	15.2	1	16				Stierman and Ellsworth, 1976 (#111)
294	1973	3	7	34.095	119.041	13.8	1.9	17	114	54	82	Stierman and Ellsworth, 1976 (#112)
295	1973	3	7	34.063	118.979	12.5	1	10				Stierman and Ellsworth, 1976 (#113)
296	1973	3	7	34.068	119.007	13.1	0.8	17				Stierman and Ellsworth, 1976 (#114)
297	1973	3	7	34.068	118.979	12.4	0.8	12				Stierman and Ellsworth, 1976 (#115)
298	1973	3	10	34.078	118.964	13.3	2	22	172	72	260	Stierman and Ellsworth, 1976 (#116)
299	1973	3	16	34.074	118.997	13	3.5	18	88	34	234	Stierman and Ellsworth, 1976 (#117)
300	1973	3	17	34.071	118.992	13.7	3.7	18	342	74	244	Stierman and Ellsworth, 1976 (#118)
301	1973	3	21	34.089	119.001	15.7	1.3	16				Stierman and Ellsworth, 1976 (#119)
302	1973	3	22	34.076	119.043	17.2	1.6	11				Stierman and Ellsworth, 1976 (#120)
303	1973	3	22	34.086	119.018	14.8	1	12				Stierman and Ellsworth, 1976 (#121)
304	1973	3	23	34.074	118.995	13.7	1.9	9				Stierman and Ellsworth, 1976 (#122)
305	1973	3	25	34.065	118.971	15.3	1.1	15				Stierman and Ellsworth, 1976 (#123)
306	1973	3	26	34.062	118.973	12.5	1.7	10				Stierman and Ellsworth, 1976 (#124)
307	1973	3	26	34.058	118.978	13.4	2	9				Stierman and Ellsworth, 1976 (#125)
308	1973	3	26	34.073	118.983	13.2	3	17	314	44	196	Stierman and Ellsworth, 1976 (#126)
309	1973	3	26	34.074	118.99	11.5	1.7	20	14	30	194	Stierman and Ellsworth, 1976 (#127)
310	1973	3	27	34.071	118.986	12.2	1.9	7				Stierman and Ellsworth, 1976 (#128)
311	1973	3	28	34.09	118.988	4.3	0.5	8				Stierman and Ellsworth, 1976 (#129)
312	1973	3	28	34.061	118.957	11.7	1	6				Stierman and Ellsworth, 1976 (#130)
313	1973	3	28	34.072	118.977	11.6	1.6	8				Stierman and Ellsworth, 1976 (#131)
314	1973	3	29	34.056	118.984	13.2	1.4	8				Stierman and Ellsworth, 1976 (#132)
315	1973	3	29	33.98	118.547	2.4	2.6	23				Lee et al., 1979 (#298)
316	1973	3	31	34.038	118.772	8	1.6	7				Lee et al., 1979 (#299)
317	1973	3	31	34.048	118.969	13.5	1.6	9	320	50	321	Stierman and Ellsworth, 1976 (#133)
318	1973	4	1	34.067	119.01	6.1	0.9	7				Stierman and Ellsworth, 1976 (#134)
319	1973	4	2	34.042	118.978	8.2	0.8	13				Stierman and Ellsworth, 1976 (#135)
320	1973	4	2	34.077	118.981	11.5	1.3	13				Stierman and Ellsworth, 1976 (#136)
321	1973	4	2	34.089	119.013	14.6	1.3	14				Stierman and Ellsworth, 1976 (#137)
322	1973	4	4	34.138	118.988	10.9	1.4	6				Lee et al., 1979 (#302)
323	1973	4	5	34.031	119.022	12.2	1.9	16	348	52	210	Stierman and Ellsworth, 1976 (#138)
324	1973	4	5	34.073	118.986	12	1.6	9				Stierman and Ellsworth, 1976 (#139)
325a	1973	4	7	34.101	118.978	13.1	1.7	14	335	30	231	Stierman and Ellsworth, 1976 (#140)
325b	1973	4	7	34.101	118.978	13.1	1.7	14	50	10	230	Webb and Kanamori, 1985 (#64)
326	1973	4	8	34.038	119.067	10.6	1.8	15				Lee et al., 1979 (#310)
327	1973	4	11	34.098	119.027	14.7	1.2	16				Stierman and Ellsworth, 1976 (#141)
328	1973	4	12	34.097	119.039	13.9	1.6	11				Stierman and Ellsworth, 1976 (#142)
329	1973	4	19	33.95	118.715	1.9	2.1	11				Lee et al., 1979 (#317)
330	1973	4	20	33.998	118.932	7.3	2.1	7				Lee et al., 1979 (#318)
331	1973	5	11	33.973	118.55	3.7	2.5	17				Lee et al., 1979 (#324)
332	1973	5	12	34.013	119.032	6.4	3.1	14				Lee et al., 1979 (#326)
333	1973	5	14	34.032	119.042	10.7	2.2	8				Lee et al., 1979 (#327)

				Hypocenter/Epicenter Location					Focal Mechanism Soln			
EQ Ref. No.	Year	Date Mo	Da	Lat (°N)	Long (°W)	Depth (km)	Mag	Reported Arrivals	Dip Azim	Dip Angle	Slip Azim	Source
334	1973	6	21	34.053	118.835	3.6	1.4	6				Lee et al., 1979 (#339)
335	1973	6	22	34.055	118.805	1.5	1.7	6				Lee et al., 1979 (#340)
336	1973	6	27	34.05	118.992	2	1.9	9				Lee et al., 1979 (#342)
337	1973	7	5	34.058	119.018	13.3	2.1	9				Lee et al., 1979 (#343)
338	1973	7	8	34.06	118.99	12.2	2	12				Lee et al., 1979 (#344)
339	1973	7	14	34.012	118.82	13.5	2	13				Lee et al., 1979 (#345)
340	1973	7	14	34.035	119.033	13.1	2	13				Lee et al., 1979 (#346)
341	1973	7	15	34.067	119.063	17.6	1.6	10				Lee et al., 1979 (#347)
342	1973	7	18	34.035	118.74	5.7	1.6	10				Lee et al., 1979 (#350)
343	1973	7	24	34.038	119.018	12.5	2.5	21				Lee et al., 1979 (#351)
344	1973	7	26	33.995	118.732	2.4	1.6	8				Lee et al., 1979 (#353)
345	1973	7	29	34.053	118.96	11.8	2.3	15				Lee et al., 1979 (#354)
346	1973	8	3	34.062	119.083	16.2	1.6	12				Lee et al., 1979 (#356)
347	1973	8	13	34.047	118.98	15.8	1.9	14				Lee et al., 1979 (#363)
348	1973	8	16	34.062	118.813	2.6	1.4	9				Lee et al., 1979 (#367)
349	1973	8	19	34.065	119.038	7.5	1.8	11				Lee et al., 1979 (#369)
350	1973	8	21	34.073	118.997	11.7	1.3	7				Lee et al., 1979 (#372)
351	1973	8	23	34.075	119.072	17.8	1.8	8				Lee et al., 1979 (#374)
352	1973	8	23	34.052	118.965	12.5	1.8	8				Lee et al., 1979 (#375)
353	1973	8	27	34.047	118.99	3.6	2	10				Lee et al., 1979 (#378)
354	1973	8	27	34.042	118.987	2.6	1.9	9				Lee et al., 1979 (#379)
355	1973	8	28	34.045	118.79	6	1.5	8				Lee et al., 1979 (#380)
356	1973	8	29	34.052	118.998	2.4	1.8	9				Lee et al., 1979 (#381)
357	1973	9	2	34.018	118.748	13.9	2.3	17	316	44	181	Lee et al., 1979 (#385)
358	1973	9	3	34.033	118.84	13.7	1.2	9				Lee et al., 1979 (#387)
359	1973	9	4	34.037	118.802	6.1	1.7	7				Lee et al., 1979 (#390)
360	1973	9	20	34.017	119.012	11.1	2	19				Lee et al., 1979 (#400)
361	1973	10	6	34.033	119.01	8	1.8	17				Lee et al., 1979 (#403)
362	1973	10	10	34.053	118.797	1.1	1.3	6				Lee et al., 1979 (#405)
363	1973	10	12	34.053	118.898	10.7	2.2	17				Lee et al., 1979 (#406)
364	1973	10	15	34.05	118.795	2.2	1.1	7				Lee et al., 1979 (#408)
365	1973	10	21	34.078	118.965	14.6	1.1	9				Lee et al., 1979 (#410)
366	1973	10	24	34.043	118.798	6	1.1	6				Lee et al., 1979 (#411)
367	1973	10	26	34.031	118.898	4.5	1.9	8				Lee et al., 1979 (#413)
368	1973	10	30	34.042	118.98	14.1	1.3	9				Lee et al., 1979 (#414)
369	1973	11	6	34.04	119.02	16.4	1.4	9				Lee et al., 1979 (#416)
370	1973	11	8	34.048	118.798	4.9	1	7				Lee et al., 1979 (#417)
371	1973	12	5	34.062	119.042	7.9	1.4	12				Lee et al., 1979 (#422)
372	1973	12	12	34.068	118.98	12.3	1.8	11				Lee et al., 1979 (#424)
373	1973	12	20	34.073	118.933	13.3	2.1	18	62	50	276	Lee et al., 1979 (#426)
374	1973	12	28	34.053	118.797	2.4	1.3	7				Lee et al., 1979 (#431)
375	1973	12	30	33.972	118.772	16.3	1.7	9				Lee et al., 1979 (#432)
376	1974	1	10	34.06	119.055	13.7	2.1	12				Lee et al., 1979 (#434)
377	1974	1	10	34.092	119.013	11.3	1.5	8				Lee et al., 1979 (#435)
378	1974	1	12	34.063	118.965	15.7	2.2	9				Lee et al., 1979 (#436)
379	1974	1	17	34.095	119.045	13.8	1.5	8				Lee et al., 1979 (#437)
380	1974	1	18	34.085	118.863	17.2	1.5	8				Lee et al., 1979 (#438)
381	1974	1	25	34.06	118.903	12.7	1.2	8				Lee et al., 1979 (#441)
382	1974	1	25	33.917	118.715	8	1.9	14				Lee et al., 1979 (#442)
383	1974	2	1	34.062	119.005	2.3	1.3	8				Lee et al., 1979 (#443)
384	1974	2	1	34.038	119.005	8	1.5	10				Lee et al., 1979 (#444)
385	1974	2	23	34.055	118.938	14.9	1.3	7				Lee et al., 1979 (#448)
386	1974	3	3	34.033	118.993	9.2	2.3	14				Lee et al., 1979 (#451)
387	1974	3	3	34.055	119.005	8.9	2.3	14				Lee et al., 1979 (#452)
388	1974	3	6	33.924	118.671	5	2.1					CDMG via NEIC, 1995
389	1974	3	7	33.925	118.71	8	1.9	11				Lee et al., 1979 (#455)
390	1974	3	17	34.058	118.997	1.9	1.5	8				Lee et al., 1979 (#458)
391	1974	3	18	34.047	118.912	12.7	2	15				Lee et al., 1979 (#459)
392	1974	3	30	34.085	118.847	13.1	1.8	11				Lee et al., 1979 (#461)
393a	1974	3	31	34.02	118.748	5.9	2.6	16				Lee et al., 1979 (#462)
393b	1974	3	31	34.018	118.744	5.1	1.6	17	358	60	16	Buika and Teng, 1979 (#24/210)
394	1974	4	1	34.068	118.992	14.5	2.2	17				Lee et al., 1979 (#463)
395	1974	4	2	34.052	118.965	13.7	1.5	8				Lee et al., 1979 (#464)
396	1974	4	3	34.055	118.897	11.3	2.5	14				Lee et al., 1979 (#466)
397	1974	4	5	34.047	118.938	11.4	2.5	14				Lee et al., 1979 (#467)
398	1974	4	11	34.07	119.01	15.7	1.4	6				Lee et al., 1979 (#468)
399	1974	4	14	34.095	119.04	19.2	1.6	10				Lee et al., 1979 (#469)
400	1974	4	24	34.095	118.862	1.7	1.2	8				Lee et al., 1979 (#471)
401	1974	4	25	34.03	119.083	9.9	1.9	16				Lee et al., 1979 (#473)

EQ				Hypocenter/Epicenter Location					Focal Mechanism Soln			
Ref. No.	Year	Date Mo	Da	Lat (°N)	Long (°W)	Depth (km)	Mag	Reported Arrivals	Dip Azim	Dip Angle	Slip Azim	Source
402	1974	5	10	34.063	118.905	13.8	1.1	8				Lee et al., 1979 (#475)
403	1974	5	22	34.052	118.977	14.1	1.5	11				Lee et al., 1979 (#477)
404	1974	5	22	34.038	119	9	1.4	8				Lee et al., 1979 (#478)
405	1974	6	21	34.092	119.018	15.8	2.3	17				Lee et al., 1979 (#480)
406	1974	7	6	34.047	119.03	16.4	1.8	12				Lee et al., 1979 (#481)
407	1974	7	12	34.007	118.815	9.8	1.9	16				Lee et al., 1979 (#483)
408	1974	7	23	34.063	118.98	14.2	1.5	9				Lee et al., 1979 (#484)
409	1974	7	25	33.937	118.862	7.2	2.3	12				Lee et al., 1979 (#485)
410	1974	8	25	33.937	118.672	10.8	2	11				Lee et al., 1979 (#491)
411	1974	10	8	34.038	118.983	2.1	3.4	14				Lee et al., 1979 (#509)
412	1974	10	8	34.057	119	1.7	1.4	6				Lee et al., 1979 (#510)
413	1974	10	8	34.057	118.997	1.9	1.4	7				Lee et al., 1979 (#511)
414	1974	10	8	34.06	118.998	1.9	1.7	7				Lee et al., 1979 (#512)
415	1974	10	8	34.062	119.002	1.6	1.2	6				Lee et al., 1979 (#513)
416	1974	10	8	34.057	118.997	2.1	1.7	7				Lee et al., 1979 (#514)
417	1974	10	8	34.06	119	1.9	1.6	7				Lee et al., 1979 (#515)
418	1974	10	8	34.057	118.998	1.8	1.5	7				Lee et al., 1979 (#516)
419	1974	10	8	34.057	118.992	2	1.7	7				Lee et al., 1979 (#517)
420	1974	10	8	34.058	118.993	2	1.7	7				Lee et al., 1979 (#518)
421	1974	10	8	34.058	118.99	2	1.5	5				Lee et al., 1979 (#519)
422	1974	10	8	34.055	118.997	2.5	1.5	7				Lee et al., 1979 (#520)
423	1974	10	9	34.053	118.998	2.1	1.1	6				Lee et al., 1979 (#521)
424	1974	10	9	34.058	118.998	1.7	1.1	7				Lee et al., 1979 (#522)
425	1974	10	9	34.055	118.993	2	1.1	6				Lee et al., 1979 (#523)
426	1974	10	9	34.058	118.997	2.2	1.7	8				Lee et al., 1979 (#524)
427	1974	10	10	34.06	118.995	1.9	1.3	7				Lee et al., 1979 (#525)
428	1974	10	12	34.055	118.988	3.3	2.9	17				Lee et al., 1979 (#526)
429	1974	10	12	34.075	118.988	4.4	1.6	9				Lee et al., 1979 (#527)
430	1974	10	12	34.058	118.997	1.9	1.8	8				Lee et al., 1979 (#528)
431	1974	10	12	34.048	119.005	1.2	1	7				Lee et al., 1979 (#529)
432	1974	10	18	34.058	119.003	1.7	1.2	7				Lee et al., 1979 (#531)
433	1974	10	22	34.057	119.007	2.3	1.1	7				Lee et al., 1979 (#532)
434	1974	11	6	34.055	118.998	3.9	1.1	7				Lee et al., 1979 (#533)
435	1974	11	11	34.065	118.993	14.9	1.6	10				Lee et al., 1979 (#534)
436	1974	11	14	34.06	118.998	1.9	1.3	7				Lee et al., 1979 (#535)
437	1974	11	14	34.058	118.998	1.9	1	7				Lee et al., 1979 (#536)
438	1974	11	14	34.06	118.998	1.9	1	7				Lee et al., 1979 (#537)
439	1974	11	15	34.055	119.003	2.1	1.2	7				Lee et al., 1979 (#538)
440	1974	11	27	34.088	118.965	16.8	1.4	8				Lee et al., 1979 (#540)
441	1974	12	4	34.067	119.002	14.7	1.2	6				Lee et al., 1979 (#542)
442	1974	12	7	34.09	119.007	8	1	6				Lee et al., 1979 (#543)
443	1974	12	19	34.063	118.742	4	1.3	8				Lee et al., 1979 (#545)
444	1974	12	20	34.092	118.867	12.5	2.1	12				Lee et al., 1979 (#547)
445	1974	12	25	34.038	119.008	8.7	1.8	7				Lee et al., 1979 (#548)
446	1975	1	7	34.113	119.025	17.3	1.2	9				Lee et al., 1979 (#552)
447	1975	1	11	33.99	118.862	13	2.5	14	5	45	185	Lee et al., 1979 (#553)
448	1975	1	23	33.917	118.633	12	3					PDE via NEIC, 1995
449	1975	1	24	34.023	119.018	10.9	2.1	13				Lee et al., 1979 (#556)
450	1975	2	4	34.065	118.793	8.3	1.4	9				Lee et al., 1979 (#562)
451	1975	2	8	34.067	118.787	7	1.8	12				Lee et al., 1979 (#563)
452	1975	2	23	34.063	118.985	13.3	2.7	21				Lee et al., 1979 (#566)
453	1975	3	1	34.02	118.72	6.6	2	13	38	56	162	Lee et al., 1979 (#570)
454	1975	4	11	34.052	118.997	9.6	3.1	22				Lee et al., 1979 (#578)
455	1975	4	12	34.053	118.992	11.9	2.1	13				Lee et al., 1979 (#579)
456	1975	4	14	34.033	119.025	16.6	1.7	12				Lee et al., 1979 (#580)
457	1975	4	24	34.048	118.992	1.9	2	8				Lee et al., 1979 (#582)
458	1975	4	25	34.048	118.988	16.5	1.4	9				Lee et al., 1979 (#583)
459	1975	4	27	34.09	119.007	14.3	1.4	8				Lee et al., 1979 (#584)
460	1975	5	26	34.078	118.98	16.8	1.5	8				Lee et al., 1979 (#588)
461	1975	5	28	34.035	118.993	12.5	2.1	14				Lee et al., 1979 (#590)
462	1975	6	9	34.038	119.032	13.3	1.5	10				Lee et al., 1979 (#594)
463	1975	6	10	34.015	118.752	8.7	2.1	11				Lee et al., 1979 (#595)
464	1975	6	21	34.027	119.018	4.6	1.9	10				Lee et al., 1979 (#596)
465	1975	7	6	34.062	118.885	9.9	2.3	8				Lee et al., 1979 (#600)
466	1975	7	12	34.077	118.975	10.9	1.4	9				Lee et al., 1979 (#602)
467	1975	7	13	34.073	118.968	11.3	1.6	10				Lee et al., 1979 (#603)
468	1975	9	2	34.047	118.973	6.9	1.4	9				Lee et al., 1979 (#611)
469	1975	9	25	34.935	118.925	13	1.5	9				Lee et al., 1979 (#613)
470	1975	9	26	34.047	119.018	8	1.3	8				Lee et al., 1979 (#614)

EQ		Date		Hypocenter/Epicenter Location					Focal Mechanism Soln			
Ref. No.	Year	Mo	Da	Lat (°N)	Long (°W)	Depth (km)	Mag	Reported Arrivals	Dip Azim	Dip Angle	Slip Azim	Source
471	1975	10	5	34.042	118.952	13.4	2	13				Lee et al., 1979 (#617)
472	1975	12	25	34.018	119.075	9.9	2.1	11				Lee et al., 1979 (#627)
473	1976	2	12	33.999	118.829	8	2.6					DNAG via NEIC, 1995
474	1976	5	4	34.09	119.014	13.4	3.1	21	222	70	224	Buika and Teng, 1979 (#25/358)
475	1976	6	9	34.041	118.973	11	2.5					DNAG via NEIC, 1995
476	1976	6	20	33.998	118.818	8	3.8	26	341	50	224	Buika and Teng, 1979 (#23/365)
477	1976	11	22	33.956	118.621	2	3.8					DNAG via NEIC, 1995
478	1976	11	22	33.937	118.626	8	4.2	37	350	90	260	Buika and Teng, 1979 (#12/410)
479	1976	11	22	33.977	118.581	8	2.9					DNAG via NEIC, 1995
480	1976	12	11	33.953	118.664	10	2.8					DNAG via NEIC, 1995
481	1976	12	13	34.042	119.031	8	2.5					DNAG via NEIC, 1995
482	1977	7	29	33.986	118.9	7	2.7					DNAG via NEIC, 1995
483	1977	9	10	34.049	118.989	9	2.7					DNAG via NEIC, 1995
484	1977	9	10	34.044	118.99	5	2.7					DNAG via NEIC, 1995
485	1977	10	14	34.051	118.811	10	2.8					DNAG via NEIC, 1995
486	1977	12	7	34.047	118.913	11	2.9					DNAG via NEIC, 1995
487	1978	3	14	34.001	118.674	13.6	3.1	28	3	35	219	Hauksson, 1990
488	1978	4	22	34.06	118.978	13	3.4					DNAG via NEIC, 1995
489	1978	5	1	33.947	118.737	12.9	2.5	37	320	41	189	Hauksson, 1990
490	1978	7	21	34.055	118.901	15	3					DNAG via NEIC, 1995
491	1978	11	19	34.013	118.628	11.8	2.8	76	64	24	190	Hauksson, 1990
492a	1979	1	1	33.951	118.673	12.1	5	80	20	52	175	Hauksson, 1990
492b	1979	1	1	33.948	118.688	9.6	5		10	60	200	Hauksson and Saldivar, 1986 (#1)
492c	1979	1	1	33.944	118.681	11.1	5		10	60	200	Hill et al., 1990 (#60)
492d	1979	1	1	33.944	118.681		5.2					Hutton and Jones, 1993
493	1979	1	1	33.97	118.72	8.5	3.2		10	45	200	Hauksson and Saldivar, 1986 (#2)
494	1979	1	1	33.96	118.692	6.3	3.1		15	40	179	Hauksson and Saldivar, 1986 (#3)
495a	1979	1	1	33.937	118.698	9.4	3.4		350	65	220	Hauksson and Saldivar, 1986 (#4)
495b	1979	1	1	33.933	118.714	13	3.4		63	22	289	Webb and Kanamori, 1985 (#24)
496	1979	1	1	33.95	118.665	7.3	3		355	52	196	Hauksson and Saldivar, 1986 (#5)
497	1979	1	1	33.958	118.673	3.5	3		10	62	240	Hauksson and Saldivar, 1986 (#6)
498	1979	1	1	33.95	118.673	7.7	3.9		360	50	225	Hauksson and Saldivar, 1986 (#7)
499	1979	1	1	33.952	118.682	7	3		20	72	224	Hauksson and Saldivar, 1986 (#8)
500	1979	1	1	33.996	118.638	5	3					DNAG via NEIC, 1995
501	1979	1	1	33.942	118.692	9	2.5					Hauksson and Saldivar, 1986
502	1979	1	1	33.943	118.673	7.2	2.6					Hauksson and Saldivar, 1986
503	1979	1	1	33.937	118.677	10.1	3.7		10	60	225	Hauksson and Saldivar, 1986 (#9)
504	1979	1	2	33.948	118.688	8.8	3		20	56	236	Hauksson and Saldivar, 1986 (#10)
505	1979	1	2	33.96	118.693	8.9	2.9					Hauksson and Saldivar, 1986
506	1979	1	2	33.95	118.693	9.3	2.6					Hauksson and Saldivar, 1986
507	1979	1	2	33.94	118.695	9.3	2.7					Hauksson and Saldivar, 1986
508	1979	1	2	33.96	118.692	9.5	2.7					Hauksson and Saldivar, 1986
509	1979	1	2	33.953	118.697	9.9	3		25	48	230	Hauksson and Saldivar, 1986 (#11)
510	1979	1	2	33.943	118.708	8.2	3.7		10	51	206	Hauksson and Saldivar, 1986 (#12)
511	1979	1	2	33.948	118.705	5.9	2.7					Hauksson and Saldivar, 1986
512	1979	1	2	33.94	118.687	8.6	2.5					Hauksson and Saldivar, 1986
513	1979	1	2	33.935	118.665	8.2	2.7					Hauksson and Saldivar, 1986
514	1979	1	2	33.953	118.682	9.8	2.9					Hauksson and Saldivar, 1986
515	1979	1	2	33.933	118.685	8.3	3.4		10	50	190	Hauksson and Saldivar, 1986 (#13)
516	1979	1	2	33.935	118.677	9	2.5					Hauksson and Saldivar, 1986
517	1979	1	2	33.955	118.678	8.2	2.6					Hauksson and Saldivar, 1986
518	1979	1	3	33.94	118.662	7.3	2.8					Hauksson and Saldivar, 1986
519	1979	1	3	33.938	118.702	9.3	2.7					Hauksson and Saldivar, 1986
520	1979	1	3	33.928	118.695	7.8	2.5					Hauksson and Saldivar, 1986
521	1979	1	3	33.943	118.682	7.7	2.6					Hauksson and Saldivar, 1986
522	1979	1	3	33.998	118.705	9.2	2.9					Hauksson and Saldivar, 1986
523	1979	1	3	33.967	118.685	7.9	3		360	51	196	Hauksson and Saldivar, 1986 (#14)
524	1979	1	4	33.942	118.672	8.7	3		355	62	225	Hauksson and Saldivar, 1986 (#15)
525	1979	1	5	33.935	118.662	8.4	2.6					Hauksson and Saldivar, 1986
526	1979	1	6	33.94	118.695	9.4	2.5					Hauksson and Saldivar, 1986
527	1979	1	6	33.963	118.67	9.1	2.6					Hauksson and Saldivar, 1986
528	1979	1	8	33.95	118.682	9.4	2.7					Hauksson and Saldivar, 1986
529	1979	1	8	33.928	118.673	8.1	2.8					Hauksson and Saldivar, 1986
530	1979	1	9	33.935	118.688	7.2	2.6					Hauksson and Saldivar, 1986
531	1979	1	13	33.953	118.667	7.2	2.8					Hauksson and Saldivar, 1986
532	1979	1	15	33.952	118.7	9.3	3.7		15	62	236	Hauksson and Saldivar, 1986 (#16)
533	1979	1	16	33.96	118.682	9	2.9					Hauksson and Saldivar, 1986
534	1979	1	29	33.943	118.663	10.8	3.1		10	62	211	Hauksson and Saldivar, 1986 (#17)
535	1979	2	18	33.997	118.925	7	2.6					DNAG via NEIC, 1995

EQ				Hypocenter/Epicenter Location					Focal Mechanism Soln			
Ref. No.	Year	Date Mo	Da	Lat (°N)	Long (°W)	Depth (km)	Mag	Reported Arrivals	Dip Azim	Dip Angle	Slip Azim	Source
536	1979	2	20	34.046	119	16	2.8					DNAG via NEIC, 1995
537	1979	2	28	33.958	118.7	6.5	2.5					Hauksson and Saldivar, 1986
538	1979	3	5	33.948	118.712	10.1	3.7		15	60	189	Hauksson and Saldivar, 1986 (#18)
539	1979	3	13	33.926	118.975	5	2.8					DNAG via NEIC, 1995
540	1979	6	29	34.006	118.988	5	2.7					DNAG via NEIC, 1995
541	1979	8	29	33.967	118.698	8.8	2.7					Hauksson and Saldivar, 1986
542	1979	9	5	34.029	118.935	14	3.4					DNAG via NEIC, 1995
543	1979	9	5	34.017	118.932	14	2.5					DNAG via NEIC, 1995
544	1979	9	6	33.958	118.698	6.3	2.5					Hauksson and Saldivar, 1986
545	1979	10	17	33.932	118.667	9.4	4.2		5	57	205	Hauksson and Saldivar, 1986 (#19)
546	1979	10	18	33.943	118.667	5.8	2.6					Hauksson and Saldivar, 1986
547a	1979	10	18	33.938	118.662	8.4	3		10	70	184	Hauksson and Saldivar, 1986 (#20)
547b	1979	10	18	33.932	118.676	12.8	3		177	15.2	7	Webb and Kanamori, 1985 (#37)
548	1979	10	26	33.935	118.657	3.6	2.5					Hauksson and Saldivar, 1986
549	1979	11	28	33.952	118.662	7.3	2.7					Hauksson and Saldivar, 1986
550	1979	12	2	33.932	118.668	7.2	2.7					Hauksson and Saldivar, 1986
551	1979	12	16	33.953	118.66	8.7	3.2		360	62	230	Hauksson and Saldivar, 1986 (#21)
552	1979	12	18	33.945	118.657	11.8	2.8	89	20	31	220	Hauksson, 1990
553	1980	2	20	34.038	118.971	13	3.2					DNAG via NEIC, 1995
554	1980	3	16	33.995	118.885	18	2.5					DNAG via NEIC, 1995
555	1980	3	25	33.945	118.682	13	2.9					DNAG via NEIC, 1995
556	1980	4	1	34.009	118.662	14	2.8	31	34	41	166	Hauksson, 1990
557	1980	4	12	34.052	118.717	11	2.9	16	37	39	185	Hauksson, 1990
558	1980	8	30	34.052	118.999	12	2.6					DNAG via NEIC, 1995
559	1980	11	18	34.059	118.809	11	2.6					DNAG via NEIC, 1995
560	1980	12	1	34.068	118.966	15	2.6					DNAG via NEIC, 1995
561	1981	1	8	33.939	118.677	12	3.3					DNAG via NEIC, 1995
562	1981	2	24	33.95	118.667	6	2.4					PDE via NEIC, 1995
563	1981	2	27	34.156	118.594	14.3	3.5	84	255	75	345	Hauksson, 1990
564	1981	6	18	33.931	118.668	5	2.6					DNAG via NEIC, 1995
565	1981	8	12	34.126	118.608	3.3	2.7	67	129	67	85	Hauksson, 1990
566	1981	8	14	33.963	118.572	8.3	3.4	94	225	75	327	Hauksson, 1990
567	1982	4	13	34.054	118.964	16	4.3					DNAG via NEIC, 1995
568	1982	5	3	33.952	118.763	14	3.2					DNAG via NEIC, 1995
569	1982	7	29	34.084	119.012	12	3					DNAG via NEIC, 1995
570	1982	7	29	33.947	118.72	11	3.4					DNAG via NEIC, 1995
571	1982	12	30	33.955	118.823	0	4					DNAG via NEIC, 1995
572	1983	1	10	33.979	118.731	8	3.1					DNAG via NEIC, 1995
573	1983	1	28	33.941	118.719	12	3.8					DNAG via NEIC, 1995
574	1983	2	24	34.094	118.885	13	3.1					DNAG via NEIC, 1995
575	1983	3	6	34.064	118.881	13	2.5					DNAG via NEIC, 1995
576	1983	6	14	34.083	118.85	3	2.2					PDE via NEIC, 1995
577	1983	11	23	34.031	118.569	8.1	2.5	55	71	50	169	Hauksson, 1990
578	1984	1	23	33.943	118.825	12	2.7					DNAG via NEIC, 1995
579	1984	3	24	34.124	118.546	14.9	2.6	75	300	57	170	Hauksson, 1990
580	1984	6	10	33.987	118.763	10	2.6					DNAG via NEIC, 1995
581	1984	10	3	33.983	118.653	13.2	3.3	123	337	56	224	Hauksson, 1990
582	1984	10	26	34.016	118.988	13	4.6					USHIS via NEIC, 1995
583	1984	11	3	33.961	118.789	9	2.5					DNAG via NEIC, 1995
584	1985	3	4	33.993	118.575	9.8	3.2	107	59	48	180	Hauksson, 1990
585	1985	3	5	34.078	118.966	15	2.9					DNAG via NEIC, 1995
586	1985	3	18	33.989	118.576	8.9	2.7	135	65	60	145	Hauksson, 1990
587	1985	4	8	34.05	118.922	13	3.4					DNAG via NEIC, 1995
588	1985	4	8	34.055	118.932	9	2.8					DNAG via NEIC, 1995
589	1985	4	8	34.049	118.922	13	3					DNAG via NEIC, 1995
590	1985	4	20	34.046	118.925	11	2.6					DNAG via NEIC, 1995
591	1985	9	26	33.944	118.591	10.3	2.5	108	42	48	196	Hauksson, 1990
592	1986	4	5	33.991	118.721	12.4	2.7	121	354	51	230	Hauksson, 1990
593	1986	5	20	33.94	118.659	12.4	2.8	110	30	45	210	Hauksson, 1990
594	1986	7	11	33.993	118.699	11.6	2.6	72	14	43	165	Hauksson, 1990
595	1986	9	5	33.988	118.549	4.6	2.5	98	4	57	135	Hauksson, 1990
596	1987	7	2	33.918	118.64	12.8	2.8	95	30	70	120	Hauksson, 1990
597	1987	10	17	33.989	118.687	9	2.7	104	355	43	205	Hauksson, 1990
598	1988	3	26	33.99	118.701	13.1	3.7	127	27	55	219	Hauksson, 1990
599	1988	9	9	33.974	118.762	12.5	2.5	55	358	20	255	Hauksson, 1990
600	1989	1	19	33.917	118.623	13.8	5	139	19	45	186	Hauksson, 1990
601	1989	1	19	33.92	118.62	12	3.1					PDE via NEIC, 1995
602	1989	1	19	33.917	118.622	10	2					PDE via NEIC, 1995
603	1989	1	19	33.929	118.657	10	2					PDE via NEIC, 1995

EQ				Hypocenter/Epicenter Location					Focal Mechanism Soln			
Ref. No.	**Year**	**Date Mo**	**Da**	**Lat (°N)**	**Long (°W)**	**Depth (km)**	**Mag**	**Reported Arrivals**	**Dip Azim**	**Dip Angle**	**Slip Azim**	**Source**
604	1989	1	19	33.92	118.62	12	3.2					PDE via NEIC, 1995
605	1989	1	19	33.92	118.61	11	3.3					PDE via NEIC, 1995
606	1989	1	19	33.923	118.622	10	2					PDE via NEIC, 1995
607	1989	1	19	33.92	118.62	11	3.1					PDE via NEIC, 1995
608	1989	1	19	33.92	118.64	12	3.8					PDE via NEIC, 1995
609	1989	1	19	33.92	118.64	12	3.5					PDE via NEIC, 1995
610	1989	1	27	33.947	118.588	5	3.1					PDE via NEIC, 1995
611	1989	2	2	33.94	118.86	8	3.8					PDE via NEIC, 1995
612	1989	2	2	33.94	118.82	5	3					PDE via NEIC, 1995
613	1989	2	25	33.93	118.63	11	3.7					PDE via NEIC, 1995
614	1989	3	8	34.107	118.513	5	3.1					PDE via NEIC, 1995
615	1989	4	11	33.93	118.628	6	3.1					PDE via NEIC, 1995
616	1989	4	26	33.93	118.58	11	3.4					PDE via NEIC, 1995
617	1990	6	18	34.046	118.958	10	3					PDE via NEIC, 1995
618	1991	4	12	33.976	118.794	10	2.7					PDE via NEIC, 1995
619	1992	1	22	33.995	118.725	10	2.5					PDE via NEIC, 1995
620	1992	2	28	33.986	118.676	13	2.4					PDE via NEIC, 1995
621	1992	9	5	34.085	119.025	16	2.8					PDE via NEIC, 1995
622	1993	7	26	33.982	118.737	13	3.5					PDE via NEIC, 1995
623	1994	1	9	33.988	118.504	2	3.7					PDE via NEIC, 1995
624	1994	1	12	33.988	118.501	2	2.2					PDE via NEIC, 1995
625	1994	1	12	33.984	118.504	11	3.5					PDE via NEIC, 1995
626	1994	1	12	33.985	118.508	11	3.2					PDE via NEIC, 1995
627	1994	1	18	34.128	118.559	10	3.1					PDE via NEIC, 1995
628	1994	1	18	34.127	118.723	10	2.9					PDE via NEIC, 1995
629	1994	1	20	34.104	118.678	10	2.6					PDE via NEIC, 1995
630	1994	2	3	34.141	118.632	10	2.9					PDE via NEIC, 1995
631	1994	2	3	34.023	118.929	8	2.6					PDE via NEIC, 1995
632	1994	2	5	34.116	118.5	16	3					PDE via NEIC, 1995
633	1994	2	16	34.097	118.51	5	3.2					PDE via NEIC, 1995
634	1995	2	19	34.049	118.915	15	4.3					PDE-W via NEIC, 1995
635	1995	2	19	34.046	118.922	15	3.7					PDE-W via NEIC, 1995
636	1995	7	22	34.053	118.927	15	2.7					PDE-W via NEIC, 1995
637	1995	12	9	34.035	118.937	13.8	3.5		24	38	150	Kate Hutton, pers. com. 1995
638	1995	12	9	34.038	118.938	15.3	3		24	35	135	Kate Hutton, pers. com. 1995

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