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RELATED CORRESPONDENCE

UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION
BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

In the Matter of)
)
SOUTHERN CALIFORNIA EDISON COMPANY,)
ET AL.)
)
(San Onofre Nuclear Generating Station,)
Units 2 and 3))

Docket Nos. 50-361 OL
50-362 OL

WRITTEN TESTIMONY OF
MARK R. LEGG

I. INTRODUCTION

My name is Mark R. Legg. I am presently employed as a student Research Assistant with the California Division of Mines and Geology studying offshore faulting and earthquakes and I am also a member of the Professional Staff of J. H. Wiggins Company conducting earthquake hazard studies. My educational background includes a Bachelor of Science degree in Space Sciences and Mechanical Engineering from Florida Institute of Technology (1973) and a Masters of Science degree in Oceanography from University of California, Scripps Institute of Ocenaography (1980). I am presently enrolled at the University of Santa Barbara and working on my Ph.D. thesis entitled: "Tectonics of the Inner Continental Borderland Offshore Southern California and Northern Baja California, Mexico."

My areas of specialization include: undersea faulting and earthquakes, earthquake risk and hazards, applied oceanography (physical and geophysical) and seismicity studies. I recently prepared

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detailed bathymetric charts for the region offshore of Northern Baja California and analyzed seismic reflection profiles and geomagnetic profiles offshore of Northern Baja California for purposes of determining the northerly extension of the Agua Blanca and other faults. I also recently performed studies of the character and recency of faulting offshore of Southern California. My biographical sketch and list of publications is attached hereto and incorporated herewith.

II. NORTHWARD CONTINUATION OF THE AGUA BLANCA FAULT

As part of my thesis research, I have conducted two seismic reflection profiling cruises in the inner continental borderland offshore of northern Baja California, Mexico (Figure 1). The purpose of these cruises was to collect data to be used to map the geological structure of this offshore region and determine the geotectonic evolution of the area and its relation to similar regions to the north in United States waters. One particular question for which data was sought to provide an answer was "does the San Clemente fault connect with the Agua Blanca fault as suggested by Allen, *et al.* (1960) based upon earthquake epicenters" and "what is the lateral extent and character of these faults?"

Data from the first cruise (CFAULTS, 1978 - Figure 1) was sufficient to demonstrate that the Agua Blanca fault and the San Clemente fault are not directly connected (Legg and Ortega, 1978) but that the San Clemente fault probably connects

with the San Isidro fault (Figure 2) 60 km west of Ensenada. The Agua Blanca fault trends northward from Punta Banda, subparallel to the coast. The magnetic data of Krause (1965) suggest this trend (Figure 3). As stated by Legg and Kennedy (1979) "The fault (Agua Blanca) passes very near the coast at Punta Salipuedes, and there are no data close enough to shore to accurately delineate its northward extent." The second cruise (CFAULTS - 1979, Figure 1) was undertaken to supply data closer to shore to accurately delineate the possible connections between the Agua Blanca and Coronado Bank (or other faults to the north) as well as map the southward continuation of the San Clemente-San Isidro fault, and its intersection with the offshore Santa Tomás fault of Krause (1965). Data from the second cruise have not yet been interpreted in detail, but preliminary review of this data confirms the northward continuation of the Agua Blanca fault past Punta Salsipuedes (about 6 km offshore) and through the middle of a submarine embayment southwest of Punta Descanso (Figure 2). In this region, it is observed as two conspicious, subparallel fault traces, which in places cut near surface sediments, as seen on sparker and 3.5 khz high-resolution echo sounder profiles. The data from the second cruise only allow detailed mapping of the Agua Blanca fault northward to a point 6.5 km southwest of Punta Descanso, and from there, only the data from the first cruise are available for mapping the faults in this region. These data do not pass close enough to shore to delineate all the nearshore branches of the Agua Blanca

fault between Rosarito Beach and Punta Descanso, but do show the northward continuation of one (or more) main trace(s) of the Palos Verdes Hills-Agua Blanca-Coronado Banks fault zone. (Legg and Kennedy, 1979) In this region, the zone appears to have branches which continue northward, much closer to shore and are seen in the northernmost profiles of CFAULTS-1978. These branches appear to be related to (or connected with) the offshore branches of the Rose Canyon fault zone as mapped by Kennedy and Welday (1980), specifically the Silver Strand, Spanish Bight and Coronado faults. The presence of north trending branches in these right-lateral wrench fault zones is very commonly observed in the Southern California coastal area (Harding, 1973; Greene, *et al.*, 1979; Legg and Kennedy, 1979).

In conclusion, the data from the two seismic reflection profiling cruises (CFAULTS-1978, 1979) demonstrate the northward continuation of the Agua Blanca fault, subparallel to the coast from Punta Banda/Islas Todos Santos to the Coronados Islands region. Individual fault traces within the zone show evidence of Quarternary displacements in the area, as near surface sediments (and in some cases, the sea floor) are disrupted. In the region near Punta Descanso, the Agua Blanca fault appears to branch into several strands, but the detailed mapping of the easternmost splays is not possible with the present data. Some of these strands are believed to connect with or be related to the offshore

branches of the Rose Canyon fault zone as mapped by Kennedy and Welday (1980). The western branches of the Agua Blanca fault zone merge into the Coronado Bank fault zone of Kennedy, *et al.* (1981) and are a part of the Palos Verdes Hills-Coronado Banks-Agua Blanca fault zone of Legg and Kennedy (1979).

III. SEISMICITY, FOCAL MECHANISMS AND FAULTS IN THE SAN ONOFRE REGION.

Biehler (1975) has examined the seismicity in the region near to the Cristianitos fault, around and to the north of the SONGS site. In his study, he examined historical seismicity, relocated selected epicenters and plotted body wave first motion diagrams for several events, in particular the events of 3 January 1975.

Biehler states that the Cristianitos fault has "certainly been inactive for the past 40 years." The fact that numerous epicenters have been located in the region of the Cristianitos fault, as shown by his map (his Figure 1 and Simons, 1981) demonstrates that faults in the area are active at present. Considering the uncertainties in the epicentral (and especially hypocentral) data as listed by the Caltech catalog, and Biehler's own location attempts,(many epicenters are located with no better accuracy than 15 km) many events may be located directly along the trace of the Cristianitos fault. (For a more detailed discussion, see Simons, 1981). At any rate, the presence of

numerous epicenters in the region indicates that the region is under stress of an unknown amount, and some structures are seismically yielding to this stress.

Any faults in the region which may be "favorably oriented" (i.e. oriented in such a fashion that slip along these existing fault planes will occur at a lower level of stress in the existing stress field than through creation of new faults in competent rock) will continue to slip until such a time as the state of stress changes to a less favorable orientation.

Ehlig (1980) describes the Cristianitos fault as a westward dipping normal fault, and probably a listric normal fault which has shallower dip at depth and merges into a bedding plane fault. The data is not adequate to confirm his suggestion that the Cristianitos fault is a listric normal fault, although if it is, then the hypocenters of the 3 January 1975 earthquakes relocated by Biehler (1975) may well be on the shallow dipping portions of the Cristianitos fault at depth. The focal mechanisms of Biehler (1975) indicate predominately strike-slip with a significant thrust component (which is opposite to the normal motion observed from geologic data on the near surface traces of the Cristianitos fault), and Biehler interprets this as additional evidence that these earthquakes are not associated with the Cristianitos fault. Recurrent motion on faults, in directions opposed to previous motions under a different stress regime is possible, and

evidence of varying motions has been observed.

In the region of the Cristianitos fault according to Ehlig (1980), the tectonic stress has changed from extension in an east-west direction (during the formation of the Cristianitos fault) to compression in a northeast-southwest direction. The focal mechanisms of Biehler indicate general north-south compression, with variations from northwest-southeast to northeast-southwest. P-axes shown by Legg (1980) also suggest general north-south compression for the inner continental borderland region, (offshore of southern California) although some unexplained variability suggested northwest-southeast compression in one region. If we accept the present state of stress to be one of general north-south compression in the region, with room for variation between northwest-southeast to northeast-southwest as seen in the earthquake focal mechanisms of Biehler (1975) and Legg (1980) then release of this stress will occur along faults "favorably oriented" to this stress regime.

The Cristianitos fault is favorably oriented for slip under the current stress regime. This is demonstrated by the focal mechanism presented by Biehler (1975) for the 13 February 1967 earthquake in the region which has one nodal plane oriented approximately north-south, and dipping to

to the west as does the Cristianitos fault as mapped and described by Ehlig (1980). Legg (1980) shows other focal mechanisms in the nearby offshore region which have nodal planes subparallel to the Cristianitos fault (e.g. 1 May 1939, 10 April 1968, 22 December 1964, 12 January 1975).

It is not significant (in regard to present day activity) that the Cristianitos fault may have formed as a normal fault under a different stress regime than the present one. It is very significant that the Cristianitos fault is "favorably oriented" for slip and release of stress under the present stress regime (even though perhaps in a different direction than earlier episodes). This, as stated above, is demonstrated by focal mechanisms of real earthquakes which have occurred in the region. Evidence suggesting reversal of deformational styles in this region comes from the geology which shows that regions have alternately subsided and then been uplifted to near sea level or above (Ehlig, 1980).

Other features which are "favorably oriented" for slip and release of stress under the present stress regime include Faults A, B. and D*, located under the site of SONGS Unit 2.

*Based upon the data of NRC Report (1975) and according to the American Geological Institute (1976), these features are faults. "Fault - a fracture or fracture zone along which there has been displacement of the sides relative to one another, parallel to the fracture." Also, from Billings (1972) "There has been no visible movement parallel to the surface of the joint, otherwise it (fracture) would be classified as a fault."

Faults A and B are suggested by the Applicants to have been generated by regional northwest-southeast compression. As stated above, earthquake mechanisms consistent with regional northwest-southeast compression have been recorded nearby. Within the accuracy of the data, Biehler's focal mechanism for the earthquakes of 25 November 1960, 26 July 1970, 28 December 1973 and 3 January 1975 (both events), have P-axes within 30° of the appropriate maximum principal stress axes for conjugate vertical strike-slip faults, striking N 10° E and N 50° W (Faults A and B). In fact, Biehler's compression axes for the two events on 3 January 1975 are very close to the position inferred for the formation of Faults A and B. Therefore, it is possible that similar stress regimes created both Faults A and B and caused the 3 January 1975 earthquakes.

The Type C feature is of limited lateral extent according to the NRC (1975) and the FUGRO report (1976) and strikes N 50° W to N 60° W, with dips varying from 5° and 19° northeast. The focal mechanism as shown by Biehler (1975) for the event of 13 February 1967 is consistent with the formation of the Type C features. Similarly, the Type D feature, a minor thrust fault, according to FUGRO (NRC, 1975) striking approximately N 70° W, and dipping 15° - 20° NE could have been formed by a stress regime similar to that which caused the 13 February 1967 earthquake. The earthquake, as shown on Figure 1 of the Biehler (1975) report, is one of the events located closest to the

San Onofre site.

Conclusions

The stress regime that formed Features A, B, C, and D is similar (if not the same) as that which now exists in the SONGS region, as demonstrated by mechanisms of earthquakes in the region. Therefore, it is possible that any, or all of these features (faults) may slip in future earthquakes under the present tectonic style.

III. STRUCTURAL RELATIONSHIP BETWEEN CRISTIANITOS ZONE OF DEFORMATION (CZD) AND OFFSHORE ZONE OF DEFORMATION (OZD)

I concur with the conclusions reached by Greene and Kennedy (1980) regarding the description of the Offshore Zone of Deformation and the Cristianitos Zone of Deformation in the region offshore of the SONGS site. According to Greene and Kennedy (1980), the OZD is a generally continuous and well defined northwest trending fault zone located on the distal part of the nearshore shelf, approximately 7 km from the SONGS at its closest point. The CZD is a north trending "extensively faulted structure that is grossly manifested as a complex asymetrical anticline" and consists of en echelon faults and folds that extend offshore from SONGS." I have inspected the Nekton profiles in the region of the projected intersection of the CZD and the

OZD and agree with the conclusions reached by Greene and Kennedy, specifically, that the CZD either "merges with or is truncated by the OZD in the area offshore from SONGS." (Addendum (1980), Greene and Kennedy). I also agree with the conclusions reached by Green and Kennedy (1980) regarding the activity of the OZD in the region offshore of SONGS, i.e. that the OZD is "a recognized Quarternary fault zone) (Greene and Kennedy, 1980), and exists "as a series of subparallel, en echelon, and conjugate faults characteristic of a wrench zone" (Legg and Kennedy, 1979). As stated by Greene and Kennedy (1980), the CZD exhibits characteristics similar to those of the OZD." These characteristics are "highly fractured and faulted asymetrical anticlinal structures."

On the basis of the evidence that the "structure (of the OZD) noticeably changes southeast of the OZD-CZD intersection" (Addendum (1980), Greene and Kennedy), I conclude that the OZD and the CZD form a structural relationship such that movement or deformation in one has been influenced by the presence of the other, and it is possible that movement on one zone has caused movement on the other, as is frequently seen in strike-slip (and other types) earthquakes where secondary faulting is observed at some distance from the main fault (Borrego Mountain, 1960; Hayward, 1868; San Andreas, 1906; etc.). The sense of this secondary faulting may be of similar style, or of a different type than the slip on the main rupture, such as was observed in 1868 on the Hayward fault, where normal faulting was observed on a secondary fault (Radbruch, 1965).

North trending branch and secondary faults are common in the northwest trending right-lateral wrench fault zones of California (See Figure 1 of Legg and Kennedy, 1979) and these are frequently normal faults. For example, in the Newport-Inglewood fault zone, the Sunset Beach oil field structure, (Harding, 1973, Fig. 14) note how the north trending normal faults do not cut the surface of the upper Miocene, just as is suggested by Moore for the CZD. This structure is remarkably similar to the CZD and its relation to the OZD. A map view of this relationship is shown in Figure 2 of Yeats (1973). Greene, *et al.*, (1979) note that "short, <u>en echelon</u>, second-order faults are associated with each major fault zone and commonly splay from the primary faults at angles from 20 to 40 degrees. Second order fold axes are similarly related to these fault zones. These structural relationships follow the stress pattern of wrench faulting . . . " (Table 361.38-3 FSAR) also notes the similarity between the south coast offshore zone of deformation and the Newport Inglewood Zone of Deformation, in particular the "north trending branch faults near basement". These statements further support my conclusions regarding the standard relationship between the OZD and the CZD.

IV. ON THE MAXIMUM MAGNITUDE EARTHQUAKES FOR THE OZD

In the report by Slemmons for the Safety Evaluation Report (1980), several estimates of the maximum magnitude for the Offshore Zone of Deformation, and the general Newport-Inglewood-Rose Canyon-Vallecitos-San Miguel fault zone of Legg and Kennedy (1979) or possible connections with the Agua Blanca fault zone offshore at northern Baja California, were described using many different assumptions and methods of analysis. The magnitudes he derives by the various methods range from 6.3, for the historical Long Beach earthquake to 7.2 based upon a 30% of total fault zone length including a portion of the Agua Blanca fault zone. He finally concludes that a value of $M_s = 7.0$ is a conservative design value.

I disagree with his conclusion for the following reasons. Slemmons (1980) has derived larger maximum magnitude estimates in his studies ($M_s = 7.2$), yet uses a lower value in his conclusions. His estimate of 7.2 was derived using the maximum fractional fault length method, for the OZD, with a possible connection to the Agua Blanca fault. He has made several assumptions in his method which are not correct, and tend to reduce the value of maximum magnitude he derives, which also reduces the conservatism of his estimates. In his estimate of the percentage of the total length of a fault zone which ruptures during major earthquakes, he includes several events

which are not maximum magnitude earthquakes for the appropriate fault zone. This biases his estimate to smaller percentages, and hence, his method will underestimate the "true" value. Since maximum magnitude earthquakes are rarely observed during short historical time periods, this method will only find a minimum estimate of the appropriate percentage of total fault length involved in a maximum earthquake rupture. One case which demonstrates the inappropriateness of some of this data is for the Hayward fault zone. He uses the 1868 Hayward earthquake fault rupture which is estimated at $M_s = 6.7$, whereas in 1836, a larger earthquake occurred on this fault ($M_s = 7$, Bonilla and Buchanan, 1970).

In his estimates, Slemmons (1980), uses the fractional rupture length method, for the OZD extending from Santa Monica to San Diego Bay, he has ignored the results presented by Greene, et al. (1979) which state that the structural features of this fault zone "form a discrete belt that extends at least 240 km from near the Santa Monica Mountains into Baja California." Using Slemmons' value of 22%, a rupture length of 53 km, corresponding to a maximum earthquake of $M_s = 7.0$ is suggested. However, as above stated, this is a minimum estimate, so it would be more appropriate to use the value of 30% (or even 31.5% as shown for the San Andreas 1906 earthquake, since that is generally accepted as a maximum earthquake), a rupture length of 72 km is derived, which corresponds to a maximum earthquake of $M_s = 7.2$ (+). This

is still not a conservative value, for the relationship between fault rupture length and maximum magnitude gives a value for the median value of maximum magnitude. This means that 50% of the earthquakes observed with that rupture length had a greater magnitude. A conservative value would use the median plus one standard deviation (84% confidence) or even plus two standard deviations (95% confidence).

Still, we have ignored the possibility of the continuation of this fault zone into Baja California as the Newport-Inglewood-Rose Canyon-Vallecitos-San Miguel fault zone of Legg and Kennedy (1979). This increases the length of the total fault zone to 420 km (using 180 km as the combined length of the San Miguel-Vallecitos faults). Using Slemmons minimum percentage estimate (22%) and the more conservative (30%), maximum earthquake rupture lengths (and magnitudes) of 92 km, (M_s = 7.3) and 126 km (M_s = 7.5) respectively, are derived.

Slemmons uses a total fault zone length of 275 km for his example including a connection to the Agua Blanca fault. This value is based on the southward continuation of the fault zone to a point on the Agua Blanca fault offshore at Punta Salsipuedes (See page E-38, SER). This is only to the point where the data I used in drafting the figure for the report by Legg and Kennedy (1979) was inadequate to accurately delineate the trace(s) of the Agua Blanca fault. As stated in earlier parts of this testimony, the Agua Blanca fault can be traced (reliably) through

this entire region, and so the possible connection of the OZD to the Agua Blanca fault zone increases the total fault zone length to 460 km (to a point west of Canon San Matias) This does not include possible connections with the San Pedro Martir fault through the Valle Trinidad (See, Gastil, et al., 1975 for discussion of these areas). Again, using both the minimum estimate (22%) and the more conservative (30%) ratios of maximum earthquake rupture length versus total fault zone length, values of rupture length (and magnitude of 101 km (M_s = 7.4 -) and 138 km (M_s = 7.5 +) are derived.

From the foregoing discussion, the value of M_s = 7.0 does not represent a conservative estimate for the maximum earthquake magnitude on the OZD. In fact, it probably represents a minimum estimate. A more realistic, and possibly with sufficient conservatism, is the value M_s = 7.5, as has been proposed by the USGS (1980) (Open File Report 81-115)

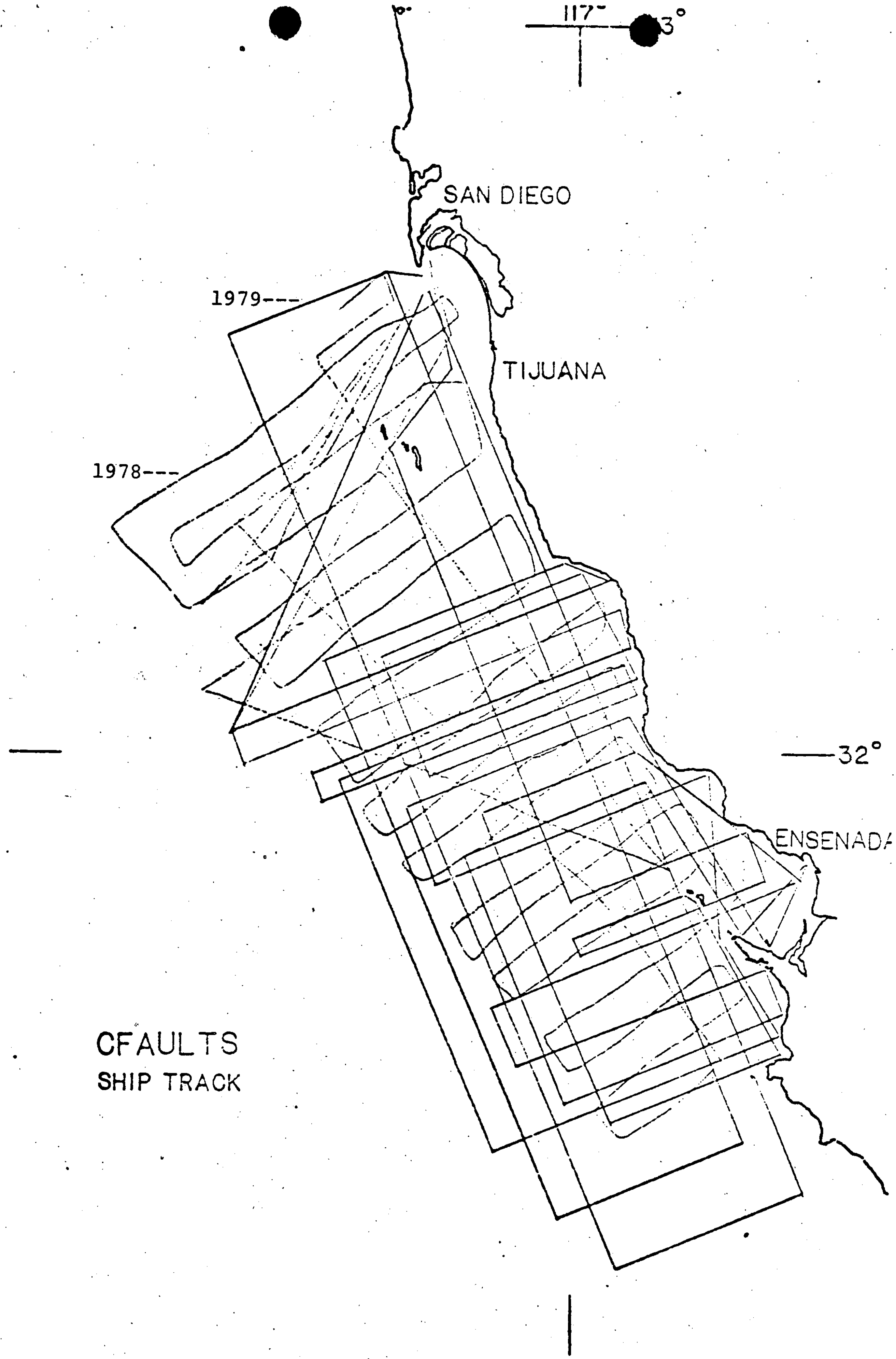
117°
33°
SAN DIEGO
TIJUANA
1979---
1978---
32°
ENSENADA
CFAULTS
SHIP TRACK

FIGURE 1

FIGURE 2

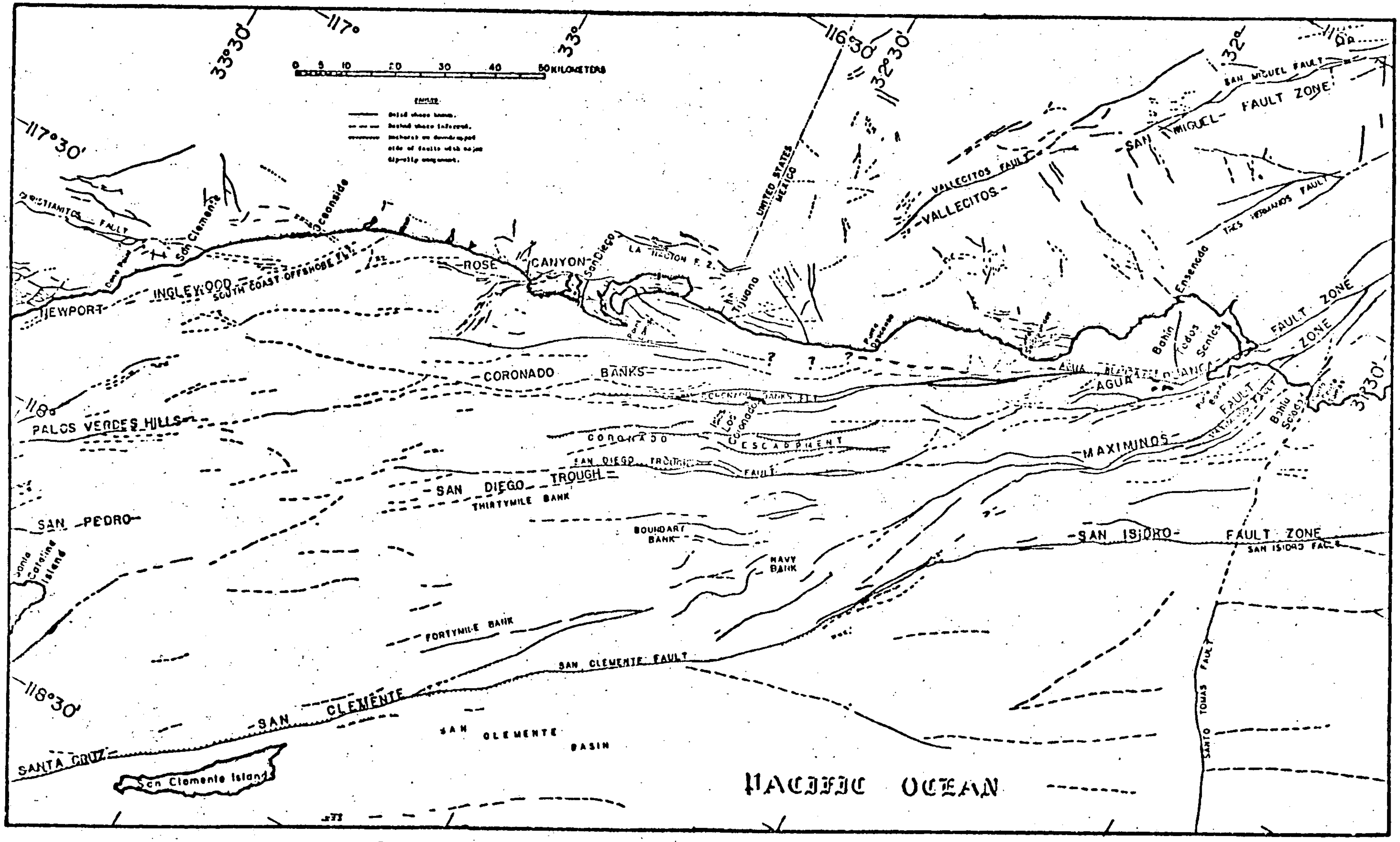

Figure 2 FAULTING OFFSHORE SAN DIEGO AND NORTHERN BAJA CALIFORNIA, MEXICO

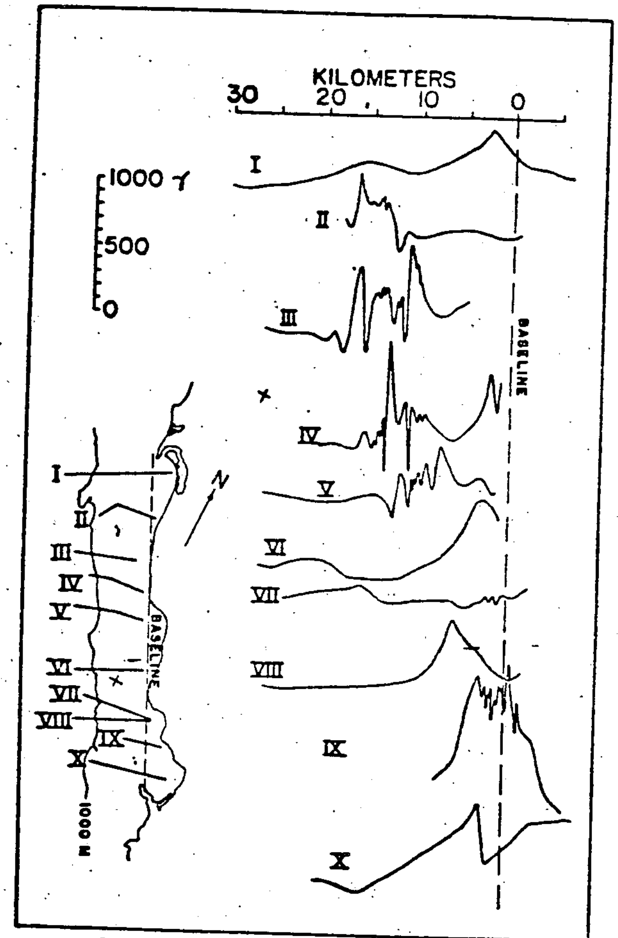

Figure 3. Magnetic profiles across the fault zone between Islas Los Coronados and Bahía Todos Santos. The fluctuations are too great to be contoured on the basis of present information.

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BIOGRAPHICAL SKETCH

MARK R. LEGG

AREAS OF SPECIALIZATION: Undersea faulting and earthquakes, earthquake risk, applied oceanography (physical and geophysical), seismicity studies.

EDUCATION:

B.S. Space Sciences and Mechanical Engineering, Florida Institute of Technology, 1973

M.S. Oceanography, Scripps Institute of Oceanography, 1980

Full-Time student in Ph.D. program at University of California, Santa Barbara, working on Ph.D. Thesis: Tectonics of the Inner Continental Borderland Offshore Southern California and Northern Baja California, Mexico

EXPERIENCE:

J. H. Wiggins Company, Member of the Professional Staff (1979 to present)

* Evaluated and compared recent U.S. seismic hazard maps by computing annualized building losses predicted from each map.

* Prepared user's manual for United States building exposure model for use in natural hazards evaluations.

California Division of Mines and Geology, Research Assistant (1979 to present)

* Performed studies of the character and recency of faulting offshore of southern California; analyzed offshore earthquakes and their effects including tsunami generation

* Prepared detailed bathymetric charts for the region offshore of northern Baja California; analyzed seismic reflection profiles and geomagnetic profiles offshore of northern Baja California.

Scripps Institute of Oceanography, Sea Grant Trainee (1977-1979)

* Compiled and analyzed historical records of earthquakes and other environmental hazards for coastal stabliity study of northern San Diego County; documented methodology and results.

BIOGRAPHICAL SKETCH CONTD.

MARK R. LEGG

Institute of Geophysics and Planetary Physics, University of California, San Diego, Research Assistant (1973-1977)

* Served as chief scientist on oceanographic expeditions to collect data for oceanic seismicity studies; analyzed data on aftershocks of offshore earthquakes and microearthquake activity along oceanic plate boundaries.

Foundation for Ocean Research, Research Assistant (1974)

* Performed applied oceanographic design and analysis.

MEMBERSHIPS AND HONORS:

National Science Foundation Graduate Fellowship
Marine Technology Society
Seismological Society of America
American Geophysical Union
American Association for the Advancement of Science
American Institute of Aeronautics and Astronautics
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PUBLICATIONS:

- "Earthquake History and Recent Seismicity of Coastal San Diego County, California, 1800-1976," (1977) w/D.C. Agnew & R.S. Simons, in "Coastal Zone Geology and Related Sea-Cliff Erosion: San Dieguito River to San Elijo Lagoon, San Diego County, California." by Gerry Kuhn for the San Diego County Board of Supervisors, Study #11596-0800E-KUHN.

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