CUIMR-T-79-009 C. 2

FAULTING OFFSHORE SAN DIEGO AND NORTHERN BAJA CALIFORNIA

Mark R. Legg[1] and Michael P. Kennedy[2]

[1]Institute of Geophysics and Planetary Physics

[2]California Division of Mines and Geology

Scripps Institution of Oceanography
University of California
La Jolla, CA 92093

INTRODUCTION

The offshore area considered in this discussion (Figure 1) comprises the inner continental borderland of southern California and northern Baja California, Mexico. It is bounded on the west by the San Clemente fault zone and on the east by the shoreline. It extends north to Santa Catalina Island and south to Punta Santo Tomás, Baja California. Although the northern and southern boundaries are well removed from metropolitan San Diego, it is important to discuss several major faults that extend from these boundaries to the San Diego area, since they directly affect the seismic hazard in San Diego. It is becoming more apparent, as more data are collected, that a significant portion of the earthquake hazard in the San Diego area is from offshore sources (Anderson, 1979; Legg and Ortega, 1978). It has been estimated that as much as 20% of North American--Pacific relative plate tectonic motion in southern California occurs offshore (Anderson, 1979). This paper describes the significant faults in the offshore region which directly affect the San Diego area. Legg (1979) suggested that faults in the inner southern California borderland are capable of accommodating most, if not all of the Quaternary offshore relative plate motion.

The offshore faults are divided into four major fault zones as suggested by Junger (1976) and Legg (1979). These zones are represented by one or more relatively long and continuous faults with many sub-parallel, *en echelon*, or conjugate faults forming a wrench fault zone as shown by Wilcox, *et al* (1973). The fault zones are, from west to east: (1) Santa Cruz-San Clemente-San Isidro; (2) San Pedro-San Diego Trough-Maximinos; (3) Palos Verdes Hills-Coronado Banks-Agua Blanca; (4) Newport-Inglewood-Rose Canyon-Vallecitos-San Miguel. Three of these zones pass onshore within the area shown in Fig. 1.

Many faults studied have existed since the middle Miocene, when the spreading center to the west of North America collided with the continent, and a triple junction migrated southward along the Pacific coast of Baja California (Atwater, 1970). These faults have had recurrent movement to the present. Total amounts of displacement in the offshore area are unknown in general, because of the obvious difficulty in finding genuine "piercing points". Most estimates of displacements on offshore faults have been based upon bathymetry (Shepard & Emery, 1941; Krause, 1965; Legg, 1979).

SANTA CRUZ-SAN CLEMENTE-SAN ISIDRO FAULT ZONE

The first, and probably longest and most continuous fault zone in the inner continental borderland consists of the San Clemente-San Isidro fault (Moore, 1969; Legg, 1979). There are many sub-parallel and oblique conjugate faults that also show sea-floor breaks associated with the San Clemente-San Isidro fault zone, especially in the vicinity of Fortymile, Boundary, and Navy Banks (Loc. 3,4,5, respectively, Fig. 1).

The San Clemente-San Isidro fault appears to be more than 350 km in length and quite continuous in nature. It has dramatic sea-floor scarps along much of its length. The most familiar escarpment along this fault forms the eastern side of San Clemente Island (Loc. 1, Fig. 1) which shows a total vertical relief of up to 2300 m (Junger, 1976). Lonsdale (1979) observed a 50-75 m high scarp, with an upper slope inclined 60 degrees, and with mounds of barite believed to have been deposited by hydrothermal activity, along the San Clemente fault in the vicinity of the Navy submarine fan (Loc. 6, Fig. 1). The San Clemente fault continues southward, through the San Clemente Rift Valley (Loc. 2, Fig. 1), (Shepard & Emery, 1941), and along the northeastern margin of the San Clemente basin. The fault forms the western face of Fortymile Bank (Loc. 3, Fig. 1), which might suggest 25 miles (40 km) of right-lateral, strike-slip displacement between Fortymile Bank and San Clemente Island (Shepard & Emery, 1941). Also in the vicinity of Fortymile Bank are several sub-parallel faults associated with the San Clemente-San Isidro fault zone, some of which appear to be splays of the main fault. In particular, one at the southern end of Fortymile Bank turns more easterly and appears to trend toward Navy Bank (Loc. 4, Fig. 1) and beyond, possibly connecting with the

Maximinos fault zone to the south. This branch is suggested by Legg (1979) to be the previously inferred connection between the San Clemente and Agua Blanca faults (Moore, 1969), although Legg (1979) finds a "gap" (Loc. 5, Fig. 1) in the continuity of this fault southeast of Navy Bank.

The main trace of the San Clemente fault continues south along the northeast side of San Clemente basin where it has a small bend (~25 km long) south of Navy Bank. This bend (Loc. 6, Fig. 1) trends more westerly (N65°W) than the typical strike (N45°W) of the San Clemente fault and has a 250 m high ridge associated with it. This ridge is commonly cut by the most prominent trace of the fault zone. Where this fault does not displace rocks of the ridge itself, it lies along its base. There are many small, sub-parallel reverse faults cutting the sea-floor along the flanks of the ridge. The more westerly strike of this possibly compressional feature is suggestive of right-lateral, strike-slip along the northwest trending San Clemente fault. In addition, apparent vertical offsets of as much as 500 m (Junger, 1976) and additional compressive features along this fault indicate that there is also a significant dip-slip component.

Moore (1969) and Legg (1979) trace the San Clemente fault southward, connecting it with the San Isidro fault offshore Mexico, at a point more than 30 km southwest of Punta Banda and the Agua Blanca fault. Major sea-floor scarps alternating from west-side up to east-side up are common along this part of the fault zone, and may further indicate combined strike-slip and dip-slip faulting (Loc. 7, Fig. 1). The offshore Santo Tomás fault of Krause (1965) (Loc. 8, Fig. 1) has 15 km of reported left-lateral offset and is truncated by the San Clemente-San Isidro fault as shown by the long, eastward-facing escarpment (Krause, 1961; Moore, 1969). The onshore Santo Tomás fault passes offshore at Bahia Soledad (Loc. 9, Fig. 1) and appears to have had right-lateral movement (Allen, *et al*, 1960; Suarez, personal communication), which is inconsistent with the movement reported offshore by Krause (1961, 1965). Legg (1979) concludes that the Santo Tomás fault offshore is not continuous with the Bahia Soledad (or onshore Santo Tomás) fault, but is probably closely related to the San Clemente-San Isidro fault zone.

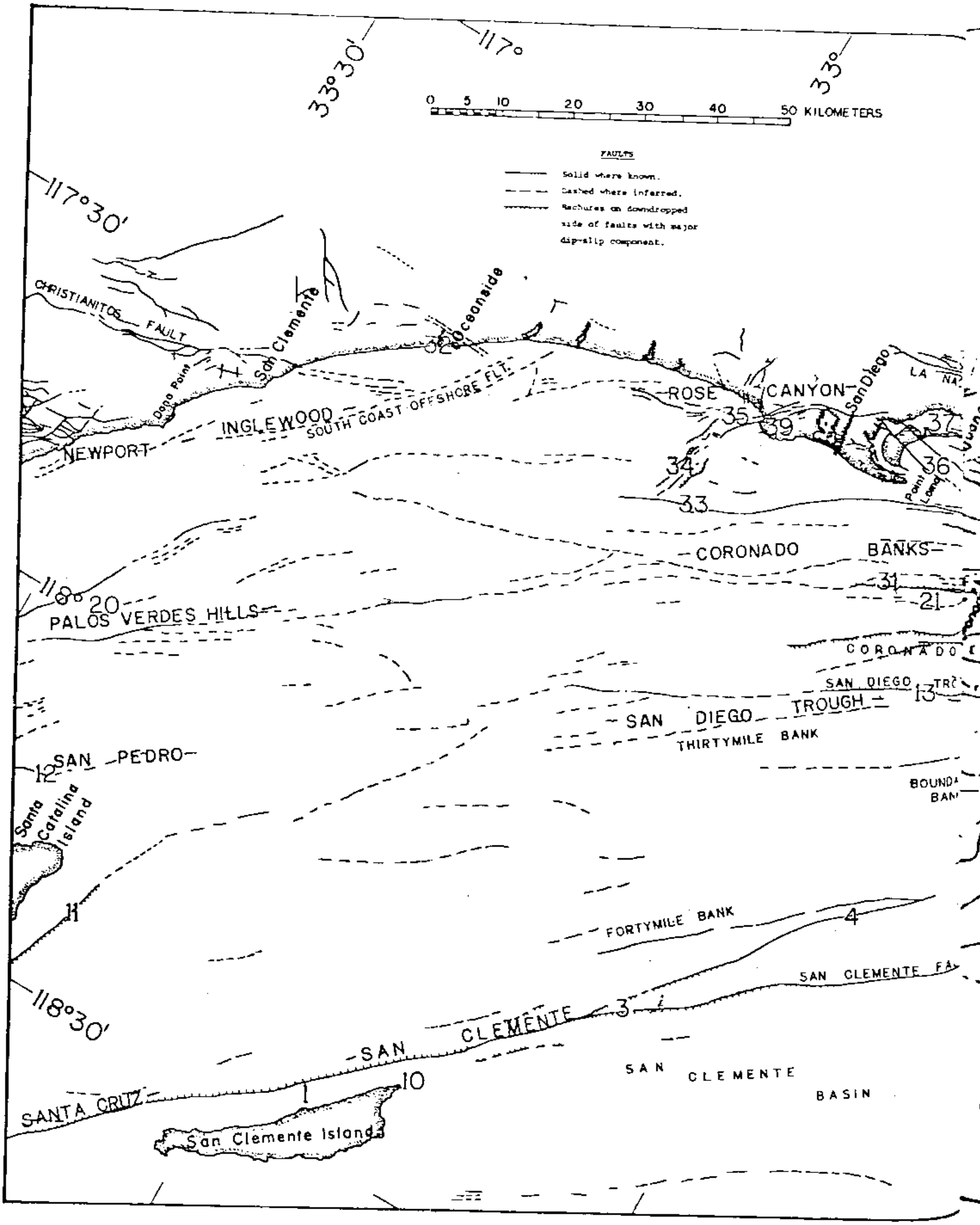
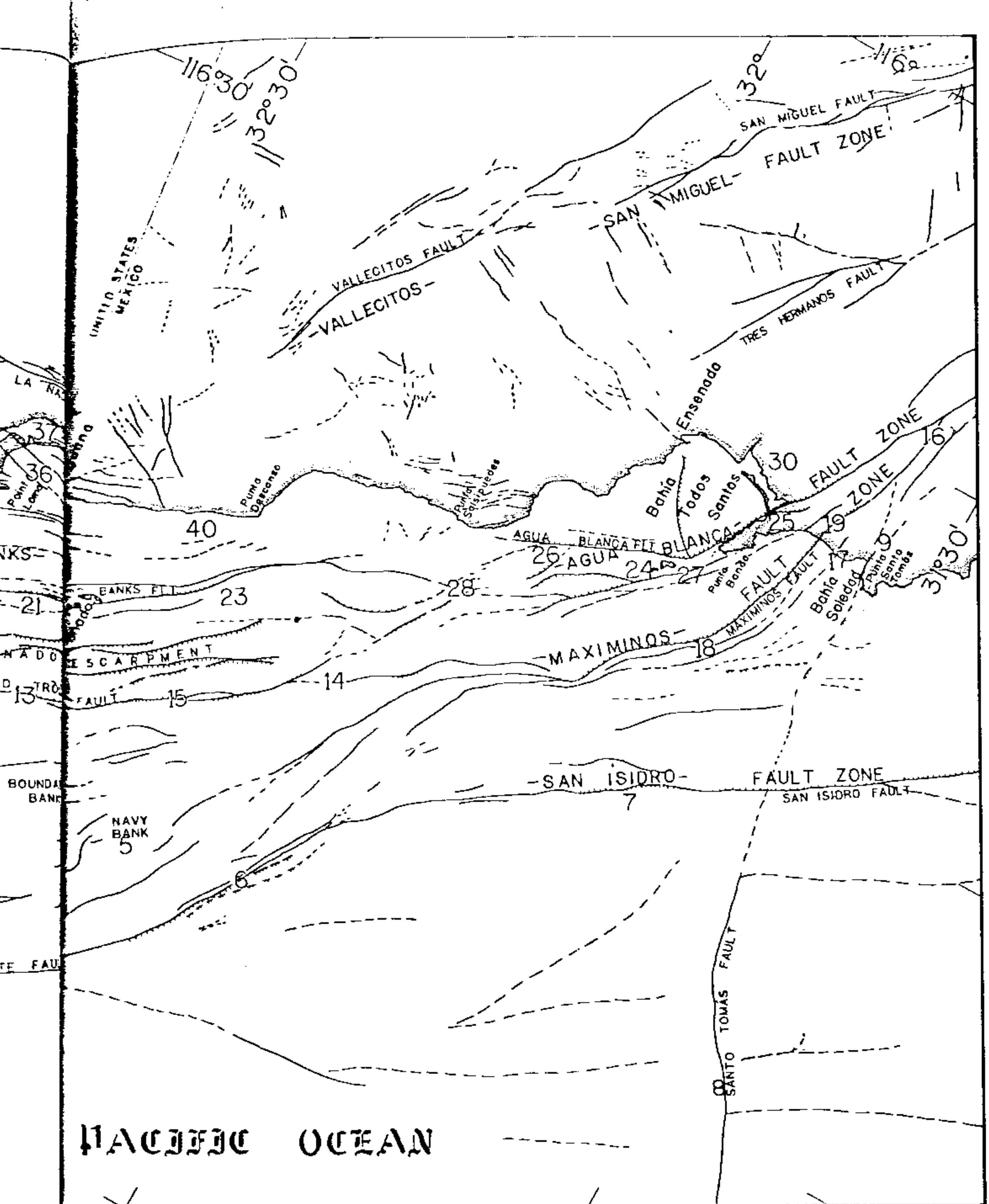


Figure 1. FAULTING OFFSHORE SAN DIEGO A



GO AN THERN BAJA CALIFORNIA, MEXICO

In summary, the known length of the San Clemente-San Isidro fault is more than 350 km . If this fault were to rupture along half of its mapped length, it could conceivably produce an $M_L \geq 7\frac{1}{2}$ earthquake as inferred from the fault length *versus* magnitude relationships of Housner (1969) The frequency of occurrence of such large events, if they occur at all, is probably much lower than that of the San Andreas fault. The largest earthquake recorded along the San Clemente-San Isidro fault zone since 1932 was $M_L = 5.9$, occuring on December 25, 1951 at the southern tip of San Clemente Island (Loc. 10, Fig. 1). Due to the close proximity of the San Clemente-San Isidro fault zone to San Diego (and because of the tsunami potential) an event of this size or greater, with associated sea-floor displacement, could be very destructive to the coastal cities of San Diego, Tijuana, and Ensenada. Moderate earthquakes ($M_L \sim 4$-5) occur along this fault zone every few years, demonstrating the seismically active nature of this major, offshore fault zone.

SAN PEDRO-SAN DIEGO TROUGH-MAXIMINOS FAULT ZONE

The San Pedro-San Diego Trough-Maximinos fault zone lies somewhat closer to San Diego. Principal faults of this zone are the San Pedro (Loc. 11, Fig. 1) and Santa Catalina faults (Loc. 12, Fig. 1), the San Diego Trough and Thirtymile Bank faults, and the Maximinos fault. There may not be one continuous, through-going fault in this zone, but based upon current studies of seismic profiles of these faults, they appear to be sub-parallel or *en echelon* segments of a deeper, continuous wrench fault system. The Santa Catalina and San Pedro faults are discussed in more detail elsewhere (Vedder, *et al.*, 1974; Junger & Wagner, 1977). To the south, the San Diego Trough fault forms the major component of this zone (Loc. 13, Fig. 1), extending from the central San Diego trough to a point about 20 km southwest of Punta Salsipuedes (Loc. 14, Fig. 1). At its southern end the structure is very complex, and the fault may be continuous with, or *en echelon* to, the Maximinos fault or branches of the Agua Blanca fault (Legg, 1979). The San Diego Trough fault breaks the sea-floor with alternating east- and west-side up scarps (as high as 10-20 m) suggesting strike-slip. The fault splays along its strike many times, but re-connects with sub-parallel branches, suggestive of wrench faulting as described by Wilcox, *et al.* (1973). Eastward-facing scarps (Loc. 15, Fig. 1) of the San Diego Trough fault act to block the downstream end of the Coronado submarine canyon and force the channel to the south (Shepard & Emery, 1941; Shepard & Dill, 1966; Emery, *et al.*, 1952).

The Maximinos fault extends from a splay in the Agua Blanca fault, near Valle Santo Tomás, Mexico (Loc. 16, Fig. 1), and passes through Cañada Maximinos, and offshore near Punta Los Maximinos, turning more northerly to a point where it connects with the San Diego Trough and/or Fortymile Bank fault zones. The details of faulting at both the northern end of the Maximinos fault and southern end of the San Diego Trough fault are extremely complex and not completely understood. There are two or more major, sub-parallel faults associated with the Maximinos fault that trend offshore north of Bahia Soledad (Loc. 17, Fig. 1) and along the channel of a submarine canyon that heads near Bahia Soledad (Loc. 18, Fig. 1). To the north, these sub-parallel branches splay and trend towards Navy Bank (Loc. 4, Fig. 1). Based upon 3.5 kHz echo-sounder records, all of these faults either break the sea-floor, or displace the upper sedimentary layers interpreted as Quaternary in age (Legg, 1979). The Maximinos fault passes through a small canyon north of the Canada Maximinos immediately before it passes offshore (Loc. 19, Fig. 1). Here it is seen to have scarps with very youthful appearances, right laterally offset stream channels, and aligned ground-water barriers as manifested by contrasting vegetation. Scarps are uplifted to the south and west along the main branch of the Maximinos fault.

In summary, the San Diego Trough-Maximinos fault zone is considered herein to be a principally right-lateral, strike-slip, northwest-trending, Quaternary fault zone. The main, through-going traces of the San Diego Trough fault lie within 40 km of metropolitan San Diego, where the eastward-facing scarps force the Coronado Canyon to turn southward along the base of the Coronado escarpment. The presence of sea-floor scarps suggests a small dip-slip component, but certainly not as great as that observed along the San Clemente-San Isidro fault zone. The San Diego Trough-Maximinos fault zone appears to have very few earthquake epicenters located near it in the southern portion, although the inaccuracies in the epicentral locations in the southernmost part of the area do not allow definite conclusions regarding activity. Some of the smaller faults associated with this system might suggest possible connections with the San Clemente fault near Navy Bank and Fortymile Bank, but Legg (1979) finds "gaps" within the sedimentary cover through this area.

PALOS VERDES HILLS-CORONADO BANKS-AGUA BLANCA FAULT ZONE

Greene, *et al.* (this volume) discuss the Palos Verdes Hills fault zone in more detail. The Palos Verdes Hills-Coronado Banks-Agua Blanca fault zone is typified by high vertical relief at Palos Verdes Hills (not shown in Fig. 1), Coronado Banks (Loc. 21, Fig. 1), Islas Los Coronados (Loc. 22, Fig. 1), Descanso Shelf-Ridge (Loc. 23, Fig. 1), Islas de Todos Santos (Loc. 24, Fig. 1) and Punta Banda (Loc. 25, Fig. 1). Vertical displacements of several hundred meters occur locally along these segments, even though the major component of slip is lateral. At the southern end of the offshore portion of this fault zone, the Agua Blanca fault shows clear evidence of vertical movements as shown by dramatic Quaternary sea-floor scarps (Loc. 26, Fig. 1). Right-lateral, strike-slip is suggested by stream offsets on Punta Banda (Allen, *et al.*, 1960; Gastil, *et al.*, 1975), offsets in the Punta Banda (Loc. 27, Fig. 1), Salsipuedes (Loc. 28, Fig. 1), and Coronado (Loc. 29, Fig. 1) submarine canyons (Legg, 1979), and by the configurations of Punta Banda and the Coronado Banks (Legg, 1979). Legg (1979) suggests 11 km of post-Pliocene displacement along the Coronado Banks fault by realigning the north bank with the south bank. Allen, *et al.* (1960), Gastil, *et al.* (1975), and Suarez (personal communication) suggest that not more than 20 km of right-lateral displacement exists along the onshore segment of the Agua Blanca fault. Since the San Diego Trough-Maximinos fault zone joins the Agua Blanca fault onshore, the total displacement on this, plus that on the Coronado Banks fault zone is probably limited by the amount suggested for the onshore Agua Blanca fault zone.

The region just offshore from Punta Salsipuedes is very complex, and direct connections between the Agua Blanca and Coronado Banks fault have not been established. Krause (1961, 1965) inferred northward continuation of the Agua Blanca fault through the Islas Los Coronados using magnetic data. The Agua Blanca fault is also very complex along and to the north of Punta Banda. There are at least two sub-parallel traces of this fault that lie along opposite sides of Punta Banda, forming the Punta Banda horst (which includes the Islas de Todos Santos). The main trace of the fault on the north side of Punta Banda marks a major structural boundary between the Punta Banda basement ridge high and the sediment-filled Valle Maneadero (Loc. 30, Fig. 1) which extends into Bahia Todos Santos. The faults on the south side of Punta Banda offset the Punta Banda submarine canyon (Loc. 27, Fig. 1) as much as 4 km in a right-lateral sense, and control the shape of a northwest trending canyon to the west of the Islas de Todos Santos (Legg, 1979). The main trace on the northeast side of the Punta Banda ridge passes along the east side of the Islas de Todos Santos, forming a steep escarpment. This trace curves through a 25° - 35° angle between Punta Banda and the Islas de Todos Santos. East of the Islas de Todos Santos, acoustic basement highs are juxtaposed where the Valle Maneadero ends in an east-west trending normal fault that trends toward the Ensenada breakwater. This relationship was observed on gravimetric and magnetic data by Serrano (1977). Farther north along the fault, and southwest of Punta Salsipuedes, the acoustic basement is again deeper ($\sim$500+ m) to the east, and sea-floor scarps are present along the main trace of the Agua Blanca fault. The fault passes very near the coast at Punta Salsipuedes, and there are no data close enough to the shore to accurately delineate its northward extent.

The Coronados Banks fault zone is found west of Punta Salsipuedes, along the Descanso ridge (Loc. 23, Fig. 1), within the sediment-filled channel between the ridge and the coast. To the north, the fault splays around Middle and South Coronados Islands, with one trace passing very near to the west side of Middle Island. Coronado Canyon (Loc. 29, Fig. 1) cuts transversely across the Coronados Banks fault zone and a right-lateral offset is suggested. Loma Sea Valley (Loc. 31, Fig. 1) is eroded along the Coronado Banks fault and its main trace lies along the steep, western flank of the valley where a major basement discontinuity exists (Legg, 1979). In addition to the main trace of the fault, numerous sub-parallel fault traces lie along the more gently sloping eastern side of the Loma Sea Valley.

Legg, *et al.* (1977) suggested that the Coronado Banks fault zone extends northward from the Coronado Banks along a N45°W trend of earthquake epicenters (Fig. 2). The trend of epicenters becomes more diffuse in the vicinity of Lasuen Knoll (Loc. 20, Fig. 1), perhaps because of complexities in the fault zone (Greene, *et al.*, this volume). South of Coronado Banks (Loc. 21, Fig. 1), the activity appears to cease at about the latitude of south San Diego Bay until the Salsipuedes area where earthquake swarms have been recorded (Hileman, *et al.*, 1973).

In summary, the Palos Verdes Hills-Coronado Banks-Agua Blanca fault zone is a complex, multi-part, Quaternary zone of deformation suggestive of wrench faulting (Wilcox, *et al.*, 1973; Legg, 1979). Earthquake epicenters located near these faults, as well as questionably faulted Holocene sediment, indicate that this fault zone is active. However, it is significantly less active seismically than the San Clemente or Elsinore faults, based upon data reported by Hileman, *et al.* (1973). Its close proximity to the San Diego greater metropolitan area (∿25 km) makes it of great interest with respect to producing moderate-sized (M_L = 5-6) earthquakes. Although large vertical relief is present along this fault zone in the vicinity of San Diego, fault movement appears to be dominated by strike-slip, and so tsunami generation is probably less likely in this fault zone than from the San Clemente fault, (notwithstanding the possibility of seismically induced submarine slumping and associated sea wave generation along the steep slopes of the Coronado escarpment or the Loma Sea Valley).

NEWPORT-INGLEWOOD-ROSE CANYON-VALLECITOS-SAN MIGUEL FAULT ZONE

The Newport-Inglewood-Rose Canyon-Vallecitos-San Miguel fault zone passes closest to metropolitan San Diego as a series of sub-parallel, *en echelon*, and conjugate faults characteristic of a wrench zone (Wilcox, *et al.*, 1973; Harding, 1973). The Newport-Inglewood zone is described elsewhere (Harding, 1973; Barrows, 1974; Ziony, *et al.*, 1974), and is especially well known for the 1933 Long Beach earthquake (M_L = 6.3). Barrows (1974) discussed the similarities between the Newport-Inglewood and South Coast Offshore fault zones, and Euge, *et al.* (1973) suggested a branch of the Rose Canyon fault passes northeastward, onshore in the Oceanside area (Loc. 32, Fig. 1). Moore (1972), Moore and Kennedy (1975), and Kennedy, *et al.* (1978) have mapped in detail, the offshore portions of the Rose Canyon fault zone in the immediate San Diego area.

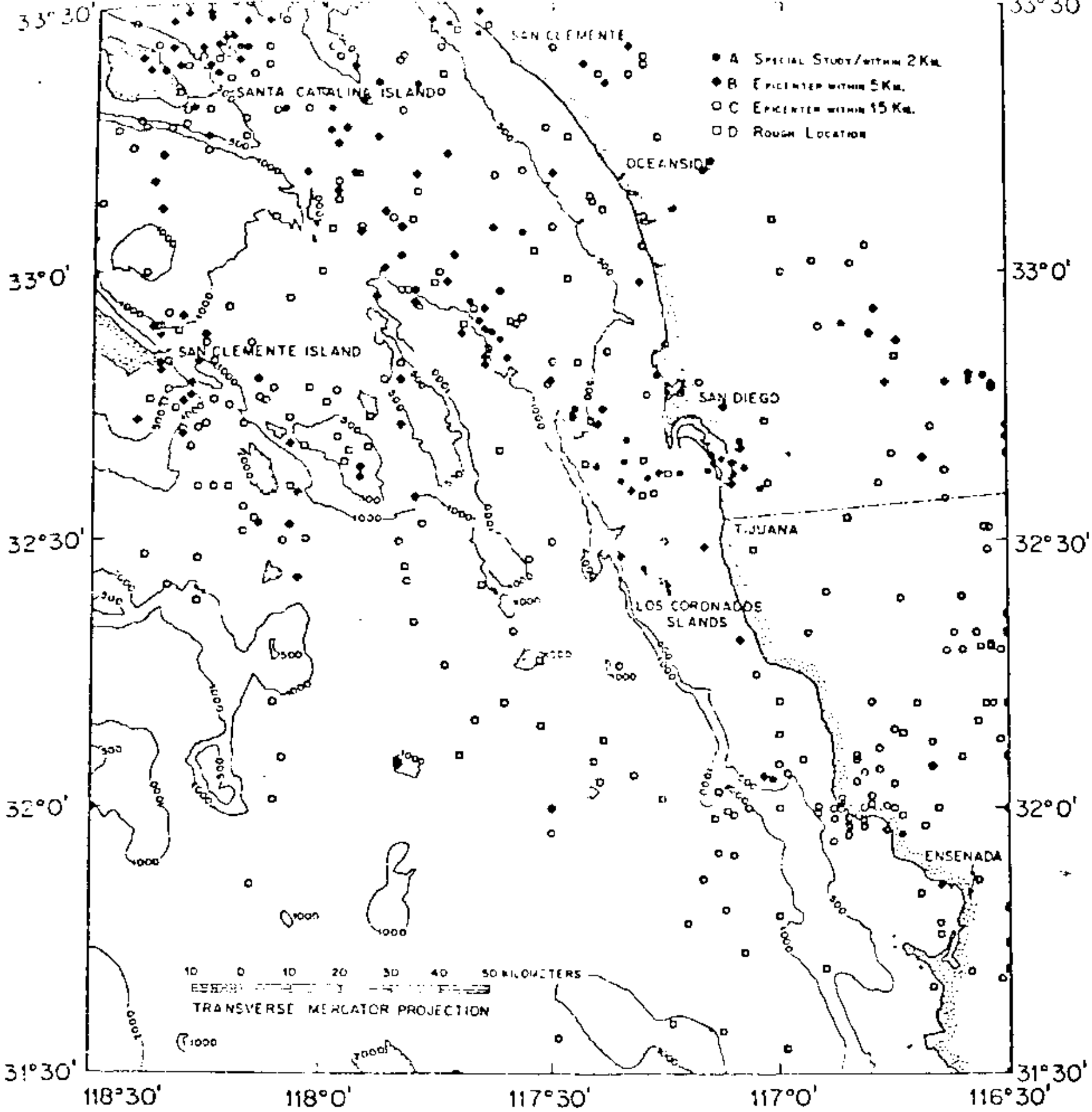


Figure 2: Map showing epicentral locations of earthquakes in the offshore region of southern California and northern Baja California, Mexico. The data covers the period from 1 January, 1932 to 30 September, 1976, and are from the Caltech seismograph array in southern California. Sources for the locations are Hileman, *et al.* (1973), Friedman, *et al.* (1976), Fuis, *et al.* (1977), and Simons (1977). Magnitudes for the earthquakes in the figure range from M_L=1.5 to M_L=5.9, and the epicenters have been coded for accuracy of the location. Note the linear trend of more accurately located epicenters that delineate the Coronado Banks fault zone, and also the trend of epicenters further offshore that marks the San Clemente-San Isidro fault zone.

North of Point La Jolla, Kennedy, *et al.* (1978) described four disti fault patterns constituting the Rose Canyon fault zone in that area. Th westernmost faults (Loc. 33) trend northwesterly, and are, in general, e overlain by 5 m of unfaulted Quaternary sediments, or lie totally withi older (Late Cretaceous to Tertiary) acoustic basement. Most of these fa segments are relatively short (~10 km), discontinuous, sub-parallel or *en echelon*. The central zone of faulting forms the almost symmetrical, Jolla graben, through which the La Jolla submarine canyon is cut (Loc. 3 Fig. 1). Faults in this sub-zone consist of short segments (~1 km) with thin, discrete zones of slip, and stratigraphic separations of more than 9 m. The general trend of the La Jolla graben is N70°-80°W, although individual fault segments may strike from WNW to NNE. Fault or fault-li scarps are observed, and disruption of the acoustically transparent, uppermost sedimentary layer in this zone suggests Holocene activity.

A nearshore sub-zone of northwest trending faults, to the east of the La Jolla Canyon, is described by Kennedy, *et al.* (1978), (Loc. 35, Fig. 1). The faults are discontinuous, sub-parallel and *en echelon* break similar to those observed onshore in the Rose Canyon fault zone (Kennedy, 1975; Kennedy & Peterson, 1975; Kennedy, *et al.*, 1978), and display some surface manifestations such as sea-floor scarps and small submarine canyo Reflection profiles indicate these faults to be nearly vertical with the faulting extending into the near surface, Quaternary sediments. Kennedy, *et al.* (1978) suggest a right lateral offset of 2.5 km since early Pleistocene, by realignment of the Scripps Canyon with an abrupt change i course in the lower La Jolla Canyon (Loc. 35, Fig. 1).

Along the onshore coastal plain, Kennedy (1975) delineated many northeasterly-trending faults that pass offshore. Vertical separations on these faults is small (~10 m), and Kennedy *et al.* (1978) do not observ these faults, in general, in their seismic profiles. Onshore, however, displacement of the Pleistocene Bay Point Formation (~120,000 years) is observed locally on some of these small faults (Kennedy, 1975).

As the Rose Canyon fault zone is traced south, the main faults form a gentle S-shaped curve around Mt. Soledad (Loc. 39, Fig. 1) and Mission and San Diego bays. Structural relief of these highs and lows is suggest to be a consequence of alternating local compression and tension respecti created by the predominantly strike-slip movement across the bends in the Rose Canyon fault zone (Moore & Kennedy, 1975; Kennedy, *et al.*, 1978).

complex, multi-part, *en echelon*, right-stepping faults characterize the zone throughout the San Diego area with Mission Bay, San Diego Bay and La Jolla Canyon forming structural lows in the tensional zones, and Mt. Soledad (Loc. 39, Fig. 1) and Point Loma forming the structural highs in the compressional zones. Moore and Kennedy (1975) described faulting in the San Diego Bay and offshore bight (Loc. 36, Fig. 1), and suggested that these faults form the western side of a graben. They observed Quaternary (and in some places, Holocene?) displacements along the faults in San Diego Bay (Loc. 37, Fig. 1), which display strike-slip character as expressed by fault bounded anticlines, chevron-shaped dilational synclines, and other complex folds not characteristic of dip-slip drag. The eastern boundary of the San Diego Bay structural low (graben) is marked by the La Nación fault, (Loc. 38, Fig. 1), described by Artim and Pinckney (1973) and Marshall (this volume).

South of Point Loma, the Point Loma anticline, and associated faults, are observed in the seismic profiles of Legg (1979) and Kennedy and Welday (1979). This feature is traced as far south as Rosarito Beach, Baja California, Mexico (Loc. 40, Fig. 1), by Legg (1979), but it trends too close to the shoreline to be seen in their profiles farther south. Connection or relation to the Tres Hermanos or Agua Blanca faults is possible, but not known at this time. Krause (1961, 1965) also observed this fault in his magnetic data, just south of Point Loma, and, perhaps, offshore of Punta Descanso.

In summary, the Newport-Inglewood-Rose Canyon-Vallecitos-San Miguel fault zone is characterized by right-stepping, *en echelon* faults with Quaternary to Holocene offsets in many places. Gastil, *et al.*, (1975) and Brune and Simons (this volume) discussed the details of the Vallecitos and San Miguel fault zones, and Greene, *et al.* (this volume) discussed the details of the Newport-Inglewood zone. Curvature in the Rose Canyon fault zone bounds prominent structural lows in Mission Bay, San Diego Bay, and La Jolla Canyon, and structural highs at Mt. Soledad and Point Loma. This vertical relief is suggested to be a result of the right-stepping, oblique-slip along the Rose Canyon fault zone, forming local regions of tension and compression. To the north, the fault zone merges with the Newport-Inglewood fault zone; to the south, it apparently merges with the Vallecitos-San Miguel fault zone, although a connection with the Tres Hermanos or

Agua Blanca fault zones is also possible.

Since the Rose Canyon fault zone passes directly through the San Diego metropolitan area, it may pose the greatest seismic hazard to the city. The seismicity of this zone has been very low since the establishment of the Caltech seismograph network in southern California (Simons, 1977), although several small (M_L=3.5-3.7) earthquakes have been located within this zone. The occurrence of moderate sized (M_L=5-6) earthquakes along this fault zone, within heavily populated regions of the San Diego coastal area could cause extensive damage.

CONCLUSIONS

The faulting in the inner continental borderland offshore from San Diego County, and northern Baja California, Mexico is a region extensively deformed and tectonically active. The faults in the region are predominantly strike-slip in character, and form a part of the broad shear zone associated with the San Andreas fault and the North American-Pacific tectonic plate boundary in southern California. The four fault zones discussed are the Santa Cruz-San Clemente-San Isidro, San Pedro-San Diego Trough-Maximinos, Palos Verdes Hills-Coronado Banks-Agua Blanca, and Newport-Inglewood-Rose Canyon-Vallecitos-San Miguel. All four zones are typical of major wrench fault zones as described by Wilcox, *et al.*, (1973). These zones are typified by one or more relatively continuous main faults and numberous smaller, sub-parallel, *en echelon*, and oblique faults. Transversely-oriented folds near steps or curves in the main faults were also observed. All of these fault zones show signs of Quaternary activity, and in many areas, sea-floor displacements, faulted Holocene sediment and/or associated seismicity.

Previous seismic-risk studies in the area (McEuen & Pinckney, 1972) briefly mentioned the hazard from offshore faults, but only the San Clemente and Rose Canyon faults were known in any detail at that time. Now it is known that the San Clemente-San Isidro fault zone is currently active with moderate seismicity, and it appears capable of large, though infrequent, earthquakes. Its distance from the San Diego metropolitan area lessens the hazard from the more frequent, moderate-sized (M_L=4-6) events, although some of these have caused slight damage in San Diego (Agnew, *et al.*, this volume). Closer to the populated coastal area of San Diego, the San Diego Trough and Coronado Banks fault zones may pose a significant earthquake hazard from even moderate-sized events. Perhaps the greatest hazard from earthquakes may be presented by the Rose Canyon fault zone which passes directly through metropolitan San Diego. Small earthquakes in this zone (M_L=3.5-3.7) have caused slight damage (Legg, *et al*, 1977), and moderate-sized events located within the metropolitan area could cause more extensive damage. Quantitative studies of the risk in San Diego including the newly collected offshore fault data have only recently begun, thus it cannot be said which, if any, of these offshore faults pose the greatest earthquake hazard to the city. It can be stated that the four fault zones described appear to be capable of generating earthquakes large enough to be damaging to metropolitan San Diego.

ACKNOWLEDGEMENTS

This paper represents preliminary results of research supported by the NOAA office of Sea Grant, project #04-8-M01-189, California State Resources Agency project #R/CZ-43, NSF grant #EAR76-84324, and U.S.G.S. contract #14-08-0001-17699.

REFERENCES

Allen, C.R., Silver, L.T., and Stehli, F.G., 1960, The Agua Blanca fault - a major transverse structure of northern Baja California, Mexico: Geological Society America Bulletin, v. 71, p. 357-482.

Anderson, J.G., 1979, Estimating the seismicity from geologic structure for seismic risk studies: Seismological Society America Bulletin, V. 55, p. 753-797.

Artim, E.R., and Pinckney, C.J., 1973, La Nación fault system, San Diego, California: Geological Society America Bulletin, v. 84, p. 1075-1080.

Atwater, J., 1970, Implications of plate tectonics for the Cenozoic tectonic evolution of western North America: Geological Society America Bulletin, V. 81, p. 3515-3536.

Barrows, A.G., 1974, A review of the geology and earthquake history of the Newport-Inglewood structural zone, southern California: California Division Mines Special Report 114, 155 pp.

Emery, K.O., Butcher, W.S., Gould, H.R., and Shepard, F.P., 1952. Submarine geology off San Diego, California: Journal of Geology, v. 60, p. 511-548.

Euge, K.M., Miller, C., and Palmer, L., 1973, Evidence for a possible onshore extension of the Rose Canyon fault in the vicinity of Oceanside, California: Geological Society America Bulletin, Abstracts with Program, v. 5, n. 1, p. 39.

Friedman, M.E., Whitcomb, J.H., Allen C.R., and Hileman, J.A., 1976, Seismicity of the southern California region 1 January, 1972 to 31 December 1974: California Institute Technology, Division Geological & Planetary Sciences *Contribution # 2734*, 404 pp.

Fuis, G.S., Friedman, M.R., and Hileman, J.A., 1977, Preliminary catalog of earthquakes in southern California, July 1974 - September 1976: U.S. Geological Survey, Open File Report # 77-181.

Gastil, R.G., Phillips, R.P., and Allison, E.C., 1975, Reconnaissance geology of the state of Baja California, Mexico: Geological Society America Memoir 140, 170 pp.

Harding, T.P., 1973, Newport-Inglewood trend, California - an example of wrench style deformation: American Association Petroleum Geologists Bulletin, v. 57, p. 97-116.

Hileman, J.A., Allen, C.R., and Nordquist, J.M., 1973, Seismicity of the southern California region, 1 January 1932 to 31 December 1972: California Institute Technology, Division Geology and Planetary Sciences *Contribution # 2385*, 64 pp.

Housner, G.W., 1969, Engineering estimates of ground shaking and maximum earthquake magnitude, *in* Proceedings of Fourth World Conference on Earthquake Engineering, p. 1-13.

Junger, A., 1976, Tectonics of the southern California borderland: *in* Howell, D.G. (ed.), Aspects of the Geologic History of the California Continental Borderland: American Association Petroleum Geologists, Special Publication 24, p. 486-498.

Junger, A., and Wagner, H.C., 1977, Geology of the Santa Monica and San Pedro basins, California continental borderland: U.S. Geological Survey, Misc. Field Studies MF-820.

Kennedy, M.P., 1975, Geology of the San Diego metropolitan area, California Division Mines, Bulletin 200, p. 1-39.

Kennedy, M.P., and Peterson, G.K., 1975, Geology of the San Diego metropolitan area, California, Section B - Eastern San Diego metropolitan area: California Division Mines, Bulletin 200, p. 40-56.

Kennedy, M.P., Tan, S.S., Chapman, R.H., and Chase, C.W., 1975, Character and recency of faulting, San Diego metropolitan area, California: California Division Mines Special Report 123, 33 pp.

Kennedy, M.P., Bailey, K.A., Greene, H.G., and Clarke, S.H., 1978, Recency and character of faulting offshore from metropolitan San Diego, California: Final Technical Report - FY 1977-1978, U.S. Geological Survey, 47 pp.

Kennedy, M.P., and Welday, E.E., 1979, Recency and character of faulting offshore from urban San Diego, California: California Division of Mines Map Sheet (in press).

Krause, D.C., 1961, Geology of the southern continental borderland west of Baja California, Mexico: Scripps Institution of Oceanography, Ph.D. dissertation (unpub.), 205 pp.

________, 1965, Tectonics, bathymetry, and geomagnetism of the southern continental borderland west of Baja California, Mexico: Geological Society America Bulletin, v. 76, p. 617-650.

Legg, M., Agnew, C., and Simons, R., 1977, Earthquake history and Seismicity of coastal San Diego County, California, 1800-1976, *in* Kuhn, G. (ed.), Coastal zone Geology and Related Sea Cliff Erosion: San Dieguito River to San Elijo Lagoon, San Diego County, California, Project Study # 11695-0800E-KUHN, San Diego County Board of Supervisors.

Legg, M.R., and Ortega, V.W., 1978, New evidence for major faulting in the inner borderland off northern Baja California, Mexico: Abstract *in* EOS, v. 59, p. 1134.

Legg, M.R., 1979, Faulting and earthquakes in the inner borderland offshore southern California and northern Baja California: M.S. Thesis (unpub.), Scripps Institution of Oceanography, 75 pp.

Lonsdale, P., 1979, A deep-sea hydrothermal site on a strike-slip fault: M.S. submitted to Nature.

McEuen, R.B., and Pinckney, C.J., 1972, Seismic risk in San Diego: Transactions San Diego Society Natural History, v. 17, p. 33-62.

Moore, D.G., 1969, Reflection profiling studies of the California continental borderland: structure and Quaternary turbidite basins: Geological Society America Special Paper 107, 142 pp.

Moore, G.W., 1972, Offshore extension of the Rose Canyon fault, San Diego, California: U.S. Geological Survey Paper 800-C, p. C113-C116.

Moore, G.W., and Kennedy, M.P., 1975, Quaternary faults at San Diego Bay, California: U.S. Geological Survey, Journal of Research, v. 3, p. 589-595.

Serrano. A.G., 1977, Anomalias gravimétricas y magnéticas de la Bahia de Todos los Santos: Tesis, Universidad Autonoma de Baja California, Ciencias Marinas, 52 pp.

Shepard, F.P., and Dill, R.F., 1966, Submarine Canyons and Other Sea Valleys: Chicago, Rand McNally Co., 381 pp.

Shepard, F.P., and Emery, K.O., 1941, Submarine topography off the California coast: canyons and tectonic interpretations: Geological Society America Special Paper 31, 171 pp.

Simons, R.S., 1977, Seismicity of San Diego, 1934-1974: Seismological Society America Bulletin, v. 67, p. 809-826.

Vedder, J.G., Beyer, L.A., Junger, A., Moore, G.W., Roberts, A.E., Taylor, J.C., and Wagner, H.C., 1974, Preliminary report on the geology of the continental borderland of southern California: U.S. Geological Survey, Misc. Field Studies MF-624.

Wilcox, R.E., Harding. T.P., and Seely, D.R., 1973, Basic wrench tectonics: American Association Petroleum Geologists Bulletin, v. 57, p.74-96.

Ziony, J.I., Wentworth, C.M., Buchanan-Banks, J.M., and Wagner, H.C., 1974, Preliminary map showing recency of faulting in coastal southern California: U.S. Geological Survey, Misc. Field Studies MF-585.